Coupled coordination of scientific and technological innovation capability in the Pearl River Delta under the background of green Economy

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Abstract. Science and technology innovation has been recognized as the driving force behind productivity, and understanding the coordination mechanism between science and technology innovation inputs, outputs, and the environment is of great practical significance in promoting the development of the green economy. This study aims to develop a green economy index measurement system and a science and technology innovation level measurement system to measure the green economy, science and technology innovation input, output, and environment. Additionally, this study examines the coordination between inputs, outputs, and the environment for scientific and technological innovation, conducts a regional convergence analysis, and investigates the impact mechanisms of science and technology innovation subsystems on the green economy using a panel regression model.The combination weight method and comprehensive index method are employed to measure the green economy, science and technology innovation input, output, and environment. The coupling coordination model is then used to examine the coordination between inputs, outputs, and the environment for scientific and technological innovation. Regional convergence analysis is conducted on the coupling coordination of science technology and innovation, and a panel regression model is used to investigate the impact mechanisms of science and technology innovation subsystems on the green economy, study found that the green economy and science technology innovation level have improved during the period of 2010-2020, and the variability of the green economy index between regions has been decreasing year by year. The coupling and coordination between the inputs and outputs of science and technology innovation and the environment have also achieved a significant leap forward, and the variability among regions has shown a decreasing trend. Science and technology innovation input, output, and environment all contribute significantly to the growth of the green economy.The findings of this study suggest that the coupling and coordination between science and technology innovation inputs, outputs, and the environment is crucial in promoting the development of the green economy. The results of this study also provide relevant recommendations for the implementation of the strategy of scientific and technological innovation.

Keywords: Green Finance, Science and Technology Innovation, Coupled Coordination, Panel Data Analysis.

1. Introduction

As China's economy enters a new era, it is imperative to prioritize innovation for sustainable development. Specifically, innovation serves as a critical driver to harmonize the tension between economic growth and natural resources and environment, thus promoting sustainable development. To further enhance the innovation-driven strategy, it is crucial to consider the development of green economies and the integration of innovation in a synergistic manner, which can facilitate social progress. Accordingly, research on the coordination and interaction among subsystems, as well as the examination of the impact of science and technology creation on the green economy, holds practical significance for the realization of high-quality integrated planning in the context of the new development pattern.

The green economy has been extensively studied in recent years, with scholars focusing on different aspects of its development. For example, Xiaoguang Xu et al. [1] utilized the entropy concept to construct a green economy development index system in China. They analyzed the effects and significance levels of various variables in each year using the geographically weighted model. Bingnan Guo [2] evaluated the green economic efficiency of the Yangtze River Economic Belt using the Super-SBM model. They further explored regional differences, their sources, and spatial convergence characteristics. Jinshan Liu [3] assessed the efficiency of green economic cooperation among cities in the Guangdong-Hong Kong-Macao Greater Bay Area, highlighting differences in each city's development and providing political insights for inter-city collaboration. Meanwhile, Yang, long [4] measured the green economic efficiency of 29 provinces and municipalities in China based on the entropy weight method and DEA model.

Research on science, technology, and innovation (STI) capability has also been conducted to support high-quality economic development. For instance, Yifei Lai [5] used the super-efficient SBM-Malmquist model to measure STI efficiency in each province and city. They further regressed factors imaging STI efficiency by the Tobit model. Cheng, Fengyu [6] investigated the convergence mechanism of science and technology innovation development by measuring the spatial differences in science and technology innovation growth in the Guangdong-Hong Kong-Macao Greater Bay Area. Cai, Xiaolin [7] constructed a combined model based on the standard deviation method and TOPSIS method to evaluate the science and technology innovation capacity of nine cities in the PRD. They also analyzed the factors influencing their science and technology innovation capacity. Additionally, Huiyan Wang [8] developed a conceptual model and evaluation index system to assess the efficacy of science and technology innovation-driven high-quality economic development. They utilized the network WSBM model to evaluate the performance level of technological and scientific innovation-driven high-quality economic development in 30 Chinese provinces.

In light of the existing literature, there remains a dearth of research examining the influence of science, technology, and innovation (STI) on the green economy across three dimensions: STI input, innovation output, and innovation environment, as well as the interplay and coordination among these factors. Based on this, the marginal contributions of this paper are shown below: I. Integrating the combined weights with the composite index method, we construct a measurement model for the green economy, STI input, innovation output, and innovation environment respectively, and explore the coupling and coordination mechanism among STI input, innovation output, and innovation environment. II. The regional convergence of the coupling coordination of green economic development level and science and technology innovation was analyzed, and the coupling coordination of the subsystem of technological and scientific innovation capability was graded for the PRD region. III. Analyzed the green economy, the three aspects of science and technology innovation input, output and environment, and the influence mechanism of their interaction on the growth of the green economy. In the end, based on the empirical results, this study puts forward relevant policy suggestions for the development of a high-quality green economy under the new pattern concept.

2. Theory and Methodology

2.1. Construction of Green Economy Indicator System

The level of green economy in cities is influenced by numerous indicators, and the evaluation systems used in academic circles to assess this level are varied. For example, Zhang Wei [9] developed a green economy indicator system in China based on three levels: economic development, social development, and resources and environment. Similarly, Hou Chunguang et al. [10] employed a green economy indicator system consisting of three levels: economic efficiency, environmental quality, and social construction. Through the comparison and screening of various indicator systems, this paper has identified and compiled 14 indicators to comprehensively assess and analyze the green economy level of nine cities in the Pearl River Delta region. The proposed green economy indicator evaluation system encompasses three dimensions: economy, society, and environment and resources, and is presented in Table 1.

Table 1. Green Economy Evaluation Indicator System

Economic Dimension	GDP per capita	RMB 10,000/person
	Urban disposable income per capita	RMB/year
	Per capita consumption expenditure	RMB/person
	Tertiary sector as a share of GDP	%
	Tertiary sector growth rate	%
Social Dimension	Education expenditure as a proportion of local fiscal expenditure	%
	Registered urban unemployment rate	%
	Number of beds per 1,000 population	Sheets/1,000
Environmental and Resource Dimension	Green space per capita	sqm/person
	Forest cover	%
	Water resources per capita	Cubic metres per person
	Annual average sulphur dioxide emissions	million tonnes
	Electricity usage	million kWh
	General industrial solid waste utilization rate	%

From an economic perspective, this study has selected five positive indicators to summarize the main national economic levels. Larger figures indicate a better economic environment. From a social perspective, three indicators were selected, which include education investment, social employment, and healthcare levels. The proportion of education expenditure to local fiscal expenditure and the number of hospital beds per 1,000 people are considered positive indicators, whereas the urban registered unemployment rate is considered a negative indicator. The level of green environment is reflected by indicators such as green area per capita, forest coverage, and per capita water resources. Additionally, the average annual sulfur dioxide emissions and electricity consumption represent the level of resource consumption of the main harmful emission levels, with smaller figures indicating a better resource environment. Lastly, the comprehensive utilization ratio of regular industrial solid waste is used to evaluate the level of waste recycling.

2.2. Construction of the index system for measuring technological innovation capability

In the realm of academia, there exists no standardized criterion for evaluating the science and technology innovation capability of each city, as it is influenced by several factors. Li Dapeng and others [11] adopted an indexing system to gauge the scientific and technological innovation level at three levels: the input of innovation, the output of innovation, and the environment of innovation. Meng Yan and others[12] adopted an indexing system to assess the level of scientific and technological innovation on three levels: the input of scientific and technological innovation, the output of scientific and technological innovation, and the environment of scientific and technological progress. By comparing and screening the importance of the available data, this paper selects nine indicators to comprehensively assess and analyse the scientific and technological innovation capacity of nine cities in the PRD region at three levels: innovation input, output and environment, and builds an assessment system of science and technology innovation ability indicators, as presented in Table 2 below.

Table 2. Technology and innovation capability evaluation index system

Innovation input	Number of R & D per 10,000 people	People per 10,000
	Number of university students per 10,000 population	People per 10,000
	Research and Experimental Development R&D expenditure as a proportion of GDP	%
	Scientific research expenditure as a percentage of regional financial outlays	%
	Education expenditure as a proportion of regional financial outlays	%
Innovative output	Number of patents granted per 10,000 people	Pieces per 10,000 people
	Tertiary sector as a share of GDP	%
Innovative environment	Public library holdings per 10,000 population	Ben/ 10,000 people
	Total exports and imports per capita	USD/person

The five indicators in the innovation investment perspective are selected from both financial and human investment, including investment in research and investment in education. These five indicators are all positive indicators, and as the data for these indicators increase, the intensity of innovation investment increases. The two indicators chosen in terms of innovation output, patents granted per 10,000 people, specifically quantify the results of STI output, and as STI levels increase the share of the tertiary sector in GDP also increases. These two indicators are positive indicators, as patents granted per 10,000 people and the share of the tertiary sector in GDP increase, the more innovation output is produced. In terms of the innovation environment, two representative indicators have been selected. The number of public libraries is a very basic indicator of the education and research environment. The total exports and imports per capita is an indicator of how well the city is connected to foreign markets. These two indicators are also positive indicators, with higher public library collections per 10,000 people and higher imports and exports per capita being associated with a better innovative environment.

For the purpose of examining the impact of various aspects of innovation capacity and the overall influence on the green economy, this article will give the following four hypotheses: H1: innovation input has a strong effect on the level of green economy development; H2: innovation output has a major bearing on the level of green economy growth; H3: innovation environment has a great influence on the level of green economy development; H4: science and technology innovation as a whole has a significant impact on the green economy development' level, and the hypotheses were tested through panel data analysis.

2.3. Combined index method based on portfolio weights

Because the individual data indicators have different unit scales, the raw data for the first indicator of the Green Economy Index System and the first indicator of the Science and Technology Innovation Index System are normalised. k'_{xi} is the normalised data. Regarding the combined weights, we use the entropy method in combination with the critic method, in which we consider both the informativeness of the indicators and also incorporate the volatility and relevance measures of the indicators. Let the entropy weight be W^1, the critic weight be W^2 and the combination weight be $W = W^1 * W^2 / \sum(W^1 * W^2)$. The formula is shown below.

$$\mathrm{IFI_i} = 1 - \frac{\sqrt{(W_1-E_1)^2+(W_2-E_2)^2+\cdots+(W_k-E_k)^2}}{\sqrt{w_1{}^2+w_2{}^2+\cdots+w_k{}^2}} \tag{1}$$

Where $\mathrm{IFI_i}$ is the i the composite development index for the first region. $E_k = w_k * k'_{xi}$ denotes the K dimension measured; where k'_{xi} denotes the standardised value of the i of the Kth indicator for the first province, and w_k denotes the weight of the k dimension. When $\mathrm{IFI_i}$ is 1, it means that the level is the highest, and when it is 0, it means that the level is the lowest. The evaluation of the comprehensive development level in this paper, where Y_{IK} denotes the i The value of the Kth indicator of a province after standardization.

2.4. Coupling coordination factor

Firstly, the scores of innovation input, innovation output and innovation environment for the three subsystems of STI are calculated based on the composite index method M_1, M_2 and M_3. Calculate the coupling degree C.

$$C = \left\{\frac{M_1 \times M_2 \times M_3}{\left[\frac{M_1+M_2+M_3}{3}\right]^3}\right\}^{\frac{1}{3}} \tag{2}$$

Where the value of the coupling degree C ranges from 0 to 1. When it tends to 1, the coupling degree between the systems are greater; when it tends to 0, the coupling degree between the systems are smaller. Next, the coupling coordination degree is calculated D.

$$D = \sqrt{C \times T} \tag{3}$$

Where T is the composite average index of the level of coupling development, and the overall rating of STI. The following table 3 shows the criteria for dividing the degree of scientific and technological innovation coupling coordination.

Table 3. Classification of STI coupling coordination

values	$0 \le D \le 0.3$	$0.3 < D \le 0.5$	$0.5 < D \le 0.8$	$0.8 < D \le 1.0$
Basic type	Low	Moderate	Highly	Extremely

2.5. Convergence metrics

The convergence coefficient and the coefficient of variation are quoted to measure the convergence characteristics and the degree of the coupling coordination's deviation, where D_l is the coupling coordination degree of the city l, the $\overline{D_l}$ is the mean of the nine cities' coupling coordination, τ and V are the coefficient of convergence and variation respectively. The smaller the τ and V, the stronger the convergence.

$$\tau = \sqrt{\frac{1}{n}\sum_{l=1}^{n}\left(\ln(D_l) - \frac{1}{n}\sum_{l=1}^{n}\ln(D_l)\right)^2} \tag{4}$$

$$V = \frac{\sqrt{\frac{1}{n}\sum_{l=1}^{n}\left(D_l - \overline{D_l}\right)^2}}{\overline{D_l}} \tag{5}$$

The level of variation in coupling coordination is measured using the Thiel index. The smaller the difference in coupled development between the nine cities as the Thiel index tends towards 0, and the greater the difference in coupled development between the nine cities as the Thiel index tends towards 1.

$$Tl = \frac{1}{n}\sum_{l=1}^{n}\left(\frac{D_l}{\overline{D_l}} \times \ln\frac{D_l}{\overline{D_l}}\right) \tag{6}$$

3. Results and Analysis

3.1. Sources of data and pre-processing

This paper collects and collates panel data for nine cities in the PRD region from 2010 to 2020. The data were mainly from the China Urban Statistical Yearbook, the Guangdong Provincial Statistical Yearbook, the Environmental Bulletin, Water Resources Bulletin, and other bulletins of each city from 2011 to 2021, etc. Some individual missing data were supplemented by linear interpolation and SPSS prediction. Taking into account the difference in magnitude between indicators, the raw data were standardized to measure the Green Economy Composite Index and science and technology innovation capability.

3.2. Analysis of green economy development level

Using the combined index method to calculate the Green Economy Composite Index in the PRD region. The results are shown in Table 4. From a longitudinal comparison, the green economy development in the PRD region has made greater progress from 2010 to 2020. Among them, Dongguan, Zhuhai and Jiangmen all have more than 50% increase, which is a good development trend. The increase of the comprehensive green economy index of PRD cities is in a higher position from 2016 to 2017, mainly because a ministry-province cooperation agreemen are signed by the Ministry of Environmental Protection and the Guangdong Provincial Government in 2016 on the joint construction of the Pearl River Delta National Green Development Demonstration Zone [13].

Table 4. Pearl River Delta region green economy comprehensive score

Year	Guangzhou	Fo shan	Zhao qing	Shen zhen	Dong guan	Hui zhou	Zhuhai	Zhongshan	Jiangmen
2010	0.375	0.252	0.310	0.345	0.274	0.298	0.231	0.248	0.211
2011	0.400	0.259	0.287	0.369	0.285	0.304	0.265	0.195	0.234
2012	0.425	0.270	0.297	0.392	0.269	0.331	0.299	0.198	0.258
2013	0.441	0.236	0.326	0.403	0.291	0.367	0.317	0.224	0.268
2014	0.465	0.243	0.323	0.417	0.283	0.364	0.321	0.225	0.267
2015	0.479	0.276	0.326	0.412	0.325	0.370	0.329	0.243	0.291
2016	0.489	0.305	0.350	0.429	0.344	0.422	0.365	0.262	0.316
2017	0.498	0.314	0.353	0.426	0.392	0.443	0.381	0.290	0.330
2018	0.472	0.327	0.377	0.422	0.399	0.431	0.365	0.293	0.341
2019	0.529	0.308	0.378	0.479	0.448	0.470	0.289	0.229	0.331
2020	0.533	0.311	0.360	0.462	0.448	0.468	0.289	0.230	0.332

The construction of this demonstration zone for green development has given new impetus to the green development of PRD cities. A comparison of the Green Economy Composite Index reveals significant variations across cities, with Guangzhou and Shenzhen consistently maintaining the highest scores. Notably, Huizhou, as the flagship city in Guangdong Province's green development initiative, has made remarkable progress in the green economy since 2016, with its Green Economy Composite Index rising from 0.37 in 2015 to 0.468 in 2020, surpassing Shenzhen to become the second-largest city in the PRD region with regard to green development.

3.3. Regional convergence analysis of comprehensive green economy evaluation

Figure 1 shows the variation’s coefficient, the Thiel index and the convergence coefficient of the comprehensive green economy index of the PRD region, which all show a trend of first increasing then decreasing, and all show a rapid decreasing trend in the years 2015-2018. The green transformation of PRD cities was first carried out in Guangzhou, Shenzhen, Zhuhai and Huizhou, and five parks, including Guangzhou Economic Development Zone, Shenzhen Guangming Hi-tech Industrial Park, Shenzhen Pingshan Park, Zhuhai Economic and Technological Development Zone and Huizhou Daya Bay Industrial Park, were included in the national pilot recycling transformation. So before 2015, the gap between the green economic development of PRD cities gradually increased.

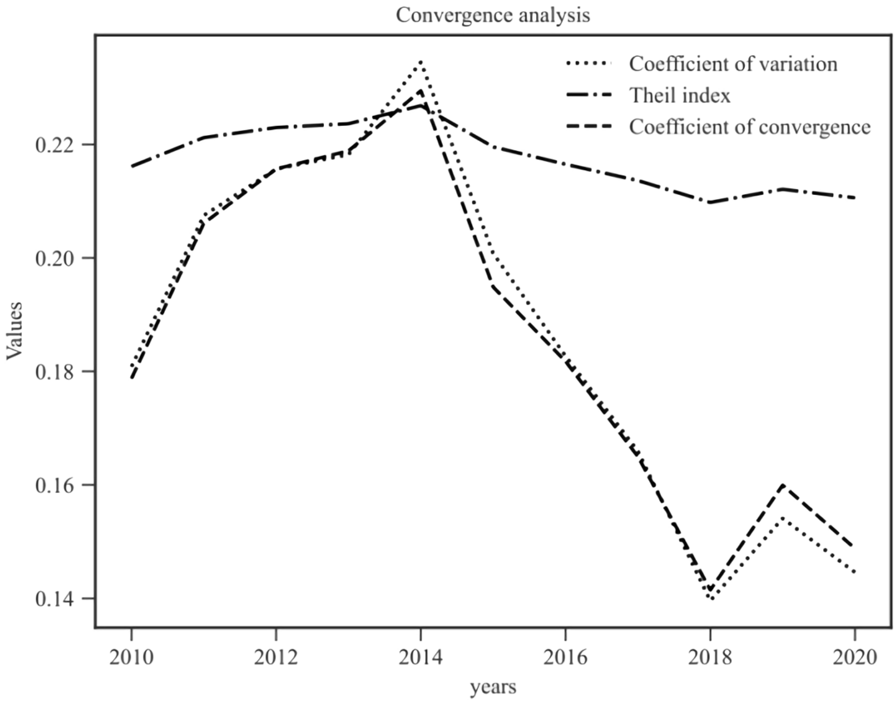

Figure 1. Coefficient of variation, Theil index and Coefficient of convergence

3.4. Evaluation of STI capability subsystem

With the construction of the pilot cities and the continuous development of green and low-carbon development, the relevant support policies for green development spread from the representative cities to the whole region, the development of the better-based cities slowed down, the development of the lagging cities accelerated, and the green and low-carbon PRD city cluster was comprehensively built. The gap between cities temporarily lagging behind in the early stage of green economic development and cities with higher levels gradually decreases, and the green economic development among cities in the region gradually tends to be balanced, thus narrowing the development gap among regions and showing obvious regional convergence. Using the data related to the PRD cities from 2010 to 2020, the composite scores of the three subsystems were obtained by the critic weight method and the independent weight coefficient method. Table 5 shows the corresponding weights of the specific indicators.

Table 5. Scientific and technological innovation index weight

Index	Weight
R&D personnel per 10,000 population (persons)	0.0692
Number of university students per 10,000 population (persons)	0.1522
Research and Experimental Development R&D expenditure as a percentage of GDP(%)	0.0641
Science and technology expenditure as a percentage of total local fiscal expenditure (%)	0.1238
Education expenditure as a percentage of total local fiscal expenditure (%)	0.1487
Number of patents granted per 10,000 people (pieces)	0.0820
Tertiary sector as a share of GDP (%)	0.0843
Public library collections per 10,000 population (items)	0.0846
Total exports and imports per capita (US$/person)	0.1910

In terms of investment in STI, the overall level of investment in STI in all nine PRD cities has increased to varying degrees from 2010 to 2020. Huizhou shows the fastest growth rate, whose innovation investment index increasing from 0.0332 in 2010 to 0.0959 in 2020, with an average annual growth rate of 18.85%. As for STI environment, the overall score of STI environment in the

PRD region is slower than the improvement of STI investment in terms of growth rate. Shenzhen has the highest sub-system score of 0.16 in 2020, which is 0.02 points higher than Huizhou. Shenzhen, as the leading city in the field of high-tech industries in China, has formed a more complete and mature industrial chain foundation and has an absolute advantage in the development of STI. And about science and technology innovation output, the level of STI output in the PRD region increased significantly between 2010 and 2020. Guangzhou and Shenzhen are leading the PRD region in science and technology development, and their science and technology innovation continues to grow in a high output state.

3.5. Contribution of STI capacity subsystem to green economy development

3.5.1. Model setting

To further probe the influence of STI capacity subsystem on the green economy development, this study selects the standardized STI subsystem scores M_1 , (Investment), M_2 (Output)and M_3 (Environment) as explanatory variables, and the combined green economy score F (Green Economy) as explanatory variables, and constructs the following panel data analysis model.

$$F_{it} = \beta_0 + \beta_1 M_{1it} + \beta_2 M_{2it} + \beta_3 M_{3it} + \lambda_i + \gamma_t + \varepsilon_{it} \tag{7}$$

Where $i = 1,2,\dots,N$ denotes N individuals; $t = 1,2,\dots,T$ denotes T periods; λ_i is the individual effect; γ_t is the time effect.

3.5.2. Empirical results

The panel regression and Hausman test results in Table 6 demonstrate that the model P-value is less than 0.01 for both the fixed effect model and the random effect model, so the STI input score, STI output score and STI environment score have a significant impact on the overall green economy score. The P-value in the Hausman test result is 0.4712, so this study mainly analyses the random effect model results. The coefficients of the three sub-systems of STI capability were all positive and significant at the 5% level, with coefficients of 0.0591, 0.038 and 0.0211 respectively, which indicated that STI input, STI output and STI environment all contributed significantly to the level of green economy development.

Table 6. Panel regression and Hausman test results

Variables	Fixed effects model	Random effects model
M_1	0.0666***	0.0591***
	(0.0197)	(0.0189)
M_2	0.036*	0.038**
	(0.0188)	(0.0185)
M_3	0.0222**	0.0211***
	(0.009)	(0.0077)
Constant term	0.382***	0.382***
	(<0.0001)	(0.0224)
Sample size	99	99
Adjusted R^2	0.4484	0.4478
P	0.0007	<0.0001
Hausman-stats	$chi^2(4) = 3.54$	
	(0.4721)	

3.6. Coupling and coordination analysis of STI capacity subsystem

The coupling coordination degree between the three subsystems from 2010 to 2020 was calculated using the coupling coordination degree model.

From the time-series evolution, the coupling coordination degree of the three subsystems in nine PRD cities from 2010 to 2020 has increased to different degrees, with the average value increasing from 0.41 in 2010 to 0.64 in 2020, and the overall coupling degree of the PRD region has increased from moderate to high coupling coordination, indicating that in recent years the degree of synergy between the three subsystems has been increasing.

In terms of STI input and STI output, the average coupling coordination between the two systems increases from 0.39 in 2010 to 0.66 in 2020, developing from coupling coordination to high coupling coordination stage. Guangdong and Shenzhen, which have stronger STI capability, have a coupling coordination between STI input and STI output of 1 and 0.82 respectively in 2020, both at the stage of extreme coupling coordination. In terms of science and technology innovation input and science and technology innovation environment, the average coupling coordination degree of the two systems rises from 0.45 in 2010 to 0.64 in 2020, developing from moderate coupling coordination to high coupling coordination. In terms of science and technology innovation output and science and technology innovation environment, the average coupling coordination degree of the two systems steadily increases from 0.42 in 2010 to 0.63 in 2020, developing from a moderate coupling coordination to a high coupling coordination stage.

3.7. Convergence analysis of the coupling coordination degree

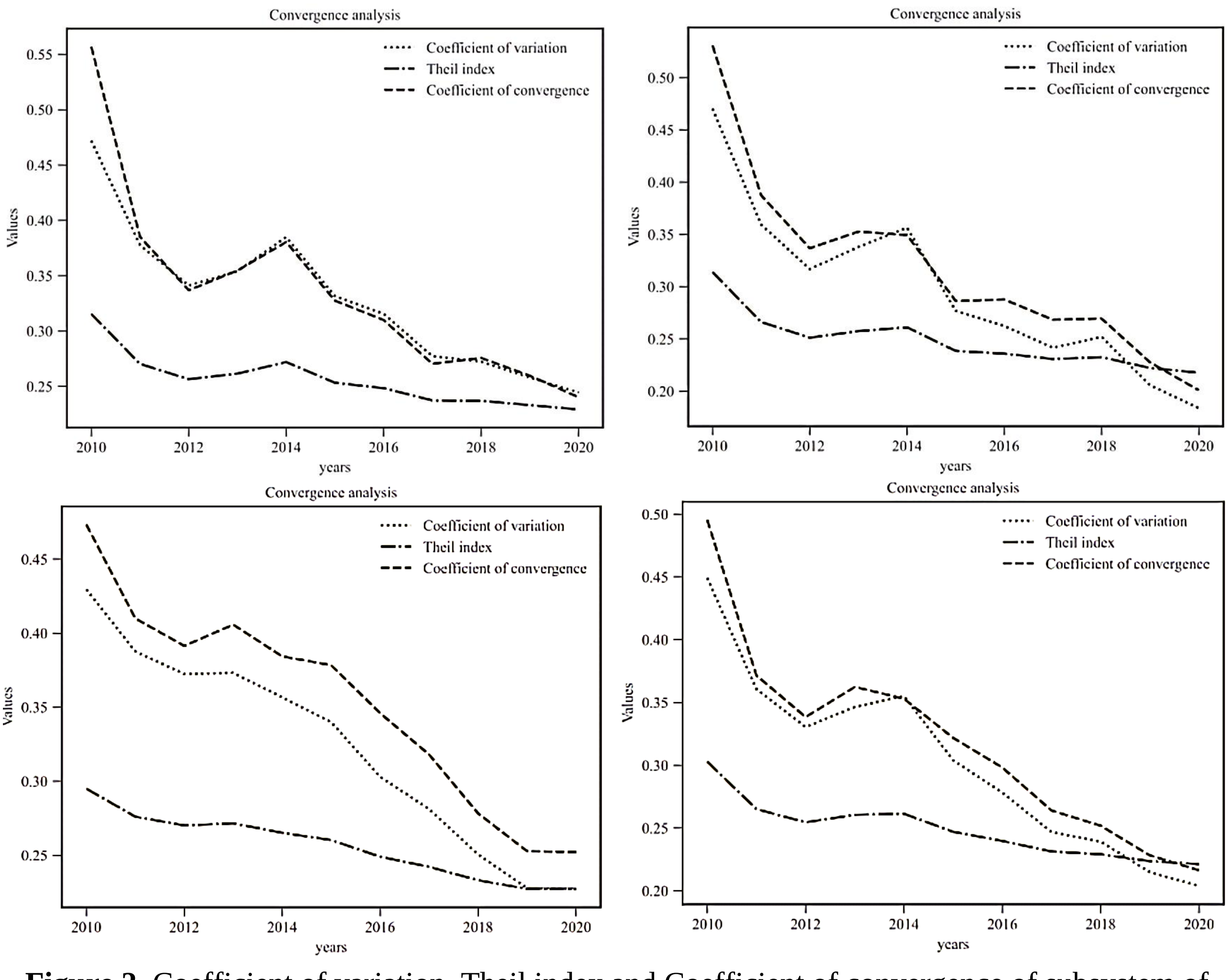

Figure 2. Coefficient of variation, Theil index and Coefficient of convergence of subsystem of science and technology innovation capability

Figure 2 shows that the coefficient of variation, the Thiel index and the convergence coefficient of the coupling and coordination degree of each subsystem of the science and technology innovation capability from 2010 to 2020 show an overall decreasing trend, indicating that the development of the coupling and coordination degree among the subsystems in the PRD cities gradually tends to be balanced.

The PRD region has achieved rapid upgrading of its science and technology innovation capacity based on industry, and the transformation and upgrading needs of the manufacturing industry constitute the main driving force for the upgrading of science and technology innovation. The foundation of manufacturing development for many years and the continuous upgrading and optimisation of manufacturing results have formed the PRD region to deepen the development of science and technology A deep industrial foundation. With the improvement of science and technology infrastructure and policy support in the nine cities of the PRD, the differences in synergy between science and technology innovation input, output and environment in each city were significantly reduced.

To further analyze the interaction of the STI capability subsystem on green economic development, interaction terms for STI input and STI output, STI input and STI environment, and STI output and STI environment were added to the model. To circumvent the effect of heteroskedasticity, the panel regression results were obtained after logging the variables (Table 7).

The regression results show that the Hausman value is 3.11, which is not significant at the 5% level. In the random effects model, the positive effect of each of the three subsystems of STI capability on green economic development remains significant, and the coefficients of the interaction terms are all positive, but not significant at the 5% level.

Table 7. Panel regression and Hausman test results

Variables	Fixed effects model	Random effects model
$\ln M_1$	0.0664***	0.0604***
	(0.0172)	(0.0156)
$\ln M_2$	0.047**	0.0492**
	(0.2005)	(0.0202)
$\ln M_3$	0.0264*	0.0236**
	(0.1304)	(0.0108)
$\ln M_1M_2$	0.0129	0.0121*
	(0.0069)	(0.0066)
$\ln M_1M_3$	0.0069	0.007
	(0.0127)	(0.0129)
$\ln M_2M_3$	0.0162	0.0165
	(0.0185)	(0.0195)
Constant term	0.3601***	0.3605***
	(0.0072)	(0.024)
Sample size	99	99
Adjusted R^2	0.4792	0.4787
P	0.0003	<0.0001
Hausman-stats	$chi^2(7) = 3.11$	
	(0.8748)	

4. Conclusions and recommendations

Based on the data of nine cities in the Pearl River Delta from 2010 to 2020, this paper constructs an evaluation index system for the green economy and each subsystem of science and technology innovation, analyses the coupling and coordination relationship among the three subsystems of science and technology innovation through the coupling and coordination degree model, further explores the regional convergence of the coupling and coordination degree of the system through indices such as the coefficient of variation. Finally, the study examines the impact of each subsystem of science and technology innovation on the green economy using the panel analysis model.

From 2010 to 2020, the level of development of China's green economy and scientific and technological innovation capacity has increased significantly, with an overall unbalanced regional development and obvious urban stratification. The dispersion coefficient, Thayer index and convergence coefficient of the Green Economy Index all show a decreasing trend, indicating that the gap in green economy development among PRD cities has narrowed and regional convergence is significant. As for the sub-system of science and technology innovation capability, the level of science and technology innovation input, science and technology innovation output and science and technology innovation environment in the nine cities of the PRD remained basically consistent, with the majority of cities achieving significant improvements during the period 2010-2020. The degree of coupling and coordination among the three subsystems of STI input, STI output and STI environment all maintain a stable upward trend, and the overall level of coupling and coordination crosses from moderate to high. The coefficient of variation, the Thiel index and the convergence coefficient of the coupling and coordination of the subsystem show an overall decreasing trend, indicating that the development of the coupling and coordination of the subsystem in each city in the PRD tends to be balanced. From the panel data analysis model, it can be seen that science and technology innovation input, science and technology innovation output and science and technology innovation environment have a significant contribution to the green economy, and the higher the level of science and technology innovation capability, the more conducive to the development of the green economy.

In order to facilitate the coordinated development of science and technology innovation capabilities within the Pearl River Delta (PRD) region, it is imperative for the region to strengthen intercity cooperation, with particular emphasis on leveraging the leadership roles of Guangzhou and Shenzhen. The objective is to narrow the gap between the science and technology innovation systems of PRD cities and enhance the overall science and technology innovation driving force of the region. Given the regional convergence trend in the coupling and coordination of the science and technology innovation subsystems of PRD cities, it is essential to actively promote cooperation and learning between cities. In view of the regional convergence trend in the coupling and coordination of the science and technology innovation subsystems of the cities in the PRD region, in order to narrow the coupling and coordination gap, realise the radiation effect of the "first" cities and the catch-up effect of the "second" cities, the cities actively cooperate and learn from each other. This will enable the limited resources of each city to flow effectively and complement each other's strengths to enhance the coupling and coordination of sub-systems and promote the coordinated development of the whole region. It is recommended that the PRD region adopts a two-wheel drive strategy for science and technology innovation and institutional reformation in the PRD cities [14].

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