Research on the Driving Factors of Regional Innovation Quality Based on Multiple Linear Regression Model

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Abstract. The efficiency of urban green development is deeply rooted in the innovation capabilities of urban clusters. Adhering to innovation-driven strategies to lead green development enhances the innovation quality of urban clusters. This study employs grey comprehensive evaluation to select indicators that represent innovation quality and establishes a principal component regression model for researching the driving factors of innovation quality in the Yangtze River Delta urban cluster. Empirical research is conducted using data related to the overall green innovation quality driving factors for 41 cities in the Yangtze River Delta from 2010 to 2020. The study indicates that the regional gross domestic product (GDP) is the most representative indicator of innovation quality. Factors such as technological research and development, the number of patents, economic foundations, and business development exhibit significant positive effects, while environmental planning, management systems, human capital, and international openness show significant negative effects. To enhance the innovation quality in the Yangtze River Delta, it is essential to address the deficiencies in policy and market-driven approaches. Emphasizing green, high-quality development, taking into consideration both economic and ecological benefits, enhancing technological innovation capabilities, and aligning expansion of business plans with environmental planning are key strategies. Additionally, optimizing the structure and quality of higher education, making sensible investments in human capital, and focusing on the quality of foreign capital inflow are crucial steps towards achieving this goal.

Keywords: Regional Development, Innovation Quality, Driving Factors

1 Introduction

1.1 Research background

The Yangtze River Delta urban cluster is a crucial intersection point for China's "Belt and Road" initiative and the Yangtze River Economic Belt. The Yangtze River Delta region is one of the most economically active, open, and innovation-driven areas in China. Rapid economic growth has brought about extensive expansion and a shift from heavy to light and high-quality production methods. However, this regional economic development has also exposed numerous drawbacks, including environmental degradation. With the introduction of the "Five Development Concepts" - innovation, coordination, green development, openness, and shared growth, and the popularization of the concept that "green mountains and clear waters are as valuable as golden and silver mountains," the idea of green development has gained prominence.

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Innovation serves as the driving force behind green development, and the efficiency of urban green development is deeply rooted in the innovation capabilities of urban clusters. In his theory of national competitive advantage, American economist Michael Porter suggests that economic development driven by competition between nations can be categorized into four stages, with the third stage being innovation-driven, representing an advanced stage of development. Taking a perspective of green development, this research aims to investigate the driving factors of innovation in the Yangtze River Delta region, evaluate the level of green innovation quality in this region, and analyze the deficiencies in driving factors during the process of transforming regional innovation quality.

2 Literature review

Since the introduction of the concept of "high-quality development," it has become the guiding principle for economic and social progress, representing the outcome of the coordinated efforts of various factors [1]. The Yangtze River Delta region is home to industries with high levels of pollution and energy consumption, and issues like environmental pollution and resource shortages have constrained the high-quality development of the regional economy. Therefore, the strategic utilization of green innovation has been identified as a catalyst for promoting high-quality economic development in the Yangtze River Delta [2].

In the context of the literature review on green innovation development, there has been a significant surge in attention towards both green and innovation aspects in recent years. The application of geographic spatial models has unveiled the structural dynamics of innovation networks. While there has been substantial research on innovation in certain domains and achievements at the provincial level in China, there has been relatively less focus on the driving factors of comprehensive innovation development, especially in key urban clusters, such as the Yangtze River Delta. This limitation is due to methodological and perspective constraints, leading to a less in-depth analysis of the role of innovation in driving green development. The academic contribution and unique features of this paper lie in the following aspects: (1) The use of grey comprehensive evaluation to select indicators that best represent innovation quality, thus providing a clear definition of regression independent variables; (2) To mitigate multicollinearity among variables, a principal component approach is applied, considering four dimensions: technology-driven, industry-driven, policy-driven, and market-driven factors [3-7]. The analysis of multiple linear regression results, followed by back substitution [8-10]; (3) A comprehensive examination of the driving factors behind insufficient innovation quality within the framework of green development, which allows for drawing conclusions and proposing corresponding policy recommendations. This research aligns not only with the premises of grey evaluation and principal component regression but also with the strategic orientation of green innovation development in the Yangtze River Delta region.

3 Evaluation of innovation quality in the Yangtze River Delta region

3.1 Construction of the innovation quality indicator system

3.1.1 Sampling

The Yangtze River Delta region is a fertile alluvial plain located before the Yangtze River flows into the sea. It is one of the most economically developed areas in China, characterized by its unique geographical location and natural environment. The region's economic development model is highly representative(As shown in Table 1).

Table 1. Overview of the expanding scope of the Yangtze River Delta urban cluster over time.

Time	Yangtze River Delta Urban Cluster
1992	Shanghai, Wuxi, Ningbo, Zhoushan, Suzhou, Yangzhou, Hangzhou, Shaoxing, Nanjing, Nantong, Taizhou, Changzhou, Huzhou, Jiaxing, Zhenjiang
2003	Taizhou (Zhejiang)
2009	Anhui
2010	Hefei, Yancheng, Ma'anshan, Jinhua, Huai'an, Quzhou
2013	Xuzhou, Wuhu, Chuzhou, Huainan, Lishui, Wenzhou, Suqian, Lianyungang
2018	Tongling, Anqing, Chizhou, Xuancheng
2019	Huangshan, Bengbu, Lu'an, Huaibei, Suzhou, Hefei, Fuyang

In the past, the economic achievements of the Yangtze River Delta urban cluster were often obtained at the cost of sacrificing resources and the environment. Currently, the region's development is shifting towards a direction where resource and environmental constraints play a crucial role. It is setting a typical example for other regions in China in terms of green and innovative development. The development of urban clusters must consider the region as a whole, and the effectiveness of green economic development in each city not only depends on their respective levels of green innovation but also on the interplay of the entire urban cluster's development. Therefore, the entire Yangtze River Delta urban cluster, consisting of 41 cities, is selected as the study area.

3.1.2 Indicators selection

Based on the definition of regional innovation quality provided earlier, assessing the level of regional innovation quality in the Yangtze River Delta region should encompass five key dimensions: technological support, economic foundations, social support, human capital, and environmental protection. This comprehensive approach ensures the completeness and accuracy of indicator selection.

3.1.3 Data sources

The data was sourced from the Yangtze River Economic Belt Data Center of the EPS Data Platform, as well as publications such as the *China Statistical Yearbook, China Science and Technology Statistical Yearbook, Shanghai Statistical Yearbook, Zhejiang Statistical Yearbook, Anhui Statistical Yearbook, and Jiangsu Statistical Yearbook,* etc(As shown in Table 2).

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Technology Statistical Yearbook, Shanghai Statistical Yearbook, Zhejiang Statistical Yearbook, Anhui Statistical Yearbook, and Jiangsu Statistical Yearbook, etc.)

Table 2. Overview of the innovation quality indicator system for the Yangtze River Delta.

Goal Level	System Level	Indicator Level	Measurement Unit	Symbol	Influence
Regional Innovation Quality	Technological Support	Research and Development (R&D) Personnel in Research and Development Institutions	People	A_1	Positive
		Publication of Scientific and Technical Papers by Research and Development (R&D) Institutions	Articles	A_2	Positive
	Economic Foundations	Regional Gross Domestic Product (GDP)	Hundred Million	A_3	Positive
		Industrial Added Value	Hundred Million	A_4	Positive
	Social Support	Urban Population	Ten Thousand People	A_5	Positive
		Social Organizations	Units	A_6	Positive
	Human Capital	Number of Full-Time Faculty Members with Ph.D. Degrees in Higher Education Institutions	People	A_7	Positive
		Personnel in Higher Education Research Institutions	People	A_8	Positive
	Environmental Support	Urban Wastewater Daily Treatment Capacity	Tons	A_9	Positive
		Natural Gas Supply Volume	Tons	A_{10}	Positive

3.2 Empirical analysis

Since all ten selected evaluation indicators are positive, meaning that sample data increases as the indicator data increases, there is no need for indicator normalization.

The original data for the ten indicators have different units, which can potentially result in heteroscedasticity during calculations. Therefore, a dimensionless transformation was applied to the original data. The data was first pre-processed by calculating the mean for each year, and then each element for that year was divided by the mean. The pre-processed data is presented in the following table(As shown in Table 3):

Table 3. Overview of pre-processed data.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
A_1	0.8528	0.7566	0.7107	0.6773	0.6614	0.6422	0.6169	0.5655	0.2469	0.5011
A_2	0.3050	0.2623	0.2478	0.2324	0.2228	0.2096	0.2029	0.1884	0.0767	0.1611
A_3	0.4956	0.5167	0.4888	0.4839	0.4750	0.4715	0.4908	0.4913	0.5479	0.4921
A_4	0.2209	0.2284	0.2107	0.2031	0.1922	0.1815	0.1848	0.1831	0.1938	0.1696
A_5	0.0584	0.0582	0.0518	0.0477	0.0442	0.0417	0.0402	0.0373	0.0479	0.0321
A_6	1.3385	1.1724	1.1221	1.1455	1.1637	1.1828	1.1733	1.1483	0.4896	1.0949
A_7	0.6330	0.5767	0.5594	0.5573	0.5570	0.5604	0.5740	0.5635	0.2552	0.5571

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
A_8	0.1006	0.0737	0.0631	0.0537	0.0519	0.0484	0.0463	0.0424	0.0221	0.0393
A_9	0.0167	0.0152	0.0134	0.0132	0.0123	0.0117	0.0112	0.0104	0.0116	0.0097
A_{10}	5.9784	6.3398	6.5321	6.5859	6.6195	6.6501	6.6596	6.7697	8.1083	6.9430

Using MATLAB to perform grey comprehensive evaluation, we obtained the correlation coefficients and relevance of each year from 2010 to 2019 with respect to the evaluation of innovation quality for various indicators. The results are presented in the following table(As shown in Table 4):

Table 4. Overview of correlation coefficients for various indicators by year.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
A_1	1.0000	0.9161	0.8799	0.8553	0.8441	0.8309	0.8142	0.7822	0.6289	0.7455
A_2	1.0000	0.9706	0.9575	0.9439	0.9356	0.9244	0.9188	0.9070	0.8253	0.8856
A_3	0.9438	0.9704	0.9454	0.9411	0.9335	0.9305	0.9471	0.9476	1.0000	0.9483
A_4	0.9801	1.0000	0.9830	0.9758	0.9658	0.9562	0.9592	0.9576	0.9673	0.9457
A_5	0.9848	1.0000	0.9937	0.9898	0.9865	0.9841	0.9827	0.9800	0.9900	0.9751
A_6	1.0000	0.8561	0.8216	0.8373	0.8499	0.8636	0.8568	0.8392	0.5447	0.8039
A_7	1.0000	0.9533	0.9382	0.9364	0.9361	0.9390	0.9510	0.9418	0.7335	0.9362
A_8	1.0000	0.9888	0.9787	0.9700	0.9684	0.9651	0.9633	0.9598	0.9418	0.9569
A_9	0.9854	1.0000	0.9983	0.9981	0.9972	0.9967	0.9962	0.9954	0.9966	0.9947
A_{10}	0.3333	0.3664	0.3935	0.4018	0.4072	0.4122	0.4138	0.4331	1.0000	0.4674
correlation	0.9227	0.9022	0.8890	0.8850	0.8824	0.8803	0.8803	0.8744	0.8628	0.8659

The calculated weights for each year from 2010 to 2019 are presented in the following table(As shown in Table 5):

Table 5. Overview of weights for each year.

2010	2011	2012	2013	2014
0.107328635	0.100525821	0.099005972	0.099118963	0.099347025
2015	2016	2017	2018	2019
0.099613934	0.099299155	0.098588521	0.099353327	0.097818646

3.3 Results analysis

Table 6. Overview of normalized scores and rankings for various indicators.

Indicators	Scores	Rank
A_1	0	10
A_2	0.108918475	6
A_3	0.117416028	1
A_4	0.107983445	7
A_5	0.116650361	3
A_6	0.116821699	2
A_7	0.114149766	4
A_8	0.106383697	8
A_9	0.113819419	5
A_{10}	0.09785711	9

According to the grey comprehensive evaluation, the indicator with the highest normalized score and ranking is 0.117416028, which places it in the top position. The higher the score, the closer the evaluated object is to the optimal indicator. Therefore, the indicator with the highest score, which is the Gross Regional Product (GRP), is chosen as the representative of innovation quality(As shown in Table 6).

4 Exploring insufficient innovation driving factors through principal component regression

4.1 Construction of the indicator system for innovation driving and green development

4.1.1 Selection of indicators

Based on research in the field of innovation driving and green development over the years [11-12], it is evident that there are primarily four driving factors: technological, industrial, policy, and market-driven factors. Building upon these four dimensions, we derived eight indicator levels, including technology research and development, the number of patents, economic foundations, enterprise development, environmental planning, management systems, human capital, and external engagement [13-15]. Using these dimensions, we constructed an indicator system for the study of innovation factors in the Yangtze River Delta.

4.1.2 Data sources

The data was sourced from the EPS Data Platform's Yangtze River Economic Belt Data Center, as well as publications such as the *China Science and Technology Statistical Yearbook*, *Shanghai Science and Technology Statistical Yearbook, and Shanghai Statistical Yearbook,* etc.

4.1.3 Symbol explanation and indicator system

The following table provides explanations for some of the variable symbols used in the text to facilitate a better understanding of the entire paper. Specific symbols that are not commonly known will be explained when they are first used(As shown in Table 7).

Table 7. Overview of variable symbols and explanations.

Variable Name	Variable Symbol	Symbol Explanation
Technology Research and Development	Trad	Technology research and development
Number of patent rights	Nopr	Number of patent rights
Economic base	Eb	Economic base
Enterprise development	Ed	Enterprise development
Environmental planning	Ep	Environmental planning
Management system	Ms	Management system
Human capital	Hc	Human capital
Opening to the outside world	Ottow	Opening to the outside world

Based on the selected indicators and data retrieval as mentioned above, we obtained an indicator system for innovation quality driving factors from the perspective of green development(As shown in Table 8).

Table 8. Overview of the indicator system for innovation driving and green development.

Goal Level	System Level	Criterion Level	Indicator Level	Influence
Regional Innovation Driving and Green Development	Technology -Driven	Technology research and development	Growth Rate of Scientific and Technological Expenditure	Positive
		Number of patent rights	Percentage of Effective Invention Patents by Research and Development Institutions	Positive
	Industry-Driven	Economic base	Percentage of the Added Value of the Secondary Industry	Positive
		Enterprise development	Percentage of Non-Public Fund Foundations	Positive
	Policy-Driven	Environmental planning	The ratio of the population using natural gas and liquefied petroleum gas (LPG).	Positive
		Management system	Percentage of individuals receiving maternity insurance benefits	Positive
	Market-Driven	Human capital	Growth rate of Full-Time Equivalent (FTE) Research and Development (R&D) personnel	Positive
		Opening to the outside world	Growth rate of total foreign enterprise investment	Positive

4.2 Descriptive statistics

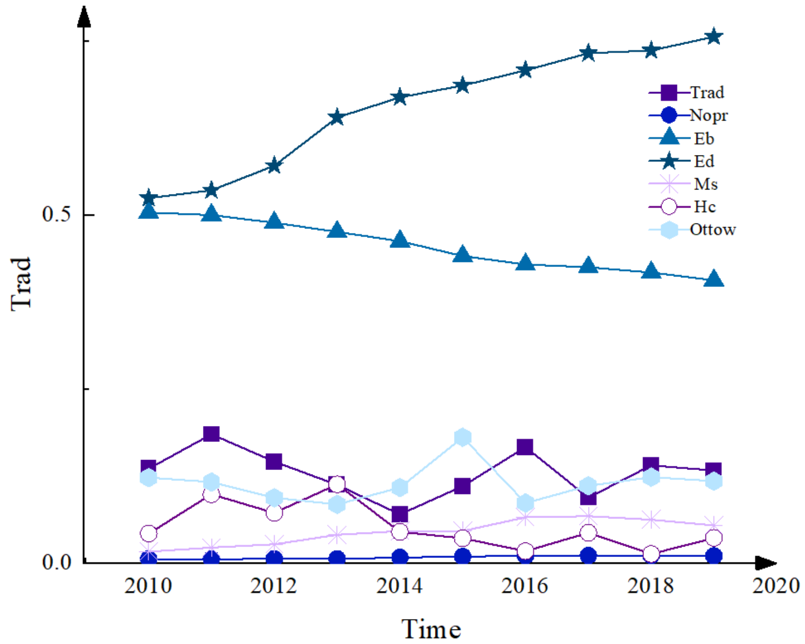

Fig. 1. Visual analysis of data for various indicators.

Based on the original data, the ratio of the population using natural gas and liquefied petroleum gas (LPG) shows a significant difference and a noticeable trend change when compared to the other seven indicators. From 2010 to 2020, the ratio increased significantly, rising from an initial value of 0.9672 to 3.8893. This data indicates that as time has progressed, people have become more focused on the use of natural gas and have placed a greater emphasis on environmental planning, adhering to green development principles(As shown in Figure 1).

According to the visual analysis in the above figure, it can be observed that over time, there has been continuous growth in enterprise development. The percentage of the added value of the secondary industry has been steadily decreasing. There have been slight fluctuations in the areas of technological research and development, the number of patents, management systems, human capital, and openness to the outside world, but the overall trend has remained relatively stable(As shown in Table 9).

Table 9. Overview of descriptive statistics for innovation driving and green development indicators.

	N	Min-Value	Max-Value	Mean-Value	Standard Deviation
Trad	10	0.0700	0.1900	0.1297	0.0339
Nopr	10	0.0100	0.0100	0.0087	0.0023
Eb	10	0.4100	0.5000	0.4552	0.0359
Ed	10	0.5200	0.7600	0.6562	0.0853
Ep	10	0.9700	3.8900	2.1751	0.9899
Ms	10	0.0200	0.0700	0.0451	0.0182
Hc	10	0.0100	0.1100	0.0520	0.0330
Ottow	10	0.0800	0.1800	0.1149	0.0273

Overall, it can be observed that there has been significant variation in environmental planning trends in the Yangtze River Delta region over the past decade, while the other aspects have shown less noticeable changes.

4.3 Solution Using Principal Component Analysis (PCA) Model

Using MATLAB, a principal component analysis was conducted on the eight indicators. The eigenvalues and their contribution rates for the correlation matrix are shown in the table below(As shown in Table 10):

Table 10. Overview of principal component results for 8 indicators.

	Eigenvalues	Indicator Contribution Rate	Cumulative Contribution Rate
Trad	5.2860	66.0756	66.0756
Nopr	1.1341	14.1760	80.2517
Eb	0.9708	12.1352	92.3868
Ed	0.4158	5.1979	97.5847
Ep	0.1634	2.0430	99.6277
Ms	0.0257	0.3208	99.9485
Hc	0.0038	0.0481	99.9966
Ottow	0.0003	0.0034	100.0000

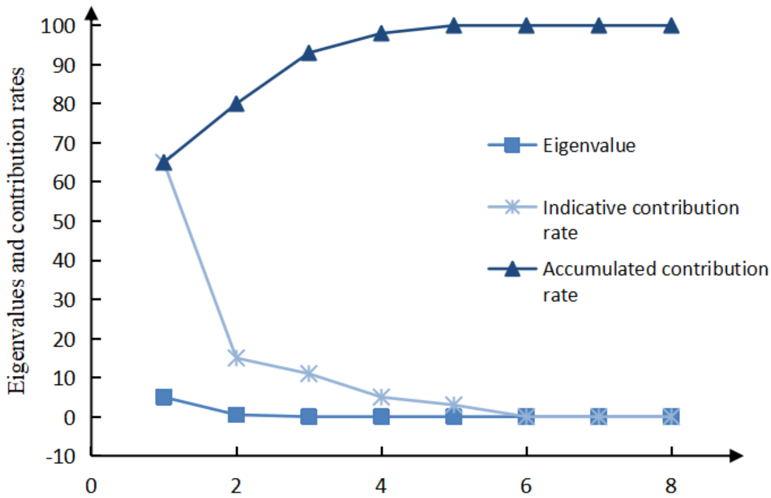

Fig. 2. Visualization of principal component results.

It can be observed that the cumulative contribution rate of the first four eigenvalues reaches 97.58%, indicating a good result in principal component analysis(As shown in Figure 2). Therefore, the first four principal components are selected for comprehensive evaluation. The eigenvectors corresponding to the eight eigenvalues are shown in the table below(As shown in Table 11).

Table 11. Eigenvectors corresponding to the 8 eigenvalues.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	-0.1265	0.3627	0.8773	0.1879	0.1550	-0.1146	0.0938	0.0388
x_2	0.4278	0.0050	0.1149	-0.0497	0.2621	0.5068	-0.4483	0.5241
x_3	-0.4293	-0.0643	-0.0407	-0.1735	0.0598	0.4233	0.6318	0.4448
x_4	0.4223	0.0816	-0.1597	0.1915	0.0509	-0.5835	0.3434	0.5402
x_5	0.4010	0.1188	0.0894	0.3206	-0.6968	0.3815	0.2664	-0.1103
x_6	0.4070	0.2118	-0.1229	-0.0254	0.5895	0.2141	0.4090	-0.4617
x_7	-0.3235	0.2449	-0.3242	0.8058	0.1960	0.1370	-0.1439	0.0555
x_8	0.0849	-0.8595	0.2484	0.3778	0.1721	0.0120	0.1189	-0.0757

Based on the eigenvectors corresponding to the eigenvalues, the first four principal components are as follows:

$$y_1 = -12.65\tilde{x}_1 + 0.3627\tilde{x}_2 + \cdots + 0.0388\tilde{x}_8 \tag{1}$$

$$y_2 = 0.4278\tilde{x}_1 + 0.0050\tilde{x}_2 + \cdots + 0.5241\tilde{x}_8 \tag{2}$$

$$y_3 = -0.4293\tilde{x}_1 - 0.0643\tilde{x}_2 + \cdots + 0.4448\tilde{x}_8 \tag{3}$$

$$y_4 = 0.4223\tilde{x}_1 + 0.0816\tilde{x}_2 + \cdots + 0.5402\tilde{x}_8 \tag{4}$$

4.4 Solution using multiple linear regression analysis

To ensure that the regression model has excellent explanatory power and predictive effectiveness, considering the correlations between the indicators and based on the results of principal component analysis, a multiple linear regression analysis is conducted. The four principal components from earlier are used as independent variables, and the Gross Regional Product (GRP) is used as the dependent variable.

Table 12. Overview of multiple linear regression results.

Source	SS	df	MS	Numberofobs	=	10
Model	8.37E+09	4	2.0913e+09	F(4,5)	=	3.44
				Prob>F	=	0.1038
Residual	3.04E+09	5	607529263	R-squared	=	0.7336
Total	1.14E+10	9	1.2670e+09	Adj Rsquared	=	0.5205
				Root MSE	=	24648
y	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
x_1	-679886.5	387742.3	-1.75	0.140	-1676610	316836.9
x_2	-1.95E+07	1.46E+07	-1.34	0.239	-5.72e+07	1.81E+07
x_3	-5256861	2119701	-2.48	0.056	-1.07e+07	192003.4
x_4	-1508589	729280.9	-2.07	0.093	-3383265	366087
_cons	3802978	1524126	2.50	0.055	-114911.6	7720868

When $p < 0.05$, it indicates that at a 95% confidence level, the regression coefficient is significantly different from 0, showing good significance. From the table above, the p-values are 0.140, 0.239, 0.056, 0.093, and 0.055, all of which are greater than 0.05. The joint significance test is 0.1038, suggesting that the regression effect is not significant and further analysis is required(As shown in Table 12).

From the table above, it can be observed that:

$R^2 = 0.7336$, however, due to the relatively small reduction in SSE introduced by the new independent variables, the adjusted R-squared is 0.5205.

This multiple linear regression model primarily focuses on explanatory variables, and its impact on the goodness of fit is not substantial. It is sufficient to maintain overall model significance, statistical significance of the independent variables, and economic significance. Therefore, the goodness of fit can be considered acceptable.

To further investigate this regression model, BP (Breusch-Pagan) and White tests were conducted to test for heteroscedasticity. The scatter plots of residuals versus fitted values and residuals versus independent variables are shown below(As shown in Figure 3-7):

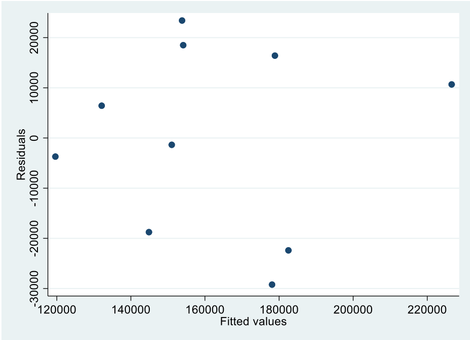

Fig. 3. Scatter plot of residuals vs. fitted values.

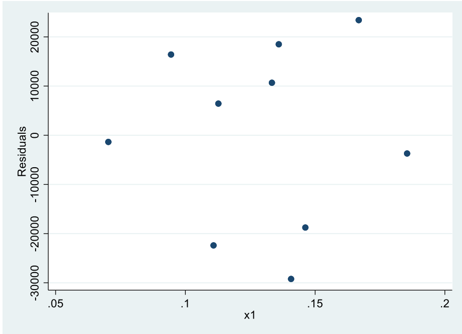

Fig. 4. Scatter plot of residuals and x_1.

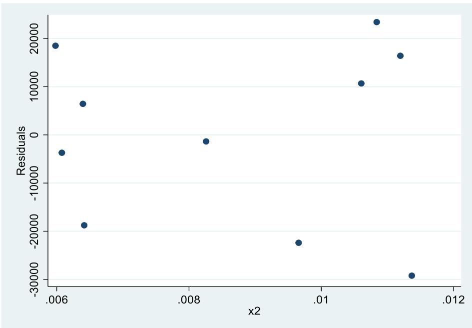

Fig. 5. Scatter plot of residuals and x_2.

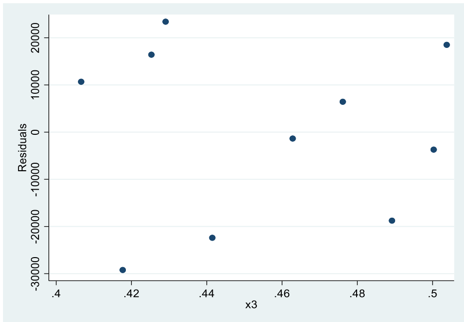

Fig. 6. Scatter plot of residuals and x_3.

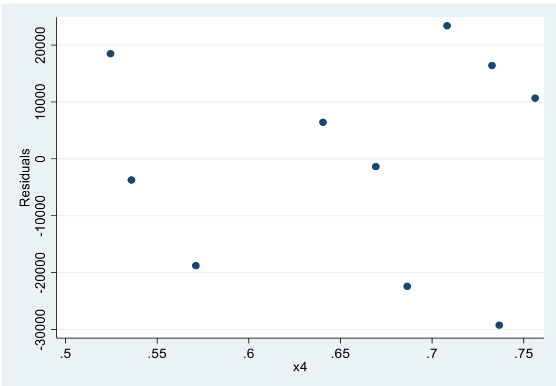

Fig. 7. Scatter plot of residuals and x_4.

(1) BP: Test

$$chi2(4) = 5.05$$

$$Prob > chi2 = 0.2827$$

The p-value is 0.2827, which is greater than 0.05. This indicates that at a 95% confidence level, we fail to reject the null hypothesis, suggesting that there is no heteroscedasticity in the disturbance term.

(2) White Test

$$chi2(9) = 10.00$$

$$Prob > chi2 = 0.3505$$

Table 13. Results of white heteroscedasticity test.

Source	chi2	df	p
Heteroskedasticity	10	9	0.3505
Skewness	1.16	4	0.8851
Kurtosis	1.42	1	0.2334
Total	12.58	14	0.5601

In summary, the presence of heteroscedasticity in the disturbance term has been ruled out as the p-value (0.3505) is greater than 0.05, indicating that the original hypothesis is accepted at a 95% confidence level(As shown in Table 13).

Table 14. Values of Variance Inflation Factor (VIF).

Variable	VIF	1/VIF
x_3	85.62	0.01168
x_4	57.25	0.017467
x_2	16.73	0.059765
x_1	2.56	0.390614
Mean VIF	40.54	

From the table above, it can be seen that only the VIF for x_3=2.56<10. This indicates that the regression model does not have severe multicollinearity(As shown in Table 14).

The results obtained from both forward stepwise regression and backward stepwise regression are the same(As shown in Table 15).

Table 15. Overview of stepwise regression results.

Source	SS	df	MS	Number of obs	=	10
Model	5.39E+09	1	5.39E+09	F(1, 8)	=	7.17
				Prob > F	=	0.0281
Residual	6.02E+09	8	751897729	R-squared	=	0.4725
				Adj R-squared	=	0.4065
Total	1.14E+10	9	1.27E+09	Root MSE	=	27421
y	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
x3	-682200.6	254856	-2.68	0.028	-1269900	-94501.68
_cons	472731.6	116343.1	4.06	0.004	204443.9	741019.4

From the table above, it is evident that only the coefficient for the "Second Industrial Value Added Ratio" will not lead to multicollinearity issues in the regression model. Therefore, in this analysis, we will focus on the regression coefficient for the "Second Industrial Value Added Ratio."

The results are as follows:

$$\begin{aligned} y &= -68220.6x_3 + 472731.6 \\ se &= (254856) \quad (116343.11) \\ p &= \quad 0.028 \qquad 0.004 \end{aligned} \tag{5}$$

4.5 Principal component regression results analysis

The third principal component (y_3) obtained in the principal component analysis corresponds to the variable (x_3) in the multiple linear regression analysis. Substituting the expression for y from the regression into the equation gives:

$$\begin{aligned} y = 292898.69x_1 + 43895.86x_2 + 27754.34x_3 + 118348.88x_4 - 40805.84x_5 \\ -288767.76x_6 - 431026.23x_7 - 303428.52x_8 + 472731.6 \end{aligned} \tag{6}$$

5 Conclusion

5.1 Impact of overall driving factors in the Yangtze River Delta region

To ensure the accuracy and comprehensiveness of the innovation quality assessment, a grey comprehensive evaluation was conducted, resulting in a final score of 0.117416028 for the regional gross domestic product (GDP), ranking it first. According to the definition of regional innovation quality in this paper, the GDP of the Yangtze River Delta region serves as the primary indicator for measuring the innovation quality of the Yangtze River Delta city cluster.

From 2010 to 2020, there has been a significant increase in the ratio of natural gas to liquefied petroleum gas usage, rising from an initial 0.9672 to 3.8893. This data suggests that, with changing times, people have been using natural gas more than liquefied petroleum gas, emphasizing environmental planning and embracing innovative green development. To mitigate multicollinearity among various indicators, principal component regression was employed for analysis. Based on the known results, it can be concluded that technology-driven and industry-driven factors have a significant positive effect. This means that as technology research and development, the number of patents, economic foundations, and business development increase, the innovation quality of the Yangtze River Delta region also improves. On the other hand, policy-driven and market-driven factors have a negative impact. This implies that with increased emphasis on environmental planning, management systems, human capital, and international openness, the innovation quality in the Yangtze River Delta region decreases.

5.2 Empirical analysis of the overall driving factors in the Yangtze River Delta region

5.2.1 Technological-driven factor

"Technology Research and Development, as well as the number of patents, both exhibit significant positive effects. For every unit increase in technology research and development, the innovation quality in the Yangtze River Delta region increases by 292,898.69 units. Similarly, for every unit increase in the number of patents, the innovation quality in the Yangtze River Delta region increases by 43,895.86 units. This suggests that the level of economic development and technological support can significantly drive the improvement of green technology innovation capabilities in the Yangtze River Delta region. This may be attributed to the fact that higher levels of economic development and technology can provide financial support and technical backing to a certain extent for green innovation activities, effectively promoting the research and transformation of green innovation outcomes."

5.2.2 Industrial-driven factor

Both economic foundation and enterprise development show significantly positive effects. For every unit increase in the economic foundation, the innovation quality in the Yangtze River Delta region improves by 27,754.34 units, while for every unit increase in enterprise development, the innovation quality in the Yangtze River Delta region increases by 118,348.88 units. Regarding regional development patterns, economic growth serves as a vital guarantee for regional development. This could be attributed to the fact that optimizing the industrial structure can effectively reduce resource consumption, decrease undesired outputs, and enhance resource allocation efficiency, thereby promoting the enhancement of green innovation quality.

5.2.3 Policy-driven factor

"Environmental planning and management systems both exhibit significantly negative effects. For every unit increase in environmental planning, the innovation quality in the Yangtze River Delta region decreases by 40,805.84 units, and for every unit increase in management systems, the innovation quality in the Yangtze River Delta region decreases by 288,767.76 units. Environmental regulations in the cities within the Yangtze River Delta region have become increasingly stringent, prompting businesses to reduce pollutant emissions by decreasing production in the short term. This suggests that government support in the Yangtze River Delta region has not effectively promoted the enhancement of green innovation quality. Government investments in innovation funds possess a "public goods" characteristic, and businesses make decisions regarding the allocation of these funds based on their own development priorities. When businesses allocate funds to other areas at the expense of green innovation research and outcome transformation, it hinders the improvement of green innovation quality."[16]

5.2.4 Market-driven factor

Human capital and foreign openness both exhibit significantly negative effects. For every unit increase in human capital, the innovation quality in the Yangtze River Delta region decreases by 431,026.23 units, and for every unit increase in foreign openness, the innovation quality in the Yangtze River Delta region decreases by 303,428.52 units. This may suggest that the educational goals of higher education in China often lag behind market demand, exacerbated by deficiencies in public services in the social welfare sector, which prevent Chinese human capital from effectively promoting the enhancement of regional green innovation quality. With the increasing total investment by foreign enterprises, not only does it intensify market competition, but China may also be perceived as a "pollution heaven", thereby impeding the effective enhancement of regional green innovation quality.

6 Recommendations

(1) It is essential to unwaveringly adhere to green and high-quality development.

Unwaveringly pursue economic transformation, achieving sustained and healthy economic development based on effective protection of the ecological environment, efficient utilization of energy resources, and steady improvement of quality and benefits. Regardless of changing development conditions, reject short-sighted practices that sacrifice the ecological environment for temporary economic growth and inappropriate approaches that excessively rely on resource development and consumption to drive industrial development. Strictly control high-energy consumption and high-emission projects, eliminate outdated and excess production capacity, and prevent behavior that disregards excessive debt, blind investment, and redundant construction.

(2) Consider both economic benefits and ecological benefits.

Promote high-efficiency and energy-saving technologies, fostering a cycle where green consumption guides green innovation development, and green innovation development stimulates green consumption. As we enter a new era and embark on a new journey, green development and high-quality development have become the overarching theme of economic and social progress. This is not only a requirement of our time but also a call from the people. By balancing environmental protection and development, we can achieve a win-win situation for ecological and economic benefits. Simultaneously, optimizing energy structures and improving energy efficiency will contribute to the realization of carbon neutrality and peak carbon emissions targets.

(3) Enhance technological innovation capabilities and nurture the growth of new development drivers.

Enhance technological innovation capabilities with a focus on nurturing and strengthening new development drivers[17]. Elevate independent innovation capabilities and improve technological standards, directing high-quality resources towards the secondary industry. This promotes the establishment of a resource-efficient and environmentally friendly industrial system, ensuring the harmonious development of the economy and environmental protection. Facilitate two-way resource flows, timely release the dividends of green technological innovation, reinforce intellectual property protection, effectively expand the market application of innovative outcomes, propel technological innovation integration in the Yangtze River Delta, and establish a source of innovation in science and technology.

(4) Incorporate environmental planning and moderately expand enterprise planning.

While emphasizing the expansion of production scale in Chinese manufacturing enterprises, the government should strengthen and raise environmental protection standards and exercise control over the expansion of enterprise scales. Additionally, businesses should avoid blind expansion based on current levels of investment and, in conjunction with environmental planning, work toward optimizing production scale. It is essential to maintain innovation as a core element in the overall plan for China's modernization. This involves building innovation chains and industry chains, accelerating the formulation of standards for emerging industries, guiding the rational layout of industries, and promoting the optimization and upgrading of the industrial structure in the Yangtze River Delta region.

(5) Achieve innovative higher education and expedite structural and quality optimization.

China's higher education system should be market-oriented, aligned with the nation's green development direction, and focus on nurturing highly skilled individuals who better meet market demands. Moreover, the emphasis in Chinese higher education should be on cultivating innovation knowledge and capabilities in young people, strengthening creativity in basic education. Promote the flow of teachers and students within universities, encourage the sharing of educational resources, allowing various types of universities to find their own niches and promote the transformation from the single development of higher education in the Yangtze River Delta to a multi-comprehensive development model.

(6) Invest in human capital rationally and focus on the quality of foreign investment.

Enhance the development of basic education, allocate investments in a balanced manner, and make scientifically informed decisions regarding investment directions, with a focus on increasing educational investments in resource conservation, environmental protection, and related fields. Improve regional healthcare plans, ensuring rational investment and distribution of healthcare infrastructure to guarantee that a wide segment of the population has access to healthcare services. Optimize industrial structure and prioritize the attraction of high-quality foreign investments that feature characteristics such as environmental protection, energy efficiency, and resource conservation. Leverage foreign investment to enhance ecological efficiency and integrate the market environment to ensure fair competition.

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