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The dynamic relationship among green logistics, technological innovation and green economy: Evidence from China

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ABSTRACT

Under the background of "double carbon", exploring the growth path of green logistics and enhancing the driving force of technological innovation is the urgent need of our country to comply with the green transformation of its economy and realize high-quality economic growth. Taking the panel data of 30 Chinese provinces from 2010 to 2020 as the sample, the green logistics index evaluation system is constructed based on the driver-press-state-impact-response (DPSIR) theoretical framework, and the green economic efficiency of each province in the sample period is measured by using the non-expected output Super- Slacks-based measure (SBM) model, and by constructing the panel vector autoregressive (PVAR) model including technological innovation is used to systematically elaborate the dynamic influence paths among the three. The study found that: China's green economy, technological innovation, and green logistics all have their own mechanisms for growth, which will gradually diminish over time. In the near and long term, green logistics will promote technological innovations and the evolution of a green economy, but there is a lag in the long-term benefits of green logistics on technological progress. In the short term, technological innovation does not lend support to the growth of a green economy, but over time, the impact of technological innovation on the growth of that economy will shift from negative to positive. This shows that improving technological innovation capability is an important path for green logistics to promote green economic efficiency. The findings of the study provide a basis for decision making to achieve the emission reduction target and improve the efficiency of the green economy.

1. Introduction

All of humanity faces the challenge of climate change, and carbon neutrality has emerged as a key issue in the latest stage of the global technological and economic revolution [1]. At present, The Chinese economy has progressed to a high-quality development stage. To address resource and environmental constraints, achieve sustainable development, and promote economic structural transformation and modernization, we cannot do without the drive of "double carbon" [2]. The main strategy to reach peak carbon and carbon-neutral is going green and low-carbon, as it is a prerequisite for qualitative growth and integration of old as well as new dynamics [3]. China has actively addressed climate change and promoted a radical transformation of economic and social growth to a more environmentally friendliness type, and played a key role in global climate governance. Since the 18th National Congress of the Communist Party of China, The Communist Party of China Central Committee with Comrade Xi Jinping at its core has promptly

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changed its development philosophy and thinking and proposed a modern vision of innovation, co-ordination, green, openness and sharing, which has guided the direction for green economic growth [4]. On October 16, 2022, General Secretary Xi Jinping stated in the reports of the 20th National Congress that we should accelerate the restructuring anoptimization of industry, energy and transportation, speed up the transformation of the green development mode, and actively and steadily promote the achievement of peak carbon emissions and carbon neutrality [5]. Looking at the long-term development trend, China will strengthen its confidence; continue to speed up scientific and technological innovation, and actively practice low-carbon and green development. Circulation, as an essential part of the social production cycle, is crucial to promoting the green development of social production. Therefore, to explore the long-term equilibrium and dynamic relationship among green logistics, technological innovation and green economy is an important subject to implement the Party's twenty Great spirits and achieve the peaceful coexistence of man and nature.

Driven by the “double-carbon” goal, scholars at home and abroad have made rich research achievements in green logistics, technological innovation, green economy and other aspects. In terms of technological innovation and green logistics, most scholars have relatively consistent views, believing that there is an interaction between technological innovation and green logistics. Zhang and Jiang [6] used the dynamic panel data model and believe that technological innovation is expected to make greater contributions to the long-term development and logistics quality of the logistics industry. According to the PVAR model, Zhu and Lai [7] discovered that technology innovations have a stronger contribution to green logistics in eastern and central areas and a weaker contribution to western areas, while from the perspective of different regions, green logistics also has a positive contribution to technology innovations. Wei and Wang [8] proposed through an empirical study of case companies that along with the evolution of the times, green supply chains and technological innovation will maintain a mutually reinforcing relationship to realize the continuous growth of the logistics industry. Liang et al. [9] by building a spatial Durbin model found that technological advancement can successfully lower emissions of carbon in the logistics sector and accomplish low-carbon development in the logistics sector.

There are many studies related to technology innovations and green economics, and most researchers believe that technology improvements have a uniquely positive effect on green economy growth, but the green economy does not contribute much to the growth of technology innovations. Wang and Wu [10] believe that technological innovation, as a moderating variable, can significantly improve the contribution of environmental supervision to the high-quality growth of the green economy. Chen et al. [11]studied relationship between the development of green technology and green economy in Yangtze River Economic Zone and found that green technology development hinders green economy growth in short term and helps green economic growth in the long run, while the green economy has a technology growth has a weaker positive influence. Feng [12] suggests that green technological innovation is helpful in improving efficiency of the green economy. Li et al. [13] argue that within the context of green growth, technological innovation can have a positive impact upon green economies in the distribution sector. Su [14] used a panel vector autoregressive method of studying the influence of coordinated technology and innovations and ecological environment development on the green economy and found that the levels of coordinated growth of both have a lagged direct influence on green industries. According to Lahouel scientific and technological innovation can raise the productivity of green total factors and advance the growth of the green economy [15].

There are few relevant studies on green logistics and green economy, and domestic scholars mainly study the relationship between the two qualitative studies, but few quantitative studies. Zhang [16] proposed that green logistics is regarded as an important trend in urban logistics, and also a strong support for the green economy. Foreign scholars have highlighted the positive influence of green logistic the growth of green economy through empirical studies. Seroka-Stolka and Ociepa-Kubicka [17] proposed that green logistics is an internal condition for the growth of circular economy and is conducive to the closed-loop of circular economy. Yang et al. [18] studied the spillover impact of logistics efficiency on economy under low-carbon economy based on spatial econometric model, and found that reducing carbon dioxide emissions can improve economic efficiency. Gan et al. [19]analyzed the green logistics efficiency of 11 prefecture-level cities in Jiangxi Province using a three-phase data envelopment analysis (DEA) and found that the growth of green logistics has produced preliminary success in promoting economic development and is progressing toward a high-quality stage of “innovation, coordination, green, open and shared” development.

In conclusion, there is a close relationship between technological innovation, green economy and green logistics. Since 1978, when the strategy of sustainable development was put forward, the Chinese Government has introduced a series of relevant policies and laws to promote green development in the light of the actual situation of the country, such as the 14th Five-Year Plan for the Development of the Circular Economy, and the Action Program for Carbon Peak by 2030. As the role of modern logistics in supporting and guaranteeing the development of the national economy has increased significantly, the Chinese government has emphasized the important role of the logistics industry in promoting energy conservation and low carbon, and has successively formulated the “14th Five-Year Plan” for the development of modern logistics, and the “14th Five-Year Plan” Comprehensive Work Program for Energy Conservation and Emission Reduction, in the hope of establishing a modern green logistics system. Combing through the literature, we found that many scholars have carried out many useful explorations in the fields of ecological environment, energy and economy, and the unidirectional impact of technological innovation on green logistics and green economy as a key factor to promote low-carbon development has been explored in existing studies, but the interaction between technological innovation and green logistics and green economy needs to be further researched, and at the same time, it is unclear whether there is any mutual influence between green logistics and green economy. In summary, the motivation of this paper is threefold:First, it attempts to study green logistics, technological innovations and green economy under the identical frameworks, to fill in the blank of the comprehensive study of the three to some extent. Through the construction of panel vector autoregressive model, the interactive relationship among green logistics, technological innovation and green economy is analyzed empirically, and their dynamic influence path is discussed. Second, as one of the three variables, there is no unified standard for the development of green logistics index system, and the guidance of theoretical framework is lacking. This paper attempts to construct a green logistics growth system according to the driving force-pressure-state-influence-response (DPSIR) theory, thereby providing theoretical support to the construction of a green logistics evaluation structure. Thirdly, it overcomes the limitation of static research and explores the relationship and influence degree of the three under different periods from the dynamic perspective through impulse response analysis and variance decomposition.

This paper is structured as follows: Section 2 introduces the methodology used. Section 3 introduces the construction and selection process of three variables, namely, green logistics, technological innovation and green economy, and the related data sources, where the green logistics evaluation index system is constructed based on the DPSIR theoretical framework. Section 4 analyzes the empirical results. Section 5 provides a discussion. Section 6 draws research conclusions and recommendations.

2. Research methods

2.1. Entropy weight method

The choice of index weights has a direct effect on the accuracy of the test outcome. The entropy approach is widely used as an objectively assigned approach to measuring the weight of an indicator objectively. According to the research of Zhou [20], this paper calculates the comprehensive growth level of green logistics on the basis of entropy weight method.

The first step is the standardization of indicators. There are h years, m provinces and cities, and n indicators, and $x_{\lambda ij}$ is the index value of the j indicator of the i province and city in the λ year.

Positive index

$$Z_{\lambda ij} = \frac{x_{\lambda ij} - x_{\min}}{x_{\max} - x_{\min}} + 0.0001 \tag{1}$$

Negative indicators

$$Z_{\lambda ij} = \frac{x_{\max} - x_{\lambda ij}}{x_{\max} - x_{\min}} + 0.0001 \tag{2}$$

In equations (1) and (2), in order to eliminate the logarithmic influence, the data generally needs to be shifted to the right by 0.0001.

The next stage is the normalization of metrics.

$$p_{\lambda ij} = \frac{Z_{\lambda ij}}{\sum_{\lambda=1}^{h} \sum_{i=1}^{m} Z_{\lambda ij}} \tag{3}$$

The third stage is to calculate the entropy in every index.

$$E_j = -k \sum_{\lambda=1}^{h} \sum_{i=1}^{m} \left(p_{\lambda ij} \ln p_{\lambda ij}\right) \tag{4}$$

where $k = 1/\ln h$.

Step four, calculate the weights of each indicator.

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n} \left(1 - E_j\right)} \tag{5}$$

Fifth, calculate the influence index of each province and city in each year.

$$C_{\lambda i} = \sum_{j=1}^{n} W_j Z_{\lambda ij} \tag{6}$$

2.2. Non-expected output Super-SBM model

To assess the effectiveness of the green economy, the super-efficient SBM model of non-expected output is chosen [21], the model formula used in this paper is as follows:

$$\theta^* = \min_{\lambda,s^-,s^+} \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}^t}}{1 - \frac{1}{q+h}\left(\sum_{r=1}^{q}\frac{s_r^+}{y_{ro}^t} + \sum_{k=1}^{h}\frac{s_k^-}{b_{ko}^t}\right)}$$

$$\text{s.t. } x_{io}^t \geqslant \sum_{t=1}^{T}\sum_{j=1,j\neq o}^{n}\lambda_j^t x_{ij}^t - s_i^-; i = 1,2,\cdots,m$$

$$y_{ro}^t \leqslant \sum_{t=1}^{T}\sum_{j=1,j\neq o}^{n}\lambda_j^t y_{rj}^t + s_r^+; r = 1,2,\cdots,q \tag{7}$$

$$b_{ko}^t \geqslant \sum_{t=1}^{T}\sum_{j=1,j\neq o}^{n}\lambda_j^t b_{kj}^t - s_k^-; k = 1,2,\cdots,h$$

$$\lambda_j^t \geqslant 0(\forall j), s_i^- \geqslant 0(\forall i), s_r^+ \geqslant 0(\forall r), s_k^- \geqslant 0(\forall k)$$

In formula (7), n represents the number of decision-making units, and each decision-making unit has m inputs: $x_{io}^t(i = 1,2,\cdots,m)$, q expected outputs: $y_{ro}^t(r = 1,2,\cdots,q)$, and h unexpected outputs: $b_{ko}^t(k = 1,2,\cdots,h)$.

2.3. Panel vector autoregressive model

This method does not require prior research hypothesis, and can be used to directly test the interaction mechanism between variables. In this paper, panel vector autoregression (PVAR) model is applied to process each variable [22], in order to prove the influence relationship between green logistics, technological innovations and green economic. This model is constructed as follows:

$$Y_{it} = \alpha_0 + \sum_{j=1}^{p}\beta_j Y_{i,t-j} + f_i + d_t + \varepsilon_{it} \tag{8}$$

In formula (8), Y_{it} is a 1 × 3-order matrix, $Y_{it} = [\ln GL, \ln TE, \ln GE]$, *GL* is the level of green logistics, *TE* is the ability of technological

Table 1
Green logistics level index evaluation system based on DPSIR theoretical framework.

Target layer	Guideline layer	Factor layer	Indicator layer	Units	Properties of indicators
Green logistics development evaluation index system	Driving force (D)	Economic development	Gross domestic product (GDP) per capita (D_1)	Yuan/person	is
		Urbanization level	Urban/permanent population (D_2)	%	negative
		Consumer demand	Total retail sales of consumer goods per capita (D_3)	Hundred million yuan/ ten thousand people	is
	Pressure (P)	Logistics transport intensity	Turnover of goods/GDP(P_1)	Billions of tonnage kilometers/billions of yuan	negative
		Transportation demand	Freight volume per capita (P_2)	Tons/10,000 people	is
		Energy consumption	Energy consumption per unit of logistics output (P_3)	Tons of standard coal/ 100 million yuan	negative
		Environmental pollution	Carbon emissions per unit of logistics output (P_4)	Tons/billion yuan	negative
	State (S)	Infrastructure	Civilian truck ownership per 10,000 people (S_1)	Cars/10,000 people	is
			Per hundred square kilometers of highway (S_2)	Kilometers/hundred square kilometers	is
		Number of employees	Number of persons employed in road freight transport (S_3)	people	is
		Transportation structure	Proportion of road freight volume to total freight volume (S_4)	%	negative
	Impact (I)	Environmental impacts	Fine particulate matter concentration PM2.5(I_1)	Micrograms per cubic meter	negative
		Social impact	Unit logistics output accidents (I_2)	From/billion yuan	negative
	Response (R)	Financial input	Investment in environmental pollution control as a percentage of GDP (R_1)	%	is
			Investment in transportation fixed assets (R_2)	10,000 yuan	is
		Ecological construction	Green coverage rate of built-up areas (R_3)	%	is

innovation, *GE* is the level of green economy, and ln represents logarithm to eliminate the influence of heteroscedasticity on the model. α_0 is the vector of intercept term, j is the number of lag periods of variables, β_j is the regression coefficient matrix of lag endogenous variables, f_i is the fixed effect, d_t is the time effect, and ε_{it} is the random disturbance term.

3. Variable selection and data source

3.1. Variable selection and description

3.1.1. Green logistics index construction

With the continuous development of green logistics, what kind of index system and model to scientifically and effectively analysis the level of green logistics has become the direction of active exploration by scholars. At present, domestic scholars on the amount of green logistics research, to construct multi-dimensional index system evaluation methods. Zhu and Lai [7] proposed a comprehensive evaluation of China's green logistics level from five dimensions: ecological environment friendliness, sustainable development of logistics economy, logistics infrastructure, logistics development benefit and transformation of logistics power. Zhang and Zou [23] based on input, output, resource consumption, environmental pollution and environmental protection, the green transformation index evaluation system of logistics is constructed. Zhang et al. [24]considered subjective qualitative indicators and objective quantitative indicators. Zhang et al. [24]constructed a green logistics framework from the four perspectives of green packaging, green transportation, green logistics technology and green reverse logistics, and evaluated the level of green logistics in the express industry. These studies have enriched the theoretical connotation of green logistics evaluation. The index systems constructed by most scholars are based on the main features of green logistics, considering the economic and environmental benefits of logistics. However, the selected indicators are easy to have obvious regional characteristics and strong subjective judgment, so the constructed index system still lacks the support of the theoretical framework. In recent years, the driving force -pressure-state-impact-response (DPSIR) model has been constructed [25]. Because of its systematic, comprehensive and integrated features, it has drawn the concern of scholars and is widely used in the field of low-carbon transportation and green transportation. In order to accurately and scientifically measure the amount of green logistics, the paper builds a green logistics level assessment indicator framework according to the theoretical framework of DPSIR model, and the findings are presented in Table 1.

The action mechanism of green logistics under DPSIR theoretical framework is [26]: "Driving force" (D) is the fundamental factor impacting the change of green logistics and the rapid growth of social economy is the key to promote the growth of logistics. The improvement of urbanization level may lead to high population density, which will lead to a series of issues like environmental contamination and excessive consumption of materials, which may restrict the development of green logistics to some extent. Meanwhile, a large number of online purchases have formed a huge consumer demand, which provides opportunities and challenges for the growth of logistics. "Pressure" (P) represents the burden on resources and environment formed under the influence of driving forces. The rapid growth of logistics demand puts forward higher requirements on the transportation capacity of enterprises, while causing resource pressure and corresponding environmental pollution problems. Under the combined influence of the driving force and pressure, the logistics system will reach a state of "balance" (S) through the adjustment mechanism, that is, the current status of logistics facilities, including the current infrastructure construction and human input, and at the same time, it will adjust its transport structure to meet the needs of sustainable growth. The operation of the logistics system in this state will have some negative effects on the society and environment (I), such as increased possibility of traffic accidents, decreased air quality, etc. Therefore, in order to maintain this equilibrium, policy makers take a number of actions to respond to (R) and improving the condition of the logistics system. By increasing financial investment and strengthening ecological construction, we will improve the green amount of the logistics system and realize the green and sustainable progress of the logistics system.

3.1.2. Technological innovation

Learning from the research of Wang and Wu [10], the number of patent applications per capita was utilized to gauge technological innovations.

3.1.3. Construction of green economy indicators

Most scholars use data envelopment analysis to measure the effectiveness of green economics. Zhang and Guo [27] According to the super-efficiency SBM model, the green economic impact of cities in the Yellow River Basin was measured by considering capital, labor

Table 2
Input-output index system of green economy efficiency.

First-level index	Secondary indicators	Indicator measure	Units
Input indicators	Capital input	Fixed capital stock	Hundreds of millions
	Labor input	Urban employment	10,000 people
	Energy input	Electricity consumption	Gigawatt hours
Output metric	Desired output	Real GDP	Hundred million yuan
	Undesirable output	Industrial wastewater discharge	Tons
		Industrial sulfur dioxide emissions	Tons
		Industrial smoke (powder) dust emissions	Tons

and resources from the input perspective, economic and environmental benefits from the expected output and three industrial wastes from the non-expected output. Starting from the input of energy, capital and labor, Wang et al. [28]used the actual GDP of every province as the anticipated outcome, and the combined output of the three industrial wastes to obtain the total industrial pollution as the unanticipated output, and calculated the green economic efficiency using the super efficiency SBM of the unanticipated output. Zeng and Xiao [29] used the global malmquist luenberger (GML) index to analysis the green economy efficiency of 253 Chinese cities at prefecture level and above. This study measures the effectiveness of the green economy employing the super-efficiency SBM model of undesirable output. Input-output indicators commonly used by scholars are used in the selection of indicators. This specific indicator sample is indicated in Table 2.

Among them, the fixed capital stock is measured by the permanent inventory approach using the equation that follows:

$$K_t = I_t + (1 - \delta_t)K_{t-1} \tag{9}$$

In formula (9), I is the overall quantity of fixed assets created during this time, which is analyzed by employing the overall amount of fixed assets formed and the price deflator of fixed assets. δ is the depreciation rate, referring to the practice of Shan [30], which is 10.96%. The base period fixed capital stock uses the total fixed capital formation of each province in 2001 divided by the sum of the depreciation rate and the average of the investment growth rate between 2001 and 2005. Expected output is gauged by gross regional products. To prevent output measurement due to price fluctuations, GDP is treated by the index subtraction method, using 2000 as the base period, which is similar to the statistical caliber of capital stock. The entropy method is used to sort out the three indexes of non-expected output into the comprehensive index of environmental pollution.

3.2. Data sources

Existing studies are based on different methods, research regions and evaluation indexes, and the results obtained are difficult to compare, and the generalizability of the research conclusions is low, which is not conducive to macro decision-making at the national level. As a practitioner of green economic development, it is necessary for China to break through the limitations of a single industry or region, clarify the comprehensive development level of the three major subsystems in each province, and systematically consider the interactive response relationship among the three. According to the research needs, the panel data of green logistics, science and technology innovation and green economy of 30 provinces and cities in China (including municipalities, autonomous regions and administrative regions) in 2010–2020 were selected, excluding Hong Kong, Macao and Taiwan, and Tibet was not included due to the lack of multivariate data. The database comes from China Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, as well as statistical yearbooks and bulletins of each province. Meanwhile, to ensure the reliability and robustness of the results and avoid heteroskedasticity, all variables are treated with logarithms. Table 3 summarizes the results of the statistical analysis for each variable.

4. Empirical results and analysis

4.1. Panel data unit root test and co-integration test

Before panel vector autoregression, in order to prevent spurious regression problems arising from unstable variable observations, unit root stationarity test should be conducted for each variable. In the present work, four methods are adopted to carry out stationarity test. If the original logarithm sequence test results are not stable, first-order difference processing should be performed and unit root test should be carried out again until the result is stable. For further analysis, the results of the test are displayed in Table 4.

As indicated by Table 4, the test results of variables D (lnGL), D (lnTE) and D (lnGE) after first-order difference are all stable, and differential variables can be introduced later for PVAR model estimation. In order to examine further if there is cointegration among the variables, the Pedroni test is chosen for cointegration testing in this paper. The findings demonstrate that there is a co-integration connection because each of the three test statistics denies the original hypothesis at a level of importance of 1%.

4.2. The optimal lag order is determined

After the stability test of the panel unit root, the panel vector autoregressive model also needs to define the optimized lag order. In the present work, the optimized lag order of the model is identified on the basis of the lowest of the akaike information criterion (AIC), bayesian information criterion (BIC), and hannan-quinn information criterion (HQIC), and the findings are presented in Table 5. The optimized lag order of PVAR sample is 1.

Table 3
Descriptive statistics of each variable.

Variables	Sample size	Mean	Standard deviation	Minimum	Maximum
GL	330	0.446	0.061	0.261	0.585
TE	330	11.014	13.172	0.469	74.383
GE	330	0.653	0.278	0.167	1.53

Table 4
Test results of panel unit root.

Variables	LLC test	IPS test	Fisher ADF test	Fisher PP test	Conclusion
lnGL	-6.283 ***	-3.766 ***	65.702	108.186 ***	Uneven
D (lnGL)	-19.348 ***	-7.234 ***	261.438 ***	327.798 ***	Smooth
lnTE	-6.328 ***	-0.025	115.083	111.423	Uneven
D (lnTE)	-12.546 ***	-5.376 ***	161.193 ***	336.915 ***	Smooth
lnGE	-8.770 ***	-5.787 ***	111.328 ***	218.056 ***	Smooth
D (lnGE)	-9.021 ***	-7.465 ***	111.773 ***	430.890 ***	Smooth

Note: *, **, and *** mean significant at the 10%, 5%, and 1% confidence levels, respectively.

Table 5
Optimal order of hysteresis selection of the model.

Lag order	AIC	BIC	HQIC
1	-2.489 *	-1.054 *	-1.911 *
2	-1.619	0.102	-0.923
3	0.599	2.675	1.441
4	3.149	5.678	4.177
5	3.217	6.353	4.491

4.3. Model stability test

Next, the stability test of the PVAR model is carried out. If all the unit root eigenvalues of the model are distributed inside the unit circle, it is stable. The results are shown in Fig. 1. The model is deemed to be stable because, as shown in Fig. 1, the modes of the three feature roots are all contained within the unit circle.

4.4. Generalized method of moments (GMM) estimation result analysis and impulse response analysis

In this paper, the PVAR model is estimated based on generalized distance estimation (GMM), and the detailed findings are presented in Table 6.

It can be indicated by Table 6, Green logistics as a response variable, the coefficient of technological innovation and green economy lagging one stage behind is negative and not significant, indicating that technological innovations and green economy development in the early stage cannot promote the growth of green logistics. Technological innovation as a response variable, the coefficient of green logistics lagging one stage behind is positive and significant at the 1% level, and the effect of green economy is not significant. It shows that growth in green logistics is a driver of technical progress, while growth in the green economy does not contribute much to

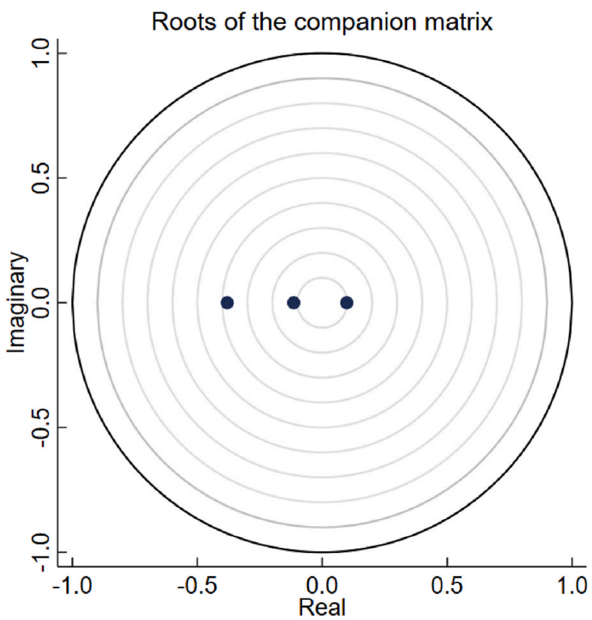

Fig. 1. Stability test of PVAR model.

Table 6
GMM estimation results.

Variables	h_D (lnGL)	h_D (lnTE)	h_D (lnGE)
L1.h_D (lnGL)	-0.494***	2.187***	30.179***
	(0.054)	(0.306)	(4.012)
L1.h_D (lnTE)	-0.003	-0.483***	0.285
	(0.009)	(0.061)	(0.341)
L1.h_D (lnGE)	-0.002	-0.021	-0.818***
	(0.004)	(-0.021)	(-0.131)

Note: L1.h means lag 1 period; Standard error in brackets; *, **, and *** mean significant at the 10%, 5%, 1% level, separately.

technological innovation. When the green economy is used as the response variable, the co-efficient of green logistics is positive at one stage lag and remarkable at the 1% level, while the effect of technological innovations is not significant, suggesting that green logistics develops a good influence on green economy. However, in the short term, technological innovation cannot contribute to the growth of a green industry.

Generalized distance estimation can only allow the analysis of short-term dynamic relationships among variables. Impulse response analysis is needed to better understand the long-term mechanisms of influence between variables. Impulse responses can model the magnitude of the normalized impact of one variable on other variables, assuming that the rest of the variables are held constant. Fig. 2 represents an impulse response function with three variables, the middle line represents the impulse response value, the two outside lines represent the upper and lower bounds of the 95% confidence interval, the vertical axis represents the positive, negative and strong responses, and the horizontal axis reflects the final count of lags of the impact.

As can be seen from Fig. 2, when green logistics is impacted by itself, the first phase is when the impact on itself is at its greatest, and then tends to decline, maintaining a stable positive response. This indicates that green logistics has its own strengthening mechanism, but with the passage of time, its strengthening effect will gradually weaken. After the impact of technological innovation, it will have a

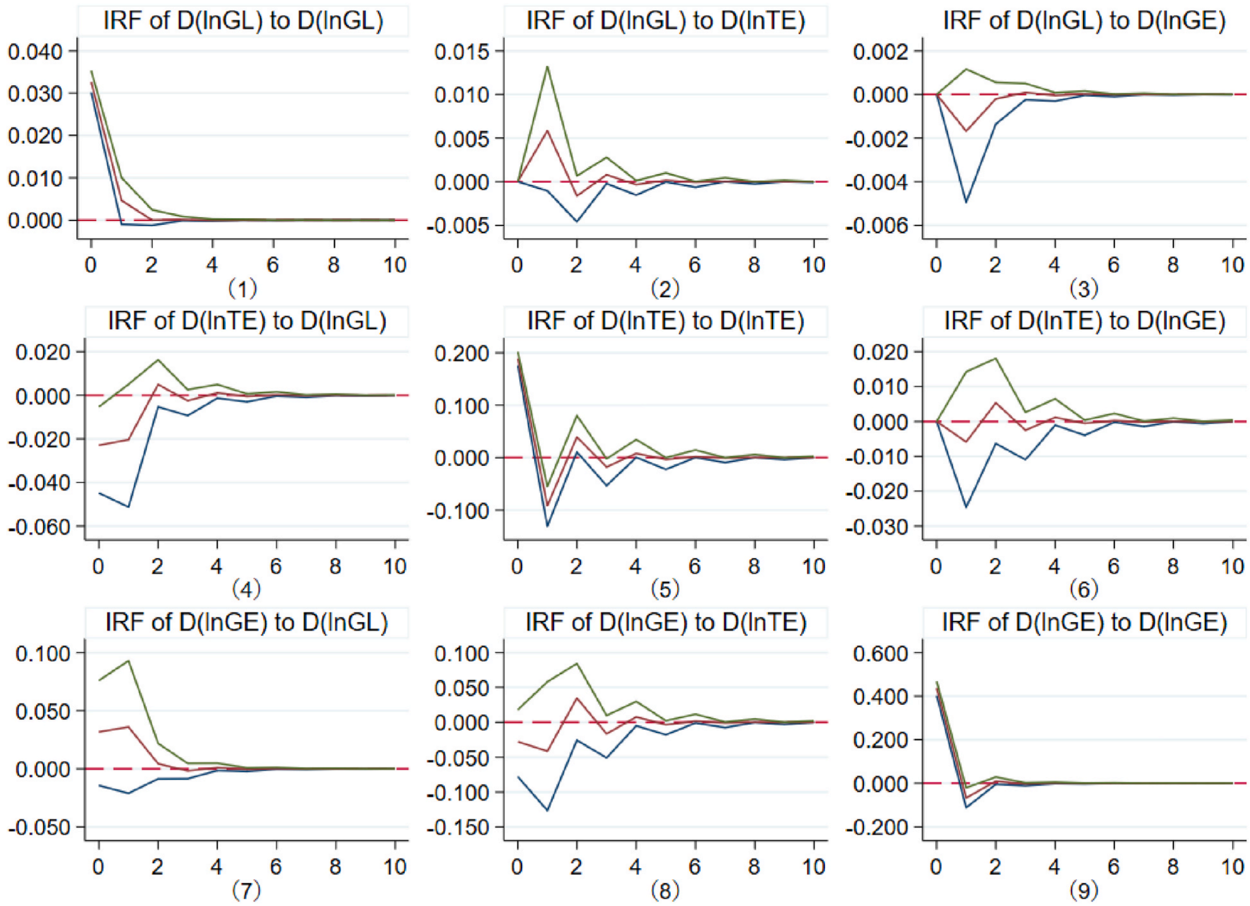

Fig. 2. Impulse response of green logistics, technological innovation and green economy. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

slight positive effect on itself, and this positive effect gradually weakens with the passage of time, and will gradually disappear after the fourth phase, demonstrating the insufficient influence of technological improvement on green logistics. When impacted by green economy, the negative impact on itself "increases first and then decreases". The third period lags behind and the negative impact fades away, indicating that the green economy is not the primary driver of green logistics, and even impedes the development of green logistics to some extent.

When technological innovation is influenced by itself, it exhibits a large positive reaction in the current phase, while in the next lag period, the positive impact turns to a negative impact, and then shows a slight floating trend until it disappears. When impacted by green logistics, it represents a huge negative impact on itself. This adverse effect diminishes when the number of lag periods increases and will gradually turn positive after the second period, suggesting that the existing green logistics developments have a lagging impact on the enthusiasm of promoting technological innovation and that the link between green logistics developments and technological innovation is not strong enough. According to the viewpoint of improving the level of green logistics, a systematic research and development system ought to be created to promote the innovation of green logistics technology. When it was hit by the green economy, it had a slight adverse effect on itself, and this effect picked up in the third period, indicating that the developing green economy cannot effectively enhance the scientific and technological innovation capabilities, probably because the current green economy model and the existing degree of scientific and technological innovation are not high, so the scientific and technological innovation should be increased to improve the development of the green economy, thus promoting the process of green economic growth.

When green economy is impacted by itself, the current period realizes the greatest value for the positive impact, and then the slight negative impact appears until it disappears. It is possible that there are still some aspects of green economy development in our country that are not sustainable. When it is impacted by green logistics, it has an obvious affirmative influence on itself, which gradually decreases and disappears after 2 periods lag, which proves that the green logistics will contribute to the improvement of the level of green economic growth. When it is impacted by technological innovation, it has obvious negative influence on itself. After three lagging periods, the negative impact shifts to a positive one, the increase in technological capacity increases the growth level of green economy to some extent over time. Therefore, the establishment of specialized research and development institutions and the strengthening of green technology innovations can ensure the sustainable expansion of green economy.

4.5. Variance decomposition

According to the results of the impulse replies, further variance analysis can be conducted to know the extent of mutual influence

Table 7
Variance decomposition prediction.

Variables	Forecast period	Shock variables		
		D (lnGL)	D (lnTE)	D (lnGE)
D(lnGL)	1	1.000	0.000	0.000
	2	0.967	0.030	0.003
	3	0.965	0.033	0.003
	4	0.964	0.033	0.003
	5	0.964	0.033	0.003
	6	0.964	0.033	0.003
	7	0.964	0.033	0.003
	8	0.964	0.033	0.003
	9	0.964	0.033	0.003
	10	0.964	0.033	0.003
D (lnTE)	1	0.014	0.986	0.000
	2	0.021	0.978	0.001
	3	0.021	0.978	0.001
	4	0.021	0.978	0.001
	5	0.021	0.978	0.002
	6	0.021	0.978	0.002
	7	0.021	0.978	0.002
	8	0.021	0.978	0.002
	9	0.021	0.978	0.002
	10	0.021	0.978	0.002
D (lnGE)	1	0.005	0.004	0.991
	2	0.011	0.012	0.976
	3	0.011	0.018	0.970
	4	0.011	0.019	0.969
	5	0.011	0.020	0.969
	6	0.011	0.020	0.969
	7	0.011	0.020	0.969
	8	0.011	0.020	0.969
	9	0.011	0.020	0.969
	10	0.011	0.020	0.969

between green logistics, technological innovation, and green economy. Table 7 presents the outcomes.

It can be seen from Table 7 that green logistics makes the greatest contribution to itself. Meanwhile, the contribution of technological innovation to green logistics also increases with the passage of time; while the contribution of green economy to green logistics is stable at a low level, indicating that the improvement of the growth level of green logistics mainly according to its own strengthening effect. For technological innovation, its contribution to itself is far greater than that of other variables, which suggests that technological innovation possesses a significant self-reinforcing influence. Over time, the response of green logistics to technological innovations has increased, while the response of the green economy to technological innovations has increased slightly and is smaller than the contribution of green logistics, suggesting that technological innovations are more dependent on the evolution of green logistics than the green economy. For the development of green economy, the greatest degree of contribution to itself, at the same time, the degree of contribution of both green logistics and technological innovation to the green economy has increased over time, and the contribution of technological innovation to the development of green economy is greater than that of green logistics, indicating that the development of green economy depends more on technological innovation than on the development of green logistics.

4.6. Granger causality test

Granger causality test was used to identify whether there is a causal link with the three variables of green logistics, technological innovation and green economy, and the results can be found in Table 8.

As seen in Table 8, neither technological innovation nor green economy are Granger causes of green logistics, indicating that they are not the main driving factors of green logistics; Green logistics is the Granger cause of technological innovation; But green economy is not the green reason of technological innovation, which indicates that green economy is not the main driving factor of technological innovation; Green logistics and technological innovation are both the green reasons for green economy. Granger causality test further confirms the above view that green logistics significantly contributes to the growth of technological innovation and the green industry, and technological innovation also contributes to the green economy.

5. Discussion

From the results of the empirical analysis, green logistics plays a positive role in promoting technological innovation, but its positive effect has a certain lag effect, which is consistent with the existing research [7,31], indicating that green logistics creates a good environment for the development of technological innovation, but when the initial level of green logistics is low, the standard of requirements for green logistics is low, and then the development of technological innovation is not enough attention, with the improvement of green logistics efficiency, the higher the demand for technological innovation, so the investment in technological innovation will increase [32]. Generally speaking, technological innovation has a tendency of increasing marginal returns to the development of logistics industry, and the long-term positive effect is more significant [33], but the study in this paper shows that the driving effect of technological innovation on green logistics is not significant, and the conclusion of Xie [34] is consistent with this paper. It indicates that the gap between existing logistics technology and low carbon standards is large, and although some advanced technologies have been introduced, they still cannot meet the requirements of green transformation of logistics industry in the new era, and there are still certain problems in the process of technological innovation and transformation of results, which fail to significantly play the leading role of technological innovation on green logistics. Of course, some scholars believe that the relationship between the two is a mutual promotion [32]. Green logistics plays a leading role in the development of green economy, which reached a consensus with Xie et al. [35]. At the same time, technological innovation has a significant role in promoting the green economy, and Chen et al. [11]also concluded that there is a short-term inhibitory and long-term positive promotion effect of technological innovation on the green economy. However, due to the high cost of technological innovation and the difficulty of transforming the results, there is a time-varying effect on the green economy, thus some scholars believe that technological innovation will have a dampening effect on the green economy in the short term due to the high cost of investment [36], while others consider that technological innovation will be influenced by other factors and thus have different indirect effects on the green economy [37,38].

The contribution and significance of this study can be summarized as follows: from a theoretical perspective, it provides a theoretical framework to guide the construction of an evaluation system for the level of green logistics development, which is different from the previous studies that constructed the evaluation system of green logistics indicators from the connotation of green logistics

Table 8
Results of Granger causality test.

Null hypothesis	χ2 value	Degrees of freedom	*P*-value	Results
D (lnTE) is not the Glencause of D (lnGL)	1.072	1	0.300	Acceptance
D (lnGE) is not the Glencause of D (lnGL)	0.744	1	0.388	Acceptance
All variables are not D (lnGL) for Glencause	2.177	2	0.337	Acceptance
D (lnGL) is not the Glencause of D (lnTE)	20.826	1	0.000	Rejection
D (lnGE) is not the Glencause of D (lnTE)	0.932	1	0.334	Acceptance
All variables are not D (lnGL) for Glencause	22.178	2	0.000	Rejection
D (lnGL) is not the Glencause of D (lnGE)	44.290	1	0.000	Rejection
D (lnTE) is not the Glencause of D (lnGE)	2.887	1	0.089	Rejection
All variables are not D (lnGE) for Glencause	48.499	2	0.000	Rejection

development. Considering that the green logistics system involves multiple aspects such as the environment, economy, society, resources, and so on, and that the introduction of the DPSIR model, as a kind of effective integration, is It can clarify the connection, role and feedback relationship between each indicator, and has significant advantages in analyzing the complex logical relationship of multiple indicators. Therefore, this paper adopts the DPSIR model to analyze the interaction between logistics resources and the environment from a system perspective, which can reflect the influence and constraints between human logistics activities and the economic environment, and make the structure of the indicator system clearer by decomposing the complex process of the role of each indicator, avoiding to a certain extent the strong subjectivity in the construction of the indicator system and the repetition of the indicators. From a practical point of view, China's green economy is in the early stage of development, and has not yet been harmonized with the development of green logistics. According to the dynamic response mechanism between green logistics, scientific and technological innovation and green economy, the logistics industry needs to conform to the development trend of the times, establish a low-carbon development system for green logistics, and actively transform to green logistics, so as to further promote green technological innovation, lay a solid foundation for the development of the green economy, and realize the sustainable development of the economic environment.

The article has some limitations: (1) data from some provinces are missing and cannot be included in the study, resulting in a less comprehensive study area (2) the findings are only applicable to the scope of this paper. In the future, the authors hope that the research area can be extended to other countries. In addition, the authors would like to divide the study into different regions and study the dynamic response relationship among the three from the perspective of regional heterogeneity in order to make more specific suggestions.

6. Conclusions and suggestions

6.1. Conclusions

With the deepening of green development research, green logistics and green economy have attracted the attention of scholars, and technological innovation is closely related to the development of green logistics and green economy, and the research on the interaction between technological innovation and green logistics and technological innovation and green economy has achieved certain results. By constructing a panel vector autoregressive model, this paper adopts a scientific approach to study the dynamic response mechanism between green logistics, technological innovation and green economy, explore a growth model that takes into account economic growth, energy conservation and emission reduction and environmental friendliness, and provide an empirical basis for the formulation of relevant policies. The main findings can be summarized as follows:First, green logistics, technological innovation and green economy all have strong self-dependence characteristics, which can promote their own development the most. Second, Granger causality test confirms the results of the above analysis. In the short term, technical advancement and the growth of the green economy cannot contribute to the growth of green logistics. In a long run, the promotion of technological innovation to the growth of green logistics is not obvious, and the green economy is not the main driving factor for the growth of green logistics, and even hinders the growth of green logistics to a certain extent. In terms of technological innovations, on a short-term basis, the growth of green logistics is a driver of technical progress, and growth of the green economies does not contribute much to technological innovation. In a long-term basis, the existing development of green logistics has a lagging impact in promoting the enthusiasm of technological innovation, and the growth of green economy cannot effectively promote the ability of technological innovations. For green economy, in a short-term basis, the growth of green logistics has a positive contribution to green economy; yet, technical advancements cannot support the growth of the green economy. In the long term, the positive impact of green logistics gradually decreases and disappears after a lag of 2 periods, indicating that the growth of green logistics will promote the growth amount of green economy. The positive effect of technological innovation towards green economy lags behind, and the negative effect turns to positive effect after three lagging periods, indicating that technological achievements need to be absorbed and transformed for a long time before they can play a promoting role in green economy. Thirdly, variance decomposition results show that green logistics is more strongly strengthened by itself; Technological innovation is more likely to be affected by green logistics; for green economy, technological innovation contributes more to it than green logistics.

6.2. Suggestions

This present research proposes the below recommendations on the basis of the aforementioned findings.

Firstly, enhance the growth of green logistics and green economics with technological innovation as the core. In the long term, technological innovation contributes to the development of green logistics and green economy, but its contribution to green logistics and green economy is relatively small. For the logistics industry, this may be due to: on the one hand, the transition cycle of technological innovation results is longer and the enhancement of green transformation in the logistics sector is slower; on the other hand, technological innovation may exist, but the hardware conditions such as infrastructure have not reached the applicable technical level. We can enhance the role of technological innovation in facilitating the growth of green logistics and green economies through self-improvement mechanisms, and accelerate the development of environment-friendly and low carbon technology including new energy, fresh materials, energy conservation and recycling, promote the use of environment-friendly logistics technologies and more sustainable equipment, actively develop environment-friendly logistics packaging, promote packaging recycling and reduce excessive packaging. And gradually realize the greening of commodity packaging. At the same time, we should reinforce the building of logistics infrastructure and guide logistics enterprises to increase the research and growth of new green logistics technology and the wide applications of green energy.

Secondly, accelerate the growth of green economy based on improving the growth level of green logistics. Green logistics is a vital component of green economy, through the establishment of green logistics can lower the overall cost and improve efficiency, but still have much room to improve the amount of development of the green economy. At present, the growth of green logistics should be on the basis of the Internet of Things and big data technology, combine intelligent hardware infrastructure and logistics information platform, commit to realizing intelligent distribution and transportation, fully employment of energy resources and equipment, enhance the intensive growth of logistics industry, and promote the realization of green business objectives.

Thirdly, take the development of green economy as the starting point to push China's green growth to the next level. Green logistics development is being hampered by the growth of the green economy, probably because green economy development involves consumption, investment, trade and other aspects, the promotion of energy conservation and environmental protection industry is not obvious, the state in the macro-control of economic green development can give green logistics enterprises appropriate policy support, to provide more convenience for the growth of green logistics, To improve the competitiveness of green logistics enterprises. At the same time, make full use of green economic benefits, constantly change the concept of traditional logistics enterprises, encourage them to innovate logistics management mode, practice the idea of green environmental protection, and realize the integration of economic, environmental and social benefits.

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The data presented in this study are available upon request from the corresponding author.

CRediT authorship contribution statement

Chaoyi Xu: Writing – review & editing, Writing – original draft. **Lan Li:** Writing – review & editing.

Declaration of competing interest

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