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An empirical study on the relationship between economic growth and forest carbon sink value based on PVAR model

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The dynamic relationship between the value of forest carbon exchange and economic growth has a significant impact on the sustainable development of China's economy and society. Hence, the consequences cannot be ignored even when China enjoys a win-win situation concerning environment and development. This study examines the economic growth and forestry data from 1995 to 2020 (2021 data from the Statistical Yearbook of China Forestry and Grassland in February 2023 has not been released) to calculate the forest carbon sink (using the forest stock method), estimate the forest carbon sink price, and establish a panel vector autoregression model. Pulse response analysis and variance decomposition are also used to test the dynamic relationship between economic growth and forest carbon sink value. The study finding reveal that during the research period, economic growth promoted the development of forest carbon sinks; forest carbon sinks "suppressed" economic growth in the short term; and the inhibitory effect of forest carbon sinks is no longer significant. The possible innovations and contributions of this study are: 1) Expanding relevant research on the calculation of the value of forest carbon exchange, using the forest accumulation method to calculate the province's forest carbon exchange, and using the production function of the number to estimate the price of forest carbon exchange. 2) Based on the requirements of the high-quality development stage of the economy, it can serve as a reference to formulate and improve policies for relevant departments (according to the empirical results), thereby helping the country achieve the "dual carbon" goal as soon as possible.

KEYWORDS
forest carbon sink value, economic growth, PVAR model, high-quality development, carbon sink development policy

1 Introduction

As socialism reflecting Chinese features has entered a new era, the country's economy has shifted to a high-quality development stage. Ecological civilization has emerged as a common demand worldwide. The "Outline of the 13th Five-Year Planning of the National Economic and Social Development" clearly mentions that it is essential to tackle the issue of climate change actively and promptly. Since the 18th National Congress of the Communist Party of China (CPC), China has accumulated 960 million acres and 1.24 billion acres of forests, thereby increasing the forest coverage rate to 24.02%. Contributing approximately a quarter of the new green area to the world, China is being recognized today as the fastest-growing forest resource in the world. The area of preserved plantation forests has reached

1.314 billion mu in China, ranking first in the world. At the 75th Session of the United Nations General Assembly, the "double carbon" goal also put forward higher requirements for China's economic development. In the process of achieving a win-win dynamic balance between the environment and development, the role of forest carbon sinks cannot be neglected.

Hence, the 2035 vision of a "stable decline in carbon emissions after peaking, fundamental improvement of ecological environment, building a beautiful China" in accordance with the standards for a progressive economic development phase, is in perfect alignment with the principal social and economic development objectives highlighted in the 14th Five-Year Plan period, aiming for "new progress in ecological civilization construction." Therefore, from the perspective of forest carbon sequestration, this study organically integrates the value of forest carbon sequestration with the pace of economic growth, exploring the dynamic relationship between the two factors. In addition, this study proposes several policy recommendations based on the empirical results, provides references for the relevant departments to formulate and improve policies, and promotes the development of forest carbon sink project effectively. To sum up, it realizes the ecological, social, and economic benefits of the win-win scenario for China to help the achieve the "double carbon" goal in the nearest future.

2 Literature review

As highlighted by Lin Ling, considering the volume and calculation of forest carbon exchange, diverse tree species in a respective locality display fluctuations in carbon exchange volume. Also, differences in geographical locations and climate conditions across diverse areas call for the consideration of additional factors (Wang, 2022). Liu et al. (2023) evaluated the carbon sink capacity of Canadian boreal forests; approximately 43% of the forest experienced a significant increase in tree mortality, thus resulting in a significant loss of biomass carbon. With an increase in drought conditions, the capacity of the Canadian boreal forest as a carbon sink is expected to reduce further. Girardin et al. (2022) evaluated the effects of different winter conditions on tree growth and forest carbon sequestration potential. Anderegg et al. (2022) provided risk maps of key climate-sensitive disturbances in the United States to improve forest carbon cycle modeling. Using six dynamic global vegetation models, Yu et al. (2022) estimated spatially explicit patterns of biomass losses from large unmanaged forest plots to constrain predictions of net primary productivity, heterotrophic respiration, and net carbon sinks. As defined by Shi et al. (2014), forest carbon sink measurement methods are principally dependent on sample surveys and micrometeorology techniques, including biomass, forest stock, sample land inventory, micrometeorology, box, and remote sensing estimation. Wang (2022) underlines the geographical distinctions in adopting various measurement models for forest carbon sink, thereby ensuing significant variations in parameter. Therefore, the establishment of a comprehensive forest carbon sink measurement and detection system is recommended. Zhang and Lin (2021) highlighted that the forest carbon sink calculated (based on data provided by the national forest resources inventory) is simple and practical, offering the advantage of directly and macroeconomically estimating the forest carbon sink in each province.

The determination of forest carbon sink price is a prerequisite for value measurement. Even though there is a fundamental difference between the two points, they affect each other considerably. The measurement of the value of forest carbon sink refers to the monetary measurement of the carbon dioxide that can be absorbed and stored by the forest. The determination of the unit price of a forest carbon sink and accurate measurement of forest carbon storage are the core processes to obtain the value of a forest carbon sink. The common forest carbon sink pricing methods in academia include the afforestation cost method, artificial fixed carbon dioxide method, carbon tax law, market price method, and mean value method. Zhang and Yi (2022) calculated the forest carbon storage of Chengde City using the accumulation expansion method. They also calculated the optimal price of forest carbon sinks using the optimal price model. Zhang and Chen (2021) calculated forest carbon storage in Fujian Province using the stock expansion method. In addition, they estimated the forest carbon sink value using the market value method. Cao et al. (2021) combined the self-value and option value of carbon sinks and built a carbon sink value evaluation model. They also engaged in the evaluation, analysis, and testing of the carbon sink value of the carbon sink afforestation project of the Fengning Qiansongba Forest Farm. According to Zhang et al. (2019), the evolutionary game has the evolutionary stable strategy (under the dynamic carbon trading price). Dynamic carbon trading pricing policy is effective in accelerating carbon reduction.

The development of forest carbon sinks contributes to both ecosystem betterment and economic development. Using the global forest product model, Ke et al. (2023), simulated the dynamic changes in China's forest resources from 2018 to 2060 under different carbon sequestration price scenarios. Thereafter, it was suggested that China's forest carbon sink would facilitate carbon peaking and carbon neutrality. Raihan and Tuspekova (2022) investigated the potential of economic growth, renewable energy utilization, and forest carbon sink capacity to achieve environmental sustainability in Malaysia. Yao et al. (2022) established a panel vector autoregression (PVAR) model based on the data from Chinese forestry from 1998 to 2018. Their findings demonstrated that economic growth could promote the development of forest carbon sinks; however, forest carbon sinks would negatively "inhibit" economic growth in the short term. Qin and Qu (2021) analyzed the advantages, disadvantages, opportunities, and challenges of county economic development to achieve carbon neutrality in Yiyang City using SWOT analysis. Du et al. (2021) discussed the transnational spillover effects of forest carbon sinks and expounded the direct effects of various economic development factors on forest carbon sinks. Xu et al. (2021) asserted that the forestry foreign exchange increase inflicts numerous positive effects on economic and social development with the tendency to promote the realization of the "carbon neutrality" goal. Based on the perspective of the social economy, Zhang and Lin (2021) claimed that the current improvement of the social and economic development may negatively enhance per capital GDP on forest carbon sinks. Miao et al. (2020) found that an increase in forest carbon storage promotes the growth of the total forestry output value in the province.

Despite the existence of different studies on forest carbon sinks, no conclusive study related to the long-term interaction between economic growth and the value of forest carbon sinks is available. Quantitative research is relatively scarce, the online carbon market time is short, and the operation situation is comparatively immature. Therefore, there is a need to further enrich the data and quantitative models. It is particularly important to select appropriate indicators to measure the price of forest carbon sinks (Wang and Zhi, 2018). In this study, 32 provinces (municipalities and autonomous regions) were selected as research samples from 1995 to 2020. The forest stock accumulation method was utilized to calculate the forest carbon sink in each province, whereas the translog production function was used to estimate the price of the forest carbon sink. Based on the available data and resources, a PVAR model was established using panel data. The dynamic relationship and mechanism between economic growth and forest carbon sink value were explored from the perspective of economic value, revealing that economic growth can positively promote the development of forest carbon sinks. Additionally, the realization of forest carbon sink value has a "negative" effect on economic growth in the short term. Hence, this study proposes the formulation of long-term forest carbon sink development policies, improvement in forest carbon sink trading platform, improvement in forest carbon sink pricing mechanism, solidification of forest protection, strengthening forest carbon sink poverty reduction function, and implementation of forest ecological compensation mechanism (Liu, 2021).

Based on the previous research experience, it can be concluded that there are mutually restricting factors in the synchronous development of economy and ecology. When it comes to the interaction between the development of forest carbon sinks and economic development, "whether constraints have always existed," "whether constraints have always existed" and "how to overcome them" are the major issues to study, address, and resolve. The possible innovations and contributions of this study are reflected in two aspects:

1) enrichment of the research theory on the relationship between forest carbon sink and economic growth. By using the transcendental logarithmic production function to estimate the price of forest carbon sink, and then calculating the value of forest carbon sink, the study could be considered persuasive and pertinent.
2) In this paper, the interaction between forest carbon sink and economic growth is explored. Additionally, the assumptions are made from the perspective of forest carbon sink and economic growth. Factors that may affect each other are analyzed in detail. Likewise, the stages of mutual promotion and constraint are deeply studied, thereby helping in the expansion of research content in related fields.

3 Theoretical analysis and hypothesis

In 1993, Panayotou propounded the Environmental Kuznets Curve (EKC) hypothesis while studying the relationship between the environment and economic growth. The EKC hypothesis describes the relationship between environmental quality and per capital income with an inverted U-shaped curve. Chinese scholars have studied the relationship between environmental quality and economic growth in the country employing both theoretical and empirical perspectives. The conclusions drawn resembled Panayotou's. The EKC pattern has a certain reference value for analyzing China's economic development practice. The above studies provide references for the analysis of the interaction between economic growth and forest carbon sink value (Figure 1).

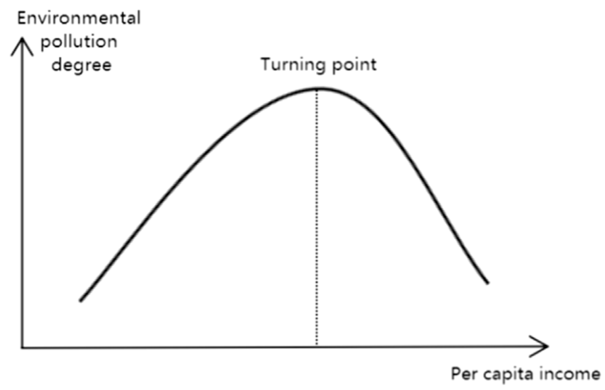

FIGURE 1
Environmental Kuznets curve.

Considering this specific study area, it is expected that economic development will experience a steady increase in environmental pollution, especially if Kuznets Curve Theory principles are employed. After reaching a critical threshold, pollution levels are expected to decline, adding to a general improvement in environmental conditions. This relationship between economic growth and environmental impact is truly dynamic. An underdeveloped economy is affected by uncontrolled population growth and the subsequent food demand. As the agricultural production level is low, more land will be reclaimed for planting food crops, crowding out forestry land. Additionally, extensive use of resources and increasing demand for wood and other forest products lead to the degradation of forest resources and low forestry economic returns. In this case, forests serve as carbon sources. However, with economic development and advancement of planting technology, food production is no longer dependent on farmland planting areas. In contrast, many farmlands with low economic yield have been returned to the forest. Scientific and technological progress has brought improvements in people's living standards; society has started to pay more attention to environmental protection; laws and regulations related to environmental protection have been improved; the structure of the forestry industry has become more reasonable; forest resources have gradually recovered; the forest carbon sink function has emerged.

Hence, this study analyzes the following two aspects:

3.1 Economic growth helps increase the value of forest carbon sinks

Despite China's switch to high-quality development, there is still a long way to go when it comes to ecological environmental protection with more emphasis on the green and low-carbon economic development model. Since the 18th National Congress of the CPC, China's key forestry ecological projects have been successful in achieving remarkable results. Forest carbon sequestration is not only an important way to offset industrial carbon emissions, but also an economic option to develop a green and low-carbon economy. Ding Shiyong, a member of the National Committee of the Chinese People's Political Consultative Conference and Vice Chairman of Chongqing, stressed in an interview that to help the green transformation of traditional industries, the development of a financial hierarchical incentive method with a combination of points and points is crucial. According to Jiang et al. (2022), when the profits of the manufacturing industry exceed the investment, enterprises can form a stable situation of adopting corporate green and low-carbon innovation technologies. Forest carbon sinks have both natural and socio-economic attributes. Therefore, the study of forest carbon sink value should be concerned with nature and social economy aspects. As identified in this study, the impact of economic growth on the value of forest carbon sinks has three aspects. First, economic growth promotes technological progress and produces a substitution effect, making forestry industry structure more reasonable. The more developed the forest economy is, the higher the output value of the tertiary industry will be. Weakening the dependence of forest farmers on the primary and secondary forestry industries helps change the extensive economic model. The impact of social economic activities on the ecosystem also increases the input to the forest ecosystem. Increasing investment in the tertiary industry, making use of the former state-owned forest farm department and other existing buildings and existing construction land, constructing the infrastructure for the integrated development of the three industries in the forest area, and constructing the infrastructure for tourism in the forest area, are conducive to the healthy development of forestry, the improvement of forest carbon reserves, and the increase of forest carbon sink value. Second, with the sustainable and healthy economic development, the government increases the investment in the forest ecosystem, continuously improves the policies supporting forest operation, expands the supply of forestry investment, promotes the increase of forest resources, and increases the value of forest carbon sink. At the same time, increasing government financial appropriation has a positive effect on improving enterprises' enthusiasm to participate in carbon sink trading activities, ultimately promoting the development of forest carbon sinks, and improving the forest carbon sink value. Third, China's traditional growth mode of "high energy consumption and high emission" did achieve high growth to some extent in the early stage of economic development. However, in recent years, as economic development gradually enters a high-quality development mode, the government gives more importance to the environment with strong efforts to reduce emissions. Consequently, it results in the reduction of carbon emissions, and forest carbon sinks become a scarce commodity. It is, therefore, essential to promote the increase of forest carbon sink scale and the value of forest carbon sink. Hypothesis H1 is proposed in this study.

H1: Economic growth promotes the development of forest carbon sinks and increases the value of forest carbon sinks.

3.2 The realization of forest carbon sink value can promote economic growth

Since the 18th National Congress of the CPC, the government has attached great importance to environmental protection. Local governments have intensified their efforts to protect forest resources. While realizing the value of forest carbon sinks, certain measures have been taken to promote economic growth, including increase in the income level of forest farmers, augmentation of training and employment opportunities, and improvement in the regional forestry industry structure. According to this study, the impact of forest carbon sink value on economic growth can be explained considering the following three aspects:

1) The route to carbon finance; through the direct implementation of carbon sink projects, expansion of financing channels, realization of diversified social capital financing, and stimulation of the vitality of carbon financial capital can be achieved. In turn, it may help in the transformation of "ecological value" to "economic value."
2) The government ecological compensation route; with forest natural capital investment as the intermediary, the diversified economic benefits of forest resources can be realized, and government financial revenue can be increased using carbon trading and carbon credit. The government will then implement long-term investment projects and forest carbon sink equity financing and issue forest carbon sink bonds. The government will also implement forestry ecological engineering projects and forest ecological benefit compensation projects. If the income is distributed to rural households, forest land investment, property rights transfer, participation in reforestation projects, forest tourism development projects, and other economic activities could help them increase their income using diverse channels. Thus, the forest carbon sink can play a critical role in poverty reduction, effective expansion of the total social supply, development of opportunities for the poor, and promotion of sustainable and healthy economic development.
3) The industrialization route of forest carbon sink; the ecological basis of forest resources provides the premise for establishing industries with forest carbon sinks as the core and promotes the optimization of the forestry industry structure. Reliance on forest carbon sinks' development and industrialization, their economic value, high-value-added agricultural and forestry products, and ecological tourism and similar economic values can be shown. The economic income can be reinvested in the forest carbon sink and other projects to ensure running a positive cycle. For example, in provinces with developed forest resources, ecological tourism can be developed utilizing the resources to achieve coordinated development of forest carbon sinks and economic growth. Therefore, hypothesis H2 is proposed in this study.

H2: The realization of forest carbon sink value can promote economic growth.

4 Research design

4.1 Research sample and data source

In this study, data from 32 provinces (municipalities and autonomous regions) from 1995 to 2020 was used for analysis.

Missing data from the Hong Kong Special Administrative Region, Macao Special Administrative Region, Taiwan Province, and Chongqing Municipality was excluded. Due to the lack of data on the number of employees and the amount of investment in fixed forestry assets at the end of 2001 in the Tibet Autonomous Region, the arithmetic average of the end of 2000 and the end of 2002 were calculated to replace it. To eliminate data heteroscedasticity and reduce data fluctuation, log processing was performed on the original data. The logarithmic gross regional product per capital (lnGDP) and the value of the forest carbon sink after logarithmic growth (lnV) were calculated. After the screening process, the study samples comprised 792 observations from 30 provinces (municipalities and autonomous regions).

Data was obtained from several authentic sources, including the National Bureau of Statistics, the State Forestry and Tobacco Administration, the China Statistical Yearbook, the China Forestry and Grassland Statistical Yearbook, the China Forestry Statistical Yearbook, National Forestry Statistical Data, and the National Tai' and Financial Research Database (CSMAR). Since the latest edition of the China Forestry and Grassland Statistical Yearbook has not yet been published, latest data from 2020 was used for empirical research and analysis.

4.2 Primary variable definition

The per-capital gross regional product of each province was selected as an indicator of economic growth, and the product of the calculated forest carbon sink and forest carbon sink prices was used to measure the value of the forest carbon sink. The variables used in this study are as follows:

4.2.1 Economic growth

Economic growth refers to the increase in the production capacity of goods and services in a country or region within a certain period. The indicators used to measure economic growth include GDP, per capital GDP, and GDP growth rate. This study used the per capital GDP of each province (city or autonomous region) to measure economic growth.

4.2.2 Forest carbon sink–related variables

4.2.2.1 Forest carbon sink (C)

Forest carbon sink can be regarded as the carbon sequestration capacity of the forest ecosystem, that encompasses tree species, understory vegetation, and woodlands. Hence, these features must be considered when analyzing and calculating forest carbon sinks. Considering data availability and calculation simplification, the forest stock method was adopted to calculate the forest carbon sink in each province. The principle of the forest stock method is to multiply the measured unit stock biomass of dominant forest tree species by the total stock to obtain the total biomass. The carbon content coefficient is also multiplied to obtain the desired forest carbon sink. Forest carbon sinks consist of three parts: biological carbon sequestration of trees, carbon sequestration of understory plants, and carbon sequestration of woodlands. The calculation method was as follows:

$$\begin{aligned} C &= C1 + C2 + C3 \\ &= \nu \times \delta \times \rho \times \gamma + \alpha(\nu \times \delta \times \rho \times \gamma) + \beta(\nu \times \delta \times \rho \times \gamma) \end{aligned} \quad (1)$$

where C represents the total forest carbon sink obtained by the study; C1, C2, and C3, respectively represent forest carbon sink, understory plant carbon sink, and forest carbon sink; v stands for forest stock; δ, ρ, and γ denote the accumulation expansion coefficient, volume density, and carbon content, respectively; α and β represent the carbon conversion coefficients of understory plants and woodland, respectively. α and β use the default values of 0.195 and 1.244, respectively, by the Intergovernmental Panel on Climate Change. Thus, (1) can be simplified as:

$$C = 2.439(\nu \times \delta \times \rho \times \gamma) \quad (2)$$

This study used the simplified method for calculating forest carbon sink, where δ, ρ, and γ were 1.9, 0.5, and 0.5, respectively. Since the update cycle of China's forest resources inventory data is 5 years, the calculated forest carbon sink of each province remains unchanged during each inventory period.

4.2.2.2 Forest carbon sink price (P)

The unit price of carbon sink is an important parameter to measure the economic value of forest carbon sinks. Currently, there is no uniform method to calculate the pricing of carbon sinks. Therefore, previous studies have employed different calculation methods, including the Cobb-Douglas Production Function Method and the Translog Production Function Method. In the Cobb-Douglas Production Function Method, the factors of each year are constant, a characteristic not aligned with reality. Hence, several studies have demonstrated the advantage of using the Translog Production Function Method to obtain more accurate results as it complements the available data. In addition, this study examined the interactive relationship between economic growth and forest carbon sink value. The Translog Production Function Method was used for forecasting considering its better reflection of the interaction between variables. The general form of the Trans-logarithmic Production Function is as follows:

$$lnY = \alpha + \sum_{i=1}^{n} \alpha_i lnX_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} lnX_i lnX_j \quad (3)$$

Considering different factors of the national economy, this study used the inclusive Translog Production Function to effectively study the interaction of input factors in the production function and the difference in the technological progress of each input. Based on the theory of marginal productivity, panel data covering the total output value of forestry, forestry capital stock, forest carbon sink, and forestry labor force and referring to the research method of Chen et al. (2022), a translogarithmic production function was used to estimate the price of forest carbon sink in each province.

$$\begin{aligned} lnY_{i,t} = {} & \alpha_1 \ln L_{i,t} + \alpha_2 \ln K_{i,t} + \alpha_3 \ln C_{i,t} + \alpha_{lc} \ln L_{i,t} \ln C_{i,t} \\ & + \alpha_{kc} \ln K_{i,t} \ln C_{i,t} + \alpha_{lk} \ln L_{i,t} \ln K_{i,t} + \alpha_{cc} (\ln C_{i,t})^2 \\ & + \alpha_{ll} (\ln L_{i,t})^2 + \alpha_{kk} (\ln K_{i,t})^2 \end{aligned} \quad (4)$$

TABLE 1 Descriptive analysis results.

VarName	Obs	Mean	Sd.	P5	Median	P95
lnGDP	792	0.6671	1.0145	−0.9576	0.7703	2.1747
lnC	792	9.6293	1.9410	5.4399	9.9339	12.1577
P	792	70.4701	248.7848	0.7649	19.5805	208.1844
lnV	792	12.4492	1.5016	9.2431	12.6959	14.5583
lnY	792	12.9111	1.4482	9.8994	13.1662	14.9606
lnL	792	0.8980	1.2974	−1.9540	1.0402	2.8956
lnK	792	11.8448	2.0324	8.3891	12.0907	14.6862

TABLE 2 Results (LLC unit root test).

Whether the time trend item is included	Variable	LLC inspection	
		Statistical value	*p*-value
No	lnV	−1.3036	0.0962
	lnGDP	−6.7276	0.0000***
Yes	lnV	−1.8472	0.0324*
	lnGDP	−1.1483	0.1254

Description: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

where Y, L, K, and C represent the total output value of forestry, forestry capital stock, forestry labor force, and the forest carbon sink, respectively; *i* and *t* represent time and study area, respectively. α_1, α_2, and α_3 respectively represent the output elasticity of forestry labor force, forestry capital stock, and forest carbon sink. A_{lc}, α_{kc}, α_{lk}, α_{cc}, α_{ll}, and α_{kk}, respectively represent the elasticity coefficients of the cross term and square term of each element of the forestry labor force, forestry capital stock, and forest carbon sink. After deriving and further simplifying Eq. 4, we can obtain:

$$\boldsymbol{P} = \frac{\boldsymbol{Y}}{\boldsymbol{C}}\left(\alpha_c + \alpha_{kc} lnK_{i,t} + \alpha_{cc} lnC_{i,t} + \alpha_{lc} lnL_{i,t}\right) \tag{5}$$

The forestry data from provinces (municipalities and autonomous regions) during 1995–2020 were substituted into Eq. 4. Thereafter, linear regression analysis was performed using stata16.0. The elastic coefficients obtained from the regression were substituted into Eq. 5 to calculate the forest carbon sink prices for each province during 1995–2020.

4.2.2.3 Forest carbon sink value (V)

To calculate the value of the forest carbon sink, the amount of carbon dioxide absorbed by the forest was expressed in monetary form (Liu et al., 2020). To better understand the economic benefits of forest carbon sink, the product of forest carbon sink and its unit price is generally used. In this study, the product of forest carbon sink and its price was used to measure the value of forest carbon sink.

$$\boldsymbol{V} = \boldsymbol{C} \times \boldsymbol{P} \tag{6}$$

4.2.2.4 Forestry output (Y)

Considering the availability of data, this study selected the total value of forestry output, expressed in monetary form as the total amount of tangible and intangible labor achievements in the cultivation, protection, management, and utilization of forestry resources over a certain period, as the index to measure forestry output.

4.2.2.5 Forestry labor force (L)

The forestry labor force consists of all personnel engaged, directly or indirectly, in production, technology, and economic activities in the forestry sector (Li and Zhang, 2021). However, due to the complexity of forestry production, it is relatively difficult to accurately count the number of employees outside the forestry system. Therefore, this study selected the number of employees in the local forestry system at the end of the year to reflect the forestry labor force.

4.2.2.6 Forestry capital stock (K)

The investment of forestry fixed assets in the completion of forestry fixed asset investment in each province during 1995–2020 was selected to replace capital stock.

Table 1 presents the statistical information on the numerical characteristics of the variables involved in this study.

4.3 Model construction

Newey extended the time-series analysis method to panel data analysis and proposed a Panel Vector Autoregressive (PVAR)

TABLE 3 Results (Fisher-ADF unit root test).

Whether the time trend item is included	Variable	Fisher's test—ADF	
		Statistical value	*p*-value
No	lnV	168.0946	0.0000***
	lnGDP	136.7831	0.0000***
Yes	lnV	81.7400	0.0325*
	lnGDP	279.9960	0.0000***

Description: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 4 AR model (lag order selection test).

Lag	CD	J	J *p*-value	MBIC	MAIC	MQIC
1	0.9997023	19.59049	0.07542	−57.75815	−4.409513	−25.1315
2	0.9999072	17.7785	0.0229498	−33.78726	1.778497	−12.03616
3	0.9999023	5.082401	0.2789466	−20.70048	−2.917599	−9.824929

TABLE 5 Estimated results [panel vector autoregressive (PVAR) model].

Variable name	lnGDP		lnV	
	Estimated value	Z value	Estimated value	Z value
L.lnGDP	1.322***	17.28	0.371***	3.60
L.lnV	−0.404***	−4.50	0.546***	4.52

Description: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

model. The PVAR method amalgamates the advantages of both the classical VAR method and panel data to process and analyze statistical data offering better identification of the influence of individual feature differences on regression fitting. All variables in the PVAR model are analyzed as endogenous variables. The response of one variable to the impact of another variable can be obtained through the orthogonalization of the error term, thus reflecting the dynamic interaction between different variables in the model. The PVAR model can be expressed as:

$$\boldsymbol{Y_{i,t} = \alpha_i + \beta_t + \varphi_1 Y_{i,t-1} + \varphi_2 Y_{i,t-2} + \cdots + \varphi_p Y_{i,t-p} + \varepsilon_{i,t}} \quad (7)$$

where $Y_{i,t}$ is the variable q × 1-dimensional vector of the section individual i at the time point t. $\varphi_{1,} \ldots, \varphi_p$ are the coefficients of a matrix of q × q to be estimated (q is the number of variables). α_i and β_t are individual effect vectors and time effect vectors of q × 1, respectively. $Y_{i,t\text{-}p}$ is the p-order lag term of $y_{i,t}$. The perturbation $\varepsilon_{i,t}$ satisfies the expectation of zero. The covariance matrix of Γ identically distributed independent variables, namely, $\varepsilon_{i,t}$~i.id(0, Γ), simultaneously meeting the conditions of E $(\varepsilon_{i,t}{}^{q}\alpha_{i,t}{}^{q},\beta_{i,t}{}^{q},y_{i,t\text{-}2}{}^{q}, \ldots) = 0$.

The endogenous problem of mutual causality is inevitable among macro variables (Fan and Peng, 2021). Therefore, this study used the PVAR model (without considering the endogenous problem) to investigate the interactive relationship between forest carbon sink value and economic growth. The selection of a PVAR model can not only retain the excellent characteristics of the vector autoregressive model, but also extends the simple time series model to the spatial direction, reduces the requirements on data length in modeling, and fully considers the heterogeneity of cross-section individuals. The PVAR model established in this study is as follows:

$$\boldsymbol{Y_{i,t} = \omega_0 + \sum\nolimits_{j=1}^{m} \beta_j Y_{i,t-j} + \varepsilon_{i,t}} \quad (8)$$

where $Y_{i,t}$ = (GDP, V) is the column vector of variables; economic growth and forest carbon sink value; ω_0 is the intercept term; i and t represent city and time, respectively; m represents the order of lag; β_j represents the coefficient of each lag term and the degree of interpretation of $Y_{i,t}$; and $\varepsilon_{i,t}$ is the random disturbance term.

5 Empirical test based on the PVAR model

5.1 Data stationarity test

Before conducting PVAR analysis, it is important to assess data stability and whether it is used without a unit root. Considering the significance of this condition, the LLC test method was adopted to conduct a unit root test on lnV and lnGDP. The LLC test results are presented in Table 2.

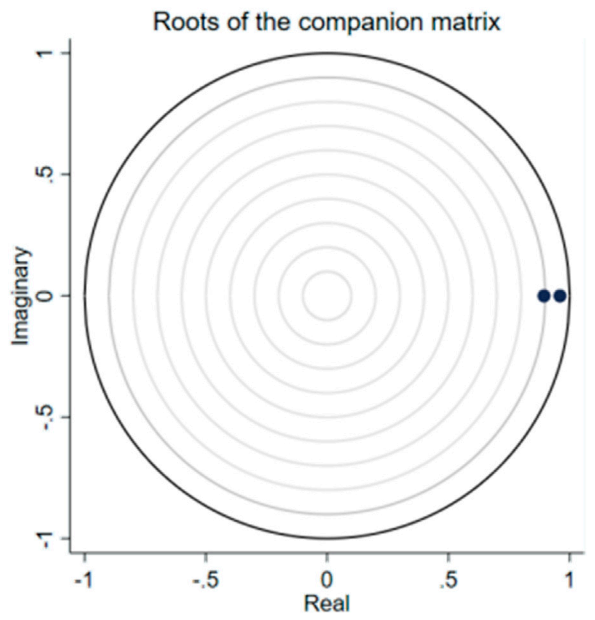

FIGURE 2
Stability test (panel vector autoregressive model).

To ensure the robustness of the unit root test results, the Fisher-ADf Test was used to conduct the second Unit Root Test for lnV and lnGDP. The results are listed in Table 3.

Based on the graph judgment, the lnV and lnGDP data passed the stationarity test, concluding that the estimation results of the model construction are significant for this study.

5.2 PVAR estimation

5.2.1 Optimal lag order selection

The PVAR model is highly sensitive to Lag Order. If the selected lag order is too large, the estimated parameters of the model will be amplified, and the degree of freedom will be reduced. If the selected lag order is too small, the reliability of the estimated results will be reduced (Ma and Zhao, 2021). Therefore, it is imperative to first determine the optimal lag order. In this study, the optimal lag order selection was conducted based on the principles of MBIC, MAIC, and MQIC (and the test results are listed in Table 4). The optimal lag order of the model was determined to be 1.

5.2.2 PVAR estimate

After the data passed the stationarity test and the optimal lag order of the model was determined, "L." was used to represent one period of lag. L.lnGDP and L. lnV are the lagged data of the primary variables, lnGDP and lnV, respectively. The PVAR model was constructed using processed data. The estimated results are shown in Table 5.

5.2.3 Model stability test

After constructing the PVAR model, it is essential to test the stability of the model. An AR root graph was used to test the stability of the PVAR model (results shown in Figure 2). The PVAR model has two real characteristic roots that fall within the unit circle. The PVAR model established in this study passed the stability test.

5.3 Granger causality test

The Granger Causality Test means that if the past information of variables X and Y are included, the prediction effect of variable Y is better than that of Y alone; that is, variable X helps to explain the future changes that may occur in variable Y; thus, variable X is considered to be the Granger cause of variable Y. Based on the PVAR model, this study further tested the Granger causality between the economic growth and forest carbon sink value of the provinces during the study period (Table 6).

At 0.01 significance level, the original hypothesis—*"economic growth is not the Granger cause of the value of forest carbon sinks"* is rejected. Instead, we suggest that economic growth is the Granger cause of the value of forest carbon sinks, indicating that the previous changes in the economic growth situation in the provinces can effectively explain the changes in the values of forest carbon sinks. Likewise, forest carbon sink value is the Granger cause of economic growth, and the early changes in forest carbon sink values in each province can also effectively explain the changes in economic growth. To sum up, a Granger causality exists between economic growth and forest carbon sink value.

5.4 Impulse response function analysis

The Impulse Response Function Model can reflect the economic significance contained in the PVAR model more intuitively and in detail. The Stata16.0 Software was used to conduct 300 Monte Carlo Simulation Impulse Response Analyses for economic growth (lnGDP) and forest carbon sink value (lnV) (results shown in Figure 3). The x-coordinate represents the number of response periods of the impact response, the y-coordinate represents the utility value of the impact, the dashed line represents the impulse response function, and the shaded part represents the standard deviation band of the 95% confidence interval. Figures 3A, B demonstrate the response of forest carbon sink value and *per capita* GDP, respectively, under the impact of forest carbon sink value. Figures 3C, D reflect the response of the forest carbon sink

TABLE 6 Results (The Granger causality test).

Null hypothesis	Chi2 statistics	Degree of freedom	*p*-value	Conclusion
lnV does not Granger-cause lnGDP	20.224	1	0.000	Refuse
lnGDP does not Granger-cause lnV	12.947	1	0.000	Refuse

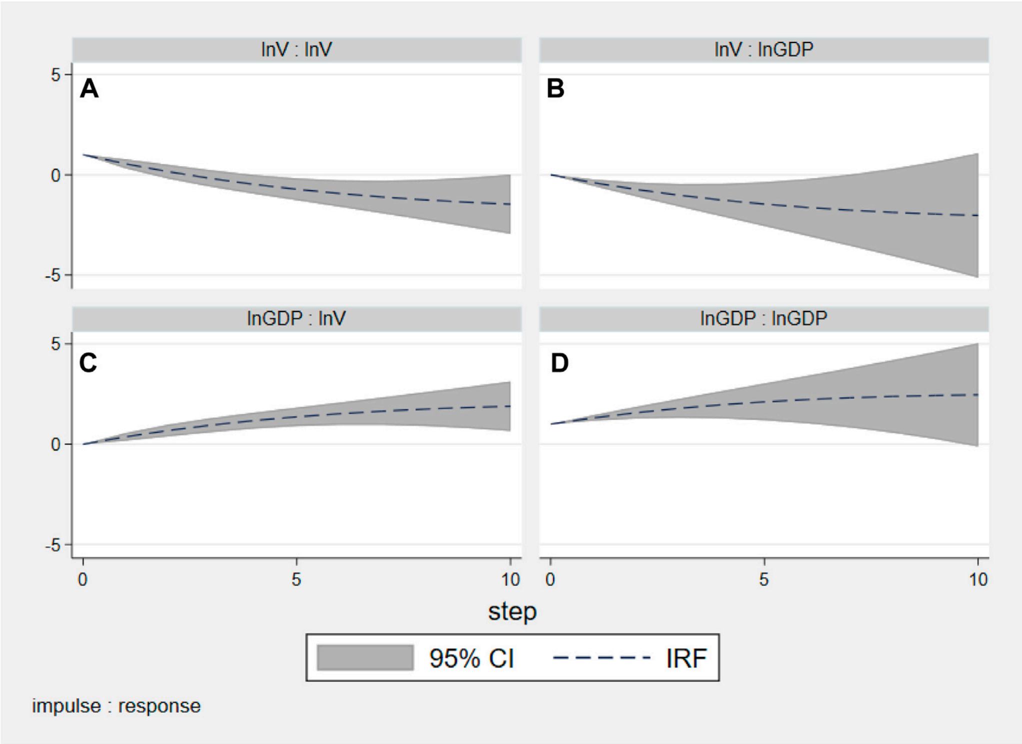

FIGURE 3
Impulse response analysis.

value and *per capita* GDP, respectively, under the impact of *per capita* GDP.

As shown in Figure 3A, the forest carbon sink value had a positive impact on itself in the first phase. However, the impact effect declined later. In the second phase, the standard deviation band of the 95% confidence interval exceeded the zero-value boundary and became a negative effect, thereby hindering the increase in the forest carbon sink value. The negative effect finally stabilized. Figure 3B shows that from the first to the fifth phase, faced with the impact of the forest carbon sink value, *per capita* GDP presented a negative inhibitory effect. In the sixth phase, the standard deviation of the 95% confidence interval covered the horizontal line y = 0. Yet, the hindrance to the increase in *per capita* GDP cannot reject the original hypothesis at the 5% significance level. As seen in Figure 3C, the shadow part gradually deviated from the horizontal line y = 0 from the first phase due to the impact of *per capita* GDP, thus indicating that the impact effect of *per capita* GDP on the value of forest carbon sink was gradually enhanced. As shown in Figure 3D, *per capita* GDP had a positive impact on itself in the first period, while the impact effect gradually became stronger and more stable.

5.5 Variance decomposition

The variance decomposition results of the endogenous variables, lnGDP and lnV, in the PVAR model obtained using the Stata16.0 Software are shown in Table 7.

According to the contribution rates of lnGDP and lnV to lnGDP, the economic growth in the first period was completely dependent on the economic growth in the previous period. To be precise, it had nothing to do with the value of forest carbon sink. In the following nine periods, the contribution rate of forest carbon sink value to economic growth showed a steady growth trend, with an average contribution degree of 43.22%. According to the contribution rates of lnGDP and lnV to lnV, the contribution of economic growth to the forest carbon sink value in the first phase was 17.8%. The remaining 82.20% was the contribution of the forest carbon sink value to itself. Progressing from the second to the fifth phase, the contribution rate of economic growth to the value of forest carbon sink gradually increased, reaching a peak of 52.61% in the fifth phase. However, there is a gradual decrease from the sixth to the tenth phase, with an average contribution of 41.04% (consistent with the conclusion of the impulse response analysis).

6 Analysis of empirical results

6.1 Economic growth has a positive effect on forest carbon sink development

In this study, the forest carbon sink value was considered the explained variable. According to the estimation results of the PVAR model, the impact of the first-order lagged economic growth on the forest carbon sink value was significantly positive, with a *p*-value <0.001, thereby indicating that economic growth had a significant positive effect on the improvement of the forest carbon sink value (supporting Hypothesis 1). The impulse response shows

TABLE7 Results (variance decomposition of forest carbon sink value and economic growth).

Period	Contribution rate to lnGDP		Contribution rate to lnV	
	lnGDP	lnV	lnGDP	lnV
0	0	0	0	0
1	1	0	0.1780283	0.8219718
2	0.8918289	0.1081711	0.2809851	0.7190149
3	0.7475816	0.2524184	0.3961055	0.6038946
4	0.624397	0.3756029	0.4868334	0.5131666
5	0.5305028	0.4694973	0.5261054	0.4738946
6	0.4604968	0.5395032	0.5188595	0.4811406
7	0.4078834	0.5921167	0.4866295	0.5133706
8	0.3676499	0.6323501	0.4469432	0.5530568
9	0.3362869	0.6637131	0.4086529	0.5913471
10	0.3113853	0.6886147	0.3749224	0.6250776
Average value	0.56780126	0.43219875	0.41040652	0.58959352

that the forward shock increased continuously from the first till the tenth period.

Economic growth has led to increased investments in forestry. Forestry, forest management, and infrastructure construction cannot be excluded or separated from capital investment. Coupled with the externality and weak condition of forestry, state financial investment is extremely important for the development of forestry. In China, with the sustained and healthy development of the economy, the central and local governments have gradually increased their investments in the forestry system, thereby vigorously implementing afforestation and forest tending projects, improving the ecological conditions of the forest, promoting the upgrading of the forestry industry, and promoting the development of the ecological economy as ongoing measures. Additionally, healthy economic growth makes forestry more attractive for social funding. Increased social investment is conducive to the construction of forest ecosystems, increasing forest stocks and promoting the development of forest carbon sinks consequently.

Economic growth has also contributed to the optimization of the structure of the forestry industry. According to the environmental Kuznets Curve, when economic development passes a critical value, the negative impact of human activities on the ecological environment weakens gradually, thus promoting an improvement in environmental quality. Presently, China's forestry industry structure is sequenced as "*two*, *one*, *three*." As China's economy enters a stage of high-quality development, the country attaches more importance to ecological environmental issues. The primary and secondary forestry industries, which were mainly based on timber harvesting, transportation, processing, and manufacturing, gradually transition to the tertiary forestry industry. It is important to note that these industries are reliant on forest landscape resources, changing the focus of the forestry economic development mode. Thus, it is significant to promote the optimization of the forestry industry structure, reduce forest resource consumption, and promote the development of forest carbon sinks through the employment of high-quality economic development, as it changes people's cognition, affects consumption preferences and consumption structures, and modifies the demand structure of forest products. This leads to the transformation of the original resource-based consumption into ecological consumption, promotion of the innovation and technological progress of forest-related science and technology, upgradation efforts to develop the forestry industry, and reduction of the irrational consumption of forest resources. Increasing the forest area and forest stock, promotion of the development of forest carbon sinks, and improvement of the value of forest carbon sinks are significantly imperative as well.

Economic growth has also optimized the allocation of forestry elements. According to the theory of economic growth, factor input serves as the principal driving force and source of economic growth. The total input of forestry capital, labor, and land, and the proportion of the input among these factors, are the key elements that affect the development of regional forestry. In the context of high-quality economic development, reliance on large-scale production factor inputs and forest resource consumption to achieve forestry production benefits and outputs is not appropriate for the current strategic position of forestry. Instead, it is suggested to utilize and depend on scientific and technological progress and employee quality as new ways of promoting the development of the forestry industry. Optimizing the input of forestry factors is an important measure to encourage high-quality development of forestry. From 1995 to 2020, the forest stock volume increased year by year, and the number of employees in the forestry system demonstrated a significant declining trend at the end of the year. In addition, forestry investment fluctuated, and the proportion of capital in the input factors increased annually. Capital investment is the key to promoting the development of high-quality forestry. It is important to mention that the forestry factor allocation is in line with the requirement of high-quality development with the propensity of effectively promoting the development of the forestry industry. In addition, it helps improve forest carbon sink capacity.

6.2 The development of forest carbon sinks "inhibits" economic growth

In this study, economic growth was taken as the explained variable, and the estimated results of the PVAR model showed that the impact of the first-order lagged forest carbon sink value (L. lnV) on economic growth (lnGDP) was −0.395, which was significant at the 1% significance level and inconsistent with hypothesis 2. It continues to reveal that forest carbon sink has a statistically significant negative "inhibition" effect on economic growth, primarily manifested in the middle and early stages. Since the sixth stage, the negative "inhibition" effect is not noteworthy at the 95% significance level.

Forest carbon sinks have a lagging effect on the economy. The development of forest carbon sinks requires the input of production factors, such as capital, land, and labor resources. Additionally, it requires a development process from factor inputs to outputs of ecological and social benefits. Moreover, it is not sustainable to promote economic growth by relying on factor driving. The reason is simple. Improvement of the total factor productivity of forestry and promotion of efficiency reform in the forestry industry would take time. The development of forest carbon sinks has a lag effect on the economy (Gupta, 2015).

The structure transformation pressure of the forestry industry is significant. With only 30 years between China's commitment to "carbon peaking" and "carbon neutrality," it is encountering several challenges, such as industrial transformation. The pressure of environmental protection is great, and forest ecosystems need to be repaired urgently. However, the economic benefits generated by the activities of increasing forest carbon sink, such as returning farmland to forest, are difficult to highlight in the early stages of forest formation. Hence, the foundation of realizing the comprehensive transformation of the forestry industry structure consequently weakens. As mentioned, the structure of China's forestry industry is presented in the form of "*two*, *one*, *three*". Under the "double carbon" goal, the primary and secondary industries of forestry can directly bring economic benefits, may be seriously impacted, and may also "restrain" the economic growth in the short term.

The forest carbon sink trading market is still in its immature phase. The national forest carbon sink trading market has recently been established, whereby several functions are imperfect, thus failing to maximize the ecological value of forest carbon sinks into economic value. Currently, the immature forest carbon sink trading market reflects the lack of laws and regulations that specifically stipulate forest carbon sink trading. A few existing departmental rules are used to guide and regulate national forest carbon sink trading, which is unauthoritative or inoperable. Further, the measurement, accounting, and pricing mechanisms of forest carbon sinks need major improvements. Forest resource endowment and forest carbon sink capacity differ in diverse parts of China. However, only the net carbon sink amount generated by approved forest carbon sink projects can participate in forest carbon sink market trading. Forest carbon sink pricing methods can be divided into direct and indirect methods. With gradual improvement in the forest carbon sink trading market, the ecological value of forest carbon sinks can be transformed into economic value. According to the pulse response chart, the negative "inhibition" effect of forest carbon sink value on economic growth will weaken gradually.

7 Research conclusion and theoretical enlightenment

7.1 Research conclusion

In this study, GDP *per capita* from 1995 to 2020 was selected as an indicator of economic growth. The product of the forest carbon sink and forest carbon sink price was utilized as an indicator of the value of forest carbon sink. Based on the PVAR model, impulse response and variance analyses were used to explore the interaction between economic growth and forest carbon sink value. Hence, it is concluded that economic growth can positively promote the development of forest carbon sinks, whereby the positive promoting effect is continuously enhanced during Period 1 to 10. These empirical results are supported by Hypothesis 1. The realization of forest carbon sink value has a "negative" effect on economic growth in the short term. It is pertinent to note that the negative effect cannot be significant at the 95% significance level since the sixth period—a finding inconsistent with Hypothesis 2. Therefore, from the perspective of development, capturing the dynamic relationship between the trend of forest carbon sink value and economic growth, and realizing the long-term development of both, are the challenging pain points. From the perspective of cost, the implementation of relevant subsidy policies and compensation measures will also play a crucial role in the realization of forest carbon sink value and economic development. Above conclusions imply that the synchronous development of economy and ecology does have mutually limiting factors. Hence, it is indeed a challenge to find out the limiting factors, find the balance point between economy and ecology, and pursue coordinated development. Due to the limitations of the current disclosed/unavailable data and reference cases related to forest carbon sink, future studies need to demonstrate the relationship between economic growth and forest carbon sink value from a multi-dimensional perspective.

7.2 Theoretical inspiration and policy suggestions

Considering China's economic and social development and the actual forest carbon sink potential, combined with the above research results, this study suggests:

7.2.1 Formulation of long-term policies for forest carbon sink development

According to the impulse response function between forest carbon sink value and economic growth obtained in this study, it is apparent that even though each curve can stabilize in the late response period, the amplitude and period of fluctuation are different. Considering the different influences exerted by forest carbon sinks and economic growth at different times in a large country with significant regional differences, it is essential to improve the long-term development policy for forest carbon sinks, design a differentiated policy combination according to the actual situation in each region, and establish and perfect the technology system of energy-saving and emission reduction. High-quality projects, enterprises, and areas with favorable conditions for the development of forest carbon sinks are required to promote the flow and agglomeration of energy factors to green, low-carbon, and circular development. For example, after the "double carbon" goal was proposed, Shanxi, Inner Mongolia, Hebei, and other heavy industry-developed regions were put under great pressure to reduce carbon and reach the peak. As there is a large space for energy conservation and emission reduction, they were compelled to employ measures to achieve industrial emission reduction. Further, these regions have low rainfall, and the cost of developing forest carbon sinks is higher than that in other regions. However, the southeastern coastal areas of China, with sufficient rain and a suitable climate, have cost advantages for the development of forest carbon sinks. Moreover, these areas are more suitable for the development of forest carbon sinks and emission reduction due to several factors—developed economy, a high proportion of tertiary industries, and small space for industrial energy conservation. Differentiated policy combinations must be implemented in different regions to reduce the cost of emission reduction for the entire society and maximize social welfare.

To increase the support for energy conservation and emission reduction according to local conditions, it is essential to take various effective measures, such as implementing tax policies conducive to the development of forest carbon sinks, strengthening the supervision of the green finance industry, provision of targeted subsidies to enterprises that exceed the level of carbon reduction target responsibility assessment, supporting enterprises to develop green energy technology, and addressing the failure of carbon market using mandatory government regulation. To legislate and supervise the development of forest carbon sink projects, it is equally important to reduce the spillover effect of the forestry economy, strengthen the macro-guiding role of the government, increase the construction and services of green infrastructure, refine the system and standards for environmental impact assessment of enterprises, mobilize enterprises to reduce carbon emissions, strengthen the supervision capacity of regulators, address both short-term benefits and long-term vision, and safeguard and regulate the legitimate rights and interests of participants. All such measures could prove critically helpful in achieving efficiency and effectiveness.

7.2.2 Improvement of trading platforms for forest carbon sinks

Carbon emission trading is a market-based environmental regulation tool that internalizes the negative external pollution of enterprises guided by the government and promoted by the market. It can encourage enterprises to adopt a low-carbon generation approach and carbon-neutral behavior. The Chinese carbon market is in the early stages of development. Therefore, it is imperative to further build and improve the carbon market trading mechanism, gradually tighten the issuing standard of the carbon quota, make carbon emission rights a scarce resource, and improve the enthusiasm of reduction enterprises to participate in carbon trading. Through the forest carbon sink market trading platform, forest carbon sinks can realize the transformation from ecological value to economic value. A sound forest carbon sink trading platform can not only guarantee the green development of the economy, but also promote the active participation of all sectors in society. Under a carbon currency market with a diversified compensation mechanism, the principle of "who invests, who gains" is followed to protect the income distribution rights of all participants. It also increases social enterprises' willingness to participate. This marketization process is beneficial for realizing carbon sink trading procedures and compliance. In the long term, such endeavors may help China realize industrial transformation and upgrading through the marketization of forest carbon sinks.

Currently, China is in the rudimentary stage of carbon sink marketization. There is, however, room for progress. In future, it is indispensable to learn from the mature carbon sink market trading modes of other countries. In this context, it is the responsibility of the government and respective authorities to take the lead and establish climate exchange as an intermediary, review forest carbon sink projects, evaluate the carbon sink credit of enterprises, promote carbon sink trading, increase publicity, and allow more enterprises to participate in carbon sink trading. This top–down participation mechanism may also contribute to the reasonable formulation of compensation standards. In the context of China's "double carbon" goal, improving the forest carbon sink trading platform would prove beneficial to adjust the interesting relationship and realize the diversification of forest carbon sink values.

7.2.3 Improvement of the pricing mechanism of forest carbon sinks

The government uses carbon pricing to regulate carbon emission reduction. It measures the impact of carbon dioxide, generated by socioeconomic activities of enterprises, on the environment in the form of money. This data allows the authorities to express the negative externalities of carbon dioxide emission of enterprises in the form of carbon emission price. The carbon emission behavior of commercial enterprises can improve their willingness to reduce emissions effectively. Simultaneously, it may also increase their enthusiasm to participate in carbon trading. Additionally, it may facilitate an increase in the government's fiscal revenue. The major types of carbon pricing include carbon emission trading system pricing, carbon taxes, and carbon pricing offset mechanisms. Carbon pricing can be interpreted as an extension of the Paris Agreement. The OECD published an environmental paper, highlighting that a joint, worldwide implementation of carbon pricing and the expansion of the carbon pricing sector can produce more economic and environmental benefits. If carbon pricing is implemented to cover non-carbon emission sectors, compared to the implementation of carbon pricing only in carbon emission sectors, the cost of emission reduction could be reduced by approximately 50%.

Owing to large differences in the measurement models and parameters of forest carbon sinks in different regions, research on the pricing of forest carbon sinks is limited to the theoretical level. Moreover, the distribution of forest resources is unbalanced. Forestry resources in the southwest and northeast areas are relatively rich, and those in the developed coastal areas are relatively short. The carbon sink price cannot accurately reflect the scarcity of resources. Regrettably, the market incentive ability is not fully utilized, and the role of resource allocation cannot be fully realized. The pricing of forest carbon sinks needs to be based on the deployment of scarce resources by the "invisible hand," with the participation of the government. Consequently, it not only supports the development of the carbon sink industry and prevents operators from altering their business strategies (due to low revenue and loss of market confidence caused by the low price of the forest carbon sink), but also prevents unreasonably high prices caused by an increased demand, which will affect the development of the forest carbon sink market.

7.2.4 Intensification of the efforts to protect forests

The development of forest carbon sinks cannot be separated from the growth of forest natural resources. Forest protection strengthening process can be initiated from the two aspects of afforestation and deforestation control, and the active prevention and control of diseases, insects, rats, and forest fires. Considering the present scenario, it is high time for all regions to increase afforestation efforts, actively implement the policies of returning farmland to forests, plan afforestation phase-wise, optimize tree species, and enrich forest vegetation diversity according to local conditions. The following processes must be considered: strictly controlling the intensity of deforestation, reasonable planning, strict examination and approval, safeguard supervision and regular inspection, and active use of biological control technology to prevent diseases, insects, and rodents. It has also provided quality training for forest management and personnel protection, strengthened forest fire prevention work, established forest fire prevention workstations, increased the number of forest patrols in dry seasons, and implemented real-time dynamic monitoring of forest land (using remote sensing and other technologies). At the same time, local governments should crack down on criminal activities related to deforestation, make authentic efforts to curb illegal occupation of forest land and other unlawful activities, and uphold the ecological red line to ensure the healthy and stable development of forestland ecosystems.

7.2.5 Giving full play to the role of forest carbon sinks in poverty reduction

Owing to the typical spatial and geographical characteristics of China's population, a large proportion is distributed in remote rural and mountainous areas, rich in forest resources. The rapid development of China's carbon market has laid a good foundation for small farmers to engage in direct participation. The government and relevant departments are constantly exploring apt models for farmer participation. As forest carbon sinks help in poverty reduction, the implementation of forest carbon sink projects in mountainous areas can help transform the external value of forest carbon sink products into financial incentives for ecological protection, thereby ensuring a win-win situation between sustainable forest development and poverty alleviation in mountainous areas. Hence, some suggestions are as follows: carbon sink projects between developed and poor areas should be coordinated, forest carbon sinks should be purchased in developed areas; from the perspective of policies, farmers' rights and interests in forestry carbon sink projects must be protected; reasonable subsidy standards for carbon sink afforestation and forest operation should be formulated; and compensation objects and ways for carbon sink afforestation must be clarified. Farmers living in mountainous areas can increase their income through participation in economic activities, such as reforestation and forest tourism projects. It vigorously conducts skill training for farmers, implements special entrepreneurship training programs for farmers, and provides training on opportunities to identify forest carbon sink participation, project selection, plan formulation, and risk avoidance. Consequently, such opportunities allow farmers to improve their understanding of current technologies, products, and models and learn about the local ecological environment. Moreover, it improves their income. In conclusion, forest carbon sequestration needs to be incorporated to combat against poverty—a measure that is conducive to the integrated development of rural primary, secondary, and tertiary industries, breaking the pattern of rural populations' dependence on agriculture.

7.2.6 Implementation of a compensation mechanism for forest ecology

Introducing and implementing a compensation mechanism for forest ecology can facilitate economic development. Currently, there are several market-based compensation methods for forest carbon sinks in developed countries, whereby the integration of ecological compensation mechanisms with the carbon sink market is relatively mature. For instance, South Korea has subsidized the declaration fees for forest carbon sink projects. Similarly, the Australian government has established a special fund for energy conservation and emission reduction to compensate for the sunk costs that forest operators give up. However, it is still dependent on the promotion and practice of the carbon emission trading market and forestry authorities. Local forest land management departments should fully understand the current situation of forest resources, forest carbon sink capacity, and related information. This information must be combined with the economic development situation for several reasons; to expand the scope and level of forest ecological compensation, to navigate through forest economic development process suitable for local conditions, to implement reasonable planning of resources, to set up special fund support and compensation, to attract high-end talent, and to intensify efforts for exploring the economic benefits of forest ecological resources. Building a forest ecological industry system and promoting low-carbon economic development would help China realize the "double carbon" goal in the nearest future.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YS: Conceptualization, methodology, software, investigation, formal analysis, and writing–original draft.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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