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The Impact of Forestry Industry Integration on the Forest Farmers' Income in China: A Theoretical and Empirical Study

Ni Chen [1,2], Mingming Jin [3,*], Shuokai Wang [3], Xu Zhang [3], Haisheng Sun [3] and Fangping Cao [3,*]

[1] College of Geography and Environmental Science, Henan University, Kaifeng 475004, China; chenni_bjfu@126.com

[2] Key Laboratory of Geospatial Technology for the Middle and Lower Yellow River Regions, Henan University, Kaifeng 475004, China

[3] School of Economics and Management, Beijing Forestry University, Beijing 100083, China; wangshuokai@bjfu.edu.cn (S.W); zhangxu0471@foxmail.com (X.Z); linxishs@163.com (H.S)

[*] Correspondence: jmm_bjfu@163.com (M.J); cfp_888@bjfu.edu.cn (F.C)

Abstract: Transforming the forestry development model and promoting the development of forestry industry integration (FII) has become an important way for forestry to break through development bottlenecks and realize the increase of farmers' income. In this study, we use the inter provincial data from 2005 to 2019 to test the effect of FII on forest farmers' income with the help of fixed effect model, quantile regression model and spatial panel model. Results showed that, firstly, the level of FII is on the rise, with most provinces in the middle or high integration stage. Among them, the Northeast region is at the highest level. Secondly, there is a positive spatial correlation in the forest farmers' income, which is gradually increasing. The income of forest farmers in coastal provinces is relatively high, forming an HH cluster. Thirdly, the FII has significantly improved the income level of forest farmers, and there is a significant spatial spillover effect. Finally, the group heterogeneity is reflected in the increasing income effect of FII with the improvement of the income level of forest farmers. Regional heterogeneity shows that the FII in Northeastern, Eastern, and Central regions significantly promotes the increase of forest farmers' income. Efforts to boost integrated forestry industry development will broaden the income channels of forest farmers by leveraging high productivity of the agglomeration effects, diffusion effect and demonstration effect, and promoting integrated forestry industry development with adjacent regions. This work may help to understand this relationship and to creating effective regional forestry development income-enhancing policies.

Keywords: forestry industry; integrated development; income of forest farmers; heterogeneity testing; analysis of spatial effect

1. Introduction

Promoting the sustained increase in farmers' income and continuously improve their sense of gain, happiness and security is a necessary part of China's comprehensive construction of a moderately prosperous society. Since 2004, the No. 1 document of the Central Government has continued to focus on the issues of "agriculture, rural areas and farmers". Accordingly, the per capita net income of farmers has rapidly increased from 2936.4 yuan in 2004 to 16021 yuan in 2019, achieving "16 consecutive increases" (Yao et al., 2022). However, in the face of the impact of the novel coronavirus epidemic, the downward pressure on the Chinese macro economy is increasing, the situation of farmers' income increase is not optimistic, and the momentum to continue to maintain a relatively rapid growth is insufficient. How to promote the sustainable and stable growth of farmers' income is still a major and difficult point. Forests often play a vital role in the lives of many poor people (Vedeld et al., 2007). Globally, nearly 735 million rural people live in or near tropical forests and savannas (FAO, 2006; World Bank, 2000). In China, most of the 592 poverty-stricken counties are located far from urban centers and in areas with poor transportation. At the same time, they tend to have relatively rich forests (Liu et al., 2009). In order to increase the income of rural residents, in the recent five years, the State Council government work report and the documents issued by the National Forestry and Grassland Administration mentioned several times to promote the integrated development of rural primary, secondary and tertiary industries, increase farmers' income through multiple channels. In this context, does the integration of forestry industry effectively promote farmers' forestry income? Will the effect be heterogeneous with subject endowment

and regional differences? Will it affect the income of forest farmers in adjacent areas? These topics are in urgent need of research.

Research on industrial integration has a long history. In the 1960s, scholars represented by Rosenberg (1963) took the lead in summarizing the concept and type of industrial convergence with technology convergence as the core. Subsequently, the research on industrial integration is becoming more and more systematic, involving the connotation (Bally, 2005; Chen, 2010; Rosenberg, 1963), characteristics (Cao, 2015), motivation types (Chesbrough, 2007; Lemola, 2002), level measurement (Dong et al., 2021; Lemola, 2002; Lu et al., 2017) and effects of industrial integration (Gambardella & Torrisi, 1998; Li et al., 2021a), but mainly focusing on the secondary and tertiary industries and their internal integration analysis. Subsequently, a small portion of the academic community began to pay attention to research on the integration of the forestry industry. Li (2007) first defined the connotation of industrial integration in the forestry field. Jin et al. (2023a) measured the current status of forestry industry integration using the Herfindahl index method. However, research on the integration of the forestry industry is still in its early stages.

Among the diversified incomes of farmers, forestry income is a very important income (Charlie et al., 2007; Kendra & Bassett, 2002). For example, Reddy and Chakravarty (1999) founded that in northern India, forestry revenues can reduce the probability of poverty. There are many factors that affect farmers' income in forestry, which can be summarized into two aspects: i)The factors of the farmer household itself, such as the size of the household and the number of adult labor force (Pyi et al., 2015), the family cultivated land (Patricia et al., 2012), the forest land area (Lu et al., 2020), and the integration degree of forestry with agriculture and animal husbandry (Adriana et al.,2019; Roberto et al.,2015). ii) Factors other than the farmer's household, such as the state of forestry resources (Getachew et al., 2007), climatic conditions (Oscar & William, 2021), sudden natural disasters (Feng & Dai, 2019), forestry technology (Nambiar, 2021), forestry capital (Hari et al., 2017), and fiscal policy (Carlos et al.,2020).

Currently, there is a blank research stage on the relationship between industry integration and forest farmers' income in the forestry industry, which has weak characteristics. However, forestry, as a subsidiary industry of agriculture, can provide an important reference for scholars to study the relationship between forestry industry integration and forest farmers' income. The existing research mainly focuses on two aspects: the research on the relationship between rural three-industry integration and farmers' income (Gullette, 2014), and the mechanism analysis on how to promote rural three-industry integration to increase farmers' income (Li & Wang, 2019).

In summary, although a series of studies have been conducted on industrial integration and farmers' income, there are limitations regarding the knowledge of both: i) Existing studies have primarily explored forestry industry integration or farmers' forestry income from a unilateral perspective or explores the impact of agricultural industry integration on farmers' income from an agricultural perspective. However, there is no established theoretical system for researching the impact of forestry industry integration on farmers' forestry income from a forestry perspective, and there is a lack of empirical research on its effect. ii) Most of the existing empirical studies focus on the national level or a certain region level, and rarely involve all provinces in the country. Comprehensive analysis of individual differences, regional heterogeneity and spatial spillovers is even less.

Accordingly, this paper took 30 provinces in China from 2005 to 2019 as the research samples and explored the spatial distribution law of forestry industry integration and the forest farmers' income. We explored the impact of the former on the latter by used the panel fixed effect model, quantile regression model and panel spatial econometric methods, in order to comprehensively grasp the problems faced by forestry industry integration in promoting farmers' forestry income. Our analysis is comprehensive and can provide a basis for the scientific formulation of differentiated regional forestry development policies.

2. Mechanism Analysis and Research Hypotheses

2.1 Mechanism of Forestry Industry Integration on Farmers' Forestry Income

Forestry industry integration mainly increases the added value of forest products, promotes the optimal allocation of forestry production factors, reduces the opportunity cost of forestry industry development, and creates more employment opportunities by extending the industrial chain and cultivating new forms of forestry industry, so as to broaden the income channels of forest farmers and thus increase their incomes. The mechanism of forestry industry integration affecting farmers' forestry income (Figure 1) is described below.
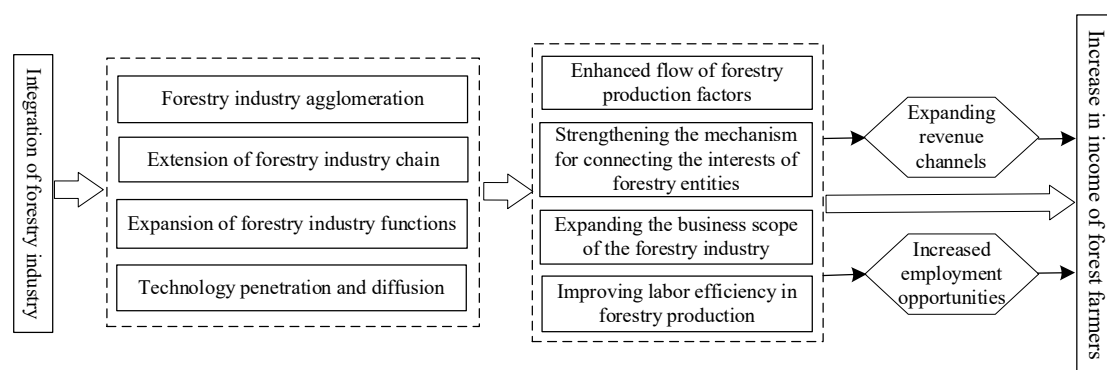
Figure 1. Mechanism of forestry industry integration on farmers' forestry income.

Specifically, firstly, forestry industry integration includes the integration of forestry technology, which is reflected in all aspects of forestry production and operation. The penetration and cross integration of high-tech industries such as biotechnology and information technology and their industries into forestry can break the technical barriers to the development of forestry industry and improve the original mode of production, which can promote the innovation of the mode and means of forestry production and management. This can not only save the cost of production and operation, improve the efficiency of forestry labor production, but also increase the forestry output, improve the quality and additional value of forest products, and thus greatly increase farmers' forestry income (Cubbage et al., 2007). Secondly, forestry industry integration can bring about the industrial agglomeration, the formation of new formats, and the extension of the industrial chain. For example, the integration of forestry and tourism, culture, education, medical care, health care, sports and other industries expand the scope of forestry business, improve the value creation ability of forestry and the added value of forest products, so that farmers have more job opportunities, expand the income channels, and thus increase their income (Sunderlin et al., 2003). Thirdly, the higher the level of integrated development of forestry industry, the more sufficient the flow of forestry production factors. The forestry management entities and foresters transform the forestry production mode into enterprise or stock cooperation through forms such as orders, land transfer or equity participation, and enterprise labor.

These interest linkage mechanisms share the risks and benefits of forestry production, thereby reducing the transaction costs of forest products in production and circulation and increasing the ability to resist natural risks, ensuring the stability of forest farmers' income. Moreover, forest farmers can also share the benefits of various links in the forestry industry chain, including sales and processing (Midgley et al., 2017). The more closely the interests of each forestry management body are connected, the more value-added forestry benefits farmers get. We propose the following accordingly.

Hypothesis 1: Forestry industry integration has a promoting effect on farmers' forestry income.

2.2 Heterogeneity of Forestry Industry Integration on Farmers' Forestry Income

The heterogeneity of the income increase effect of forestry industry integration is mainly reflected in two aspects: regional heterogeneity and individual heterogeneity. That is, the differences in the impact of forestry industry integration on farmers' forestry income in different regions and the differences in the impact of forestry industry integration on the income of heterogeneous farmers.

(1) Regional differences in farmers' forestry income affected by forestry industry integration

Due to China's vast territory, there are significant regional differences in the natural resource conditions, economic development level, and industrial structure of forestry among regions (Chen et al., 2020; Xiong et al., 2018), resulting in significant regional differences in the income level of forest farmers and the level of forestry industry integration. In recent years, although the income of forest farmers has shown a rapid growth trend, the regional income gap has also been widened. There are also Northeast-Central-West-East hierarchical differences in forestry industry integration (Jin et al., 2023a). The impact of forestry industry integration on farmers' forestry income may exhibit imbalanced characteristics at the provincial or regional level due to the high or low level of forestry industry integration. The integrated development of the forestry industry is a long-term, systematic, and dynamic complex project. Currently, China is still in the initial exploration stage, and its level of development is influenced by the external environment and supporting conditions (Jin et al., 2023b). Among them, the differences in economic development level, forestry resource endowment, and transportation infrastructure between different provinces and cities can lead to significant inter provincial differences in the integration level of regional forestry industry, which

may lead to regional differences in the driving effect of increasing income for forest farmers in different regions. Specifically, the level of regional economic development to a certain extent determines the primitive accumulation of forestry industry development (Xiong et al., 2018), while infrastructure construction and forestry resource factor endowment determine the forestry production mode and operation scale to a certain extent. Scholars have found regional differences in the impact of rural integration of the three industries on farmers' income through research. Among them, the integration of rural industries in the eastern region has the strongest promoting effect on farmers' income, followed by the northeast and central regions, and the western region is the weakest. This is mainly due to the favorable geographical advantages and external environment in the eastern region. The higher the level of economic development, the more convenient transportation, complete facilities, and more channels for rural residents to obtain income, which is more conducive to the increase of farmers' income (Bai, 2023). Therefore, in areas with high levels of regional economic development, complete infrastructure construction, and abundant endowments of forestry resources, the stronger the foundation for the development of new industries and formats, the faster the growth rate of new forestry operators, and the higher the level of forestry industry integration, the more obvious the promoting effect on farmers' forestry income. We propose the following accordingly.

Hypothesis 2: The income increasing effect of forestry industry integration is characterized by regional heterogeneity due to differences in external environment and supporting conditions, with a strong Eastern region and a weak Western region.

(2) Individual differences in farmers' forestry income affected by forestry industry integration

The difference of the effect of forestry industry integration on the income of heterogeneous farmers can be explained from the main body difference of forestry industry integration effect caused by the heterogeneity of farmers' resource endowment. This is because there is a huge gap in the endowment of forestry resources among forestry management entities, mainly reflected in the differences in the occupancy and utilization efficiency of forestry production factors such as forest land, labor, capital, technology, and so on (Chen et al., 2020; Jin et al., 2023b; Lu et al., 2018). Although forestry industry integration can improve the efficiency of forestry production, increase the added value of forest products, generate more employment opportunities, and increase the level of farmers' forestry income, there are differences in the opportunity cost and marginal revenue of different forestry management entities in carrying out forestry production and management, which makes the same level of forestry industry integration may have different income effects on different entities. Generally speaking, the group with higher forestry income has more forestry production factors, and the scale effect and multiplier effect produced by forestry industry integration are more significant, resulting in more significant income growth. We propose the following accordingly.

Hypothesis 3: The income increasing effect of forestry industry integration has individual heterogeneity, and the marginal contribution increases with the increase of income level.3. Model Setting and Variable Selection.

3. Model Setting and Variable Selection

3.1 Model Setting

To verify the income increasing effect of forestry industry integration, based on reference to relevant influencing factors, a benchmark model is constructed as follows:

$$Y_{it} = \alpha_0 + \beta X_{it} + \sum_{j=1}^{n} \beta_j Z_{jit} + \varepsilon_{it} \tag{1}$$

where Y_{it} represents the income level of forest farmers of the ith-region in the tth-year; X_{it} and β represent the integration level of forestry industry and its coefficients, respectively; Z_{it} and β_j represent, respectively, the control variables and their coefficients; ε_{it} is the random error term.

There are significant inter provincial differences in China's forestry resource endowment and income level of forest farmers, making it difficult to describe the forestry income characteristics of different groups from the perspective of "average level" regression analysis. By using the quantile regression model proposed by Kendra and Bassett (1978) to estimate the independent impact of explanatory variables on the different points of the distribution of explanatory variables, we can more comprehensively and accurately reflect the heterogeneity structure of the entire sample distribution between the integrated development of forestry industry and the income of forest farmers in different regions of China. In addition, quantile regression can eliminate heteroscedasticity in the distribution of variables to a certain extent, and the estimation results are not easily affected by extreme values, so they are more robust. Therefore, the panel quantile regression model is constructed based on Formula (1) as follows:

$$Q_{FI_{it}}(\gamma|X_{it}) = \sigma_i + \varphi(\gamma)X_{it}, i = 1,2,3\cdots n; t = 1,2,3\cdots m \tag{2}$$

where $Q_{FI_{it}}(\gamma|X_{it})$ represents the γ conditional quantile of the interpreted variable Y under the given conditions of X; X is the explanatory variables, including the core explanatory variable (forestry industry integration) and the control variables; $\varphi(\gamma)$ represents the quantile regression coefficient, which can be obtained by solving the objective function Formula (3).

$$\min_{(\sigma+\varphi)} \sum_{k=1}^{q} \sum_{t=1}^{n} \sum_{i=1}^{m_i} \omega_k \rho_{\gamma k}(FI_{it} - \sigma_i - \varphi(\gamma)X_{it}) \tag{3}$$

where ω_k represents the corresponding weight of each quantile. This paper selects 10%, 25%, 50%, 75%, and 90% of the representative points based on the current research practice.

To further investigate the regional heterogeneity and influencing factors of forestry industry integration on forest farmers' income, Spatial Panel Lag Model (SPLM), Spatial Panel Error Model (SPEM), and Spatial Panel Dubin Model (SPDM) were selected to explore the spatial effects of forestry industry integration on forest farmers' income. Among them, SPDM is most often used to investigate the spatial correlation of geographical units. It contains both independent and dependent variables' spatial dependence effects, which is a more general form than SPLM or SPEM (Elhorst, 2003). It can be expressed as follows:

$$Y_{it} = \beta_0 + \rho \sum_{j=1}^{N} W_{ij}Y_{jt} + \beta_2 X_{it} + \varphi_1 \sum_{j=1}^{N} W_{ij}X_{jt} + \beta_3 Z_{it} + \varphi_2 \sum_{j=1}^{N} W_{ij}Z_{jt} + \mu_i + \nu_t + \varepsilon_{it} \tag{4}$$

where Y_{it} represents the dependent variable value of the ith-region in the tth-year; W_{ij} represents the normalized spatial weight matrix; $W_{ij}Y_{jt}$ represents the spatial lag dependent variable; ρ represents the spatial regression coefficient; X_{it} and β_1 represent the independent variables and their coefficients, respectively; $W_{ij}X_{jt}$ represents spatial lag explanatory variables; φ_1 represents the coefficient of spatial lag independent variables; Z_{it} and β_2 represent, respectively, the control variables and their coefficients; $W_{ij}Z_{jt}$ represents spatial lag control variables; φ_2 represents the coefficient of spatial lag control variables; μ_i and ν_t represent spatial effect and temporal effects, respectively; ε_{it} is the random error term. When $\varphi_1 = 0$ and $\rho \neq 0$, Formula (4) refers to the SPLM model; when $\varphi_{1+}\rho\beta_1 = 0$, Formula (4) represents the SPEM model.

It should be noted that the spatial weight matrix adopts the adjacency spatial weight matrix W_{ij}, and spatial research is implemented using ArcGIS and GeoDA. To avoid the endogeneity problem of variables, the system generalized moment estimation (MLE) method is used to estimate the model.

3.2. Variable Selection

(1) Explained variable (Y). At present, there is no specialized yearbook data on farmers' forestry income. The existing research generally adopts two ways to deal with it: the first is to sample the net income of farmers in each province and measure the net income of farmers in forestry with the results of micro-household survey, which is generally used for the analysis of cross section data; the second method is to convert the corresponding data proportion, which is suitable for the analysis of panel data. Therefore, this paper refers to existing research (Chen & An, 2018; Liao & Zhang, 2014) and uses the net income of rural households multiplied by the ratio of forestry output value to the output value of agriculture, forestry, animal husbandry, and fishing industries to represent farmers' forestry income.

(2) Core explanatory variable (X_1). In this paper, the core explanatory variable is the degree (level) of forestry industry integration. Forestry industry integration is a dynamic development process in which forestry breaks through the original boundaries of different industries and gradually forms a new format or development model of forestry industry through phase penetration and cross between forestry and other different industries, or within the three forestry industries. This paper adopts the Herfindahl index method used by Jin et al. (2023b) in previous research to measure forestry industry integration. The specific formula and division criteria (Table 1) are as follows:

$$FIII = 1 - \sum_{i=1}^{N} \left(\frac{X_i}{X}\right)^2 \tag{6}$$

where $FIII$ represents Forestry Industry integration Index; $\sum_{i=1}^{N} \left(\frac{X_i}{X}\right)$ is the sum of squares and total proportion of all variable values, representing the Herfindahl index; X refers to the total output value of the primary, secondary, and tertiary forestry industries; and X_i represents the total output

value of the *i*th-industry (Jin et al., 2023b; Lu et al., 2017; Qu et al., 2022). It should be noted that the broad integration of forestry industry includes both the integration between forestry and other different industries, as well as the integration of primary, secondary, and tertiary industries within forestry; The narrow definition of forestry industry integration only refers to the integration of primary, secondary, and tertiary industries within the forestry industry. The empirical part of this paper is limited by data and focuses on the narrow integration of the forestry industry.

Table 1. Integration level classification.

Fusion Interval	<0.20	0.20-0.40	0.40-0.60	0.60-0.80	0.80-1.00
Fusion level	I	II	III	IV	V
Type	Low fusion	Medium-low fusion	Medium fusion	Medium-high fusion	Deep fusion

(3) Control variables. Considering that farmers' forestry income is also influenced by other factors besides the forestry industry, and addressing the endogeneity problem caused by omitted variables, we selected a series of control variables based on relevant studies and the principles of availability, comparability, and quantifiability (Abdulai et al., 2016; Abhilash, 2018; Li et al., 2021a; Lin & Chen, 2020; Lu et al., 2018; Lu et al., 2020; Wei et al., 2022; Xiong et al., 2018; Zhang et al., 2019). Control variables refer to potential factors or conditions other than experimental variables in an experiment that affect the changes and results of the experiment. If you want to investigate the influence of an independent variable on the dependent variable, it is necessary to eliminate the influence of other independent variables on the dependent variable, that is, to control the influence of other independent variables-control variables. To this end, it is necessary to add the control variable affecting the dependent variable to the model and estimate the model together with the independent variable to be investigated, so that more accurate estimation results of the variable to be investigated can be obtained (Antonakis et al., 2010; York, 2018). The selected control variables follow.

①Farmers' forest land resource level (X_2). Forest land resources have a significant impact on farmers' forestry income and are an important form of farmers' participation in forestry income distribution. The amount of forest land resources for farmers is related to the level of forestry income (Lu et al., 2020). Therefore, the per capita mountainous area in the land management situation of rural households is used to measure the level of forest land resources for farmers, that is, the per capita forestry land area.

②Rural human capital level (X_3). Rural human capital, as an important input factor in forestry production and operation, has a significant promoting effect on the growth of farmers' forestry income (Wei et al., 2022). The per capita education years of rural residents are used to measure the level of rural human capital. Improved average educational attainment can enhance the ability of forestry enterprises to introduce, absorb, and apply new technologies, improve the management level of forestry departments, and thus improving the technical efficiency of forestry production and increasing farmers' forestry income (Abdulai et al., 2016).

③Forestry fiscal expenditure (X_4). Due to the weakness of forestry and the externality of public goods, the development of forestry industry depends on national financial support. Increasing financial support can improve forestry production and increase farmers' forestry income (Zhang et al., 2019).

④Level of economic development (X_5). The performance of industrial integration development effect is closely related to the level of regional economic development (Xiong et al., 2018), that is, when forestry industry integration affects farmers' forestry income, it may be affected by the level of regional economic development.

⑤Forest resource endowment (X_6). In regions with more abundant forest resources, it is more conducive to the integration and development of forestry industry and other related industries, generating new forms of business, such as forest health care, turning resources into capital, so as to improve farmers' forestry income in the region (Abhilash, 2018; Lu et al., 2018). The level of forest coverage is a direct reflection of forest resource endowment; therefore, forest coverage is chosen as the proxy indicator of forest resource endowment.

⑥Transport infrastructure conditions (X_7). Transport infrastructure has typical externality characteristics. On the one hand, the gradual improvement of transport infrastructure can promote the flow of production factors and reduce transaction costs (Lin & Chen, 2020), drive the integrated development of forest industry, increase employment opportunities related to forests, and increase farmers' forestry income. On the other hand, the large-scale and disorderly construction of transportation facilities has led to the destruction of the quantity and quality of forest resources, resulting in the deterioration of the living environment for forest farmers and a certain degree of loss of

economic benefits (Li et al., 2021b). The traffic density value is used to measure the condition of transport infrastructure.

3.3. Data Declaration

Considering data availability, we selected panel data for 30 provinces (excluding Hong Kong, Macao, Taiwan, and Tibet due to lacking data) in China from 2005 to 2019. To test for regional heterogeneity, we also divided 30 provincial areas in China into four major regions according to the divisions of the National Bureau of Statistics: The Eastern region (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan), Central region (Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan), Western region (Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Inner Mongolia, and Guangxi), and Northeast region (Liaoning, Jilin, and Heilongjiang).The relevant data came from the *China Statistical Yearbook*, *China Forestry Statistical Yearbook*, *China Rural Statistical Yearbook*, *China Statistical Yearbook for Regional Economy*, and the *Statistical Yearbook* of each province.

Additionally, to eliminate impacts of inter-annual price changes, we used a comparable price index with 2005 as the reference year. Some missing data were supplemented by linear interpolation. In order to deal with the problems of heteroscedasticity and multicollinearity, all variables were logarithmized. This processing did not change the trend of the original time series, making our data analysis results more accurate and comparable. The descriptive statistics of the main variables are shown in Table 2.

Table 2. Definitions of relevant variables and descriptive statistics.

	Variables	Calculation Methods	Mean	Standard Deviation	Min	Max
Dependent variable	Farmers' forestry income (yuan)	$\dfrac{Forestry\ output\ value}{Output\ value\ of\ agriculture,\ forestry,\ animal\ husbandry,\ and\ fishery}$ ×Per capita disposable income of rural residents	9.547	0.367	8.600	10.615
Independent variable	Forestry industry integration level (/)	Herfindahl index method	−0.796	0.511	−3.930	−0.322
Control variables	Farmers' forest land resource level (hm²/person)	$\dfrac{Forest\ land\ area}{Rural\ population}×100\%$	1.250	1.115	−2.416	3.878
	Rural human capital level (year)	(Number of illiterate persons×1+Number of primary school graduates×6+ Number of secondary school graduates×9+Number of high school and technical secondary school graduates×12+Number of college students and Bachelor's degree or above holders×16)/Total population over 6 years old	0.850	0.118	0.449	1.039
	Forestry financial expenditure (%)	$\dfrac{Expenditure\ on\ agriculture,\ forestry\ and\ water\ affairs}{Budgetary\ expenditure}×100\%$	−2.317	0.370	−3.847	−1.663
	Level of economic development (%)	$\dfrac{Forestry\ output\ value}{Output\ value\ of\ agriculture,\ forestry,\ animal\ husbandry,\ and\ fishery}×100\%$	−3.385	0.657	−5.024	−1.086
	Forest resource endowment (%)	$\dfrac{Forest\ coverage}{Land\ survey\ area}×100\%$	3.171	0.789	1.078	4.202
	Transport infrastructure conditions (/)	$\dfrac{Total\ mileage\ of\ highways,\ railways,\ and\ inland\ waterways}{Land\ area}×100\%$	−0.410	0.809	−3.189	0.749

4. Spatial-temporal Differences of Forestry Industry Integration Level and Farmers' Forestry Income

4.1. Spatial-temporal Features of Forestry Industry Integration Level

In 2005, the "Medium-high fusion" regions (IV) included 6 provinces (Figure 2a), mainly located in Northeast, Central, and Western regions, including Jiangxi, Hunan, Chongqing, Sichuan, Gilin, Heilongjiang. Among them, Hunan Province had the highest integration (0.631). The integration level of the forestry industry in the remaining provinces was at the "Medium fusion" level or below. In 2019, the number of provinces decreased to 18 with the "Medium fusion" level or below, but the number was still more than half of all provinces (Figure 2b). The provinces with IV or above levels were mainly in the Central, Southwest, and Northeast regions, among which Hunan and Hubei had the particularly high integration index values.
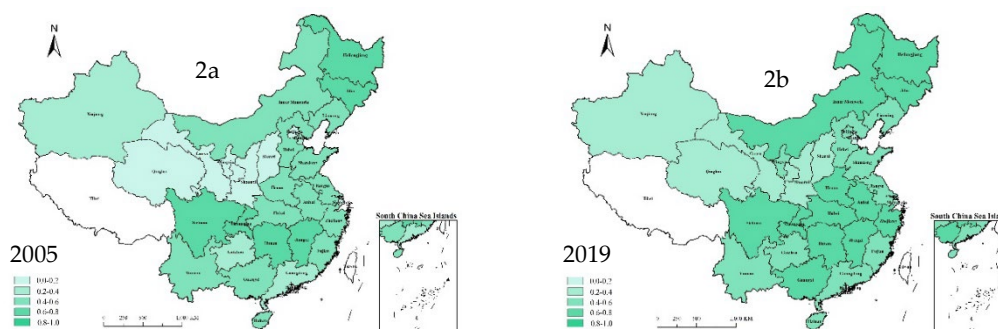

Figure 2. Regional distribution map of China's forestry industry integration level 2005−2019.

During the period 2005 to 2019, the levels of 14 provinces remained unchanged, while the levels of other provinces increased or decreased. Specifically, Tianjin dropped from II to I, Jilin slightly declined but the level did not change, and the integration index values of other provinces increased to varying degrees. As a whole, during the study period, the integration level of the forestry industry in all provinces was at "Medium fusion" or "Medium-high fusion", and the integration level of most provinces was improved while those of a few provinces was decreased. There was a hierarchical difference in the integration level between Northeast, Central, Western, and Eastern regions. The integration levels in Central and Northeast regions were higher than that of the Western and Eastern regions.

4.2. Spatial-temporal Features of Farmers' Forestry Income

4.2.1 Global Autocorrelation

According to the Tobler's (2004) first law of geography, everything is related, and things near each other are more related. Through global autocorrelation, spatial autocorrelation analysis can be carried out on a common attribute of different research objects in the same region, so as to determine whether the attribute is affected by the geographical location, and further explore its spatial evolution rule and spatial aggregation status. In this study, the spatial correlation analysis of the income level of forest farmers in China from 2005 to 2019 was carried out by using the global Moreland index, local Moreland index and Moreland scatter plot.

From 2005 to 2019, the global Moran's I index values of China's farmers' forestry income were all positive and passed the 1% significance level test, indicating that the global autocorrelation experiment was significant at a 99.9% confidence level, and the original assumption of random distribution should be rejected (Table 3). China's farmers' forestry income had a positive correlation in the overall space and exhibited agglomeration phenomenon. Overall, areas with high income from forest farmers were more likely to be adjacent to areas with high income from forest farmers, while areas with low income from forest farmers were more likely to be adjacent to areas with low income from forest farmers. From the data, the global Moran's I index was between 0.322 and 0.337, reaching its highest point in 2019, at 0.337, indicating that the clustering phenomenon of farmers' forestry income is most evident in 2019. From a dynamic perspective, the Moran's I index showed a fluctuating upward trend, indicating that the spatial agglomeration of farmers' forestry income is gradually strengthening.

Table 3. Moran's I index value of farmers' forestry income in China from 2005 to 2019.

Index	2005	2006	2007	2008	2009	2010	2011	2012
Moran's I	0.322***	0.322***	0.324***	0.325***	0.322***	0.325***	0.325***	0.325***
Z value	3.007	3.004	3.012	3.022	2.993	3.014	3.018	3.019
P value	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Index	2013	2014	2015	2016	2017	2018	2019	
Moran's I	0.324***	0.325***	0.327***	0.331***	0.334***	0.335***	0.337***	
Z value	3.005	3.020	3.031	3.064	3.09	3.099	3.121	
P value	0.003	0.003	0.002	0.002	0.002	0.002	0.002	

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

4.2.2 Local Autocorrelation

The Moran's I scatter plot is divided into four quadrants, corresponding to four types of local spatial connections between regional units and their neighbors. IL>0 indicates that a high value is surrounded by a high value or a low value is surrounded by a low value, corresponding to two distribution modes: the first quadrant represents high-high clustering, and the third quadrant represents low-low clustering; IL<0 indicates that a low value is sur-rounded by a high value or a high value is surrounded by a low value, corresponding to two distribution modes: the second quadrant represents low-high clustering, and the fourth quadrant represents high-low clustering. According to the local Moran's I scatter chart (Figure 3), during the study period, most of China's provinces were distributed in the first quadrant and the third quadrant, that is, the HH mode and the LL mode dominated, showing obvious spatial dependence, and the spatial differentiation of farmers' forestry income was serious. The aggregation of high value provinces indicates that each province can form a mutually promoting effect, while the aggregation of low value provinces indicates that each province can form a negative impact on each other, leading to a vicious cycle of constant difference.
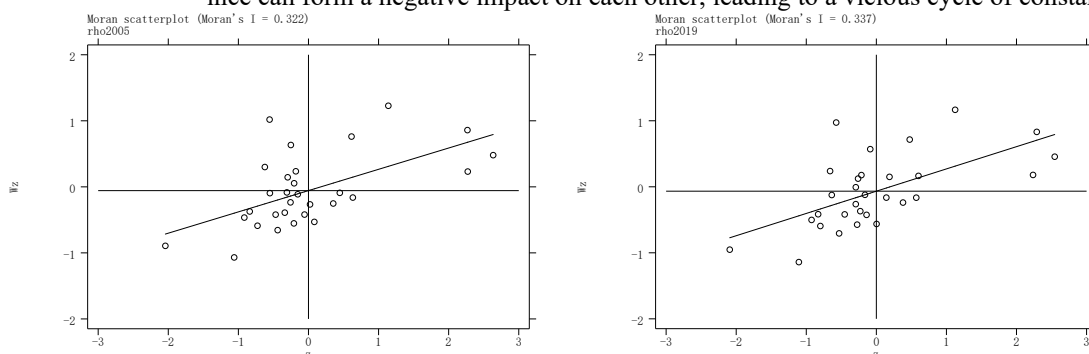

Figure 3. Moran's I scatter plot of local farmers' forestry income in China's provinces.

Among the high-high concentration areas, there are mainly Tianjin, Shanghai, Fujian, Zhejiang and Beijing, etc. These provinces are located in the coastal economically developed provinces, and their own forest farmers' income is higher, which can also drive the increase of forest farmers' income in neighboring provinces. In the low-low agglomeration zone, Hunan, Ningxia, Shanxi, Shaanxi, Chongqing, Henan, Hubei, Inner Mongolia, Liaoning, Heilongjiang, Jilin, Guizhou and Anhui are mainly represented. These provinces are mainly located in economically underdeveloped areas in the central and western regions, adjacent to provinces with lower income from forest farmers. They not only have lower income from their own forest farmers, but also have mutual constraints with other neighboring provinces, which is not conducive to driving the increase in income from forest farmers in neighboring provinces. From a dynamic perspective, the number of high-high agglomeration areas increased from 5 in 2005 to 7 in 2019, the number of low-low agglomeration areas decreased from 14 in 2005 to 13 in 2019, and the number of low-high and high-low agglomeration areas decreased, which also shows that the spillover effect increased, and the driving role played by neighboring provinces was enhanced. Overall, the local autocorrelation relationship exhibits relatively stable performance, mostly exhibiting "high-high" and "low-low" clustering types.

5. Analysis and Discussion of Empirical Results

5.1. Full-sample Spatial Regression Discussion

In order to choose a more suitable parameter estimation model, this paper used F-statistics and Hausman test to make the optimal choice between the mixed regression model and the fixed effects model, as well as the random effects model and the fixed effects model (Table 4). The test results showed that both the F-test value and Hausman test value reject the original hypothesis at the significance level of 1%. Therefore, this paper used the panel fixed effect model to estimate the impact of forestry industry integration on farmers' forestry income. At the same time, in order to minimize the problem of abnormal model results caused by missing variables, this paper followed the modeling principle of "general to special" in econometrics and used stepwise regression to introduce control variables for analysis.

Table 4. Overall sample regression results.

Variables	FE (1)	FE (2)	FE (3)	FE (4)	FE (5)	FE (6)	FE (7)
X_1	0.065***	0.025***	0.020***	0.014***	0.020***	0.021***	0.015***
	(4.786)	(2.972)	(3.458)	(2.799)	(3.916)	(4.032)	(3.106)
X_2		0.495***	0.238***	0.194***	0.200***	0.249***	0.222***
		(26.858)	(14.079)	(12.076)	(12.821)	(9.213)	(8.706)
X_3			0.917***	0.783***	0.745***	0.740***	0.589***
			(22.330)	(19.652)	(18.997)	(18.930)	(14.311)
X_4				0.134***	0.129***	0.130***	0.101***
				(9.517)	(9.421)	(9.523)	(7.677)
X_5					0.045***	0.049***	0.052***
					(5.410)	(5.763)	(6.566)
X_6						−0.058**	−0.042*
						(−2.232)	(−1.724)
X_7							0.102***
							(7.936)
_cons	9.604***	8.950***	8.487***	8.962***	9.133***	9.275***	9.368***
	(727.060)	(349.169)	(313.747)	(160.942)	(146.250)	(104.287)	(111.829)
N	450	450	450	450	450	450	450
F	0.065***	0.025***	0.020***	0.014***	0.020***	0.021***	0.015***
Hausman	-	-	-	-	-	-	12.49*

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

In Table 4, FE (1) represents the "general" estimation results, while FE (2)–FE (7) represents the "special" estimation results of gradually introducing control variables. From the results of FE (7), it can be seen that the regression coefficient of forestry industry integration is 0.015 and passes the 1% significance test. Moreover, after adding other control variables, its promoting effect is still significant. Consistent with Sears et al. (2007) and Hou et al. (2017), we find that the improvement of forestry industry integration significantly promotes farmers' forestry income, thus rejecting the null hypothesis and validating "alternative" Hypothesis 1.

From the perspective of control variables, farmers' forest land resource level, rural human capital level, forestry financial expenditure, level of economic development and transport infrastructure conditions all significantly promote the increase of farmers' forestry income, while forest resource endowment has an inhibitory effect on the increase of farmers' forestry income at the significance level of 10%. This is mainly because although the forest resources in the region are relatively abundant, they are mostly in a state of protection and cannot be fully developed and utilized due to policy restrictions (Bai & Zheng, 2018; Wang et al., 2007; Yang et al., 2015), thus having no promoting effect on farmers' forestry income.

5.2. Heterogeneity Analysis and Discussion

5.2.1 Regional Difference Analysis and Discussion

There are significant differences in forestry industry integration and farmers' forestry income among different provinces in China. Considering the practical significance of regional differences on farmers' forestry income, based on the Eastern, Central, Western, and Northeastern regions of China, a fixed effect model is used to estimate the relationship between forestry industry integration and farmers' forestry income for regional difference discussions (Table 5).

Table 5. Regression results of sub regional samples.

Variables	Eastern	Central	Western	Northeastern
X_1	0.016*	0.022*	−0.001	0.304***
	(1.744)	(0.973)	(−0.147)	(3.145)
X_2	0.125***	0.741***	0.329***	0.846
	(3.344)	(12.401)	(8.296)	(2.955)
X_3	0.553***	0.255**	0.539***	0.347**
	(9.916)	(2.136)	(8.353)	(2.550)
X_4	0.084***	0.046**	0.111***	0.070
	(3.810)	(2.444)	(4.882)	(1.250)
X_5	0.075***	−0.001	−0.006	0.004
	(6.381)	(−0.037)	(−0.475)	(0.130)
X_6	−0.014	−0.155***	−0.046	0.146
	(−0.397)	(−3.027)	(−1.214)	(0.446)
X_7	0.153***	0.027	0.067***	0.052
	(5.711)	(1.646)	(3.862)	(1.460)
_cons	9.840***	9.105***	8.796***	7.626***
	(63.128)	(50.390)	(76.469)	(7.511)
N	450	450	450	450
F	501.92***	195.12***	265.98***	47.74***

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

In Table 5, the regression coefficients for forestry industry integration in the Eastern, Central, Western, and Northeastern regions are 0.016, 0.022, −0.001, and 0.304, respectively. Meanwhile, the regression coefficients in the Eastern, Central, and Northeastern regions are significantly positive, while the regression coefficient in the Western region is negative and not significant, indicating that the integration of forestry industry in the Eastern, Central, and Northeastern regions can significantly promote farmers' forestry income, and yet in the Western region, forestry industry integration has a restraining effect on farmers' forestry income, but it is not significant. These findings reject the null hypothesis and verify "alternative" Hypotheses 2. One possible reason for this is that compared to the Eastern, Central, and Northeastern regions, in the Western region, production factors such as capital, talent, and technology are relatively scarce (Chen et al., 2020), forestry infrastructure is relatively backward, the driving capacity of new business entities is weak, the resource constraints of integrated development are prominent, and the innovation of integrated content is insufficient, which to some extent hinders the promoting role of forestry industry integration on farmers' forestry income. Furthermore, the ecological environment in the Western region is fragile, with protection as the main focus, and as an ecological conservation area (Chen & Zhang, 2019), it also restricts economic development and utilization, leading to a decrease in opportunities for forest farmers to engage in forestry production and operation activities, which is not conducive to increasing their income.

In the Eastern, Central, and Northeastern regions, the coefficient of forestry industry integration in the Northeastern region is significantly higher than that in the Central and Eastern regions. This is mainly because in the Northeast region, there are abundant forest resources (Chen & Zhang, 2019). Forest industry enterprises and state-owned forest farms have overcome the barriers and obstacles that restrict the integration of the upstream and downstream industrial chains of the forestry industry in various aspects such as financing and circulation. This plays an important role in promoting the integration of the forestry industry, ensuring that the development of modern forestry

is no longer limited by traditional forestry, releasing a large amount of surplus labor, and thus driving the increase of local farmers' forestry income.

5.2.2 Individual Difference Analysis and Discussion

In order to comprehensively reveal the impact of forestry industry integration on the income levels of different forest farmers, five typical quantiles of 10%, 25%, 50%, 75% and 90% were selected to correspond to the lowest, middle low, middle, middle high and highest groups of farmers' forestry income, respectively, to try to understand the marginal effect of forestry industry integration on farmers' forestry income under different income levels of forest farmers (Table 6). In addition, in order to make the estimation results more effective, the self-service repeated sampling technique is used to conduct 1000 repeated samples for each quantile regression.

Table 6. Panel quantile regression results.

Variables	10 Quantiles	25 Quantiles	50 Quantiles	75 Quantiles	90 Quantiles
X_1	0.013	0.014*	0.015***	0.016**	0.019*
	(1.095)	(1.735)	(2.710)	(2.259)	(1.800)
X_2	0.214***	0.218***	0.222***	0.226***	0.228***
	(2.874)	(4.383)	(6.577)	(5.308)	(4.155)
X_3	0.620***	0.604***	0.586***	0.571***	0.561***
	(6.235)	(9.104)	(13.004)	(10.060)	(7.674)
X_4	0.102***	0.102***	0.101***	0.101***	0.100***
	(3.147)	(4.692)	(6.866)	(5.423)	(4.191)
X_5	0.056***	0.054***	0.051***	0.049***	0.048***
	(2.875)	(4.131)	(5.785)	(4.393)	(3.312)
X_6	−0.008	−0.025	−0.045	−0.062	−0.072
	(−0.103)	(−0.496)	(−1.298)	(−1.420)	(−1.282)
X_7	0.120***	0.111***	0.100***	0.091***	0.086***
	(3.289)	(4.547)	(6.059)	(4.391)	(3.207)

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

In Table 6, the regression coefficients of forestry industry integration are all positive, and except for the 10th quantile, all other quantiles are significant at least at the 10% level, indicating that forestry industry integration has a promoting effect on increasing farmers' forestry income. In addition, with the increase of the quantile of farmers' income (10%→25%→50%→75%→90%), the regression coefficient of forestry industry integration continues to increase (0.013→0.014→0.015→0.016→0.019), indicating that the impact of forestry industry integration on farmers' income increases with the increase of income level. This also means that the income increase effect of forestry industry integration on areas with higher income level is greater than that on areas with lower income level (Fei et al., 2021), thus rejecting the null hypothesis and validating "alternative" Hypothesis 3.

On the one hand, forestry industry integration includes industrial activities such as understory planting and collecting industry, forest animal breeding and utilization industry, wood processing and manufacturing industry, forest ecotourism, and forestry production technology management industry. There is a certain threshold for investment in funds, technology, and other aspects, and people at high income levels can obtain more benefits from it. On the other hand, due to asymmetric information, farmers lack comprehensive control over market information, and are always in a disadvantaged position in the industry chain (Liao, 2015; Liao & Guo, 2015; Muriithi, 2011). In addition, in order to obtain excess profits, enterprises often reduce the proportion of interests of vulnerable forest farmers in the industry chain and try to realize the transfer of market value risks as much as possible. This long-term imbalance in interest distribution can undoubtedly affect the income of forest farmers and reduce their production enthusiasm. Therefore, although forestry industry integration has promoted the income increase effect of low-income forest farmers, it has not yet played a significant role.

As far as the control variables are concerned, the regression coefficient of farmers' forest land resource level is significantly positive, and the regression coefficient increases with the increase of the quantile, indicating that the income increasing effect of farmers' forest land resource level raises with the enhancement of income quantile. The regression coefficients of rural human capital level,

level of economic development, and transport infrastructure conditions are all positive at a significance level of 1%, and gradually decrease as the quantile increases, indicating that rural human capital level, level of economic development, and transport infrastructure conditions have a more significant income increase effect on low-income forest farmers. The regression coefficient of forestry financial expenditure is significantly positive at the 1% level, and there is no significant change at each quantile, reflecting the group neutrality principle of forestry finance. The regression coefficients of forest resource endowment are all negative at the significance level of 1%, and the absolute value of the coefficients increase with the increase of the quantile, which indicates that forest resource endowment inhibits farmers' forestry income and has a more significant effect on high-income groups. The possible reason is that the index of regional forest resource endowment is measured by the regional forest coverage rate. A good forest resource endowment means a high regional forest coverage rate, a large number of nature reserves and the area of returning farmland to forest (Chen et al., 2020; Zhang et al., 2019). These resources have not been effectively developed and utilized due to the restrictions of the current ecological protection policy, which also reflects that the advantages of regional forest resources have not yet been transformed into advantages of forest assets, and even some areas are still in the stage of suppression.

5.3. Spatial Effect Analysis and Discussion

To select a suitable spatial econometric model, we tested the spatial panel model (Chen et al., 2020). The results showed a significant positive spatial correlation between variables, as indicated by the significantly positive Moran's I statistic (Table 7). We also found a need to reject the original hypothesis (spatially independent residuals). Additionally, the LM-error test, Robust LM-error test, LM-lag test, and Robust LM-tag test were passed 1% significance level, which suggests that the selection of either the SPLM or SPEM model is appropriate. Further testing through LR and Wald tests led to rejection of the original hypothesis, indicating that the SPDM model was more suitable. A Hausman test was then used to screen between random effects and fixed effects models; the Hausman statistical value was 353.22 and passed the 1% significance level test, indicating that the fixed effects model was more appropriate. Finally, it can be judged from the F-test value that the spatiotemporal dual fixed effect model should be selected. Accordingly, we selected the SPDM model with spatiotemporal dual fixed effect.

Table 7. Results of spatial panel econometrics model.

Test type	Statistic	P value	Test type	Statistic	P value
Moran's I	6.184***	0.000	Wald-spatial lag	53.93***	0.000
LM-error	35.053***	0.000	LR-spatial lag	152.56***	0.000
Robust LM-error	16.593***	0.004	Wald-spatial error	215.11***	0.000
LM-lag	89.663***	0.000	LR-spatial error	187.04***	0.000
Robust LM-lag	71.203***	0.000	Hausman	353.22***	0.000

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

The estimated parameters of each index of the SPDM model with spatiotemporal dual fixed effect (Table 8) were analyzed to determine the following.

Table 8. Estimation results of spatial econometric model.

Variables	SPEM	SPLM	SPDM	LR_D	LR_I	LR_T	WX	Interaction effect
X_1	0.003** (2.186)	0.003* (1.935)	0.003** (2.412)	0.004** (2.476)	0.007* (1.268)	0.011** (1.686)	W*X_1	0.002** (0.661)
X_2	0.040*** (4.878)	0.037*** (4.600)	0.042*** (5.095)	0.043*** (5.137)	0.024 (0.769)	0.067* (1.923)	W*X_2	−0.010 (-0.585)
X_3	0.017 (1.212)	0.037** (2.466)	0.036** (2.439)	0.063*** (3.743)	0.289*** (4.160)	0.351*** (4.401)	W*X_3	0.132*** (4.000)
X_4	0.010* (1.878)	0.006 (1.186)	0.011** (2.033)	0.011** (1.977)	−0.003 (−0.198)	0.008 (0.431)	W*X_4	−0.007 (−0.817)
X_5	-0.008*** (−3.299)	-0.005** (−1.994)	-0.005** (−2.023)	-0.003 (−1.029)	0.027*** (2.686)	0.024** (2.069)	W*X_5	0.016*** (3.350)
X_6	-0.023*** (−3.170)	-0.021*** (−2.965)	-0.029*** (−4.004)	-0.026*** (−3.213)	0.028 (0.797)	0.002 (0.051)	W*X_6	0.031* (1.691)
X_7	0.014** (2.156)	0.016** (2.527)	0.011* (1.756)	0.016** (2.339)	0.058** (2.241)	0.074*** (2.598)	W*X_7	0.024* (1.680)
Rho/λ	0.568***	0.530***				0.512***		
sigma2_e	0.000***	0.000***				0.000***		
R^2	0.709	0.873				0.937		
Log_L	1358.973	1359.010				1377.047		

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

The estimated value of the forestry industry integration coefficient was 0.003, which is significant at the 10% level. This shows that the improvement of forestry industry integration significantly promotes farmers' forestry income, thus rejecting the null hypothesis and validating Hypothesis 1. Similar results have been reported in past analyses of industry integration in agriculture. For example, positive associations between farmers and industry integration were found by Das & Ganesh-Kumar (2018), Carillo et al. (2017) in places such as India and Italy. According to the theory of spatial economics, with the vertical development of national economic integration, inter-regional transaction costs will be reduced. Various input-output factors and production and management activities in the inter-regional development main body gather together in the spatial scope due to accidental factors, and thus form a "center-periphery" form of economic zoning. With the rapid development and wide application of network information technology, the supply and demand relationship between industries has already broken the restriction between regions, and the inter-regional flow of various production factors and the enhanced correlation of product trade will form the spatial agglomeration advantage of regional production factors, affecting the integration and cluster development of forestry industry and the formation of industrial chain, thus affecting the income of forest farmers. The results also show that it is necessary to study the effect of forestry industry integration on farmers' income from a spatial perspective. It should be noted that Rho/λ reflects the magnitude and direction of the spatial hysteresis effect, with a value between −1 and 1. In Table 8, Rho/λ is 0.512, passing the 1% significance level test, which means that the increase in forestry industry integration in adjacent regions has a positive effect on the increase of farmers'

forestry income. That is, there is a significant spatial spillover effect of forestry industry integration on the growth of farmers' forestry income. sigma2_e represents the variance of the spatial error term, which is the degree of spatial autocorrelation error. In Table 8, sigma2_e is 0.0002, passing the 1% significance level test and indicating that the spatial autocorrelation error is small and the SPDM model fits well.

When using the spatial econometric model to explain the impact of forestry industry integration on farmers' forestry income and spatial spillover effect, in addition to point estimation, it is also necessary to decompose the spatial effect to further determine the direct effect, indirect effect and total effect of forestry industry integration on farmers' forestry income (Table 8). Among them, the total effect represents the overall impact of forestry industry integration on the income of forest farmers, the direct effect represents the impact of forestry industry integration on the income of local forest farmers, and the indirect effect represents the impact of local forestry industry integration on the income of nearby forest farmers (Elhorst, 2003).

The total effect, direct effect, and indirect effect coefficients of forestry industry integration on the income of forest farmers were all positive, and significant at the level of 1%, with values of 0.011, 0.004, and 0.007 respectively, which indicates that forestry industry integration has a significant income increasing effect on the income of forest farmers in both the local and adjacent regions, that is, the spatial spillover effect caused by forestry industry integration is significant. At the same time, the indirect effect coefficient of forestry industry integration was greater than the direct effect coefficient, indicating that the effect of forestry industry integration on the income increase of neighboring forest farmers is greater than that of local forest farmers. This is mainly because the upgrading of local forestry related industries has effectively broken the relatively single mode of low efficiency production, free flow of talents, capital and technology among industries, and the barriers to free flow of regional factors have gradually disappeared (Deichmann et al., 2016; Fu & Zhang, 2022; Jin et al., 2023b). Resources can flow freely and efficiently in the neighboring areas, and then rely on the spatial spillover mechanisms such as "factor flow effect", "scale economy ", "diffusion effect" and "learning imitation effect" to affect the neighboring areas (Ziyu, 2022), which has a positive spatial spillover effect on the income increase of forest farmers in the surrounding areas. However, it should be noted that the spillover effect coefficient of forestry industry integration was 0.007, which is at a relatively low level, indicating that China's forestry industry integration is still in the period of transformation and upgrading, some emerging industries related to integration are in the initial stage of development, and the diffusion effect generated by factor flow still needs to be strengthened.

5.4. Robustness Test

We conducted robustness tests based on gradually adding control variables (Table 4) and replacing the explained variable (Table 9).

Table 9. Robustness test results of proposed model.

Variables	SPDM	LR_D	LR_I	LR_T	WX	Interaction effect
X_1	0.007*	0.011**	0.046***	0.057***	W*X_1	0.021***
	(1.207)	(2.218)	(2.693)	(2.838)		(2.187)
X_2	0.124***	0.101***	−0.260***	−0.159	W*X_2	−0.203***
	(5.058)	(3.919)	(−2.653)	(−1.433)		(−3.998)
X_3	−0.021	−0.039	−0.260	−0.299	W*X_3	−0.133
	(−0.474)	(−0.789)	(−1.367)	(−1.361)		(−1.334)
X_4	0.012	−0.007	0.224***	−0.231***	W*X_4	−0.124***
	(0.718)	(−0.433)	(−4.429)	(−4.076)		(−4.570)
X_5	−0.040***	−0.035***	0.055*	0.021	W*X_5	0.048***
	(−5.025)	(−4.022)	(1.871)	(0.602)		(3.229)
X_6	−0.155***	−0.127***	0.309***	0.182	W*X_6	0.247***
	(−7.241)	(−5.222)	(2.835)	(1.473)		(4.471)
X_7	0.060***	0.093***	0.393***	0.486***	W*X_7	0.175***
	(0.007)	(4.446)	(5.027)	(5.622)		(3.966)
R^2				0.517		
Log_L				881.595		

Note: ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

(1) Gradually adding control variables. In Table 4, we added control variables that affect farmers' forestry income, such as farmers' forest land resource level, rural human capital level, forestry financial expenditure, level of economic development, forest resource endowment, and transport infrastructure conditions, one by one. Not only does the goodness of fit of the model gradually increase, but the significance level of the main explanatory variable and control variables has not changed significantly, indicating that the research conclusion is robust and reliable.

(2) Salary of on-the-job employees in the forestry system as explained variable. In Table 9, the forestry industry integration level had a significant positive correlation with the salary of on-the-job employees in the forestry system. This is consistent with our conclusion that farmers' forestry income as the explained variable. The regression results in this case do not change substantially due to changes in the measures of the explained variable.

6. Conclusions and Implications

6.1. Conclusions

(1) Our results indicated that from 2005 to 2019, the forestry industry integration index value showed a positive trend at both the national and regional levels with varying levels of integration across the Northeast-Central-West-East cascade. Most provinces are currently in the stage of "Medium fusion" or "Medium-high fusion", with the level of integration improving in the majority of regions and declining in only a few areas.

(2) The spatial correlation analysis revealed that spatial factors have become an important factor affecting the income of forest farmers in various regions. The global autocorrelation showed a positive spatial correlation in the income of forest farmers, which is gradually increasing. Local autocorrelation revealed that provinces in the coastal area had high income from forest farmers, as indicated by the presence of HH clusters. In contrast, provinces such as Hunan, Ningxia had low income from forest farmers manifesting as LL clusters.

(3) Our empirical results indicated that the *FII* has a significant positive impact on the income of forest farmers. And it has spatial spillover effects, but at a relatively low level. At the same time, there were regional differences and individual differences in the income increase effect of forestry industry integration for forest farmers. Specifically, regional differences are mainly manifested in the integration of forestry industry can significantly promote farmers' forestry income in the Eastern, Central, and Northeastern regions, and yet in the Western region, forestry industry integration has a restraining effect on farmers' forestry income, but it is not significant. Individual differences are mainly manifested in the income increase effect of forestry industry integration on areas with higher income level is greater than that on areas with lower income level.

6.2. Implications

(1) In terms of the spatial-temporal evolution characteristics of forestry industry integration, the level of integration is mostly in the medium or medium-high stage and exhibits significant positive spatial correlation. Therefore, it is necessary to improve the level of forestry industry integration development and enhance its impact on adjacent regions. This can be achieved by promoting the primary processing and deep processing of forest products, linking primary and tertiary industries, and realizing the drive of industrial chain extension to extend the value chain. To make the most of the agglomeration effect of regions with high levels of forestry industry integration, it is important to improve the benefit-sharing mechanism of cross-regional cooperation and enhance the diffusion effect of forestry industry integration activities in a given region on other regions. By establishing successful cases, we can continue to build pilot areas and demonstration parks to drive the development of forestry industry integration in numerous regions.

(2) The spatial-temporal evolution of farmers' forestry income shows clear regional characteristics. To leverage the agglomeration effect of regions with high income, it is important to strengthen regional exchanges and cooperation and to promote the growth of farmers' forestry income. For regions with substantial differences in farmers' forestry income, regular experience exchange meetings can be organized to facilitate the flow of resources. Regions with high income can serve as a driving force for those with low income, ultimately promoting common development in all regions. In regions with similar income levels, organizing collective training for forestry scientific and technological personnel, as well as conducting friendly competitions, may encourage all regions to strengthen their forestry development.

(3) From the perspective of the function mechanism of forestry industry integration on farmers' forestry income, it is evident that integration can generally improve farmers' forestry income. Therefore, it is crucial to promote the development of forestry industry integration to boost farmers' forestry income. For instance, multiple regions can jointly create a batch of regional characteristic forestry industry integration enterprise brands, play a demonstration effect, bring more employment

opportunities to farmers, and expand the channels for increasing income for forestry farmers. At the same time, we should pay attention to regional economic development and individual differences, that is, formulate special support policies to promote regional coordinated development and the development of low-income groups' forestry industry in promoting the integrated development of regional forestry industry. However, it is necessary to follow the law of forestry economic development, not blindly promote the "curve overtaking" development mode in underdeveloped areas and avoid the possible rupture of new and old kinetic energy and the hollowing of forestry industry when upgrading the forestry industry. Moreover, we should guide the development of joint-stock cooperation. It is necessary to develop more forestland-based cooperation methods, include the forest contractors into the shareholders, and create a comprehensive interest linkage mechanism from the production stage to the operation stage through a variety of models such as "guaranteed income + dividend per share", so as to reduce the operational risks of disadvantaged forest farmers. Finally, it should also innovate the development of order forestry. Promote cooperation in the production and sales of forest products, establish a tracking system with information technology development, product standards and service quality functions, track the integrated products of the forestry industry, improve product quality and increase the income of forest farmers.

(4) It should be pointed out that the Herfindahl index, a previous research method, is used in this paper to measure forestry industry integration. Although it can better reflect the degree of cross-penetration and integration between industries within forestry, it cannot fully reflect the integration between forestry and other industries, resulting in relatively rough measurement results. However, the complete data that can be collected in China's forestry industry can only be used to measure the integration degree of forestry industry by using Herfindahl index method, which is also a commonly used method in more subdivided industries such as cultural tourism, major agriculture, forestry and animal husbandry. Therefore, this method is a very suitable method under existing conditions. In the future, with the increasingly complete data and the continuous improvement of measurement methods, we will further explore more reasonable and effective ways to improve our current work. And conduct smaller scope (such as county-level) research to enrich and improve the integration research of the forestry industry.

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References

Abdulai, A. N., & Abdulai, A. (2016). Allocative and scale efficiency among maize farmers in Zambia: A zero efficiency stochastic frontier approach. *Applied Economics*, *48*(55), 5364–5378. https://doi.org/10.1080/00036846.2016.1176120

Abhilash, P. C. (2021). Restoring the unrestored: Strategies for restoring global land during the UN decade on ecosystem restoration. *Land*, *10*(2), 201. https://doi.org/10.3390/land10020201

Adriana, B., Jorge, A., Frederick, C., Gustavo, F., & Valentin, P. (2019). Diverse strategies for integration of forestry and livestock production. *Agroforestry Systems*, *93*, 1–12. https://doi.org/10.1007/s10457-017-0092-7

Antonakis, J., Bendahan, S., Jacquart, P., & Lalive, R. (2010). On making causal claims: A review and recommendations. *Leadership Quarterly*, *21*(6), 1086–1120. https://doi.org/10.1016/j.leaqua.2010.10.010

Bai, L. X. (2023). *Research on the Impact of Integration of Primary, Secondary and Tertiary Industries on Farmers' Income in Rural China*. [Master thesis, Northeast Agricultural University].

Bai, Q., & Zheng, J. (2018). Analysis of the impact of natural forest protection project forestry investment on the development of forestry industry in China from the perspective of ecological civilization construction. *Ekoloji*, *27*(106), 1007–1012.

Bally, N. (2005). Deriving managerial implications from technological convergence along the innovation process: A case study on the telecommunications industry. *Swiss Federal Institute of Technology, Zurich*.

Cao, X. Q. (2015). Study on "integration of informatization and industrialization" characteristics and its interaction relationship with industrial design. *International Journal of Technology Management*, (8),33–37.

Carillo, F., Caracciolo, F., & Cembalo, L. (2017). Do durum wheat producers benefit of vertical coordination? *Agricultural and Food Economics*, *5*(1), 19. https://doi.org/10.1186/s40100-017-0088-7

Carlos, B., Alejandra, E., Roberto, J. R., & Rodrigo, A. (2020). Are forest plantation subsidies affecting land use change and off–farm income? A farm–level analysis of Chilean small forest landowners. *Land Use Policy*, *91*, 104308. https://doi.org/10.1016/j.landusepol.2019.104308

Charlie, M., Shackleton, S. E., Shackleton, E. B., & Neil, B. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics*, *9*(5), 558–577. https://doi.org/10.1016/j.forpol.2006.03.004

Chen, J. F. (2010). The mechanism analysis of social capital in industrial clusters. *2010 ETP//IITA Conference on System Science and Simulation in Engineering*, 69–72.

Chen, N., Qin, F., Zhai, Y. X., Cao, H. P., Zhang, R., & Cao, F. P. (2020). Evaluation of coordinated development of forestry management efficiency and forest ecological security: A spatiotemporal empirical study based on China's provinces. *Journal of Cleaner Production*, *260*, 121042. https://doi.org/10.1016/j.jclepro.2020.121042

Chen, S., &Zhang, X. M. (2019). Optimization of regional forestry industrial structure and economic benefit based on deviation share and multi–level fuzzy comprehensive evaluation. *Journal of Intelligent & Fuzzy Systems*, *37*(1), 145–157. https://doi.org/10.3233/JIFS-179073

Chen, Y. D., & An, X. (2018). Support effect of Chinese forest seedlings industry on revenue growth of farmers: Based on panel data of eastern, central, and western regions of China. *Journal of Beijing Forestry University (Social Sciences)*, *17*(4), 56–62. (In Chinese)

Chesbrough, H. (2007). Business model innovation: It's not just about technology anymore. *Strategy & Leadership*, *35*(6), 12–17. https://doi.org/10.1108/10878570710833714

Cubbage, F., Harou, P., & Sills, E. (2007). Policy instruments to enhance multi-functional forest management. *Forest Policy and Economics*, *9*(7), 833–851. https://doi.org/10.1016/j.forpol.2006.03.010

Das, V. K., & Ganesh-Kumar, A. (2018). Farm size, livelihood diversification and farmer's income in India. *Decision*, *45*(2), 185–201. https://doi.org/10.1007/s40622-018-0177-9

Deichmann, U., Goyal, A., & Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *The Journal of the International Association of Agricultural Economics*, *47*(Sup. 1), 21–33. https://doi.org/10.1111/agec.12300

Dong, F., Li, Y. F., Zhang, X. Y., Zhu, J., & Zheng, L. (2021). How does industrial convergence affect the energy efficiency of manufacturing in newly industrialized countries? Fresh evidence from China. *Journal of Cleaner Production*, *316*, 128316. https://doi.org/10.1016/j.jclepro.2021.128316

Elhorst, J. P. (2003). Specification and estimation of spatial panel data models. *International Regional Science Review*, *26*(3), 244–268. https://doi.org/10.1177/0160017603253791

FAO. (2006). *Global forest resources assessment 2005*.

Fei, X. M., Shen, Y. Q., & Zhao, F. M. (2021). Impact of farmers' bamboo industry integration participation and human capital on their income. *Journal of Zhejiang A&F University*, *38*(6), 1261–1269.

Feng, X., & Dai, Y. W. (2019). An innovative type of forest insurance in China based on the robust approach. *Forest Policy and Economics*, *104*, 23–32. https://doi.org/10.1016/j.forpol.2019.03.012

Fu, W. Q., & Zhang, R. W. (2022). Can digitalization levels affect agricultural total factor productivity? Evidence from China. *Frontiers in Sustainable Food Systems*, *6*, 860780. https://doi.org/10.3389/fsufs.2022.860780

Gambardella, A., & Torrisi, S. (1998). Does technological convergence imply convergence in markets? Evidence from the electronics industry. *Research Policy*, *27*(5), 445–463. https://doi.org/10.1016/S0048-7333(98)00062-6

Getachew, M., Espen, S., & Pål, V. (2007). Economic dependence on forest resources: A case from Dendi District, Ethiopia. *Forest Policy and Economics*, *9*(8), 916–927. https://doi.org/10.1016/j.forpol.2006.08.001

Gullette, G. S. (2014). Rural–urban hierarchies, status boundaries, and labour mobilities in Thailand. *Journal of Ethnic & Migration Studies*, *40*(8), 1254–1274. https://doi.org/10.1080/1369183X.2013.836959

Hari, K., AbrarJuhar, M., & Makoto, I. (2017). Impact of community forest program in protection forest on livelihood outcomes: A case study of Lampung Province, Indonesia. *Journal of Sustainable Forestry*, *36*(3), 250–263. https://doi.org/10.1080/10549811.2017.1296774

Hou, F. M., Wu, J., Li, H. X., Yang, Y. L., Luo, X. J., & Shen, Y. (2017). Analysis on the development of Chinese under–forest economy and its effect on the increase of farmers' income. *Journal of Discrete Mathematical Sciences and Cryptography*, *20*(6–7), 1263–1268. https://doi.org/10.1080/09720529.2017.1392432

Jin, M. M., Chen, N., Sun, H. S., & Cao, F. P. (2023a). Characteristics of spatial–temporal differences and measurement of the level of forestry industry integration in China. *Sustainability*, *15*(11), 8855. https://doi.org/10.3390/su15118855

Jin, M. M., Chen, N., Wang S. K., & Cao, F. P. (2023b). Does forestry industry integration promote total factor productivity of forestry industry? Evidence from China. *Journal of Cleaner Production*, *415*, 137767. https://doi.org/10.1016/j.jclepro.2023.137767

Kendra, R., & Bassett, G. (1978). Regression quantiles. Econometrica, *46*(1), 33-35. https://doi.org/10.2307/1913643

Lemola, T. (2002). Convergence of national science and technology policies: The case of Finland. *Research Policy*, *31*(8–9), 1481–1490. https://doi.org/10.1016/S0048-7333(02)00077-X

Li, B. Z. (2007). Industry melting: The path choice of the forestry industrialization in Transformation. *Forestry Economics*, (11), 59–62. (In Chinese)

Li, L., Liu, T., Xu, S. B., & Tian, Z. W. (2021a). Evaluation on sustainable development of forest tourism in Heilongjiang Province, China. *Environment, Development and Sustainability*, *23*, 13382–13402. https://doi.org/10.1007/s10668-020-01217-8

Li, W. J., Wang, Y., Xie, S. Y., & Cheng, X. (2021b). Coupling coordination analysis and spatiotemporal heterogeneity between urbanization and ecosystem health in Chongqing municipality, China. *Science of the Total Environment*, *791*, 148311. https://doi.org/10.1016/j.scitotenv.2021.148311

Li, Z. H., & Wang, X. D. (2019). Development strategies of leisure agriculture and rural tourism of Henan Province based on industry convergence. *Ecological Economy*, *15*(4), 289–295.

Liao, C. N. (2015). Game theory applications in socially responsible operations and operations–marketing interface. *UC Berkeley*, 2015. https://escholarship.org/uc/item/8qm007mz

Liao, W. M., & Zhang, G. L. (2014). Effects of China's forestry marketization on farmers' revenue from 2002 to 2011. *Forestry Economics*, *36*(9), 93–97. (In Chinese)

Liao, Z. J., & Guo, X. M. (2015). Logic and direction of Chinese agricultural operation organization system evolution: Within the framework of industry chain integration. *Chinese Rural Economy*, (2), 13–21.

Lin, B. Q., & Chen, Y. (2020). Transportation infrastructure and efficient energy services: A perspective of China's manufacturing industry. *Energy Economics*, *89*, 104809. https://doi.org/10.1016/j.eneco.2020.104809

Liu, C., Lyu, J. Z., & Yin, R. S. (2009). An estimation of the effects of China's forestry programs on farmers' income. *In An Integrated Assessment of China's Ecological Restoration Programs. Springer-Verlag*, 201–218. https://doi.org/10.1007/978-90-481-2655-2_12

Lu, C., Qiao, J. Y., & Chang, J. L. (2017). Herfindahl–Hirschman index based performance analysis on the convergence development. *Cluster Computing*, *20*, 121–129. https://doi.org/10.1007/s10586-017-0737-3

Lu, S. S., Chen, N., Zhong, X. Q., Qin, F., & Guan, X.L. (2018). Factors affecting forestland production efficiency in collective forest areas: A case study of 703 forestland plots and 290 rural households in Liaoning, China. *Journal of Cleaner Production*, *204*, 573–585. https://doi.org/10.1016/j.jclepro.2018.09.013

Lu, S. S., Sun, H. S., Zhou, Y., Qin, F., & Guan, X. L. (2020). Examining the impact of forestry policy on poor and non–poor farmers' income and production input in collective forest areas in China. *Journal of Cleaner Production*, *276*, 123784. https://doi.org/10.1016/j.jclepro.2020.123784

Midgley, S. J., Stevens, P. R., & Arnold, R. J. (2017). Hidden assets: Asia's smallholder wood resources and their contribution to supply chains of commercial wood. *Australian Forestry*, *80*(1), 10–25. https://doi.org/10.1080/00049158.2017.1280750

Muriithi, E. W. (2011). Benefits of market information access through mobile telephone among small-scale farmers: A case study of NAFIS application in Kirinyaga County. *University of Nairobi Kenya*, 2011. http://erepository.uonbi.ac.ke:8080/handle/123456789/3728

Nambiar, E. K. S. (2021). Strengthening Vietnam's forestry sectors and rural development: Higher productivity, value, and access to fairer markets are needed to support small forest growers. *Trees, Forests and People*. *3*, 100052. https://doi.org/10.1016/j.tfp.2020.100052

Oscar, A. M., & William, F. (2021). Agricultural and forestry land and labor use under long-term climate change in Chile. *Atmosphere*, *12*(3), 305. https://doi.org/10.3390/atmos12030305

Patricia, U., Carsten, S.H., & Finn, H. (2012). Forest income and dependency in lowland Bolivia. *Environment, Development and Sustainability*, *14*, 3–23. https://doi.org/10.1007/s10668-011-9306-8

Pyi, S. A., Yahia, O. A., Jiirgen, P., & Ronny, P. (2015). Distribution of forest income among rural households: A case study from Natma Taung national park, Myanmar. *Forests, Trees and Livelihoods*, *24*(3), 190–201. https://doi.org/10.1080/14728028.2014.976597

Qu, R., Rhee, Z., Bae, S. J., & Lee, S. H. (2022). Analysis of industrial diversification level of economic development in rural areas using Herfindahl index and Two–Step clustering. *Sustainability*, *14*, 6733. https://doi.org/10.3390/su14116733

Reddy, S. R. C., & Chakravarty, S. P. (1999). Forest dependence and income distribution in a subsistence economy: Evidence from India. *World Development*, *27*(7), 1141–1149. https://doi.org/10.1016/S0305-750X(99)00057-1

Roberto, P., Alejandro, L. F., & Jorge, W. V. A. (2015). Forest use and agriculture in Ucayali, Peru: Livelihood strategies, poverty and wealth in an Amazon frontier. *Forest Policy and Economics*, *51*, 47–56. https://doi.org/10.1016/j.forpol.2014.12.001

Rosenberg, N. (1963). Technological change in the machine tool industry: 1840–1910. *The Journal of Economic History*, *23*(4), 414–443. https://doi.org/10.1017/S0022050700109155

Sears, R. R., Christine, P., & Miguel, P. V. (2007). Amazon forestry transformed: Integrating knowledge for smallholder timber management in eastern Brazil. *Human Ecology*, *35*, 697–707. https://doi.org/10.1007/s10745-006-9109-y

Sunderlin, W. D., Arild, A., & Sven, W. (2003). Forests and poverty alleviation. *State of the World's Forests*, 61–73.

Tobler, W. (2004). On the first law of geography: A reply. *Annals of the Association of American Geographers*, *94*(2), 304–310. https://doi.org/10.1111/j.1467-8306.2004.09402009.x

Vedeld, P., Angelsen, A., Bojö, J., Sjaastad, E., & Berg, G.K. (2007). Forest environmental incomes and the rural poor. *Forest Policy and Economics*, *9*(7), 869–879. https://doi.org/10.1016/j.forpol.2006.05.008

Wang, G. Y., Innes, J. L., Lei, J. F., Dai, S. Y., & Wu, S. W. (2007). China's forestry reforms. *Science*, *318*(5856), 1556–1557. https://doi.org/10.1126/science.1147247

Wei, J., Xiao, H., Liu, C., Huang, X. T., & Zhang, D. H. (2022). The impact of collective forestland tenure reform on rural household income: The background of rural households' divergence. *Forests*, *13*(9), 1340. https://doi.org/10.3390/f13091340

World Bank. (2000). *Towards a revised forest strategy for the world bank group*.

Xiong, L. C., Wang, F. T., Cheng, B. D., & Yu, C. (2018). Identifying factors influencing the forestry production efficiency in Northwest China. *Resources, Conservation and Recycling*, (130), 12–19. https://doi.org/10.1016/j.resconrec.2017.11.009

Yang, J., Dai, G. H., & Wang, S. R. (2015). China's national monitoring program on ecological functions of forests: An analysis of the protocol and initial results, *Forests*. *6*(3), 809–826. https://doi.org/10.3390/f6030809

Yao, Y., Qin, S. Y., & Gao, Y. F. (2022). Research on the impact of digital literacy on the overall income of rural households: A case study of 410 questionnaires in Pucheng County, Shaanxi Province. *Highlights in Business, Economics and Management*, *1*, 285–292. https://doi.org/10.54097/hbem.v1i.2589

York, R. (2018). Control variables and causal inference: A question of balance. *International Journal of Social Research Methodology*, *21*(6), 675–684. https://doi.org/10.1080/13645579.2018.1468730

Zhang, Q., Wang, G. Y., Mi, F., Zhang, X. C., Xu, L. Z., Zhang, Y. F., & Jiang, X. L. (2019). Evaluation and scenario simulation for forest ecological security in China. *Journal of Forestry Research*, *30*(5), 1651–1666. https://doi.org/10.1007/s11676-018-0773-8

Ziyu, H. U. (2022). Integration and development of China's characteristic agricultural industry against the backdrop of rural revitalization strategy. *Asian Agricultural Research*, *14*(2), 23–25. https://doi.org/10.22004/ag.econ.329658