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The impact of financial support on forestry green total factor productivity from the perspective of environmental regulation

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Abstract

Purpose – The aim of this article is to research on forestry green total factor productivity and explore the impact of financial support on forestry green total factor productivity.

Design/methodology/approach – The methods used in this study are super efficiency SBM model of undesired output and empirical model. SBM model is a kind of Data Envelopment Analysis (DEA). The SBM model with non-expected outputs (slacks-based measure) can be used to deal with the problem of efficiency measurement with multiple input and output variables and can be used to analyze the efficiency of green development of forestry economy.

Findings – First, the overall green total factor productivity of the authors' country's forestry has shown a trend of first decline and then an increase from 2008 to 2018, and there are significant spatiotemporal differences; second, financial support has a significant positive impact on forestry green total factor productivity; third, environmental regulation has a significant threshold effect in the process of financial support on forestry green total factor productivity, and the role of financial support shows a trend of first increasing and then decreasing.

Originality/value – Secondly, taking the data of 30 provinces and cities in the authors' country from 2008 to 2018 as the research object, using the super-efficiency SBM-Malmquist index to measure the country's forestry green total factor productivity and analyze its temporal and spatial changes; finally, a dynamic panel model was established to explore the impact of financial support on forestry green total factors quantitative impact on productivity, and adding environmental regulation as a threshold variable to establish a dynamic threshold regression, and found that financial support has a nonlinear impact on forestry green total factor productivity.

Keywords High quality development, Forestry green total factor productivity, Environmental regulation, Financial support

Paper type Research paper

1. Introduction

Forestry construction is related to sustainable economic and social development. In the construction of ecological civilization, forestry occupies a major position and undertakes the task of increasing ecological resource assets, strengthening ecosystem functions and improving basic livelihood welfare and other major issues.

In the inaugural Central Forestry Working Conference of 2009, it was emphasized that the construction of an ecological civilization must prioritize the development of forestry as a fundamental task. Furthermore, the conference clearly articulated the crucial role of forestry development in implementing sustainable development.

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The forestry industry is characterized by a long production cycle and high natural risks. Moreover, its ecological benefits exhibit the characteristics of a public good, including nonexclusivity, externality and public welfare. Consequently, the development of the forestry industry largely relies on the guidance of fiscal policies and financial support. According to the "Report on the Development of Forestry and Grassland in China 2018", a total investment of 481.713 billion yuan was made in the field of forestry ecological protection and construction in 2018, of which 243.249 billion yuan came from national funds. The investment in ecological construction and protection was 212.575 billion yuan, accounting for 44.13% of the total forestry investment completion. While the investment in forestry support and protection, such as forest seedlings, forest fire prevention, forest public security and prevention of forest pests and diseases, was 60.844 billion yuan. The funds for the development of forestry industry were 192.633 billion yuan, and the central budget funds for grassland ecological protection and restoration were 3.973 billion yuan.

Based on the background and data mentioned above, it is evident that China is continuously strengthening its focus on ecological civilization construction, while the forestry industry plays a crucial role in this development. In recent years, the development of China's forestry industry should shift from extensive growth to a stage of high-quality development. Consequently, how to quantify the concept of high-quality development has become a topic of great interest among scholars. The theoretical concept of total factor productivity has gradually gained attention among researchers. Forestry total factor productivity can comprehensively measure the production efficiency brought about by the input and output of the forestry industry. The combination of forestry total factor productivity and ecological environment is more in line with the key requirements of high-quality development of the forestry industry. Therefore, measuring the forestry green total factor productivity and analyzing its influencing factors is of great practical significance for improving the sustainable, high-quality, and green development of China's forestry industry. In the continuous development of the forestry industry, financial support is an important factor in supporting its development, which is supported by the theories and empirical research of many scholars (Liu *et al.*, 2014; Pu, 2016, Ren *et al.*, 2019). They all agree that financial support is the most critical factor to promote the development of forestry industry. Based on the above reasons and background, in the context of ecological civilization development, it is of great practical importance to accurately measure the forestry green total factor productivity index that measures the high-quality green development of forestry, explore the theoretical influence mechanism and empirical test of financial support on it, and add the perspective under environmental regulation, aiming to provide a new reference for the sustainable high-quality development of forestry industry.

2. Literature review

2.1 Literature review on the theory of forestry green total factor productivity

In China, related methods for constructing forestry total factor productivity using input indicators such as labor and capital were first utilized by Ma and Liu (1992) to provide policy recommendations for improving forestry production efficiency and input factors. Based on a follow-up survey of 76 sample farmers' forestry operations in Lishui City, Zhejiang Province from 2004 to 2009, Wu *et al.* (2013) used the method of data envelopment analysis (DEA)-Malmquist index to measure and analyze. They found that forestry green total factor productivity in Zhejiang Province showed a rapid growth overall during 2004–2009. Lang and Liu (2015) used the DEA-Malmquist index to analyze the forestry green total factor productivity in China and decomposed the Total Factor Productivity (TFP) of forest resource growth in different stages and provinces. They found that "green investment", "green new policy" and "green innovation" would lead to the increase of TFP.

The burgeoning interest in the development quality of the forestry industry is becoming increasingly prominent. The integration of total factor productivity and the ecological environment is more aligned with the essence of China's high-quality development. At this time, the research results on forestry green total factor productivity are more abundant, but the forestry green total factor productivity gradually began to take off. Liu and Li (2020) incorporated nondesirable outputs, including forestry wastewater, waste gas and solid particles, into the measurement indicators for productivity. In addition, ecological output was included as desirable output. The authors utilized the SBM-Malmquist index model to measure the changes in forestry green total factor productivity in 30 provinces in China between 2005 and 2016, while also analyzing their spatial and temporal differences and the factors that influenced them. Lv *et al.* (2022) used the super-efficient SBM model to measure the forestry green total factor productivity in 30 provinces in China. He further used Markov chains for short-term and long-term analysis to propose the idea of strengthening forestry policy support. Yu and Yang (2023) have taken the ecological benefits of forestry output (per unit area of forest stock volume) as the output indicator of forestry ecological efficiency, focusing on the value of forestry ecological services. Using the DEA model and the Global Malmquist index, they have measured the forestry ecological efficiency of 31 provinces in China from 2009 to 2018. Tan (2022) utilized the SBM model and Global Malmquist–Luenberger (GML) index to measure the forestry green total factor productivity of 30 provinces in China from 2002 to 2020. Their findings indicate a general upward trend in forestry green total factor productivity, and they propose relevant policy recommendations such as strengthening forestry policies and legal protections.

2.2 Literature review on the relationship between financial support and forestry green total factor productivity

Financial support is a quality move for the forestry industry to achieve green development is an important support. In China many scholars on the forestry industry financial support for its sustainable green development and other aspects of in-depth discussion. Some scholars of modern forestry construction theory use public finance theory as the basis, the use of comparison, the successful experience of foreign forestry fiscal policy to learn from. After a systematic review of the changes in China's forestry financial investment system since the reform and opening up, some scholars analyze the effectiveness and problems of forestry financial investment.

In terms of domestic empirical studies, the existing literature basically concludes that state financial support has a significant positive contribution to the high-quality development of forestry. Cao and Wang (2019) studied the regional differences and time-series changes in forestry green total factor productivity in China using the DEA-Malmquist index method and found that both financial support and forest rights reform had a positive impact on forestry productivity. Cao and Zhai (2020) conducted an analysis of China's forestry total factor productivity and its decomposition indices using the DEA-Malmquist index model, based on provincial panel data from 2005 to 2017. Their findings suggest that national financial support plays a significant positive role in promoting forestry green total factor productivity. From the perspective of forestry investment subjects and capital interest orientation, Ren *et al.* (2019) constructed a model of the impact of forestry fiscal expenditure and social forestry investment on the accumulation of forest ecological resources using provincial panel data from 31 provinces in China from 2000 to 2015. The results show that forestry fiscal expenditure has a significant positive effect on the accumulation of forest ecological resources. But there is an inflection point and the coefficient of influence decreases as it approaches the threshold point of increase. Pu (2016) evaluated the overall efficiency of forestry policy input, scale input efficiency and policy input efficiency by constructing forestry financial input and output indicators using the DEA model. Suggestions were then proposed for the high-quality and sustainable development of forestry from various aspects such as forestry financial support funds and transfer payments. Chen and Li (2011) analyzed the fiscal policies of Sweden to examine its impact on the direction of forestry development, effective supply of forest products and international competitiveness of forest products. They proposed policy recommendations such as incorporating public forestry expenditure into the public budget and improving subsidy and compensation systems. Dai and Luo (2022) conducted a study in which they utilized the Malmquist-Luenberger (ML) index based on the SBM directional distance function to measure the total factor productivity of green industry in 284 prefecture-level cities in China from 2009 to 2017. The results indicate that the joint implementation of environmental regulation and government technological support has a long-term mechanism to promote the growth of green total factor productivity of local industry. This mechanism not only enhances the effectiveness of environmental regulation but also significantly improves the impact of government technological support.

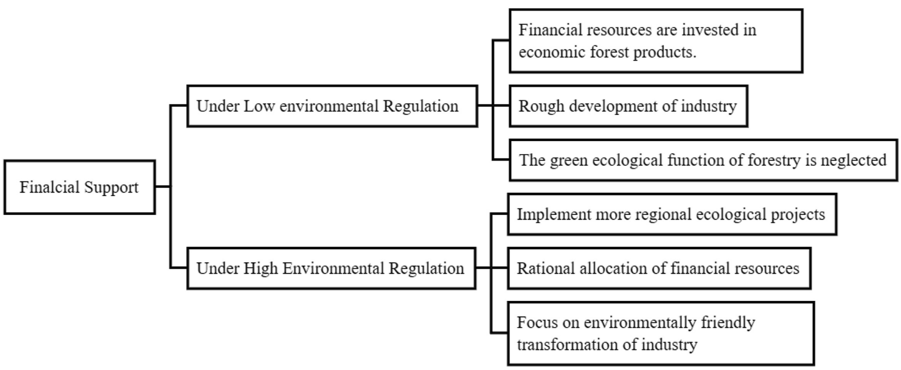
2.3 A review of the literature and theory related to environmental regulation

The impact of environmental regulation on industrial green transformation and high-quality development has been a hot topic in recent years. In the past, some scholars from traditional schools of thought abroad held the belief that environmental regulations come at the expense of sacrificing the economic interests of businesses. They argued that environmental regulations lead to increased costs for industries, and in order to comply with these regulations, a certain amount of energy efficiency must be sacrificed in exchange for the protection of the ecological environment. Consequently, this would lower the productivity of industries and ultimately decrease total factor productivity. The later "Poter" hypothesis holds the opposite view, arguing that reasonable environmental regulation can improve the green productivity of industry through technical compensation. Porter and Linde (1995) further analyzed the relationship between environmental regulation and technological innovation in terms of the intrinsic influence mechanism and theoretically argued the "Poter" hypothesis. Subsequently, many foreign scholars (Jaffe and Palmer, 1997; Berman and Bui, 2001; Hamamoto, 2006) have used empirical data to develop models to argue the validity of the "Porter" hypothesis. However, some foreign scholars argue that the relationship between environmental regulation and industrial productivity is not entirely positive and that the effect of environmental regulation on productivity is both positive and negative (Alpay *et al.*, 2002).

Environmental regulation continues to play a critical role in the impact of fiscal support on green forestry green total factor productivity. During the process of examining the impact of financial support on the forestry green total factor productivity, it has been found that environmental regulations continue to play a considerable role. Scholars have discovered that stringent environmental regulations during industrial transformation can improve the efficiency of financial expenditures. This results in directing more funds towards sustainable development in suitable industrial sectors. Therefore, the environmental regulations function as a regulatory mechanism for the allocation of financial resources (Li, 2021). According to some scholars, the presence of regional environmental regulations creates pressure on local government officials to perform well, resulting in policies that align with the environmental protection demands of the local population. As a result, more financial resources are allocated towards the greener and more environmentally friendly production processes within the forestry industry. Thereby it will contribute to the promotion of sustainable and eco-friendly development in the industry (He, 2015; Yuan and Kong, 2015).

From an intuitive perspective, fiscal support always has a positive effect on the green development of the forestry industry or the overall factor productivity of forestry green production. However, this effect may not be linear. In China, the assessment targets of environmental regulations are allocated by the state to various regions. Due to the existence of environmental regulation targets, local officials tend to invest the limited fiscal resources of the national and local governments in industries and production activities suitable for green development in the region. Compared with regions with lower levels of environmental regulation, government officials in regions with stricter environmental regulations will consider more the production efficiency of the forestry industry or green development. Similarly, the same fiscal resources will be invested in "green projects" that promote regional ecological development. At the same time, due to the existence of environmental regulation targets, more fiscal resources are used to promote enterprise technological transformation, improve industrial production efficiency, and enhance the efficiency of environmental governance. In regions where environmental regulations are relatively loose, considerations regarding environmental pollution may be relaxed in pursuit of higher economic benefits. Financial resources in these regions are more likely to be allocated towards economic or lower-tier forestry industries, resulting in different effects from the same amount of financial support. It is known that the measurement factors of forestry green total factor productivity not only include the economic benefits obtained from forestry production, but also consider the green development factors of the forestry industry, such as pollution emissions and ecological benefits. Therefore, under different environmental regulatory regimes, fiscal support will have a nonlinear impact on the forestry green total factor productivity. Figure 1 demonstrates the impact of the level of environmental regulation on the effect of fiscal support on forestry green total factor productivity.

In terms of the measurement of environmental regulation, there is a controversy on how to accurately measure the intensity of environmental regulation, and the existing literature mainly measures the magnitude of environmental regulation in a region from the following perspectives: the first approach is to use different pollutant emission densities to represent environmental regulation (Cole and Elliott, 2003); the second approach is to use the emission of a certain pollutant as a proxy variable for environmental regulation; and the third method uses the ratio of total investment in pollution control to industrial output (Tan, 2022). In China, data on this variable are difficult to obtain and the quality of data is relatively weak, and there is no uniform measure. On the other hand, research results in the forestry industry have extensively used the third method mentioned above to measure the degree of environmental regulation. Therefore, in this paper, the third method is chosen to measure the degree of regional environmental regulation using the proportion of investment in environmental pollution control to regional gross domestic product (GDP) for each province. Here, the investment in environmental pollution control includes the sum of



Source(s): Authors own work

Figure 1.
Mechanism of the role of environmental regulation in the process of financial support's impact on FGTFP

investment by the central government and local governments, and it is intuitive that a higher share indicates that more resources in the regional economy are utilized in the control of the environment.

3. Measurement of green total factor productivity in China's forestry industry

3.1 Super-efficient SBM model with nondesired output

The DEA method belongs to the category of multiple-input and multiple-output analysis methods, which evaluates the relative efficiency of input and output factors in a system. During the process of economic development, various sectors or enterprises may incur significant unexpected resource consumption and environmental pollution in order to maximize their own interests. Therefore, improving the overall performance of the system has become one of the focal points of attention. The traditional DEA methods are mostly used to focus on CCR (a model assumes constant returns to scale and is primarily used to measure technical efficiency proposed by Charnes *et al.* in 1978), and do not consider the case of nondesired outputs. The prevalence of nondesired outputs makes it impossible to obtain accurate results in the actual production process, and may even lead to invalid decision units. Some scholars have proposed a SBM model for handling nonradial output angles of unexpected output, where slack variables are directly placed in the objective function, solving not only the slackness of input and output, but also the issue of efficiency evaluation with unexpected output. Based on this, when unexpected output is taken into account, there may be multiple decisions in the SBM model that are equally efficient, resulting in efficiency values of 1. In this case, it is difficult to distinguish and rank these decision units. If there are multiple decision units with simultaneous validity in the measurement results, then a super-SBM model for unexpected output should be used to solve the problem.

The nonradial, nonangular SBM directional distance function for the nondesired output in period t is constructed as follows Eq:

$$S_v^G\left(x_k^t, y_k^t, a_k^t; g^x, g^y, g^a\right) = \max_{s^x, s^y, s^a} \frac{\dfrac{\dfrac{1}{n}\sum_{n=1}^{N}\dfrac{S_n^x}{x}}{g_n} + \dfrac{\dfrac{1}{M+1}\left[\sum_{m=1}^{M}\dfrac{S_m^y}{y} + \sum_{j=1}^{J}\dfrac{S_j^a}{a}\right]}{g_j}}{2} \tag{1}$$

$$s.t.\begin{cases} \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t x_{kn}^t + s_n^x = x_{n0}^t, n = 1, 2, \ldots, N \\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{km}^t + s_m^y = x_{m0}^t, m = 1, 2, \ldots, M \\ \sum_{t=1}^{T}\sum_{k=1}^{K} z_k^t y_{kj}^t + s_j^a = x_{j0}^t, j = 1, 2, \ldots, J \\ \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, k = 1, 2, \ldots K \\ s_n^x \geq 0, s_m^y \geq 0, s_j^a \geq 0 \end{cases} \tag{2}$$

where (x_k^t, y_k^t, a_k^t) is the input, desired output and nondesired output of k decision units in period t, $((g^x, g^y, g^a)$ denotes the direction vector and the slack vector, and the three elements in (s_n^x, s_m^y, s_j^a) represent the redundant parts of input, desired output and nondesired output, respectively.

3.2 Malmquist productivity index

The Swedish economist Malmquist proposed the Malmquist index in 1953. Later, through the DEA method, the Malmquist index gradually changed from a theoretical index to an empirical index. It is mostly used for the calculation of total factor productivity and green total factor productivity, and can also be decomposed into technology Progressive changes, changes in pure technical efficiency and changes in scale efficiency can better understand the composition and dynamic changes of productivity. At present, China's forestry investment and financing system is not perfect, and there are many problems, which restrict the healthy and rapid development of forestry industry. According to the research of Färe *et al.* (1992) and others, from period t to period t+1, the Malmquist index can be expressed as:

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \sqrt{\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} * \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}} \quad (3)$$

In the formula: $D^t(x^t, y^t)$ and $D^{t+1}(x^{t+1}, y^{t+1})$ respectively refer to the distance function of the decision-making unit in period t and period t+1 when the technology in period t is used as a reference (that is, the data in period t is used as a reference set) $D^t(x^{t+1}, y^{t+1})$, $D^{t+1}(x^t, y^t)$ in the bucket. The Malmquist productivity index indicates the degree of change in the productivity of a decision-making unit from period t to period t+1. If $M > 1$, it means that the productivity is on the rise, otherwise, it is on the decline.

Malmquist productivity index can be further decomposed into pure technical efficiency change (pech) and pure scale efficiency change (sech):

$$M(x_{t+1}\ , y_{t+1}, x_t, y_t) = \frac{D^{t+1}(x^{t+1}, y^{t+1}|VRS)}{D^t(x^t, y^t|VRS)} * \frac{D^{t+1}(x^{t+1}, y^{t+1}|VRS)}{D^{t+1}(x^{t+1}, y^{t+1}|VRS)} * \frac{D^t(x^t, y^t|VRS)}{D^t(x^t, y^t|CRS)} \quad (4)$$

3.3 Description of data and variables

Taking into account the consistency of data statistical standards and data availability, this paper selects the period from 2008 to 2018 as the sample interval for this study. At the same time, the data of Tibet autonomous region were excluded due to the incomplete data, and the final research object was a panel data set of 330 samples composed of 30 provinces and 11 years in China. The basic data used for the construction of the indicators were obtained from the China Statistical Yearbook, the China Forestry Statistical Yearbook, the China Environmental Statistical Yearbook, and the China Energy Statistical Yearbook. A very small number of missing data values were filled in using the mean or linear interpolation method.

The input indicators include land, energy, labor and capital inputs, while the output indicators include economic output, ecological output and emissions from the forestry industry. The methodology for evaluating the input and output variables of FGTFP is presented in Table 1.

3.4 Results of forestry green total factor productivity

According to the above measurement methods and input-output indicators, using DEA Solver software, the relevant representative years of China's forestry green total factor productivity measurement results are shown in Table 2.

We can see that the overall forestry green total factor productivity in the eastern region is at a high level, especially in provinces with a high level of economic development such as Beijing and Guangdong, where the values exceeded 1.3 and all reached a peak in 2018; the values in the western and central regions are generally lower, and the forestry green total factor productivity in many provinces does not exceed 1, but there are signs of increasing

Type	Variables	Data calibration and specification
Input indicators	Land input	Forestry land input
	Energy input	Total regional energy consumption * (total regional forestry output/total regional output)
	Labor input	The number of forestry employees at the end of the year
	Capital investment	The capital stock of China's forestry industry
Expected	Economic output	The total forestry output
Output	Ecological output	The afforestation area within a specific geographic region
Undesired outputs	Emissions from the forestry industry	Emissions of waste gas, wastewater and particulate matter from the forestry industry

Source(s): Authors own work

Table 1. The methodology for evaluating the input and output variables of FGTFP

Province	Region	2008	2011	2014	2017
Beijing	East	1.313	1.083	1.365	1.393
Tianjin	East	1.199	0.971	1.253	1.127
Hebei	East	1.175	1.213	1.266	1.033
Shanghai	East	1.064	1.150	1.330	1.540
Jiangsu	East	1.204	1.094	1.224	1.379
Zhejiang	East	1.089	1.067	1.359	1.331
Fujin	East	0.867	0.775	0.810	0.967
Shandong	East	1.153	1.039	1.102	1.184
Guangdong	East	1.237	1.002	1.260	1.422
Hainan	East	0.808	0.831	0.862	1.045
Neimenggu	West	0.919	0.646	0.678	0.889
Guangxi	West	0.954	0.964	0.904	0.970
Chongqing	West	1.090	0.922	0.893	1.209
Sichuan	West	0.871	0.650	0.839	0.962
Guizhou	West	0.824	0.744	0.784	0.815
Yunnan	West	0.969	0.924	0.996	0.993
Shannxi	West	1.049	0.904	1.054	0.982
Gansu	West	0.801	0.616	0.620	0.798
Qinghai	West	1.022	0.988	0.910	1.013
Ningxia	West	0.809	0.790	0.821	0.943
Xinjiang	West	0.891	0.766	0.896	0.970
Shanxi	Middle	0.987	0.548	1.011	1.271
Anhui	Middle	0.864	0.779	1.109	1.013
Jiangxi	Middle	0.806	0.708	0.872	1.003
Henan	Middle	0.990	0.755	0.962	1.093
Hubei	Middle	1.123	1.102	1.250	1.381
Hunan	Middle	0.965	0.848	1.062	1.065
Liaoning	NorthEast	1.020	1.088	1.063	1.080
Jilin	NorthEast	0.968	0.755	0.846	0.844
Heilongjiang	NorthEast	1.157	0.496	0.790	0.720

Source(s): Authors own work

Table 2. Forestry green total factor productivity in China

year by year; The provinces in the northeast region all had higher values in 2004, but decreasing year by year and already differed from the cities in other regions in 2018.

4. Empirical model

4.1 Empirical model setting

(1) Dynamic panel model

This study uses forestry green total factor productivity as the explanatory variable in the empirical study, financial support is selected as the core explanatory variable, and other control variables are economic development level, energy structure, industry size, industry structure and foreign direct investment (FDI), and the study period is 2008–2018. First, we can obtain the following static panel model:

$$FGTFP_{i,t} = \beta_0 + \beta_1 SOE_{i,t} + \gamma Controls + \mu_i + \varepsilon_{i,t} \tag{5}$$

Considering that forestry green total factor productivity generally has continuity, the previous period may have an impact on the current period and there are dynamic change characteristics, and also to eliminate errors in the test results due to endogeneity, the one-period lag term of the dependent variable is added and the Generalized Method of Moment (GMM) dynamic panel model is set as:

$$FGTFP_{i,t} = \beta_0 + \alpha FGTFP_{i,t-1} + \beta_1 SOE_{i,t} + \gamma Controls + \mu_i + \varepsilon_{i,t} \tag{6}$$

Among them, i represents the provinces and municipalities directly under the central government, t represents the year, $FGTFP_{i,t}$ represents the current forestry green total factor productivity measured above, $FGTFP_{i,t-1}$ represents the first-period lag item of the forestry green total factor productivity, SOE represents the core explanatory variable financial support, $Controls$ represents the control variable, μ_i represents the unobserved nonvariable The regional difference of time change and $\varepsilon_{i,t}$ is a random disturbance item.

(2) Dynamic panel threshold model

In addition to the aforementioned dynamic panel model, based on the theoretical analysis in the previous section and related studies by previous scholars, there may be a nonlinear effect of financial support on forestry green total factor productivity based on itself and a threshold effect based on environmental regulation, i.e. whether there is a significant difference in the hero of financial support on forestry green total factor productivity when environmental regulation is at different levels. This problem can be solved by dynamic threshold models, which have the outstanding advantages of automatic identification of sample data to estimate the specific number of thresholds and threshold values, and significance testing of threshold effects.

The threshold regression model was first proposed by Hansen (1999), and the meaning of the threshold model is roughly as follows: when the threshold variable is in two intervals around a certain threshold value (called the threshold estimate), the threshold-dependent variables have significantly different effects on the explanatory variables. Compared with traditional nonlinear analysis methods, the threshold regression model can first estimate the different intervals of nonlinear effects, and can provide a more precise description of this nonlinear effect and explore the specific nonlinear effects among variables.

In this paper, we construct the following dynamic threshold regression model (with a single threshold) using environmental regulation as the threshold variable, financial support as the threshold dependent variable and adding the first-order lagged terms of the explanatory variables:

$$FGTFP_{i,t} = \beta_0 + \alpha FGTFP_{i,t-1} + \beta_1 SOE_{i,t} I(ER_{i,t} \le \sigma) + \beta_2 SOE_{i,t} I(ER_{i,t} > \sigma) + \gamma Controls + \mu_i + \varepsilon_{i,t} \quad (7)$$

Dynamic panel multi-threshold model (double threshold as an example):

$$FGTFP_{i,t} = \beta_0 + \alpha FGTFP_{i,t-1} + \beta_1 SOE_{i,t} I(ER_{i,t} \le \sigma_1) + \beta_2 SOE_{i,t} I(\sigma_1 \le ER_{i,t} \le \sigma_2) + \beta_3 SOE_{i,t} I(ER_{i,t} \ge \sigma_3) + \gamma Controls + \mu_i + \varepsilon_{i,t} \quad (8)$$

Among them, $FGTFP_{i,t}$ is the current value of the explained variable forestry green total factor productivity, which $FGTFP_{i,t-1}$ represents the first-period lag term of forestry green total factor productivity, $I(\cdot)$ is the indicator function, σ is the estimated value of the threshold, $\beta_1, \beta_2, \beta_3$ are the estimated coefficient of different threshold intervals, $SOE_{i,t}$ and is the core explanatory variable financial Support, *Controls* represents the control variable, μ_i represents the unobserved regional differences that do not change with time, $\varepsilon_{i,t}$ and is a random disturbance item.

4.2 Variable selection and descriptive statistics

(1) Variable Selection

The explanatory variable is forestry green total factor productivity (FGT), which the result is obtained from the measurement in part 3 of this paper.

The core explanatory variable is financial support (SOE, which is used to refer to financial support), and since the explanatory variable is forestry green total factor productivity, the proportion of state investment in forestry industry (including central and local) to the total investment in forestry industry is chosen to be measured by combining the practices of related scholars (Cao and Zhai, 2020).

The threshold variable is environmental regulation (REG) we use the proportion of investment in regional environmental pollution control to regional GDP, as is mentioned in part 2 of this study.

Combining previous scholars' research on the factors influencing green forestry green total factor productivity, and considering the influence of covariance among variables, this paper selects regional economic development level (GDP), forestry industry scale (IND), forestry industry structure (STR), FDI and energy consumption knot (ECS) as control variables.

The caliber of measurement of control variables is as follows:

- Economic development level (GDP): measured by the regional per capita real GDP, taking 2008 as the base period, the regional per capita nominal GDP is deflated according to the price index to obtain the annual regional per capita real GDP;
- Forestry industry scale (IND): measured by the ratio of the regional real gross forestry product (deflated by the price level of forestry production) to the regional real GDP, to reflect the size of the regional forestry industry;
- STR: the ratio of the total value of the secondary forestry industry in the region to the regional gross forestry product is measured to reflect the industrial structure of the regional forestry industry;
- Foreign direct investment (FDI): the amount of actual foreign investment utilized in the regional forestry industry is used as a measure;

- Energy consumption structure (ECS): the ratio of the total regional electricity consumption to the total energy consumption is used as a measure of the energy consumption structure.

(2) Descriptive statistics of variables

In this paper, panel data of 30 provinces in China (Tibet Province is excluded due to serious missing data) from 2008–2018 are selected. Due to a small amount of missing data, this paper uses methods such as adjacent data mean filling to fill in the missing data. The raw data are obtained from China Statistical Yearbook, China Forestry Statistical Yearbook, China Environmental Statistical Yearbook and China Energy Statistical Yearbook, etc., while the relevant actual variables (e.g. per capita gross regional product) are deflated with 2008 as the base period. The descriptive statistical results of the variables are shown in Table 3.

4.3 Regression results of the empirical model

(1) Panel model regression results

Initially, the direct impact of financial support on the overall productivity of green forestry, without taking into account any environmental regulations, was analyzed using the models (1) and (2) presented in Table 4. The Hausman test rejected the use of the random effects model (RE) at a significance level of 1%, thus, the fixed effects (FE) were used for estimation. It can be observed that regardless of whether the lagged dependent variable was included or not, the core explanatory variable, financial support (SOE) was positively significant in both models (1) and (2), indicating an overall positive promotional effect of financial support on the productivity of green forestry. Moreover, a significant positive impact of the lagged dependent variable was observed in model (2), thus, it can be argued that the dynamic panel model is more reasonable, as the productivity of green forestry may exhibit a dynamic and sustained impact.

Because of the need to include lagged terms in the regression model, which may lead to endogeneity problems, the systematic GMM model needs to be chosen for the regression, and the two step method is used to obtain more robust and reliable results.

Table 4 regression results of model (3), model (4) and model (5) are all regressed using the systematic GMM method. The *p*-value of AR (1) (AR means AutoRegressive) test is significantly less than 0.1, which indicates the existence of first-order autocorrelation in the disturbance term, the *p*-value of AR (2) test is greater than 0.1, which indicates the absence of second-order autocorrelation, and the *p*-value of Sargen test is greater than 0.1, which

Table 3.
Descriptive statistics of variables

Variables	Code	Mean	Std	Min	Max
Forestry green total factor productivity	FGT	1.008	0.212	0.418	1.602
Financial support	SOE	0.603	0.276	0.016	1.000
Environmental regulation	REG	1.413	0.705	0.300	4.242
The level of economic development	GDP	4.652	2.503	0.882	14.021
Energy consumption structure	ECS	0.149	0.037	0.079	0.255
Industry scale	IND	0.739	0.820	0.016	6.121
Industrial structure	STR	0.362	0.228	0.005	0.896
Foreign direct investment	FDI	2.014	8.640	0.003	12.819

Source(s): Authors own work

Variables	Model (1) Fixed effect	Model (2) Fixed effect	Model (3) GMM	Model (4) GMM	Model (5) GMM
L.TFP		0.115*	0.295***	0.295***	0.294***
		(0.061)	(0.042)	(0.029)	(0.033)
SOE	0.089**	0.076*	0.089***	0.102*	0.172***
	(0.041)	(0.044)	(0.032)	(0.060)	(0.054)
REG				−0.022**	0.067***
				(0.009)	(0.023)
REG*SOE					−0.125***
					(0.035)
GDP	0.024***	0.030***	0.035***	0.034***	0.039***
	(0.008)	(0.009)	(0.003)	(0.002)	(0.003)
IND	0.019	0.009	0.005	0.001	−0.007
	(0.024)	(0.029)	(0.008)	(0.007)	(0.008)
STR	−0.047	−0.182	0.193***	0.133***	0.0715**
	(0.155)	(0.194)	(0.041)	(0.041)	(0.034)
ECS	1.294**	1.228*	0.332**	0.385***	0.301
	(0.615)	(0.657)	(0.153)	(0.145)	(0.195)
FDI	−0.829	−0.464	−4.992*	−3.931	−1.206
	(1.036)	(1.029)	(2.762)	(3.123)	(3.059)
Cons	0.654***	0.576***	0.381***	0.411***	0.369***
	(0.103)	(0.133)	(0.049)	(0.067)	(0.069)
AR(1) *p*-value			0.000	0.000	0.000
AR(2) *p*-value			0.896	0.852	0.635
Sargen *p*-value			0.687	0.752	0.932
Obs	330	300	300	300	300
R-squared	0.206	0.274			

Note(s): Standard errors are in brackets, * means significant at the 10% level, ** means significant at the 5% level, *** means significant at the 1% level, the same below
Source(s): Authors own work

Table 4. Regression results of panel data

indicates that there is no over-identification problem. The above tests indicate that the model is scientifically reliable using the GMM estimation method.

The environmental regulation (REG) variable was added to model (4) and model (5) to see the effect of environmental regulation in the model on green forestry green total factor productivity. We can see a substantial increase in the coefficient of the effect of financial support (SOE) in models (4) and (5), indicating that the model with FE estimation does underestimate the effect of the key core variables on the explanatory variables. It is worth mentioning that the interaction terms of environmental regulation itself and environmental regulation and financial support are significant, indicating that there is a mutual relationship between environmental regulation and financial support, and the coefficient of the interaction term is negative and there may be a hindering effect of environmental regulation on the effect between financial support and forestry green total factor productivity, which provides a strong evidence of a nonlinear relationship of financial support on the explanatory variables. Based on the preliminary results of this dynamic panel model regression, we will further explore a more specific presentation of the nonlinear relationship between financial support, environmental regulation and forestry green total factor productivity.

(2) Dynamic Threshold Model Regression

The previous paper found a significant positive contribution of financial support to forestry green total factor productivity using dynamic panel model and GMM method, and the interaction term of environmental regulation in which is significant with financial support, and there may be a nonlinear relationship between the explanatory variables and the explained variables. To verify whether there is a threshold effect of environmental regulation on forestry green total factor productivity in conjunction with the theory related to environmental regulation described in part 2 of this paper, the results of the regression using the dynamic threshold model are presented below.

First, we test whether the threshold variable of environmental regulation has a threshold effect. The results of the threshold effect test in Table 5 show that both the single threshold and double threshold effects of environmental regulation can pass the test, but the triple threshold fails to pass the test. Therefore, this paper considers that environmental regulation has a significant double threshold effect on the explanatory variable forestry green total factor productivity, and the model will be estimated using the double threshold in the following.

Based on the threshold theory, environmental regulation has an obvious threshold effect in the process of the impact of financial support on forestry green total factor productivity. The threshold values are 0.90 and 1.19, respectively, and the estimated values are located in the 95% confidence interval [0.60, 2.01] and [0.53, 3.10]. Therefore, this paper divides environmental regulation into three types based on the above thresholds: low environmental

Table 5. Significance test results of environmental regulation threshold

Threshold category	*F*-value	*p*-value	BS times	1%	5%	10%
Single threshold	3.944*	0.060	300	6.178	4.398	2.842
Double threshold	5.030**	0.040	300	7.722	4.404	2.363
Triple threshold	0.599	0.140	300	5.231	3.342	1.852

Source(s): Authors own work

Table 6. Threshold estimation results of fiscal support on FGTFP from the perspective of environmental regulation

Variables	Model (6) Threshold regression
L.TFP	0.337***
	(0.0513)
ECS	0.566
	−0.060
SOE (REG ≤ 0.90)	−0.121***
	(0.014)
SOE (0.90 < REG ≤ 1.19)	0.111***
	(0.037)
SOE (REG > 1.19)	0.089**
	(0.043)
GDP	0.036***
	(0.003)
STR	0.083
	(0.056)
IND	−0.005
	(0.008)
FDI	−2.401
	(3.389)
Cons	0.422***
	(0.0634)
Obs	300

Source(s): Authors own work

regulation level (ER ≤ 0.90), medium environmental regulation level (0.90≤ ER ≤ 1.19) and high environmental regulation level (ER ≥ 1.19).

The dynamic double-threshold regression results are shown in Table 6. In the process of upgrading from a low level of environmental regulation to a high level of environmental regulation, the regression coefficient changed from a negative value to a positive value and then to a negative value. The effect of environmental regulation on the impact of financial support on forestry total factor productivity has been verified. Financial support plays an important role in environmental regulation. Under the effect of the threshold, the impact coefficient on forestry green total factor productivity presents an obvious U-shaped trend, increasing from a negative value to a positive value and then decreasing. When the environmental regulation is at a low level (REG ≤ 0.90), financial support has a significant negative impact on forestry green total factor productivity, indicating that if the region does not pay much attention to environmental regulation, financial support is not conducive to the green development of forestry and will reduce forestry productivity; green total factor productivity. When the environmental regulation is at a medium level (0.90 < REG ≤ 1.19), financial support has a significant positive impact on the transformation of forestry green total factor productivity. With the further improvement of environmental regulation, when it exceeds the high level of environmental regulation (REG > 1.19), the impact of financial support will decline again and excessive environmental regulation is not conducive to improving forestry green total factor productivity.

4.4 Regression results

Initially, from a holistic perspective, apart from instances where the degree of environmental regulation is excessively low (REG ≤ 0.90), the impact of fiscal support on the all-round productivity of green forestry is consistently positive. This suggests that increased investment in forestry by China (including both central and local investment) results in higher levels of regional fiscal support for forestry, and in turn, leads to higher all-round productivity of green forestry. This is in accordance with our previous theoretical assumption.

Furthermore, it is worth noting that in the context of threshold regression, the impact of financial support on the forestry green total factor productivity has undergone a change from low to high and then to low again. When the degree of environmental regulation in the region is low (REG ≤ 0.90), financial support has a negative impact on the forestry green total factor productivity, indicating that without the constraint of environmental regulation, the forestry industry may tend to develop in an extensive manner, with insufficient incentives for technological innovation, emission reduction and ecological efficiency improvement. Therefore, the industry may choose to abandon the requirements of ecological output in forestry, and prioritize the optimal economic solution, leading to the investment of financial support in the region being used for economic expansion rather than pursuing the balanced and sustainable development of the economy and the environment. When the level of environmental regulation is at a moderate level (0.90 < REG ≤ 1.19), financial support has the most significant effect on the forestry green total factor productivity This suggests that moderate environmental regulation is to some extent the optimal solution for the green development of the forestry industry. In this context, the forestry industry is constrained by regional environmental regulations, leading enterprises to choose innovative technologies and improve the quality of forestry products. Meanwhile, local governments attach greater importance to the ecological role of the forestry industry and promote its contribution to improving the ecological environment. Therefore, under moderate environmental regulation, financial support can play the most significant role. When environmental regulations reach a high level of stringency (REG > 1.19), the impact of financial support on the forestry green total factor productivity declines again. This suggests that while financial support still has a positive effect on the green development of forestry, over-stringent environmental requirements may prevent the forestry industry from achieving optimal resource allocation and excessively demand technological improvements, resulting in a higher ecological benefit but reduced economic benefit. As a consequence, the impact of financial support cannot reach its optimum level, indicating that overly strict environmental regulations are detrimental to the growth of forestry green total factor productivity.

Finally, regarding other factors that affect the green total-factor productivity of forestry, the level of regional economic development has a positive and significant impact on the green total-factor productivity of forestry in most models. This is mainly because when the level of economic development is improved, the region will pay more attention to the high-quality and green development of the forestry industry. More ecological projects related to forestry will be implemented in the more economically developed regions which will also pay more attention to the ecological benefits of forestry and forestry-related departments and enterprises will not blindly pursue the economic growth of forestry, but will also balance the economic and ecological benefits. Therefore, the green total-factor productivity of forestry is improved. ECS in the model basically passed the test of 5% significant level, and all of them have positive effects. Given that electricity is a clean source of energy in regional energy consumption, regions with a higher proportion of clean energy use demonstrate a greater emphasis on green industrial development. Regions with energy structures that are more inclined towards environmental protection are more conducive to improving the forestry green total factor productivity The estimated coefficients of FDI in the model are all negative and relatively small, indicating that foreign investment does not improve China's forestry green total factor productivity and may even have a negative effect. This may be due to the relatively small amount of foreign investment in China's forestry industry development, as green development in the forestry industry depends more on direct government investment within China. The estimated coefficient of industrial scale in the model is positive, but it did not pass the significance test. This may be due to the fact that the scale of the forestry industry does not have a very significant promoting effect on the green development of forestry. The size of the industry is not directly related to the green development of the forestry industry, indicating that blindly expanding the scale of the forestry industry does not help improve forestry green total factor productivity.

5. Conclusions and policy recommendations

5.1 Research conclusions

Drawing on panel data from 30 provinces in China between 2008 and 2018, this paper examines the impact mechanism of fiscal support on the forestry green total factor productivity by synthesizing relevant basic theories and previous findings of scholars. Using the super-efficiency SBM-Malmquist index, the green TFP of forestry in 30 provinces of China is calculated. The positive effect of fiscal support on green TFP is demonstrated through a dynamic panel model. Moreover, environmental regulation is introduced as a threshold variable to explore the threshold effect of environmental regulation on the impact of fiscal support on the green TFP of forestry. It is found that there is a significant nonlinear effect of fiscal support on the green TFP of forestry in different intervals of environmental regulation.

The main conclusions are as follows: Firstly, the overall trend of forestry green total factor productivity in China shows a downward trend followed by an upward trend from 2008 to 2018, and it has continued to rise sharply since 2015. This indicates that China's forestry industry has made preliminary achievements in green, high-quality and sustainable development, and has initially achieved the goal of serving the construction of China's ecological civilization. Secondly, after being divided into eastern, central, western and northeastern regions, it is found that the forestry green total factor productivity in the eastern region is significantly higher than that in other regions, with a distinct gap. The forestry green total factor productivity in the northeastern region was initially higher, but the increase was relatively small, and it fell behind other regions. Finally, the situation in the central and western regions is relatively similar, both showing a downward trend followed by an upward trend, and they have great development potential.

Secondly, this study employs a dynamic panel model and finds that fiscal support has a significant positive impact on the forestry green total factor productivity. Multiple static or dynamic panel regressions are established, estimated using FE and GMM methods and the coefficient of fiscal support is positive in all models. The higher the national fiscal support, the higher the forestry green total factor productivity. It is concluded that due to its own characteristics, the forestry industry relies heavily on the investment of national financial resources and fiscal support can significantly improve the green development and transformation of the forestry industry. Fiscal support is a key factor affecting the development of the forestry industry. The related ecological projects of the forestry industry have strong externalities and nonexclusiveness of public goods, and rely on government funding support and transfer payments to help complete them. Therefore, the green development of the forestry industry needs to rely on fiscal support.

Thirdly, from a regulatory perspective, it is evident that there is a significant threshold effect in the impact of environmental regulations. When environmental regulations are at a low level, financial support from the government can inhibit the growth of forestry green total factor productivity. This is because of the lack of norms and constraints on the industry's ecology. The forestry industry will be incentivized towards extensive development, with more financial resources being invested in the production of low-quality forest products, only considering the economic benefits of the industry, rather than focusing on technological innovation and utilizing the advantages of the forestry industry to build ecological civilization. When environmental regulations gradually increase to a reasonable level, financial support has the best positive effect on forestry green total factor productivity. This indicates that under a certain degree of environmental regulation, the industry will no longer develop extensively without constraints and the region will consider more of the green development benefits of the industry, comprehensively considering the economic and ecological benefits of the industry. Only then can financial support effectively improve the green development of forestry. When the degree of environmental regulation continues to increase to the highest threshold value, the impact coefficient of financial support remains positive but decreases. The reason for this result may be that when environmental regulations are too high, the forestry industry leans towards attaching too much importance to the ecological benefits of forestry. The region attaches great importance to the environment and has high requirements for the forestry industry's green development, resulting in an inability for the industry to achieve optimal funding and resource allocation. The industry gives up a certain amount of economic benefits and most of the funds are channeled towards the construction and development of forestry ecology projects. As a result, the impact on forestry green total factor productivity remains positive but cannot reach its optimum level.

5.2 Policy recommendations

Based on the conclusions obtained from the theoretical and empirical data in this paper, and synthesizing the literature and theoretical research of related scholars, the following policy recommendations are put forward:

Firstly, it is necessary to increase financial support for forestry in order to guarantee the green and sustainable development of the forestry industry. As China's economy is currently transitioning towards high-quality development, ecological civilization construction has become a crucial element of our country's sustainable development. The development of the forestry industry serves as the main battlefield for ecological civilization construction, contributing to the achievement of national development strategic goals such as carbon peaking, ecological environment improvement and carbon neutrality. Therefore, it is imperative that the forestry industry takes on the responsibility of promoting green, low-carbon and sustainable development in our country. However, due to the public goods externalities and weak quality characteristics of the forestry industry, most of the industry's development funding depends on government financial support. Unfortunately, current levels of financial support for forestry are still insufficient for promoting green development. By drawing on relevant policy experiences from developed countries, it is suggested that total forestry financial support funds should increase in proportion to regional forestry industry output value or regional GDP, ensuring that financial support for the forestry industry grows in tandem with a region's economic development level.

Secondly, it is essential to establish a sound mechanism for introducing and managing forestry funds and expanding the channels for financial support in the forestry sector. Currently, China's forestry investment and financing system is not yet sound, with many issues that constrain the healthy and green development of the forestry industry. The government should promulgate corresponding policies, increase the attractiveness and incentives for social capital to invest in the forestry industry, improve the investment environment for social capital in the forestry sector, gradually explore mechanisms for coordinated development between fiscal and social investments, complementary and mismatched support mechanisms, and other combination mechanisms, continue to play the decisive role of the market in allocating resources for forestry development, and promote the transformation of ecological capital into economic value. Additionally, it is necessary to strengthen the management of forestry funds, and relevant departments need to use national and social funds reasonably, achieve co-development of industrial and economic benefits and ecological benefits in the local area, and rationally guide forestry financial support funds into the ecological construction of the forestry industry to achieve high-quality and green development of the forestry industry.

Thirdly, improve the financial support subsidy policy for forestry and expand the scope of financial subsidies for forestry. The green transformation of forestry urgently needs to undergo green modernization transformation. The development of the forestry industry in some areas is still quite backward, and the infrastructure construction required for industrial development cannot meet the needs of high-quality development of the forestry industry. The rich forestry natural resources are greatly restricted by the lack of machinery and technology, which hinders the high-quality transformation of regional forestry. State-owned forest areas, nature reserves, and other projects that play ecological effects require national support, relying on financial support and forest tenure reform to achieve the accumulation and development of the forestry industry. The scope of forestry financial subsidies needs to be further expanded. The forestry industry does not lack natural resource factors. The abundant forest resources have not been effectively utilized. It is necessary to expand the scope of afforestation subsidies and include timber forests, woody oil-bearing economic forests and bamboo forests in the nurturing scope. According to different regions, natural endowments and tree species, corresponding subsidy ranges should be established to mobilize the enthusiasm of relevant departments, enterprises and the society.

Fourthly, it is recommended to develop reasonable environmental regulations in accordance with the regional forestry industry resources endowment and objective conditions to serve the high-quality development of the forestry industry. The theoretical analysis and empirical model presented earlier demonstrate that environmental regulations have a significant threshold effect on the green total factor productivity of the regional forestry industry. Both excessively low and excessively high environmental regulation levels are detrimental to the industry's development, while appropriate environmental regulation can significantly promote the green development of the forestry industry. To meet the policy requirements of environmental regulation, the industry's development may focus more on the ecological benefits of forestry, and more funds may be utilized in the ecological construction of the industry. Excessive environmental regulation requirements can cause the resource element allocation invested in the industry to be unreasonable, hindering the growth of forestry economic benefits, making it impossible to achieve a balance between appropriate economic and ecological benefits. The high-quality development of the forestry industry requires the coordinated development of both. Therefore, regional government departments should develop reasonable environmental regulation policies based on the actual situation of the region, avoiding excessive constraints on the ecological function of the industry, and not relaxing environmental governance. A comprehensive balance of economic and ecological development is needed to promote the improvement of the forestry green total factor productivity.

Fifthly, to further improve the relevant policy system, to further promote the reform of the collective forestry rights system, and to improve and standardize the reform of supporting policies. At present, China has comprehensively promoted the reform of the rural property rights system and established a modern forestry property rights system that adapts to the requirements of the socialist market economy system. The new round of collective forestry rights system reform provides the basic conditions for farmers to engage in forestry production and management and the rights and interests of forestry property rights should be further completed to truly realize the ownership rights, release the management rights and maintain the rights of return. And on the basis of clarifying the right to use forest land, a scientific and effective compensation mechanism should be established to increase farmers' expectations of the future income rights of forest trees and to guide industrial entities through relevant policy guidelines to build ecologically better public welfare forests, mixed forests and other precious forest species, etc.

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