International application of global forest product model and the reference to China

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Abstract

Purpose – This article summarizes the international scientific research output of global forest product models, infers future research trends and provides reference for quantitative analysis and mathematical modeling of Chinese forest product problems, with the aim of contributing to promoting domestic production of Chinese forest products and strengthening international trade competitiveness of forest products.

Design/methodology/approach – In 1999, Joseph Buongiorno, a scholar at the University of Wisconsin in the United States of America, proposed the global forest products model (GFPM), which was first applied to research in the global forestry sector. GFPM is a recursive dynamic model based on five assumptions: macroeconomics, local equilibrium, dynamic equilibrium, forest product conversion flow and trade inertia. Using a certain year from 1992 to present as the base period, it simulates and predicts changes in prices, production and import and export trade indicators of 14 forest products in 180 countries (regions) through computer programs. Its advantages lie in covering a wide range of countries and a wide variety of forest products. The data mainly include forest resource data, forest product trade data, and other economic data required by the model, sourced from the Food and Agriculture Organization (FAO) of the United Nations and the World Bank, respectively.

Findings – Compared to international quantitative and modeling research in the field of forest product production and trade, China's related research is not comprehensive and in-depth, and there is not much quantitative and mathematical modeling research, resulting in a significant gap. This article summarizes the international scientific research output of global forest product models, infers future research trends, and provides reference for quantitative analysis and mathematical modeling of Chinese forest product problems, with the aim of contributing to promoting domestic production of Chinese forest products and strengthening international trade competitiveness of forest products.

Originality/value – On the basis of summarizing and analyzing the international scientific research output of GFPM, sorting out the current research status and progress at home and abroad, this article discusses potential research expansion directions in 10 aspects, including the types, yield and quality of domestic forest product production, international trade of forest products, and external impacts on the forestry system, in order to provide new ideas for global forest product model research in China.

Keywords Forest products market, GFPM, Global forest product model, Global forestry sector model, International trade of forest products

Paper type Literature review

1. Introduction

Forests are globally significant resources that provide important commodities and ecosystem services. As a major producer and exporter of forest products in the world, China's issues in the production and international trade of forest products are constantly changing, attracting domestic and international attention. From an internal perspective of

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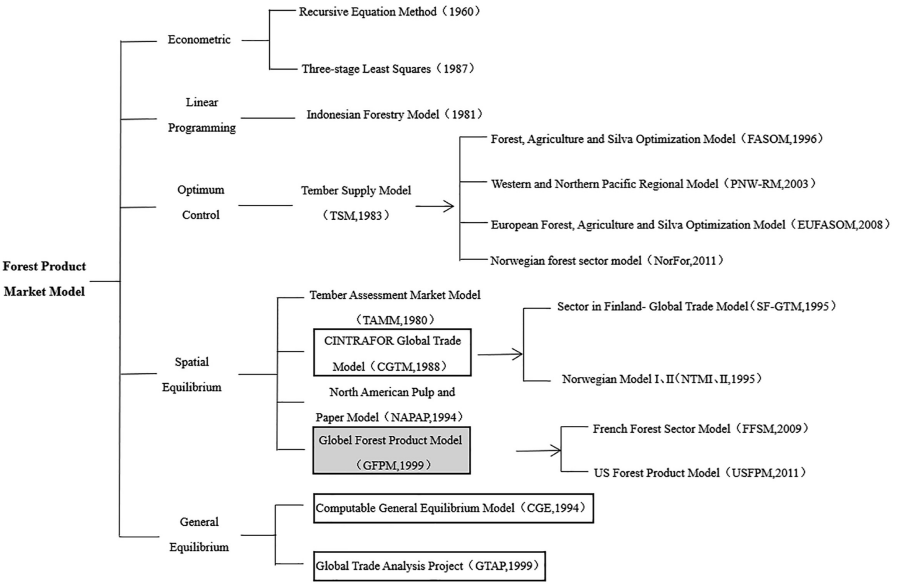
the forestry system, since the implementation of projects such as natural forest protection and returning farmland to forests and grasslands, the focus of forest utilization in China has gradually shifted from wood products and processed products to "forest+" products such as forestry biomass energy products and forest carbon sinks. While the ecological value of forests is becoming increasingly prominent, wood production is restricted, leading to a jump in forest product imports, forming a "two headed, big in, big out" situation. This is the basic pattern of long-term excessive dependence on the international market. How to explore a high-quality development path for forestry that coordinates forest economy and ecological value and builds a new dual circulation development pattern has become a key issue that urgently needs to be solved. At this time, wooden forest products, as the main component of the forest's carbon pool, play an important role in enhancing the carbon sequestration capacity of forestry. Analyzing the carbon sequestration effect of woody forest products and exploring effective ways to enhance their carbon sequestration capacity are essential for achieving coordinated development of the forest economy and ecological value and promoting the construction of a green China through forestry. In addition, the 2019 COVID-19 pandemic caused a 3.5% decline in the global economy, with 124 m people trapped in extreme poverty, which will inevitably increase the use of wood fuels. The impact of external shocks on the global forest sector caused by such forestry systems is also worth paying attention to.

Compared to international quantitative and modeling research in the field of forest product production and trade, China's related research is not comprehensive and in-depth, and there is not much quantitative and mathematical modeling research, resulting in a significant gap. This article summarizes the international scientific research output of global forest product models, infers future research trends and provides reference for quantitative analysis and mathematical modeling of Chinese forest product problems, with the aim of contributing to promoting domestic production of Chinese forest products and strengthening international trade competitiveness of forest products.

2. Overview of model

Quantitative research on the forest product market began in the 1950s. With the continuous improvement of economic theory and modeling methods, the forest product market model is gradually improving. On the basis of referring to (Sun and Yin, 2006) and (Latta *et al.*, 2013), this article summarizes the modeling methods and model evolution (Figure 1).

In 1999, Joseph Buongiorno, a scholar at the University of Wisconsin in the United States of America, proposed the global forest products model (GFPM), which was first applied to research in the global forestry sector. GFPM is a recursive dynamic model based on five assumptions: macroeconomics, local equilibrium, dynamic equilibrium, forest product conversion flow and trade inertia. Using a certain year from 1992 to present as the base period, it simulates and predicts changes in prices, production and import and export trade indicators of 14 forest products in 180 countries (regions) through computer programs. Its advantages lie in covering a wide range of countries and a wide variety of forest products. The data mainly include forest resource data, forest product trade data and other economic data required by the model, sourced from the Food and Agriculture Organization (FAO) of the United Nations and the World Bank, respectively. Adjust the variable values based on the impact of policy changes studied and set up several simulation scenarios to explore the impact of different policies on wood production and trade by comparing the predicted results of benchmark and simulation scenarios. Specifically, GFPM is based on the theory of spatial equilibrium and applies mathematical programming to solve for perfectly competitive market equilibrium, ensuring that it passes variable accuracy and data consistency tests. The



Note(s): This paper sorts out and optimizes it: (1) The solid frame means that the model takes global trade as the research object; (2) Grey bottom frame is the focus of this paper (GFPM)

Source(s): Figure is sourced from Sun and Yin (2006), and compiled by the author. The evolution comes from Latta *et al*. (2013)

Figure 1. Estimation classification and evolution of forest products market model

objective function is the net benefit of subtracting production costs, manufacturing costs and transportation costs from the final product consumption value:

$$maxZ = \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})dD_{ik} - \sum_i \sum_k P_{ik}(S_{ik})dS_{ik} - \sum_i \sum_k \int_0^{Y_{ik}} m_{ik}(Y_{ik})dY_{ik} - \sum_i \sum_j \sum_k c_{ijk} T_{ijk} \quad (1)$$

In the formula, Z = net benefit; i. J = country; K = product; P = price in US dollars; D = final product demand; S = supply of raw materials; Y = yield; M = production cost; C = unit transportation cost, including product ad valorem tax and T = transportation quantity.

And all economic activities meet resource and technological constraints, namely material balance constraints:

$$\sum_j T_{ijk} + S_{ik} + Y_{ik} = D_{ik} + \sum_n a_{ikn} Y_{in} + \sum_j T_{ijk} \quad \forall i, k \quad (2)$$

In the formula, a_{ikn} = the quantity of k products required to produce n units of products in country i. This means that any product from any country must meet the conditions of resource balance and market clearance.

Calculate new dynamic equilibrium under new supply and demand conditions, new technologies, new production capacity and new tariffs:

$$A = (1 + g_a)A_{-1} \tag{3}$$

$$I = I_{-1} + G_{-1} - pS_{-1} \tag{4}$$

$$G_{-1} = \left(g_a + g_u + g_u^*\right)I_{-1} \tag{5}$$

$$P = \alpha + \frac{\beta}{1 + L(f)}Q \tag{6}$$

$$D_{ik} = D_{ik}^* \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\delta_{ik}} \tag{7}$$

$$D_{ik}^* = D_{ik,-1}\left(1 + a_y g_y\right) \tag{8}$$

$$S_{ik} = S_{ik}^* \left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}} \tag{9}$$

$$S_i = (S_{ik} + S_{in} + \theta S_{if})\mu \tag{10}$$

$$S^* = S_{-1}(1 + \beta_I g_I + \beta_a g_a) \tag{11}$$

$$C_{ijk} = C_{ijk}^* \left(\frac{T_{ijk}}{T_{ijk,-1}}\right)^{T_{ijk}} \tag{12}$$

$$m_{ik} = m_{ik}^* \left(\frac{Y_{ik}}{Y_{ik,-1}}\right)^{S_{ik}} \tag{13}$$

$$r_p = (1 + \gamma a)^p - 1 \tag{14}$$

$$\Delta v_p = p\Delta v_a \tag{15}$$

$$S_{ir}^U = \sum_{k \in R} w_{ikr} D_{ik,-1} \tag{16}$$

$$\Delta K_k = b_{1k}\Delta Y_{k,-1} + b_{2k}\Delta Y_{k,-2} + b_3 \Delta Y_{k,-3} \tag{17}$$

$$c_{ij} = c_{ij,-1} + (t_j - t_{j,-1})P_{jk,-1} \tag{18}$$

$$T_{ijk}^U = \left(\frac{T_{ijk,-1}}{N_{ijk,-1}} + \varepsilon_{ijk}\right)N_{ik,-1} \tag{19}$$

$$T_{ijk}^L = \left(\frac{T_{ijk,-1}}{N_{ijk,-1}} - \varepsilon_{ijk}\right)N_{ik,-1} \tag{20}$$

$$N_{ik} = S_{ik} + \sum_j T_{ijk} = D_{ik} + \sum_j T_{ijk} \tag{21}$$

Formula(3) calculates the change in forest area, where A is the forest area and ga is the annual rate of change in forest area; Formula(4) (5) calculates the change in forest volume, where G_{-1} represents the change in forest volume that was not harvested in the previous period, g_u represents the growth rate of the forest without logging, and g_u^* represents the adjusted growth rate of the forest without logging, which is exogenous, such as representing invasive species or the impact of climate change; Formula(6) calculates the product price; Formula(7) calculates the final product demand, where D^* represents the current consumption at the

previous price and P_{-1} represents the previous price; Formula(8) calculates changes in product demand; Formulas (9) and (10) calculate the initial product supply, where S^* is the supply for that period at the previous price; Formula(11) calculates changes in product supply; Formula(12) calculates transportation costs; Formula(13) calculates manufacturing costs; Formula(14) is a dynamic exponential change; Formula(15) is a dynamic linear change; Formula(16) calculates the impact of waste paper recycling policies; Formula(17) calculates the change in production capacity; Formula(18) calculates tariff changes and Formulas(19), (20) and (21) calculate trade changes.

3. Review

3.1 Main field content

GFPM originated in 1987, so the limited search time for this study is from 1987 until now. In the China National Knowledge Infrastructure (CNKI) and the Web of Science database [1], of which 31 were from foreign journals or books and 16 were from domestic journals or conferences. The total citation frequency of foreign literature was 570 times, with an average of 18.39 citations and the total citation frequency of domestic literature was 90 times, with an average of 5.63 citations. Three classic works of foreign language literature not included in the database are also included in this analysis. All literature indicates that GFPM is currently mainly applied in global trade issues, biofuel demand, carbon sequestration of forest products and wood supply and a small amount is also applied in areas such as collective forest tenure reform, economic development, technological progress and Internet popularization (see Tables 1–3).

3.2 Overview of foreign and application

In the past 22 years, research about GFPM abroad has mainly involved international trade issues, biomass energy utilization and policy evaluation. Before 2002, the study was limited to the accounting of forest resources and trade of forest products in the field of international trade and then, explored the impact of trade such as abolishing GATT and accelerating trade liberalization (Zhu *et al.*, 2001) tariff barriers and non-tariff barriers (Sun *et al.*, 2010; Buongiorno *et al.*, 2014) on the global forest products market.

Since 2010, applied research has not only increased in quantity but also gradually expanded to biomass energy utilization and other environmental fields, to explore the impact of future changes such as fuelwood and bioenergy demand (Matzenberger *et al.*, 2015; Buongiorno *et al.*, 2011; Raunikar *et al.*, 2010), potential CO_2 fertilization (Buongiorno, 2015b) and carbon sequestration offset payment (Buongiorno, 2015a) on the future global forest sector. At the same time, quantify the influence of Internet popularization (Ochuodho *et al.*, 2017), technological progress (Buongiorno and Zhu, 2015), plantation utilization (Buongiorno and Zhu, 2014), promotion of wood fiber use (Morland and Schier, 2020) and other factors.

There are three kinds of evolution models: USFPM (Ince *et al.*, 2011, 2012; Nepal *et al.*, 2012, 2016), GFPM_CNC (Schier *et al.*, 2018) and GFPMX (Buongiorno, 2018, 2021). The first two classify the areas covered by GFPM or the types of forest products. GFPMX is established according to the characteristics of forest products, depending on the cobweb theorem. It can be seen that the simple application of GFPM has been difficult and the complicated, realistic research needs have never stopped expanding its content and form.

However, GFPM started late, developed slowly, and the theme deviated from the international mainstream direction in China. In 2006, Sun reviewed the main modeling of the forest products market and brought GFPM into the domestic research field of vision (Sun and Yin, 2006). In 2009, the first year of GFPM application in China, Hou applied it to research on the impact of low-carbon economic measures (Hou, 2009), but it did not set off a domestic research upsurge. Five years later, only two scholars applied it to study the impact of import and export tariffs (Hou *et al.*, 2013; Hou and Liu, 2013) and collective forest rights system

Table 1.
Research achievements and main viewpoints in the application field of GFPM

Field	Author	Scenario	Main
Global trade issues	Joseph (Buongiorno *et al.*, 2001)	Direct simulation prediction	Analyze global and Asia Pacific forest resources and forest product trade issues
	Zhu (Zhu *et al.*, 2001)	S1: Continuation on tariffs and trade S2: Accelerate cancellation	The cancellation of the General Agreement on Tariffs and Trade has limited impact on global forest product production and consumption; The rapid growth of trade will shift from logs to processed goods
	Sun (Sun *et al.*, 2010)	S1: Cancel non-tariff barriers S2: Removing tariff barriers S3: Simultaneously cancel	Non-tariff barriers have a greater impact on the forest product market than tariff barriers; The elimination of non-tariff trade barriers has led to an increase in the production and trade of all timber products worldwide, with a greater impact on trade; Non-tariff barriers have improved consumer welfare to a greater extent
	Joseph (Buongiorno, 2015a)	S1: Low impact (eliminating tariff barriers) S2: High impact (tariffs + non-tariffs)	Assess the impact of the transatlantic trade agreement (TTIP) on the global forest sector. With the deepening of integration, both consumption growth and net trade decline in the United States of America have been significant, leading to an increase in net trade in Asia. The welfare of consumers and producers in the United States of America and the European Union has increased, but there has been a decline in welfare in third countries, especially in Asia
	Joseph (Buongiorno, 2018)	S1: International trade (Benchmark) S2: No international trade	The international trade in the forest product sector has had a positive impact on global economic welfare, with developed countries benefiting far more than developing countries
	Hou (Hou, 2009)	S1: Benchmark scenario S2: Russian log tariff prices rise	Simulate the various impacts of changes in export tariffs on Russian industrial logs. The increase in raw material costs will further push up product prices, which will have long-term impacts on China and global forestry
	Chen (Chen, 2018)	S1: Benchmark scenario S2: Low growth scenario (increasing log exports by 10% annually) S3: High growth scenario (increasing log supply by 50% in the first two years and 10% from 2016 to 2020)	Study the impact of implementing timber export restrictions in British Columbia, Canada on the global forest product trade market and the forest product trade between China and Canada. Canada's relaxation of timber supply is conducive to the balance of global forest product trade; low growth supply stimulates demand for logs, reducing consumer surplus and avoiding adverse effects on the production and consumption of other forest products

(*continued*)

Field	Author	Scenario	Main
Biofuel demand	Raunikara (Raunikar *et al.*, 2010)	S1: A1 (Globalization continues) S2: A2 (Slowing globalization)	IPCC set represents the exploration of the production of biofuels from fuelwood and industrial logs. The demand for fuelwood will increase significantly in the future, and industrial logs used to manufacture sawn wood, boards and wood pulp will begin to be used for energy production, putting ecological pressure on forests
	Joseph (Buongiorno, 2015b)	S1: A1 (Globalization continues) S2: A2 (Slowing globalization)	Exploring the impact of the growth rate of bioenergy demand on the global forest sector through IPCC. The world prices and demand for all wood forest products will decrease to varying degrees and the production of countries with competitive advantages will increase, leading to a decrease in the added value of the global wood processing industry
	Zhang (Zhang *et al.*, 2020)	S1: Benchmark scenario S2: Oil prices remain high	Modeling of price driven interactions between energy and the global wood products market. The forecast indicates that if oil prices continue to remain high, the demand for lignocellulosic ethanol in the United States of America will significantly increase in the next 30 years
	Matzenberger (Matzenberger *et al.*, 2015)	S1: High salary material demand (80%) S2: Low wage demand (50%)	By 2030, 14–26% of global bioenergy demand will be traded between regions. Solid biomass energy trade will range from 700 m tons to 25 bn tons; The trade of liquid biomass energy will range from 650,000 tons to 3.6 m tons
	Morland (Morland and Schier, 2020)	S1: Highly sustainable scenario S2: Medium sustainable scenario S3: Low sustainability scenario	Incorporating emerging lignocellulosic products into the GFPM model framework reveals a shift in wood consumption patterns from firewood and traditional paper products to emerging lignocellulosic products
	Hou (Hou *et al.*, 2013)	S1: Increasing demand for salary materials S2: Increasing demand at once	Estimate the economic impact of EU energy policy on the EU forest product sector. Taking into account both consumer surplus and producer surplus, it is reasonable to gradually increase the demand for fuel materials

(*continued*)

Table 1.

Table 1.

Field	Author	Scenario	Main
Carbon sequestration	Joseph (Buongiorno *et al.*, 2014)	S1: Benchmark scenario S2: Carbon sequestration offset of 30$/t	Carbon sequestration offset payments lead to a decrease in global timber production, an increase in timber income and an increase in global carbon storage; unilateral policies focused on wealthy countries can lead to leaks and low efficiency
	Yang (Yang and Zhang, 2015)	S1: Developed country scenario S2: Major developing countries S3: Other developing country	The impact of different substitution and emission reduction capabilities of simulated HWP carbon pools and the number of countries responsible for global HWP carbon pool substitution and emission reduction on the emission reduction effect of global HWP carbon pools as well as the corresponding differences in responsibility sharing
Wood supply	Joseph (Buongiorno *et al.*, 2011)	S1: Utilizing artificial forests S2: No use of artificial forests	The utilization of artificial forests has led to a decrease in global forest product prices and an increase in production and consumption; consumer economic benefits increase, producer economic benefits are uncertain; the world's natural forest logging has decreased
	Zhang (Zhang *et al.*, 2016)	S1: Illegal production and consumption S2: Eliminating illegal timber S3: Eliminating illegal timber consumption	Eliminating illegal timber production is more economical than eliminating illegal timber consumption; however, eliminating illegal timber production will lead to uneven distribution of social wealth in the forest sector and transfer the cost of reducing illegal logging to developing countries
Reform	Zhang (Zhang *et al.*, 2012)	S1: High forest conversion scenario S2: Low forest conversion scenario	The collective forest reform policy can truly play a practical role around 2020. The high forest reform scenario will reduce China's wood supply and demand gap by 18% by 2030, which is 9.5% more than the low forest reform scenario
Economic develop	Jiang (Jiang and Huang, 2016)	S1: Benchmark scenario S2: High growth scenario (8%)	For high-speed economic growth, medium to high-speed economic growth under the benchmark scenario is more conducive to the sustainable utilization of forest resources and the increase of forest ecological service supply
Technology progress	Joseph (Buongiorno, 2015b)	S1: High tech improvement rate S2: Medium technology improvement rate S3: Low technology improvement rate	The impact of technological improvements on the prices of different types of forest products varies; Increased the value of global forest products, mainly occurring in developing countries; this has led to a certain degree of equivalent carbon dioxide storage, especially in Europe and North America
Internet popularization	Ochuodho (Ochuodho *et al.*, 2017)	S1: Popularization of the internet in 100 years S2: Popularization of the internet by 2050	The comprehensive popularization of the internet has reduced the demand for newsprint, printing and writing paper; reduce the present value GDP of most countries in the world

Source(s): Table is sourced from the authors

Period	STATE-UP	Development	Slow increase
TIME	1999–2002	2010–2019	2020 so far
THEME	Resources, trade	Trade, biomass energy and carbon emissions	Emerging forest bioeconomy, the COVID-19
REFINEMENT	Analyze the international impact of the General Agreement on Tariffs and Trade and the US paper recycling policy on the production and consumption of forest products; forest resources forecasting and forest products trade issues	The impact and changes of trade frictions such as tariff barriers, non-tariff barriers, Atlantic Partnership, technological level, illegal timber production and consumption, Internet shocks and financial risks on the global forest product market; the impact of plantation, wood biomass energy demand and policy, biomass crop assistance plan on the original forest product market; the effects and effects of carbon storage, carbon sequestration and global HWP carbon pool emission reduction under different energy consumption levels and different carbon sequestration offset payments are discussed, respectively and predict long-term carbon flow	The impact of emerging forest bioeconomics, such as lignocellulosic products and the economic recession caused by the COVID-19 pandemic on the global forest sector was analyzed
NUMBER	3	28	3
CITATION FREQUENCY	–	563	7

The total citation frequency of 31 articles was 570, with an average of about 18.39 citations per article (three articles in the initial stage were not included)

Source(s): Table is sourced from the authors

Table 2. Topics and cited frequency of international GFPM-related scientific research achievements

reform (Zhang *et al.*, 2012) on timber supply. Although the theme is consistent with the national conditions, it is inconsistent with the international mainstream research direction. After 2015, the theme of domestic GFPM research gradually shifted toward international trade issues such as restricting timber exports (Chen, 2018), illegal timber logging (Zhang *et al.*, 2016), legal timber imports (Liu *et al.*, 2015), but the development was still slow. Since 2020, some scholars have focused on the impact of recycling and utilization of waste paper (Gong *et al.*, 2022), banning the import of waste paper (Zhao, 2020) in the paper industry and carbon emission reduction under the background of COVID-19.

GFPM research in China lags behind that in foreign countries. The focus of foreign research has already shifted from the international trade field to biomass energy utilization and environmental problems and devoted to the evolution of models. The focus of domestic research is still on international trade. Only Yang (Yang and Zhang, 2015; Yang, 2015) Jiang (Jiang and Huang, 2016) have carried out the carbon storage potential of a forestry carbon sink, lacking the depth and breadth. In addition, problems such as the low attention of Chinese scientific research institutions, less international cooperation and a lack of guidance (Yuan *et al.*, 2015) need to arouse all of us.

Time	2006	2009–2014	2015–2018	2020 so far
THEME	Comprehensive. discussion	Collective forest right system reform and trade	Trade, forestry carbon sink potential and carbon storage carbon emissions	the COVID-19
REFINEMENT	The modeling method, application, advantages and disadvantages of the main forest product market model are compared	The impact of the China's collective forest right system reform and tariffs on domestic and foreign forest product markets; wood import situation	Impact of the Canada's timber export restriction policy; dynamic prediction of wood-based panel industry; forest carbon sink potential, global HWP carbon pool emission reduction effect, forest product carbon storage efficiency and carbon pool structure prediction	In the context of the COVID-19, the impact of waste paper recycling and waste paper import ban policies on the papermaking industry is predicted
NUMBER	1	5	8	2
CITATION FREQUENCY	0	13	77	0

Table 3. Topics and cited frequency of domestic GFPM-related scientific research achievements

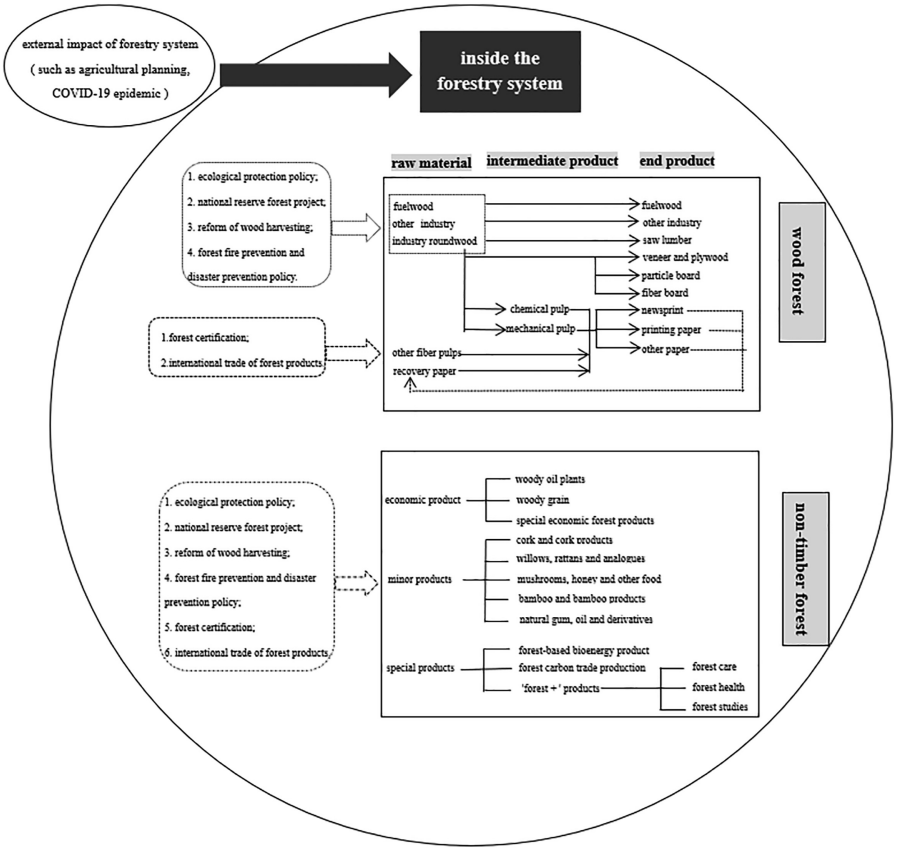
The total citation frequency of 16 articles was 90 times, with an average of about 5.63 citations per article
Source(s): Table is sourced from the authors

4. Discussion

China's forestry has undergone five major changes (Zhou, 2003), affecting domestic production and international trade in various aspects. No matter the variety, quantity and quality of domestic forest products or from the external impact of the international trade forestry system, the relevant research on China's forest products sector is lacking, important and cannot stagnate. It is extremely urgent to expand the research direction and dig deep into GFPM. This paper will discuss the following ten expandable directions around five aspects: the types, quantities and qualities of domestic forest product production, international trade of forest products and external shocks to the forestry system. The expected impact paths are shown in Figure 2.

4.1 Types

The types of forest products are becoming more and more diversified. Due to the need for ecological protection and modern forestry, the focus of domestic forest product production has gradually changed from wood products and economic forest products to forestry biomass energy products and forest carbon sequestration products. On the basis of the original model, economic forest and forest by-products, forest biomass energy products, forest carbon sequestration products and "forest +" products are included in the model in order to establish a more comprehensive forest product model that is more in line with the modern forest production and management concept. As non-wood forest products, economic forest and forest by-products also appear in the form of yield in the model. Therefore, this



Note(s): This paper expands the types of forest products, including non woody forest products in the scope of GFPM research, and presets the impact path of its expandable research direction

Source(s): Figure is sourced from the author. It was compiled and expanded by Zhu *et al*. (2001)

Figure 2.
Expected impact path of GFPM scalable research direction

paper only discusses the importance and feasibility of forest biomass energy products, forest carbon sequestration and forest healthcare, three special non-wood forest products included in GFPM.

4.1.1 Forestry biomass products. The report of the 20th National Congress of the Communist Party of China proposed to further promote the energy revolution, accelerate the planning and construction of a new energy system and actively and steadily promote carbon peaking and carbon neutralization. As a renewable, low-pollution, safe and reliable clean energy source that can replace fossil fuels, forestry biomass energy has a very broad prospect (Cao *et al*., 2003). Increasing the use of forestry biomass energy while restoring degraded forests, establishing fast-growing and high-yield plantations and improving the use of wood harvesting and processing residues can bridge the gap between forest demand and availability and help the energy sector achieve net zero emissions. Using forest product sector models such as GFPM to analyze the economic benefits of forestry biomass energy projects is

conducive to identifying the shortcomings of energy utilization and then, promoting the scale and industrialization development of forestry biomass energy.

The utilization of forest biomass energy has been a focus internationally. There are many applications of GFPM to explore the internal mechanism of the impact of future fuelwood demand changes on the forest products sector (Matzenberger *et al.*, 2015; Hou, 2009) and the research framework is becoming mature, which proves that the model in this field is completely feasible and lays a solid foundation for China. In addition, there are various ways of utilizing biomass energy in the forestry industry, the research does not need to be limited to the change in fuelwood demand but can also extend to the demand for biomass power generation and ethanol conversion.

4.1.2 Forestry carbon sequestration products. Forestry carbon sequestration refers to that forests fix carbon dioxide in the atmosphere in the form of biomass in vegetation and soil through photosynthesis to reduce greenhouse gases in the atmosphere and slow down climate change through afforestation and reforestation activities. Under the severe situation of global warming, forestry can make a great contribution to both emission sources and absorption sources at a lower cost. Forestry carbon sink is of great significance to exert forest ecological and economic benefits at the same time and achieve the goal of carbon neutrality and emission reduction.

The demand for forestry carbon sinks urges people to reduce deforestation, build plantations and strengthen forest protection, which will have an impact on the price of forest products. At the same time, because of the scarcity of forest resources, the carbon sink price will become the opportunity cost in the production of forest products. The formulation of forestry carbon sequestration policy, the improvement of technology, the perfection of the trading market and the implementation of projects will have a significant impact on the domestic forest products market and trade (Qin and Tian, 2022). In recent years, there have been some studies on the application of GFPM in carbon sink trading around the world, which can provide references for domestic research. In addition, it is of practical significance to explore whether the establishment of a domestic forestry carbon sequestration trading market, the establishment of a forestry carbon sequestration price and other measures will affect the operation of the forest products market and trade.

4.1.3 Forest health products. Forest healthcare is a general term for activities such as forest recreation, vacation, recuperation, healthcare and old-age care relying on forest resources and service facilities, including forest healthcare, cultivation of forest healthcare, rehabilitation, fitness and leisure, forest tourism, research and development and production of forest healthcare products and other emerging health industries (Zhao *et al.*, 2021). Promoting forest health is of strategic significance for giving full play to the advantages of forestry-characteristic industries, promoting the structural reform of the forestry supply side and the transformation of the forestry economy and promoting the construction of a healthy China.

China has entered a stage of rapid population aging development, and the old-age care and health service industry is facing new market opportunities. People are beginning to pursue high-quality and green life. Emerging industries represented by forest healthcare have brought impacts to traditional industries such as wood harvesting, processing, pulping and papermaking. As a special non-wood forest product, forest health products can not only create considerable economic and social value but also create ecological benefits that can not be ignored. Because ecological benefits are difficult to quantify, how forest health products should be included in GFPM still needs many considerations.

4.2 Production

The report of the 20th National Congress of the Communist Party of China pointed out that it is necessary to speed up the implementation of important ecosystem protection and

restoration projects to improve the stability of ecosystem diversity. Reducing deforestation, afforestation and improving forest management is an effective action for green restoration, mitigating and adapting climate change and reducing biodiversity loss [2]. Whether it is the natural forest protection project, the returning farmland to forest and grassland project or the principle of ecological priority protection emphasized in the new forest law [3], it fully reflects that forest ecological protection and construction are the focus at present and even in the future for a long time. The impact of a series of forestry policies and measures, such as ecological protection policies, national reserve forest projects and timber harvesting reforms on the forest products market and trade needs to be further explored.

4.2.1 Ecological protection and construction policies. The Ministry of Natural Resources pointed out that by 2035, the forest coverage rate should reach 26%, the forest volume should reach 21 bn cubic meters and the natural forest area should be stabilized at about 200 m hectares [4]. Since the end of 2021, the State Forestry and Grassland Bureau has successively issued a number of major ecological protection and restoration project construction plans [5] related to the northeast forest belt, the northern sand control belt, the southern hills and mountains, etc. promoting the improvement and promotion of the ecological protection compensation mechanism nationwide and committing to the protection and restoration of important national ecosystems. These ecological protection policies and plans will influence the forest products market and change timber production for a long time in the future.

4.2.2 National reserve forest project. In 2013, China launched the National Reserve Forest Construction Project and successively delineated the forest in Chongqing, Guizhou and other places, formulating the goal of cultivating and transforming the national reserve forest by more than 30 m mu in 2025 [6]. The establishment of a national reserve forest project plays a role in timber supply and alleviates the contradiction between supply and shortage caused by a large amount of timber to ensure national timber safety.

4.2.3 Timber harvesting reform. With the development of the market economy, the contradiction between the forest harvesting quota system that used to increase forest stock by controlling the amount of forest harvesting and forestry development is becoming increasingly apparent, so it has spawned the timber harvesting reform. In 2019, the new forest law retained the forest cutting quota and cutting licence system, innovated the forest cutting management mechanism, deleted the timber production plan and canceled the timber transportation licence system. The reform of timber harvesting will alleviate the contradiction between forest harvesting quota and economy, which will affect the market and trade of forest products.

4.2.4 Forest fire and disaster prevention policy. Forest fire is the most dangerous enemy of forests, burning a piece of forest, hurting animals in the forest, causing poor soil, conserving water resources in the forest and resulting in ecological imbalance. Around 29%–37% of the global forest loss between 2003 and 2018 is related to fire [7]. In 2008, the State Council issued the Regulations on Forest Fire Prevention, which established a complete forest fire prevention system for pre-disaster prevention, emergency response and post-disaster recovery. Forest diseases and insect pests refer to the phenomenon that forest plants are infected by other organisms or affected by unsuitable conditions and the normal functions of physiological procedures are disturbed and eventually cause economic losses and other losses (Tong, 2013). Since 1989, China has implemented the policy of putting prevention first and comprehensive management and the responsibility system of whoever manages and prevents has been used up to now [8]. Forest fire prevention and disaster prevention policies directly affect the output of wood and forest by-products provided and also affect the realization of forest ecological value.

In addition to the abovementioned policies, forestry policies such as the separation of three rights and contract circulation of forest land in collective forest areas in southern China and the establishment of forestry economic demonstration bases will change the output of

domestic forest products and have a far-reaching impact on China's forest products market and international trade. GFPM can be used to predict the future impact of some systems whose short-term benefits are not obvious and provide suggestions for the operation and revision of policies.

4.3 Quality

In 2001, China established the China Forest Certification Council (CFCC) as a potential market policy tool to promote sustainable forest management and development. Previous studies have shown that forest certification has a significant positive impact on forest area, growing stock and products, with a significant premium for certified wood and non-wood forest products (Xu, 2014). At present, the forest area and the number of enterprises that have applied for and passed forest certification in China show a significant growth trend, but the certification scale is small and the public recognition is low. Due to the reform of the collective forest rights system and the prohibition of commercial logging of natural forests, China's forest management certification model has gradually changed from independent certification to smallscale joint certification (Zhang *et al.*, 2020). The implementation of forest certification standards that match the actual situation of China's forest resources endowment and forest rights system is of great help to improve China's forest resources and management quality. Such research can visualize the benefits of forest certification, which is conducive to effectively avoiding barriers encountered in international trade and improving the market competitiveness of China's forest products.

At present, there is no international scientific research output with GFPM to explain the impact mechanism of forest certification on the forest product sector. The main reason is that most of the forest sector models are currently applied to the United States of America, Norway, Finland and other countries and regions with relatively perfect forest certification systems. Few scholars pay attention to countries with imperfect forest certification systems or unique certification systems, and there is a gap in the research field. The existence of a forest certification system significantly affects the forest volume of a country, thus affecting the output and supply of forest products. The premium of forest products after certification is obvious and the market and trade of forest products will fluctuate.

4.4 International trade

In 2014, the China Forest Certification System (CFCC) and the Forest Certification System Program (PEFC) achieved mutual recognition, but they were not recognized by the Canadian Standards Association (CSA), the Forest Stewardship Council (FSC), the Sustainable Forestry Initiative (SFI) and the Malaysian Timber Certification Commission (MTCC). The key reason for the obstruction of recognition is that there has always been an international public opinion problem such as "China's timber import growth and international illegal logging". In fact, as the world's largest timber importer and exporter of wood products and as a responsible country, China's timber imports are not necessarily related to the illegal logging of timber and the destruction of forest resources in some countries and regions. On the contrary, China has always been committed to the protection, restoration and sustainable development of global forest resources and has firmly opposed and severely cracked down on illegal logging and related trade in timber. At present, many tropical timber-producing countries are establishing national systems to ensure the legality of timber acquisition and operation (FAO and Environment, 2020). Whether China's forest certification system can be in line with the world and can internationally recognized is a question that needs to be considered in depth in the future. In the face of the false accusation that China's demand has caused the deterioration of the illegal timber trade, in order to better maintain the image of China as a responsible power, China needs to continue to study the illegal logging and trade of timber, pay attention to

high-quality development, reduce excessive dependence on foreign timber resources and forest product markets and strive to build a new pattern of dual circulation (Tian, 2021).

4.5 External impact

The COVID-19 raged and overturned the whole world. Because of the income shock caused by the pandemic, the disruption of the global supply chain and the shortage of labor have brought uncertainty to agricultural production [9], including the forest product market and trade, thus affecting the economic benefits of forestry. American scholars have predicted that because of COVID-19, the total global forest products will be reduced by nearly 32bn dollars in 2030 and the global forest products trade will be reduced by nearly 10bn dollars (Buongiorno, 2021). The COVID-19 has caused a large number of fast-growing and high-yield forests in China to miss the best time for cultivation and production (Tang, 2020). It has also restricted transportation and labor transfers across the country and affected production, transportation and sales activities. In addition, COVID-19 has forced small and medium-sized forestry enterprises in Russia and other countries to shift their attention from the foreign market to the domestic market, causing a decline in the market demand and price of domestic forest products in China. Even if the occurrence of COVID-19 has been going on for just more than two years, no one can deny that it has had a great impact on the economic and social development of China and even the world.

The most direct impact of COVID-19 on the forest products sector is the reduction of market demand, which leads to a decline in the price of forest products. Because of the long cycle and slow effect of forestry production, the impact of the new coronavirus epidemic on the supply of forest products is difficult to show in the short term. As a model that can predict the long-term impact of emergencies on the future, the advantages of GFPM are reflected. More scientifically, the cobweb theorem is used to replace the equilibrium theory of the original model, and the model is optimized to make it more in line with the production and consumption characteristics of forest products.

5. Limitations and improvement directions

5.1 Forestry economy and macroeconomics

Overall, the economic output of the forestry sector accounts for a relatively small share of the world economy, so GFPM only considers the impact of macroeconomic changes on the forestry economy and does not involve the impact of changes in the forestry economy on the macroeconomy. In fact, with the development of forestry economic construction, progress in production technology and improvement in management level, forestry has changed its original appearance of low yield, low efficiency and low added value and continuously plays a considerable industrial role in areas such as understory aquaculture and ecotourism. In future research, researchers need to pay attention to the impact of forestry economic changes on macroeconomics in order to make the internal logical chain of GFPM more complete.

5.2 Defects of local equilibrium model

Partial equilibrium analysis assumes that, under other unchanged conditions, it analyzes the price determination when the supply and demand of a certain commodity (or factor of production) at a certain time and market reach equilibrium. However, the price of goods in any department depends not only on the supply and demand of the goods themselves but also on the prices and supply and demand of goods in other departments. For example, when analyzing the demand and supply of biomass fuels for woody forest products, the energy sector where alternative products such as oil and natural gas are located should be taken into account. As a local equilibrium model, the natural shortcomings of GFPM require researchers

to conduct more comprehensive and in-depth analysis, such as simultaneously using the GATP model for analysis.

5.3 Defects in equilibrium price theory

The theoretical basis of GFPM is equilibrium price theory, which refers to the price at which the demand price and supply price of a commodity are consistent, that is, the price at which the market demand curve intersects with the market supply curve. In real life, due to the long growth cycle and other characteristics of forestry production, under the spontaneous regulation of market mechanisms, the forest product market often experiences spider web-like fluctuations, which affect the stability of forestry production. The next research direction is to replace the equilibrium price theory of the original model with the spider web theory and optimize the model to better fit the production and consumption characteristics of forest products.

Notes

1. As of February 18, 2023.
2. FAO World Forests in 2022.
3. New Forest Law.
4. Master Plan for Major Projects of National Important Ecosystem Protection and Restoration (2021–2035).
5. Major Project Construction Planning for Ecological Protection and Restoration of Northeast Forest Belt, Major Project Construction Planning for Ecological Protection and Restoration of Northern Sand Prevention Belt, Major Project Construction Planning for Ecological Protection and Restoration of Southern Hilly and Mountain Zone Major Project Construction Planning.
6. Forestry and grass industry planning (2021–2025).
7. FAO "World Forest Profile 2022".
8. "Forest pest control regulations".
9. How the COVID-19 is changing the world: a statistical perspective.

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