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A Comparison of the International Competitiveness of Forest Products in Top Exporting Countries Using the Deviation Maximization Method with Increasing Uncertainty in Trading

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Abstract: Increased uncertainty in the trade environment has become a reality. However, so far, there is no well-established indicator system to quantify the international competitiveness of forest products in the context of increased uncertainty in the trade environment. Based on expanding the concept of international competitiveness, we constructed an evaluation indicator system of international competitiveness including market performance and competitive advantage, which highlighted market stability and market sustainability indicators. We obtained a comprehensive international competitiveness index of the forest products by Deviation Maximization Method. This study aims to compare and evaluate the international competitiveness of forest products in the top 10 exporting countries using a comprehensive international competitiveness index. The results showed that it is more accurate and comprehensive to use the comprehensive international competitiveness index to evaluate the international competitiveness of forest products, compared to using only a single index. Additionally, the changes to the composite index of international competitiveness went hand-in-hand with the uncertainties the observed countries face, indicating that the indicator system is applicable to the measurement of international competitiveness in an uncertain environment. Large differences exist in the level of international competitiveness of forest products among observed countries. German paper products and wood chips, Chinese wood furniture, wood-based panels and wood products, U.S. logs and wood pulp, and Canadian sawn wood were the most competitive. On the whole, China, Germany and Italy have the highest level of overall international competitiveness in forest products, with Brazil and Poland showing the most significant increases.

Keywords: international competitiveness; deviation maximization method; forest products; uncertainty

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1. Introduction

According to trade data from the United Nations Comtrade database, exports of roundwood, sawn wood, wood chips, wood-based panels, wood pulp and wood-based paper products and their variants (referred to as wood-based paper products), wood products and wood furniture (all referred to as forest products) reached USD 410.8 billion, which accounted for approximately two percent of the world's total goods exports and was an essential part of the world's trade in goods in 2021 (source: UN Comtrade database).

However, the sustainable development of trade in forest products faces many challenges. These are caused by a number of factors, such as the decreased demand for forest products in international markets and increased uncertainty in the trading environment. For example, trade frictions between China and the United States resulted in a 28.83 percent drop in Chinese forest products exported to the United States and a 32.70 percent drop in those from the US to China. In the end, total world exports of forest products fell by 5.36 percent in 2019 as a result (source: UN Comtrade database). Moreover, the market for exporting forest products is highly competitive. Germany, Italy and the United States have seen their rankings for forest product exports change frequently over the past decade, and the same is true for Finland, Poland, Brazil and Russia. This makes it important to consider ways to accurately assess the competitive advantage of forest products in the context of increased uncertainty in the trading environment, and ways for major forest product trading countries to adapt their international competitive strategies to the current situation and maintain their competitiveness.Industrial international competitiveness is an important competitive advantage evaluation metric that provides a quantitative basis for scholars to analyze and compare the competitive advantage of different national industries. Currently, there are two main forms of international competitiveness measures for industries. One major type of method is to use indicative indicators based on the data of trade scale, such as international market share (MS) [1,2], revealed comparative advantage (RCA) [3,4], revealed symmetrical comparative advantage (RSCA) [5,6], competitive advantage (CA) [7], normalized trade balance (NTB) [8] and relative trade advantage (RTA) [9]. The other major type of method is the use of analytical indicator systems, which involves using direct and indirect factors to indicate the strength of international competitiveness, such as factor endowments, innovation capacity, level of technology, product quality and other direct or indirect factors [10].

Comparing the two types of indicators, we found that indicative indicators were easy to understand and use, but their measurement dimensions were relatively one-sided. Therefore, there could be inconsistent or even contradictory conclusions among the results of different indicators [11,12]. The indicator system is more comprehensive in terms of measurement dimensions, but more demanding in terms of indicator construction and evaluation method selection, and more cumbersome in terms of operation. In other words, researchers need to invest more time in selecting appropriate segmentation indicators and evaluating models.

Specifically for forest products, current studies have covered major forest products such as wood-based panels, wood furniture, paper products and roundwood, and have included countries such as China, the United States, some European countries and countries along the Belt and Road area [2,9,13,14]. For example, Olena (2016) used RCA, RTA and other cross-country relative competitiveness indices to study the international competitiveness of American, Swedish, and Ukrainian forest industries [13]. Rossatoa (2018) employed the RCA index and RSCA index to ascertain the underlying comparative advantages in Brazil, Canada, China, Sweden, Finland and the United States [15]. Thi (2019) constructed a comprehensive international competitiveness index of MS, RCA, TC and RTA to evaluate the international competitiveness of the wood processing industry in Vietnam [1]. Grzegorzewska (2021) used RTA and modified forms of RCA to evaluate the international competitiveness of furniture manufacturing in some European countries [9].

In summary, indicators that measure the international competitiveness of forest products are continuously improving based on actual needs. However, these indicators are predominantly indicative indicators and their modified forms, which present the results of international competition in the market and lack consideration of core competitive advantages. In addition, so far, there is no integrated and well-established indicator system to quantify the international competitiveness of forest products in the context of increased uncertainty in the trade environment.

To address the above issues in this paper, we extended the concept of international competitiveness in the context of increased uncertainty in the trade environment and proposed a set of index systems of international competitiveness, including market competitiveness and advantageous competitiveness and focusing on market stability and market sustainability indicators. The index systems can comprehensively evaluate the international competitiveness of forest products, which include the ability to adapt to the uncertainties of the trading environment. Additionally, we then applied the index systems to measure the international competitiveness of forest products in ten countries, and analyzed the present situation and development trends of the international competitiveness of forest products, which can be used as a reference for countries to adapt their international competitive strategies to enhance the competitiveness of forest products.

2. Indicator System and Research Samples

2.1. Construction of the Index System

The modern study of international competitiveness emerged in the 1980s, when international trade showed more pronounced features of liberalization. Therefore, the US Industrial Competition Commission and some scholars explicitly took the liberalized market economy as a part of the definition of international competitiveness [16,17] and believed that the free market was a prerequisite for countries to participate in international trade and competition. However, the onset of the 2008 financial crisis, the 2018 trade frictions between China and the United States, the 2020 COVID-19 pandemic, the 2022 US Chip Act, and the continued growth of national priority strategies in Western countries have increased multilateral or bilateral trade uncertainties. Then, the international trade environment entered an era when liberalism and the market economy were the main themes [18], and local trade uncertainty increased significantly [19]. These changes go beyond the "free and favorable market environment" or "international free trade conditions" clearly defined by the modern concept of international competitiveness [16,17], and affect the prerequisites for the participation of countries in international trade and competition to a certain extent. Based on the fact that the uncertainty of the local trade environment has increased and its impact is significant [19], we argue in this paper that the connotation of international competitiveness should be expanded and the method of assessing international competitiveness should be improved to obtain a scientific and objective assessment of international competitiveness.

This study revises the concept of international competitiveness in light of the impact of uncertainty in the trade environment and the connotation of international competitiveness; hence, international competitiveness can be defined as "the ability of a country's specific products or industries to adapt to the international trade situation, to provide more products that meet the needs of consumers in international markets with their relatively higher production, and to stabilize their market share or make a sustainable profit". Unlike other definitions [16,17], the above definition focuses on the ability of international competitiveness to adapt to the uncertainties of the trading environment, that is, the ability to adapt and sustain development in the presence of local uncertainties. This is concretely reflected in the requirement for stability and continuity in the development process of international competitiveness in an environment of uncertainty [20]. Stability is a higher criterion of international competitiveness in the spatial dimension, expressed as higher survival and profitability under uncertainty, and sustainability is a higher criterion of international competitiveness in the temporal dimension, expressed as more stable market share and profitability under uncertainty.

Based on the previous discussion, we believe that it is necessary to improve the system of international competitiveness evaluation indicators to reflect the connotations and characteristics of international competitiveness under uncertainty. Therefore, this paper refers to the existing evaluation indices [3,11] and adds market stability and sustainability indices to reflect the capacity for survival and sustainability under uncertain situations with spatial and temporal dimensions. Table 1 shows the index system of international competitiveness in terms of uncertainty in the trade environment, specifically divided into market competitiveness and advantageous competitiveness. Market competitiveness is the strong market performance of international competitiveness, and advantageous competitiveness is the specific performance of international competitiveness to meet the needs of consumers.

To fully reflect the various dimensions of market competition, this paper subdivides market competitiveness into four metrics: market breadth, market depth, market stability and market sustainability. Market depth reflects the dimension of the volume of trade in forest products, indicated as the international market share of the export size of forest products, with a larger market share indicating a higher market position.

Table 1. The index system of the international competitiveness of forest products in an uncertain trading environment.

Target	Segmentation Competitiveness	Specific Indicator	Unit	Property
International competitiveness	>Market competitiveness	market depth (md)	%	Benefit
		market breadth (mb)	unit	Benefit
		market sustainability (ms)	%	Benefit
		market stability (mp)	%	Cost
	Advantageous competitiveness	price advantage (p)	USD	Cost
		quality advantage (q)	%	Benefit
		technical advantage (te)	USD	Benefit

Market breadth reflects the ability to build trade channels of forest products, indicated as the proportion of forest product exporting countries in the world. The more countries to which forest products are exported, the stronger the country's ability to establish export channels and the greater the scope of export market space. Market breadth and depth reflect the static outcome of forest products participating in international competition, and market sustainability and market stability reflect the dynamic advantage of forest products participating in international competition, respectively.

Market sustainability is a dynamic outcome of international competitiveness in the time dimension and is used to measure the stability of forest product trade channels, expressed as the share of forest product export destination countries over three years in all export destination countries. A higher market sustainability indicates that the export channels for forest products are more tried and competitive and less susceptible to changes in the trade environment.

Market stability is a dynamic result of international competitiveness in the spatial dimension, expressed as the degree of deviation between the actual and expected values of forest product export size [21], as shown in Equation (1), where $\mathrm{x_{it}}$ denotes the value of forest products exported from country i in year t, and $\hat{\mathrm{x}}_{\mathrm{it}}$ denotes the long-term trend value of forest products exported from country i in year t. The smaller the deviation of the actual value of forest product exports from the trend value, the stronger the sustainability of forest product exports in that country.

$$mp = \left| \frac{(\log \mathrm{x_{it}} - \log \hat{\mathrm{x}}_{\mathrm{it}})}{\log \hat{\mathrm{x}}_{\mathrm{it}}} \right| \tag{1}$$

In this paper, we subdivided competitive advantage into three metrics: price advantage, quality advantage and technical advantage. Price advantage was expressed as the weighted average price of exported forest products, and reflected the combined cost of exported forest products; the lower the weighted average price, the more cost-effective and competitive the forest products. We obtained the average price of each product by HS code and then calculated the weighted average price of subcategory forest products weighted by their export scale. The quality advantage is measured by the Nested-Logit model [22], shown in Equation (2), where S_{iht} denotes the export share of forest products h in year t by country i in the world forest products exports, $price_{iht}$ denotes the price of forest products h, ns_{jhtg} denotes subcategory forest product j's share of h, gdp_{it} denotes per capital GDP of country i, $\widehat{\sigma}$, $\widehat{\theta}$ and $\widehat{\varphi}$ are the coefficients of the variable, estimated from the nested logit model. The better the quality, the more competitive the forest product.

$$quality = \ln S_{iht} - \widehat{\sigma} \ln price_{iht} - \widehat{\theta} \ln ns_{jhtg} + \widehat{\varphi} \ln gdp_{it} \tag{2}$$

Technological advantage is expressed as technological complexity [23], as shown in Equation (3), reflecting the technological level and international division of labor of forest products. ps_{ci} denotes the total amount of forest products i exported to country c, PS

denotes the total amount of forest products i exported, and gdp_c denotes the GDP per capita of country c. The greater the technological complexity, the more pronounced the relative technological advantage of forest products.

$$TC_i = \sum_{c=1}^{C} w_{ci} gdp_c = \sum_{c=1}^{C} \frac{ps_{ci}}{PS} gdp_c \tag{3}$$

2.2. Samples and Data

In this paper, to accurately measure the international competitiveness of forest products, they were classified in eight categories [24]: roundwood, wood chips, sawn wood, wood-based panels, wood products, wood pulp, paper products and their variants (referred to as wood-based paper products), and wood furniture. Their corresponding customs HS92 codes are as follows (Table 2).

Table 2. The forest product types and their customs HS92 codes.

Types	HS Code	Types	HS Code
Roundwood	4403	Wood products	4413-4421
Wood chips	4401-02, 4404-05	Wood pulp	4701-4705
Sawn wood	4406-07	Wood-based paper products	4801-4813
Wood-based panels	4408-4412	Wood furniture	940161, 940169, 940330-940360

To better understand the main dynamics of changes in the international competitiveness of forest products in the world, we selected China, Germany, Canada, the United States, Sweden, Finland, Poland, Brazil, Russia and Italy between 2012 and 2021 as the research sample, which ranked among the world's top 10 in regard to total annual exports of exported forest products and accounted for approximately 50 percent of the world's total forest exports from 2012 to 2021.

We obtained export trade data of forest products exports in the above countries from the UN Comtrade database and the UN FAO statistics base on HS92, which covered the export value, quantity and export partner, and we obtained GDP data from the World Bank database. For the dollar-denominated indicators, we converted them to real values with 2012 as the base period. Then, the indicator values of the international competitiveness of forest products were calculated according to the indicators in Section 2.1.

3. Methods

3.1. Deviation Maximization Method

3.1.1. Introduction of the Deviation Maximization Method

To maximize the overall differences of the evaluated objects, we chose the deviation maximization method to determine the specific weights of each index. The deviation maximization method is an objective empowerment method that determines the weights of each indicator based on the overall difference of the evaluated object, rather than on the differences of each indicator of the evaluated object [25]. Thus, the advantage of this method is that it gives the appropriate weights to the associated indicators to make the difference among the performance values of alternatives as large as possible with a higher variance [26]. To date, the method has been used in economic and social evaluation studies [26,27].

Applying the international competitiveness index system with m indicators to evaluate n objects, the international competitiveness index y can be expressed as in Equations (4) and (5), where w is the vector of weight coefficients. The criterion for determining the weight coefficients is to solve them under the constrained objective of maximizing the variance of

y, as shown in Equation (6) where s denotes the standard deviation of y and $\overline{y}$ denotes the mean of y.

$$y = \omega_1 x_1 + \omega_2 x_3 + \cdots + \omega_m x_m = w^T x \tag{4}$$

$$y = Aw = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \cdots \\ \omega_m \end{bmatrix} \tag{5}$$

$$s^2 = \frac{1}{n}\sum_{\mathrm{i}=1}^{n} (y_i - \overline{y})^2 = \frac{y^T y}{n} - \overline{y}^2 \tag{6}$$

Since the observations x are normalized, $\overline{y} = 0$. So Equation (6) can be deformed to Equation (7), where $H = A^T A$ is the real symmetric matrix.

$$ns^2 == y^T y - n\overline{y}^2 = w^T A^T A w = w^T H w \tag{7}$$

Assuming $w^T w = 1$, the solution of Equation (7) is transformed into linear programming 8, and then w is calculated.

$$\begin{aligned} \max\ & w^T H w \\ \text{s.t. } & w^T w = 1 \\ & w > 0 \end{aligned} \tag{8}$$

According to the above model derivation procedure, the longitudinal and transverse pull-out gears can be decomposed into the following steps.

Step 1: arrange the observations of the indicators in the observed countries into a panel data sheet.

Step 2: obtain standardized panel data sheets (A) after the dimensionless processing of the indicator observations in terms of the direction of the indicator's effect on the evaluation results.

Step 3: obtain the real symmetric matrix (H) according to $H = A^T A$.

Step 4: solve for the maximum characteristic root and the corresponding characteristic vector of H, and obtain the weight coefficients of each index after normalizing the characteristic vector.

Step 5: calculate the international competitiveness index of the observed countries according to Equation (4).

The above steps can be implemented with Excel or stats software.

3.1.2. Estimation of the Deviation Maximization Method

Using the deviation maximization method, the weights of each indicator in the international competitiveness evaluation system for forest products are calculated as shown in Table 3. The market breadth indicator has the largest weight of 0.147, and the price advantage indicator has the smallest weight of 0.137.

Table 3. The index weights of international competitiveness of forest products.

Indicator	Market Depth (md)	Market Breadth (mb)	Market Stability (ms)	Market Sustainability (mp)	Quality Advantage (q)	Price Advantage (p)	Technical Advantage (te)
Weight	0.143	0.147	0.142	0.146	0.142	0.137	0.143

Based on the above weights, the estimated model ic_{ijt} for the international competitiveness of forest products j in country i in year t can be obtained as shown in Equation (9):

$$ic_{ijt} = 0.143md_{ijt} + 0.147mb_{ijt} + 0.142ms_{ijt} + 0.146mp_{ijt} + 0.142q_{ijt} + 0.137p_{ijt} + 0.143te_{ijt} \tag{9}$$

The composite index of the international competitiveness of forest products is obtained by weighting the value of the exported subdivided forest products with their international competitiveness index (Equation (10)). w_{ijt} is the ratio of the export value of the subdivided forest products j to the export value of all forest products by country i in year t.

$$ic_{it} = \sum_{j=1}^{8} w_{ijt} ic_{ijt} \tag{10}$$

3.2. Kernel Density Estimation

Kernel density estimation belongs to the class of weight functions for the local approximation approach, where a kernel estimator for the density function is obtained by using a weighted average of the local observations of the weight function. The common kernel density estimate is shown in Equation (11) [28]. In Equation (11), n is the number of observations, X_i denotes the specific observation, x denotes the mean value of the observation, and $K(\cdot)$ denotes the kernel density function. h is the bandwidth, and a sensitive parameter that controls the accuracy of the kernel density estimation. In general, a smaller bandwidth leads to more flexible kernel density estimation and smoother curves, but poorer estimation accuracy. Additionally, the optimal width is the width that would minimize the mean integrated squared error [28]. In practice, scholars typically compare the central positions, wave crests, curve widths and trailing of kernel density maps at different times in order to analyze the development trend and absolute difference evolution of a phenomenon, such as agricultural drought frequency analysis and convergence analysis of basic public service supply [29,30]. In this paper, we used Stata 16.0 to produce kernel density estimates and graph the results, in which $K(\cdot)$ was the Epanechnikov kernel and the optimal bandwidth was calculated and used by the system automatically.

$$f(x) = \frac{1}{nh_n} \sum_{i=1}^{n} K(\frac{X_i - x}{h_n}) \tag{11}$$

4. Results and Discussion

4.1. Results of Major Subcategory Forest Products

According to Equation (9), we obtained the international competitiveness index for eight subcategories of forest products from 2011 to 2021 in China, Germany, Canada, the United States, Sweden, Finland, Poland, Brazil, Russia and Italy. Due to space constraints, this paper focuses on the international competitiveness of the top three forest products in terms of export value; that is, the international competitiveness status and development trends of wood-based paper products, wood furniture and wood-based panels in the observed countries.

4.1.1. Wood-Based Paper Products

Figure 1 and Table 4 show the development situation and dynamic distribution of the international competitiveness of wood-based paper products in the countries observed from 2012 to 2021, respectively. First, the following facts were found. Germany had the highest international competitiveness index for wood-based paper products, above 6.0, with an obvious advantage of market competitiveness and advantageous competitiveness. China, the United States, Canada and four other countries followed in the second tier and had small gaps in terms of the international competitiveness of wood-based paper products, and most of their rankings changed dramatically in 2021 compared to 2012. Brazil and Poland had the lowest relative international competitiveness index, between 4.5 and 5.10, showing a clear lack of market competitiveness and advantageous competitiveness.

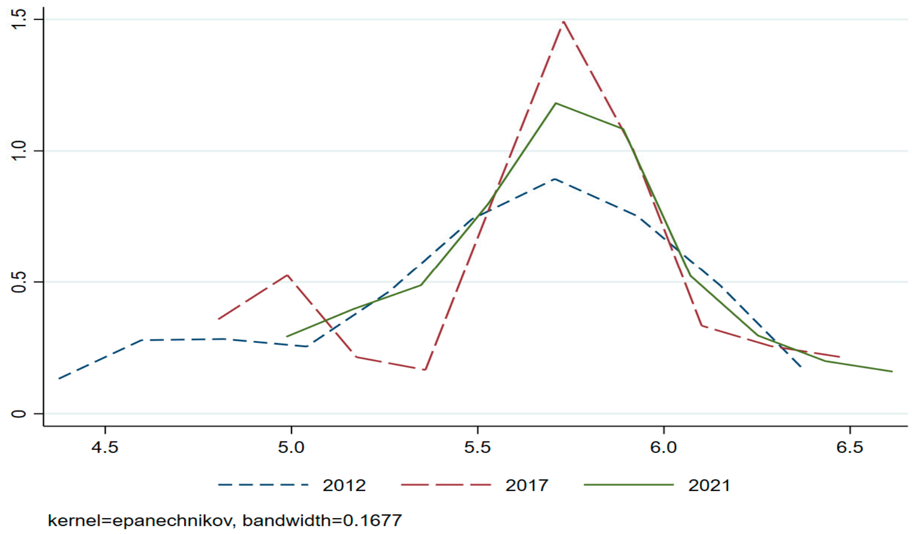

Figure 1. Kernel density map of the international competitiveness of wood-based paper products in the countries observed.

Table 4. The results of the international competitiveness of wood-based paper products.

Country	2012		2021		Mean		SD of Value	Average Growth	SD of Growth
	Value	Rank	Value	Rank	Value	Rank			
BRA	4.851	9	5.205	9	4.966	9	0.128	0.79%	0.023
CAN	5.830	4	5.696	7	5.803	4	0.110	−0.26%	0.024
CHN	5.862	3	5.946	3	5.922	2	0.074	0.16%	0.014
DEU	6.171	1	6.446	1	6.357	1	0.096	0.49%	0.020
FIN	5.674	5	5.966	2	5.772	5	0.109	0.56%	0.013
ITA	5.382	8	5.749	5	5.554	7	0.125	0.74%	0.016
POL	4.577	10	5.154	10	4.898	10	0.208	1.33%	0.019
RUS	5.424	7	5.762	4	5.505	8	0.129	0.67%	0.024
SWE	5.529	6	5.548	8	5.562	6	0.061	0.04%	0.016
USA	5.975	2	5.742	6	5.858	3	0.067	−0.44%	0.008
average	5.528		5.721		5.620			0.41%	5.528
SD	0.498		0.374		0.437			0.005	0.498

Second, the trend of the international competitiveness index of wood-based paper products varied significantly among the countries observed. The growth of the international competitiveness index of wood-based paper products in Poland was outstanding, with an average annual growth rate of 1.33%. The growth was obvious in Brazil, Italy, Russia and Finland, with an average annual growth rate of more than 0.5%. The international competitiveness index of wood-based paper products in Germany, China and Sweden maintained a slight increase, but was negative in the United States and Canada, decreasing by 3.91% and 2.30%, respectively, compared to 2012.

Third, the main peak of the kernel density distribution curve for the observed countries showed a clear upward trend, and the width of the main peak tended to converge slightly, indicating that the average value of international competitiveness of wood-based paper products generally increased from 5.528 to 5.721, and the absolute gap gradually narrowed, which was again provided by a decrease in the standard deviation of the index values. The distribution extensibility showed a convergence, and the left trailing kept converging in the kernel density image, indicating that the level of international competitiveness of wood-based paper products was rapidly improving in the lagging countries and that the gap between the lagging countries and the observed average level was clearly narrowing.

In summary, there were significant differences in the development levels and trends of the international competitiveness of wood-based paper products in the observed countries.

Additionally, the countries in the middle rank had small gaps with large variations, and the gaps gradually narrowed as the international competitiveness in the lagging countries significantly improved.

4.1.2. Wooden Furniture

Table 5 and Figure 2 show the development situation and dynamic distribution of the international competitiveness of wooden furniture from 2012 to 2021, respectively. First, the level of international competitiveness of wooden furniture in the countries observed was significantly different and relatively fixed in ranking. China had the highest international competitiveness index for wood furniture, more than 7.0, mainly in terms of market competitiveness advantage. Germany, Italy and the United States followed, with an international competitiveness index of wood furniture ranging from 6.0 to 6.5. Finland had the lowest international competitiveness index for wood furniture, and lagged behind in market competitiveness and advantageous competitiveness.

Table 5. The results of the international competitiveness of wooden furniture.

Country	2012		2021		Mean		SD of Value	Average Growth	SD of Growth
	Value	Rank	Value	Rank	Value	Rank			
BRA	4.946	9	5.669	6	5.309	7	0.239	1.53%	0.007
CAN	5.650	5	5.518	7	5.533	6	0.114	−0.26%	0.028
CHN	7.194	1	7.389	1	7.141	1	0.113	0.30%	0.022
DEU	6.207	2	6.486	2	6.435	2	0.101	0.49%	0.015
FIN	3.818	10	4.272	10	4.045	10	0.255	1.26%	0.089
ITA	5.949	4	6.312	3	6.147	3	0.110	0.66%	0.018
POL	5.202	7	5.755	5	5.550	5	0.192	1.13%	0.022
RUS	5.020	8	5.312	9	4.992	9	0.210	0.63%	0.050
SWE	5.303	6	5.338	8	5.275	8	0.074	0.07%	0.022
USA	6.039	3	5.959	4	5.979	4	0.078	−0.15%	0.019
average	5.533		5.801		5.641			0.57%	
SD	0.905		0.828		0.849			0.006	

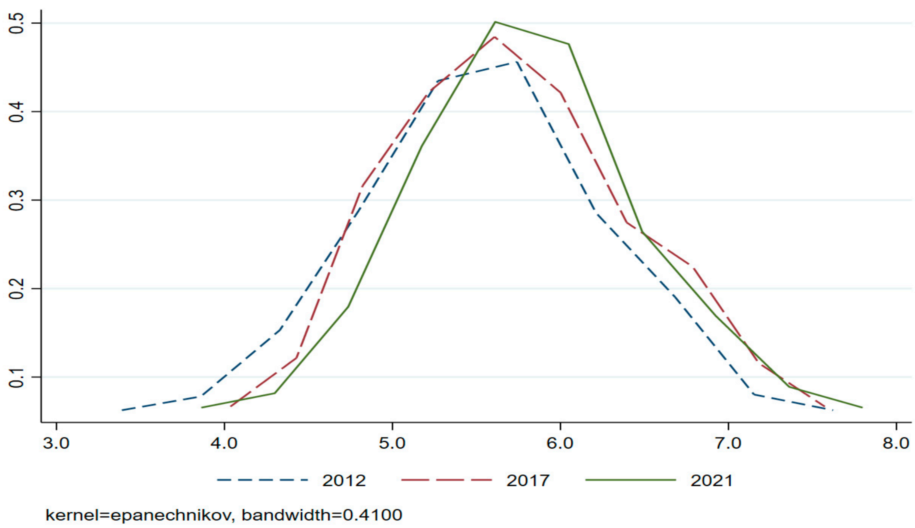

Figure 2. Kernel density map of the international competitiveness of wooden furniture in the countries observed.

Second, the growth trend of the international competitiveness index of wood furniture was significantly different among the countries observed. The international competitiveness index for wood furniture in Brazil, Poland and Poland showed outstanding growth, with an average annual growth rate of more than 1%. The international competitiveness index for wood furniture in Italy, Russia, Germany, China, and Sweden maintained a small increase. However, the international competitiveness index for wood furniture in Canada and the United States showed negative growth, down 2.33% and 1.32%, respectively, compared to 2012.

Third, the main peak of the kernel density distribution curve for the observed countries showed a clear upward trend, moving right, and the left trailing kept converging. The standard deviation of the index values decreased from 0.905 to 0.828. These changes indicate that the overall international competitiveness index for wood furniture in the observed countries had a slight trend of growth from 5.533 to 5.801, with the absolute difference decreasing slightly but still noticeable.

In summary, the international competitiveness index for wood furniture showed a slight increase, with a relatively fixed ranking among the countries observed, but there were significant differences in the level and trend of development.

4.1.3. Wood-Based Panels

Table 6 and Figure 3 show the development situation and dynamic distribution of the international competitiveness of wood-based panels from 2012 to 2021, respectively. The figure shows, first, that the international competitiveness index for wood-based panels was notably uneven among the countries observed, and the rankings among countries were continually changing. China's international competitiveness index for wood-based panels was above 6.20, in a leading position among the observed countries, mainly in terms of market competitiveness advantage. Finland and Sweden were the last two countries, with international competitiveness indices lower than 4.82, while the rest of the countries were in the middle with an index between 4.80 and 6.10.

Table 6. The results of international competitiveness of wood-based panels.

Country	2012		2021		Mean		SD of	Average	SD of
	Value	Rank	Value	Rank	Value	Rank	Value	Growth	Growth
BRA	5.496	4	5.912	3	5.659	3	0.164	7.58%	0.022
CAN	5.538	3	5.720	5	5.633	4	0.126	3.30%	0.034
CHN	6.512	1	6.508	1	6.501	1	0.132	−0.06%	0.026
DEU	5.820	2	5.780	4	5.918	2	0.094	−0.70%	0.014
FIN	4.639	9	4.608	9	4.640	9	0.101	−0.66%	0.021
ITA	4.932	8	5.163	7	5.085	8	0.125	4.68%	0.023
POL	4.975	7	5.133	8	5.110	7	0.104	3.18%	0.029
RUS	5.188	6	6.086	2	5.550	5	0.297	17.32%	0.026
SWE	4.598	10	4.535	10	4.520	10	0.081	−1.38%	0.023
USA	5.449	5	5.252	6	5.422	6	0.132	−3.61%	0.025
average	5.315		5.470		5.404			2.97%	
SD	0.581		0.640		0.593			0.060	

Second, the growth trends of the international competitiveness index of wood-based panels in the observed countries differed significantly, alternating between rises and falls during the observation period. Russia, Brazil, Italy, Canada and Poland showed increases in the international competitiveness index for wood-based panels, with increases of 17.32%, 7.58%, 4.68%, 3.29% and 3.18%, respectively, in 2021 compared to 2012. The United States, Sweden, Finland, Germany and China showed slight declines in their index of international competitiveness for wood-based panels, ranging from a decline of 3.16% to 0.5%.

Third, the height of the main peak of the kernel density distribution curve of the international competitiveness index of wood-based panels decreased significantly and moved right, and the width of the main peak expanded significantly, which verified that the international competitiveness of wood-based panel boards showed a dispersive trend and a slight increase among the observed countries, with the absolute gap gradually widening. These features were also corroborated by the decrease in standard deviation and increase in mean value.

In summary, there were significant differences in the development levels and trends with regard to the international competitiveness of wood-based panels among the observed countries. The countries showed a clear overall dispersion and a slight increase in the index as a whole, alternating between rises and falls during the observation period, and there was a further increase in the observed absolute gap.

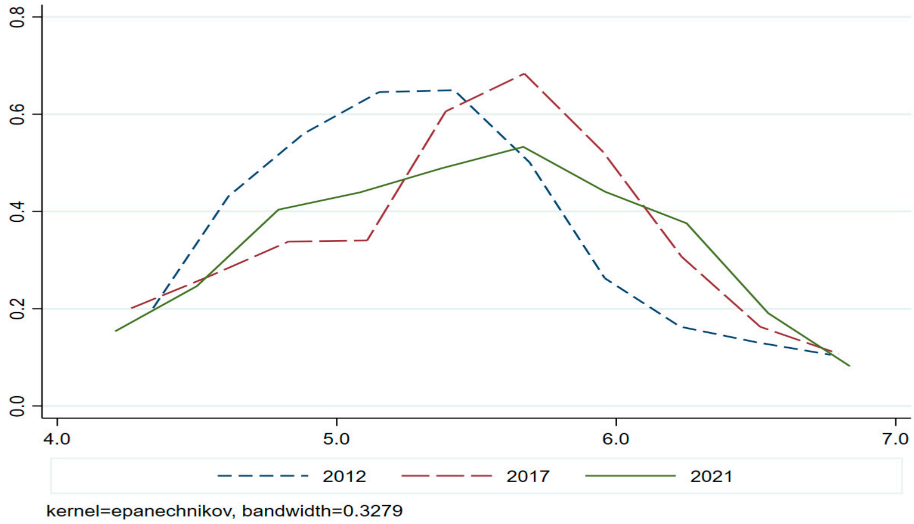

Figure 3. Kernel density map of the international competitiveness of wood-based panels in the countries observed.

4.1.4. Other Subcategory Forest Products

Table 7 lists the mean values and annual growth rates of the international competitiveness index for other forest products in the observed countries from 2012 to 2021. Figure 4 shows the kernel density distribution curve of international competitiveness for other forest products in the observed countries from 2012 to 2021, in which the same color curve represents the kernel density curve of the same forest product during different times.

Table 7. Annual average values and annual growth rates of international competitiveness for other forest products in the observed countries from 2012 to 2021.

	Roundwood		Wood Chips		Sawnwood		Wooden Articles		Wood Pulp	
	Mean	Growth	Mean	Growth	Mean	Growth	Mean	Growth	Mean	Growth
BRA	3.815	1.40%	4.208	1.13%	4.635	0.81%	5.509	0.61%	4.845	1.12%
CAN	4.348	−0.29%	4.701	0.03%	6.069	0.96%	5.925	0.48%	4.644	0.00%
CHN	3.718	−1.75%	5.310	−0.62%	3.680	0.02%	6.643	0.51%	3.604	0.91%
DEU	4.925	−0.47%	5.486	0.06%	5.404	0.52%	6.445	−0.09%	4.807	0.95%
FIN	4.199	0.39%	3.874	−0.15%	4.790	0.51%	4.437	0.11%	4.312	1.22%
ITA	4.502	−0.96%	4.738	0.45%	4.579	0.13%	5.523	0.17%	4.159	1.06%
POL	3.552	−1.58%	4.851	−0.19%	3.827	−1.71%	5.353	−0.06%	3.117	0.40%
RUS	5.182	−1.80%	5.070	0.83%	5.416	0.46%	5.495	0.40%	4.299	0.30%
SWE	4.189	0.54%	4.314	0.58%	4.797	0.29%	4.790	−0.04%	4.306	0.82%
USA	5.575	−0.73%	5.198	0.61%	5.650	−0.94%	5.755	−0.33%	5.067	0.57%

The international competitiveness index for logs ranged from 3.552 to 5.575. The United States had the highest average value of international competitiveness index, at 5.575, and Brazil had the largest average annual growth rate at 1.40%. The main peak rose significantly, and left–right trailing converged in the kernel density map, indicating that the international competitiveness index for logs in observed countries showed an overall upward trend and concentration with the absolute gap narrowing.

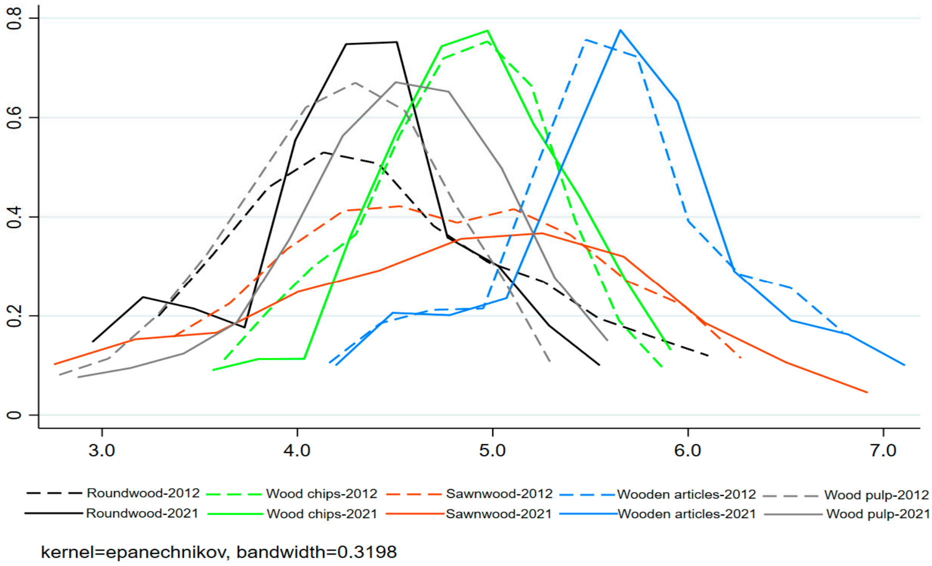

Figure 4. Kernel density map of the international competitiveness of other paper products in the countries observed.

Using similar analysis, we obtained the results of wood chips, sawn wood, wooden articles and wood pulp. The international competitiveness index for wood chips was generally stable, ranging from 3.874 to 5.486; Germany had the highest average index of international competitiveness for wood chips, at 5.486, while Brazil had the highest average annual growth rate of the index at 1.13%. The overall growth trend and dispersion of the international competitiveness index for sawn wood was evident, with the absolute gap between countries tending to widen. Canada had the highest average value of international competitiveness index, at 6.609, and China had the highest average annual growth rate at 0.96%. The overall international competitiveness index for wooden articles showed a slight increase, with China having the highest average index, at 5.925, and Brazil having the highest average annual growth rate of the index at 0.61%. The international competitiveness index for wood pulp grew significantly, with no negative growth among the countries observed. The United States had the highest average index, at 5.067, and Finland had the highest average annual growth rate at 1.22%.

4.2. Results of the Composite Index of the International Competitiveness of Forest Products

Based on Equations (9) and (10), this paper measured the composite index of the international competitiveness of forest products from 2012 to 2021 in ten countries, including China, Germany, Canada, the United States, Sweden, Finland, Poland, Brazil, Russia and Italy. The results clearly reflect the development level and dynamic changes in the international competitiveness of forest products, as shown in Table 8 and Figure 5 below.

First, the uneven composite index of the international competitiveness of forest products among the observed countries was prominent. However, the gaps between the observed countries shrank as the standard deviation decreased from 0.565 to 0.522. China, Germany and Italy had the highest composite indices of international competitiveness for forest products, above 6.582, followed by the United States and Canada, while Poland, Russia, Finland, Brazil and Sweden had the lowest composite indices. These international competitiveness rankings fully accounted for the changes in the ranks of major countries in terms of forest products exported over the previous two decades.

Table 8. The composite index of international competitiveness for all forest products.

Country	2012		2021		Mean		SD of Value	Average Growth	SD of Growth
	Value	Rank	Value	Rank	Value	Rank			
BRA	4.767	10	5.238	9	5.014	10	0.154	1.05%	0.024
CAN	5.457	5	5.767	4	5.553	5	0.099	0.62%	0.022
CHN	6.696	1	6.860	1	6.678	1	0.080	0.27%	0.018
DEU	6.023	2	6.163	2	6.166	2	0.068	0.26%	0.014
FIN	5.264	6	5.316	8	5.264	7	0.040	0.11%	0.011
ITA	5.599	4	5.911	3	5.765	3	0.098	0.60%	0.018
POL	4.955	9	5.428	7	5.240	8	0.150	1.02%	0.020
RUS	5.214	7	5.564	5	5.303	6	0.134	0.73%	0.024
SWE	5.125	8	5.106	10	5.137	9	0.050	−0.04%	0.014
USA	5.726	3	5.510	6	5.604	4	0.077	−0.43%	0.010
Average	5.457		5.623		5.535			0.42%	
SD	0.565		0.522		0.516			0.005	

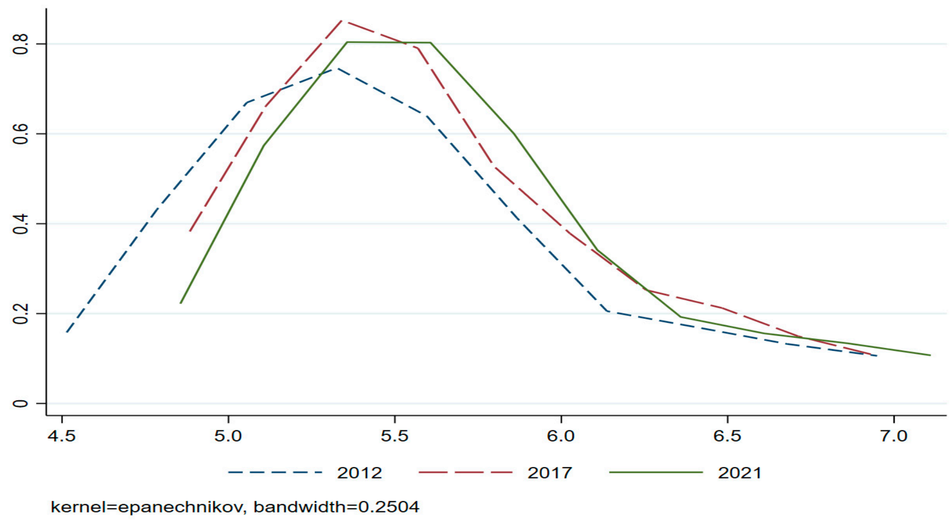

Figure 5. Kernel density map of the composite index of international competitiveness for all forest products in the countries observed.

Second, the observed countries showed an overall growth trend in the composite index of international competitiveness of forest products. Brazil and Poland had grown significantly in the composite index of international competitiveness of forest products, with average annual growth rates of more than 1%, and in 2021, they moved up one and two places, respectively, in the composite index rankings compared to 2012. The United States and Sweden showed a downward trend in the composite index, dropping three and two places, respectively, in 2021 in the composite index rankings compared to 2012.

Third, the development of the international competitiveness of forest products in the observed countries was highly compatible with the uncertain situation they face. In 2015, the introduction of full quantification by the European Central Bank, the refugee events in Europe and the first 25-basis-point rate hike in the US in 10 years simultaneously increased economic uncertainty in major export destinations of forest products, such as Europe and the United States, resulting in a consistent decline in the composite index of international competitiveness of forest products in EU countries such as Germany, Finland, Italy, Poland and Sweden. Increased regional uncertainty, fueled by the trade frictions between the United States and China in October 2018, led to a decline in the composite index of international competitiveness of forest products in eight countries in 2019, including China and the United States. The COVID-19 pandemic in 2020 cut into the global supply chain, causing the composite index of international competitiveness of forest products to decline or fluctuate slightly in the observed countries.

In summary, the composite index of the international competitiveness of forest products in the observed countries showed growth, but there were clear differences in their development levels and trends, and their changing trends were in excellent agreement with the uncertain development dynamics they faced.

4.3. Sensitivity Analysis and Method Comparisons

Starting with the simulations of changes in a single indicator, we furthermore analyzed the sensitivity of the international competitiveness of forest products to changes in indicators. Assuming the relative independence of the seven indicators, we increased the observed value of one indicator by 10% (−10%, ±20%), kept the value of the other six indicators constant, and then obtained the international competitiveness index of forest products in the observed countries. Then, we calculated the sensitive coefficient (E) according to the equation $E = \triangle IC/\triangle F$. $\triangle IC$ denotes the percentage change in the international competitiveness index of forest products, and $\triangle F$ denotes the percentage change in the observed value of one indicator. Table 9 lists the results of $\triangle IC$ and E. It can be seen that when the rate of change in each indicator was the same, the impact of market sustainability on the international competitiveness of forest products was the greatest. The international competitiveness index increased by 0.281% for every 10 percent increase in market sufficiency. The effect of market sustainability was the lowest. The international competitiveness index increased by 0.043% when the market breadth increased by 10%.

Table 9. Single factor sensitivity analysis results of the international competitiveness index.

△F	Market Breadth	Market Depth	Market Stability	Market Sustainability	Price Advantage	Quality Advantage	Technical Advantage
−20%	−0.854	−2.818	−2.409	−5.635	−2.356	−3.625	−2.309
−10%	−0.427	−1.409	−1.204	−2.813	−1.174	−1.820	−1.155
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10%	0.427	1.409	1.204	2.804	1.167	1.832	1.154
20%	0.854	2.818	2.409	5.599	2.327	3.674	2.309
Average E	0.043	0.141	0.120	0.281	0.117	0.183	0.115

To illustrate the validity of the method used in this paper, the performances obtained by the Deviation Maximization method (DM) were compared with those of the variation coefficient method (VCM), the entropy method and the equal weight method (the weight of each indicator was 1/7). Like the deviation maximization method, both the entropy method and the variational coefficient method are objective weighting approaches. Entropy is a measure of the degree of disorder in a system, and the entropy method is a method of weighting according to the entropy value (disorder degree) of the observation of the index [31]. The lower the entropy value of an indicator, the greater the variation in the observed values of the indicator, and the larger the weight of the indicator. The variation coefficient weighting method is a method of weighting according to variation coefficient of the observation of the index compared to the object to be evaluated [1]. The larger the coefficient of variation in the observations of an indicator, the larger the weight of the indicator. The equal weight method is a method where the weight of each indicator is the same and equal to 1/N (denoting the number of indicators). Both entropy and variational coefficient methods are widely used in the comprehensive evaluation of economic and social problems. Examples include international competitiveness [1], integrating different strategies of forest carbon sequestration [32], the development level of low carbon economy [33] and water quality [34].

The results of four methods are shown in Table 10. (1) The rankings of the results of the DM method, the equal weight method, and the entropy method were in relatively good agreement, while the VCM method had a different ranking. (2) The average values calculated by the DM method were greater than those calculated by the other three methods, such as 5.198, 5.108, 5.105, and 3.716. (3) The standard deviation of the values of all objects obtained by the DM method was 0.908, greater than the values of the other three methods, such as 0.881, 0.875, and 0.903. This indicates that the DM highlights the difference among the performance values greatly when compared with the other objective weighting methods, which is consistent with Yi (2019) [26].

Table 10. The values obtained by the DM method and the other three methods—wood-based paper products in 2021 as an example.

Country	Type	DM Method		Equal Weight Methods		Entropy Method		VCM Method	
		Value	Rank	Value	Rank	Value	Rank	Value	Rank
BRA	Wood-Based Paper Products in 2012	5.205	9	5.219	9	5.263	9	4.014	10
CAN		5.696	7	5.706	7	5.751	7	4.317	7
CHN		5.946	3	5.944	3	6.284	2	5.215	2
DEU		6.446	1	6.444	1	6.462	1	5.387	1
FIN		5.966	2	5.966	2	6.002	3	4.875	4
ITA		5.749	5	5.756	5	5.796	5	4.563	5
POL		5.154	10	5.166	10	5.207	10	4.133	9
RUS		5.762	4	5.784	4	5.834	4	4.269	8
SWE		5.548	8	5.551	8	5.583	8	4.547	6
USA		5.742	6	5.745	6	5.772	6	4.89	3
Average	all objects	5.198		5.108		5.105		3.716	
SD		0.908		0.881		0.875		0.903	

Note: Due to space limitations, only the International Competitiveness Index for Paper Products in 2021 is listed.

4.4. Discussion

We constructed a comprehensive index of international competitiveness and used the deviation maximization method to obtain the value of the international competitiveness of forest products among 10 major forest export countries. Based on this, we found significant differences in the level and development dynamics of their international competitiveness.

The development of the international competitiveness of forest products is influenced by a diverse set of factors such as market conditions, industrial policies, natural resources and technological development [15,35]. We observed that countries with abundant forest resources were more competitive in terms of primary or semi-finished forest products. In 2021, the five countries with the highest forest area were, in order, Russia, Brazil, Canada, the United States and China (source: FAO). Russia had a higher index of international competitiveness in roundwood and sawn wood, the United States had a higher index in roundwood, wood chips, sawn wood and wood pulp and Canada had a higher index in sawn wood and wood pulp, which is consistent with the findings of Rossato (2018) [15], Gordeev (2020) [36] and Santos (2022) [37]. However, the situation was different in Brazil and China. Brazil is moving forward with the transformation of its forest industry development, hoping to translate the advantages of its forest resources into advantages of forest products with high added value [37]. As a result, Brazil's international competitiveness in logs and chips is poor, but its international competitiveness in wood pulp is outstanding. China still has a scarcity of domestic timber and fiber materials due to its large population, and its logs and sawn wood perform poorly in international competitiveness [38].

Second, the sustainable development of forest products trade is becoming more critical as market grabbing for forest products exports becomes more intense due to the increasing uncertainty in the trade environment and the development of shipping logistics [1,39]. All major exporters of forest products attach importance to maintaining stable relations with their trading partners. The value of market sustainability showed an increasing trend among the observed countries. We found that Germany, China, the United States and Italy had a high number of trading partners with stable trade partnerships for the export of forest products, which was partly responsible for the higher international competitiveness of forest products in these countries.

Finally, we found that the overall improvement in the international competitiveness of forest products benefited from a significant improvement in the quality of forest products. In the United States, the quality of forest products declined by 4.4 percent among the ten countries observed, while in nine other countries, the quality of forest products showed significant increases or remained the same. Among them, China had the highest growth in the quality of forest products, which was closely related to China's ongoing efforts in recent years to move away from low-value-added exports and improve the global value chain [38].

At present, some scholars have analyzed the international competitiveness of forest products and obtained numerous valuable results, in which the United States, Russia, China, Brazil, Germany and other major exporters of forest products in the world are involved [15,36–38,40]. Rossato (2018) found that Finland, Brazil, Canada, Sweden and the United States have a comparative advantage in the market for pulp exports, but not China [15]. Grzegorzewska (2021) found that Poland and Italy have a clear advantage in exporting furniture, while Germany does not [9,40]. Compared with China, the United States and Sweden are competitive in logs and sawn wood, but not in their manufactured boards [15]. However, a direct comparison between our results and their findings described above is not appropriate because of the differences in the indicators and the data used.

To address the above issues, we applied market share, revealed symmetric comparative advantage (RSCA) [15], relative trade advantage (RTA) [1] and trade balance index (CTB) [37] to measure the international competitiveness of forest products in 10 countries. Due to space limitations, Table 11 lists the results and rankings of the corresponding indicators for 2021 wood-based paper. As can be seen from the table, the ranking results for the five indicators differ significantly. Differences in the evaluation dimensions of the metrics lead to differences in the results. RSCA focuses only on the performance of exportation [36], and RTA and CTB are sensitive to the export surplus of forest products. Therefore, we found that the international competitiveness of the United States, China and Germany was not outstanding according to the results of RSCA, RTA and CTB. The United States, China and Germany, which have integrated industrial systems and export a wide range and number of goods, have RSCA values close to zero because their proportion of forest products in total exports is close to the world's proportion. At the same time, the United States, China, and Germany are large exporters and consumers of forest products with small trade surpluses, so their RTA and CTB values are relatively low. However, we cannot deny the advantages in the international competitiveness of forest products in the United States, China and Germany, as their trade surpluses are small and their proportion of exports is close to the world average. Therefore, we need more integrated and comprehensive evaluation indicators and methods for the international competitiveness of forest products, which is also the objective of this research paper.

Table 11. The results of MS, RSCA, RTA and CTB for 2021 wood-based paper.

Country	IC Index		MS		RSCA		RTA		CTB	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
BRA	5.205	9	0.019	10	0.199	7	0.825	5	0.842	9
CAN	5.696	7	0.058	6	0.443	3	1.132	3	1.689	4
CHN	5.946	3	0.084	4	0.282	10	−0.111	8	0.459	10
DEU	6.446	1	0.170	1	0.400	5	0.908	4	1.479	6
FIN	5.966	2	0.082	5	0.915	1	21.615	1	9.473	1
ITA	5.749	5	0.050	7	0.298	6	−0.084	7	1.528	5
POL	5.154	10	0.037	8	0.422	4	−0.696	10	2.405	3
RUS	5.762	4	0.028	9	0.125	9	−0.141	9	0.856	8
SWE	5.548	8	0.093	3	0.833	2	9.889	2	4.836	2
USA	5.742	6	0.116	2	0.194	8	0.751	6	1.066	7

IC index is the international competitiveness index calculated in this paper.

In comparison with existing studies, the dimensions of evaluation of the international competitiveness of forest products presented in this paper are more comprehensive, covering both market and advantage dimensions, and centered around market stability and sustainability indicators. On that basis, it is easier to determine the position and trend of the international competitiveness of forest products in each country than to use only one indicator, and it is more efficient to compare, analyze and evaluate the international competitiveness of forest products among the 10 major forest export countries. The results of this study presented a more comprehensive picture of the actual situation of international competitiveness for the forest products of selected countries.

The presented research has some limitations. First of all, the results in this paper highly depend on the underlying data quality of the used databases. However, we may produce two different figures for the same flow, as the exports reported by the exporting country are inconsistent with the related imports reported by the importing country in the UN Comtrade database. We need to deal with the raw data to obtain a single consistent figure for a bilateral flow in future research. Second, due to data limitations, we measured the international competitiveness of forest products without taking into account the export value added of forest product brands. In addition, a quantitative analysis of the impact of trade policy uncertainties on international competitiveness is also an essential research direction for the future.

5. Conclusions and Recommendations

In view of the increased uncertainty in the trade environment, this study constructed a comprehensive index of international competitiveness using the Deviation Maximization Method, which included market performance and competitive advantage, and highlighted market stability and market sustainability indicators. This study aimed to compare and evaluate the international competitiveness of forest products in the top 10 exporting countries using a comprehensive index of international competitiveness. For this purpose, the study was implemented based on the panel data in the top 10 exporting countries of forest products from the UN Comtrade database for 2012 to 2021, which include China, Germany, Canada, the United States, Sweden, Finland, Poland, Brazil, Russia and Italy.

The following conclusions have been drawn in this study. First, compared to using only an indicative indicator, the results of an evaluation indicator system of international competitiveness are more accurate and comprehensive for evaluating the international competitiveness of the forest products, and the Deviation Maximization Method highlights the differences among the performance values greatly compared with the other objective weighting methods. At same time, the trends of the international competitiveness composite index of forest products were highly compatible with the uncertainties the observed countries faced, verifying that international competitiveness is applicable to the measurement of international competitiveness in an uncertain environment. Second, there were significant differences in the observed countries. German paper products and wood chips, Chinese wood furniture, wood-based panels and wood products, US logs and wood pulp, and Canadian sawn wood were the most competitive. On the whole, China, Germany and Italy had the highest level in overall international competitiveness of forest products, with Brazil and Poland showing the most significant increases. Third, abundant forest resources, stable relations with trading partners and the quality of forest products contributed to the improvement of international competitiveness in the context of increased uncertainty in the trade environment.

Based on the above results, countries should enhance the competitiveness of their major exports of forest products based on their current situation, the trade structure of forest products, their resource endowments, stable trade partnerships and the quality of forest products. China needs to improve the international competitiveness of forest products in a balanced manner, maintain its leading position in competition for the trade of five categories of products, including wood furniture, wood-based panels and wood products, and accelerate the development of lagging-behind forest products ranging from logs, sawn wood to wood pulp. The US should be aware that the international competitiveness in five sub-categories of forest products, including sawn wood, wood products, wood furniture, paper products and wood-based panels, is declining. As traditionally strong forest product exporters, Germany and Italy need to be wary of developing countries such as China and Brazil, which are grabbing their forest product markets shares. Canada and Russia need to take full advantage of their abundant forest resources to cultivate their international competitiveness across all forest products. Brazil can continue to promote its international competitiveness of forest products and accelerate its level of international competitiveness of wood products and wood furniture to a leading position. Depending on their resource endowments and the structure of their forest products, Finland, Poland and Sweden may be able to cultivate one or two key forest products to achieve a clear competitive advantage.

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