

Article

Determinants of Demand for Exports of Brazilian Sawnwood

Júlia de Oliveira Carneiro ¹, Humberto Angelo ^{1,*}, Alexandre Nascimento de Almeida ^{2,*},
Eraldo Aparecido Trondoli Matricardi ¹, Evelyn Bianca Almeida Vaz ¹ and Laura de Castro Silva ¹

¹ Forest Engineering Department, University of Brasilia, Brasília 73345-010, DF, Brazil; julia.ocarneiro38@gmail.com (J.d.O.C.); ematricardi@unb.br (E.A.T.M.); eflevelyn@gmail.com (E.B.A.V.); lauracastrosm@gmail.com (L.d.C.S.)
² Planaltina Campus, Universidade de Brasília, Planaltina 73345-010, DF, Brazil
 * Correspondence: humb@unb.br (H.A.); alexalmeida@unb.br (A.N.d.A.)

Abstract

The Brazilian non-coniferous sawnwood sector, despite producing 255.7 million m³ between 1995 and 2024 and ranking among the world's largest producers, remains predominantly oriented toward the domestic market. This study analyzes the sectoral panorama and the determinants of export demand using a time-series econometric approach. A log-log model was estimated by Ordinary Least Squares and corrected for serial autocorrelation using the Cochrane–Orcutt procedure. The results indicate that export demand is strongly influenced by external economic factors. World income showed a positive and highly significant elasticity (1.80), indicating that non-coniferous sawnwood is a superior good with demand highly sensitive to global economic growth. The price of coniferous sawnwood, a substitute product, presented a positive elasticity (0.27), while the world price of non-coniferous sawnwood showed a negative elasticity (−0.98), suggesting increased competition among exporters. Engineered wood prices exhibited a negative elasticity (−0.18), indicating limited influence on demand. The trend variable was negative and significant (−0.013), revealing a gradual decline in demand over time. Overall, export performance is highly dependent on world income and relative prices, while domestic production and regulatory constraints limit the sector's international competitiveness.

Keywords: econometrics; export; sawnwood; international market

1. Introduction

Forests have assumed a strategic role in the fight against climate change, especially due to their ability to act as important sinks of carbon [1,2]. In this context, wood and its derivatives contribute significantly to carbon sequestration and storage, showing high potential to support global climate neutrality goals by 2050 [2]. In addition to their environmental benefits, forest products play an essential role in economic development, particularly in tropical countries with a large natural resource base.

The international trade in tropical lumber faces increasing challenges, related to intensifying global competition, the need to ensure sustainable production and increasing demand for certified products. Illegal logging is one of the main obstacles to the sustainable development of the forestry sector, with environmental and economic implications [1]. In addition, studies also indicate that institutional factors, such as government corruption and poverty in producing countries, favor the expansion of these illicit practices.

In parallel, the increasing complexity of forest-based value chains and the diversifi-

Academic Editor: Stefano Grigolato

Received: 21 February 2026

Revised: 6 June 2026

Accepted: 13 June 2026

Published: 11 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article

distributed under the terms and

conditions of the [Creative Commons](https://creativecommons.org/licenses/by/4.0/)

[Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

cation of wood end-uses, including applications in sustainable construction (*Green Building*), expand the economic relevance of tropical lumber in international trade. Despite this, it is observed that, between 2001 and 2013, the global trade of primary tropical wood products showed a reduction of 13% in volume, accompanied by an approximate increase of 5% in value, evidencing structural changes in the international market [3].

In 2012, the United Nations Environment Programme and INTERPOL estimated that losses from the illegal timber trade ranged between US\$30 and US\$100 billion annually, corresponding to approximately 10% to 30% of global timber trade [3]. Although international regulations aimed at the legality of the forest trade have contributed to the reduction in the supply of timber of illicit origin, their effects remain limited, since not all global production is covered by these mechanisms, and exports may be redirected to markets with less regulatory rigor [3].

In Brazil, one of the largest exporters of tropical timber, the Forest Code establishes the rules for sustainable forest management and timber exploitation [4]. The export of sawn tropical timber requires licenses from IBAMA, the body responsible for monitoring and regulating and proof of legal origin. In addition, the Forest Products Marketing and Transportation System (SISFLORA) is used to track the production and trade of timber, ensuring the legality of the production chain. However, the country still faces significant challenges in combating illegal deforestation and in the effective implementation of these rules.

The export of forest products in Brazilian territory is regulated by several normative instructions and decrees. Law No. 11,284/2006, known as the Public Forest Management Law, establishes guidelines for the sustainable exploitation of public forests, including timber production and marketing [5]. IBAMA Instruction No. 21/2014 established the National System for Controlling the Origin of Forest Products (Sinaflor) to control the origin of wood, charcoal, and other forest products and byproducts, integrating data from different federative entities [6]. In addition, it establishes procedures for controlling the movement of these products and the requirements for issuing the Forest Origin Document (DOF), which is mandatory for their transportation.

Complementing these regulations, IBAMA Instruction No. 08/2022 provides for specific procedures for the export of forest products and byproducts, including logs and sawnwood above 250 mm [7]. Ministry of Agriculture and Livestock (MAPA) Ordinance No. 514/2022 establishes procedures for phytosanitary inspection and certification of packaging, supports, or pieces of raw wood used in the manufacture of packaging and supports that contain goods imported or exported by Brazil [8].

It is essential that exporting companies are aware of these regulations to avoid problems and ensure the legality of their products. To export tropical sawnwood from Brazil, companies need to obtain a series of documents, including the Forest Origin Document (DOF), which proves the legal origin of the wood; the phytosanitary certificate, which attests that the wood is free of pests and diseases; the export invoice, a tax document that accompanies the goods; the bill of lading, proof that the wood has been shipped; and the commercial invoice, a document that describes the goods and their value.

The Brazilian tropical sawnwood trade faces challenges such as international competition, the need to ensure the sustainability of production, and the growing demand for certified products. Compliance with regulations is essential to ensure the legality and competitiveness of the sector in the global market.

Compliance with environmental and regulatory standards has become a fundamental condition for maintaining competitiveness in the international market. In this sense, Brazil has been a member of the International Tropical Timber Agreement since 1994, an

instrument aimed at promoting the trade of wood from sustainably and legally managed forests, reinforcing commitments to environmental conservation and responsible business practices [9].

In addition to national legislation, Brazil is a signatory to international agreements such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and follows the guidelines of the World Trade Organization (WTO). Recently, IBAMA Instruction No. 28/2024 determined that all sawnwood, plywood, laminates, and processed wood, originating from species listed in Appendix B of CITES, intended for export, must be accompanied by a CITES Export License [10].

Internationally, CITES plays a crucial role, as it regulates the trade of endangered timber species, such as *Swietenia macrophylla* (mahogany), listed in Appendix B of the convention [11]. This means that the export of these species requires specific licenses and proof of legal and sustainable origin. In addition to promoting cooperation between countries to monitor and control timber trade, it contributes to the conservation of tropical forests.

International trade is not an exogenous factor to the forestry sector, being influenced by elements such as income, trade agreements, demand patterns and domestic productive capacity [12]. In recent years, the performance and competitiveness of the sector have also been affected by the volatility of the prices of essential inputs, such as fertilizers and fuels, as well as by logistical restrictions in the maritime and air modes, which increase transaction costs and make it difficult to flow production [13]. Added to this is the impact of exchange rate variations and inflationary processes, especially in the post-pandemic context, which intensified economic uncertainties and required the adoption of adaptive strategies by agents in the sector.

In view of the complexity of the institutional, economic and logistical environment that characterizes the Brazilian forestry sector, it is necessary to carry out an in-depth analysis of the dynamics that condition the performance of sawnwood exports. Thus, this study aims to identify the main determinants of demand of Brazilian sawnwood exports and quantify their respective elasticities in order to evaluate the responsiveness of international markets to economic variations and characterize the export dynamics of the sector.

2. Overview of Non-Coniferous Sawnwood Sector

The global market for sawnwood of non-coniferous (hardwood) species is characterized by a high concentration of production and trade flows dictated by large continental economies. Between 1995 and 2024, accumulated world production reached approximately 3.91 billion m³, with more than 50% of this volume concentrated in just three countries: Mainland China (17.82%), the United States (17.69%), and India (16.94%), as shown in Table 1. This scenario reflects the availability of forest resources and the consolidation of industrial parks focused on the primary processing of wood to meet domestic and external demands.

Table 1. Ranking of the main non-coniferous sawnwood-producing countries and their shares in the world market (1995–2024) [14].

		Production		
	Country	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
1	Mainland China	698,318.00	17.82	17.82
2	United States of America	693,031.68	17.69	35.51

		Production		
	Country	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
3	India	663,633.00	16.94	52.45
4	Brazil	255,753.00	6.53	58.97
5	Indonesia	137,833.87	3.52	62.49
6	Malaysia	131,579.93	3.36	65.85
7	Vietnam	119,261.70	3.04	68.89
8	Russian Federation	82,396.64	2.10	71.00
9	Thailand	77,319.00	1.97	72.97
10	Turkey	74,893.20	1.91	74.88
	World	3,918,193.63	100.00	100.00

Note: P.R. = relative participation; P.C. = accumulated participation; authors' calculations.

In this context, Brazil stands out as the fourth largest producer of non-coniferous sawnwood in the world, accounting for 6.53% of global production, equivalent to approximately 255 million m³ in the period analyzed (Table 1). The country has high forest productivity and an expanding domestic market, factors that contribute to the competitiveness of the national forestry sector. In recent decades, forestry activity has consolidated itself as a strategic segment of the Brazilian economy, characterized by production processes oriented towards sustainability and the transfer of wealth to other economic sectors [15].

The trajectory of Brazilian production has undergone important transformations over time. According to Perez and Bacha (2006), until the 1970s, production was concentrated in the South region, based mainly on coniferous species, especially the *Araucaria* [15]. Starting in the 1980s, there was a migration of the industry to the North region, driven by the exploitation of native broadleaf species. In the early 1990s, there was a slowdown in production in the North, in parallel with the resumption of reforestation in the South and Southeast regions. From the 2000s onwards, the production of non-coniferous sawnwood began to grow again, configuring a bipolarized production structure.

In international trade, Brazil presents a dynamic distinct from that observed in other major tropical producers. As shown in Table 2, the country occupies the sixth position among the world's largest exporters, participating with 3.99% of global exports of non-coniferous sawnwood. However, only 10.2% of national production was destined for the external market during the period analyzed. In contrast, countries such as Thailand and Malaysia have export coefficients exceeding 50%, with relative shares of 9.91% and 10.94%, respectively, acting as important suppliers to the Asian market.

Table 2. Ranking of the main exporting countries of non-coniferous sawnwood and their shares in the world market (1995–2024) [14].

		Export		
	Country	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
1	United States of America	94,758.60	14.51	14.51
2	Malaysia	71,410.60	10.94	25.45
3	Thailand	64,721.78	9.91	35.36

Export				
	Country	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
4	Indonesia	29,284.80	4.48	39.84
5	Russian Federation	26,407.46	4.04	43.89
6	Brazil	26,082.71	3.99	47.88
7	Canada	23,492.15	3.60	51.48
8	Cameroon	19,843.30	3.04	54.52
9	Germany	19,292.83	2.95	57.47
10	Croatia	18,837.85	2.88	60.36
	World	652,971.66	100.00	100.00

Note: P.R. = relative participation; P.C. = accumulated participation; authors' calculations.

Historically, until the early 1990s, Brazilian production was primarily directed towards the domestic market. However, from 1992 onwards, increased production enabled the formation of exportable surpluses, expanding the country's insertion into international trade [15]. Data from the Food and Agriculture Organization of the United Nations (FAO) indicate that, between 1990 and 2008, there was significant growth in Brazilian exports of sawnwood, driven mainly by gains in external competitiveness [15]. However, after 2007, a contraction in exports from the sector was observed.

On the import side, Brazil has a reduced share of the international market, corresponding to only 0.52% of world imports and occupying the 32nd position among the largest importers, as shown in Table 3. This pattern highlights the predominance of the domestic market as the main destination for national production and the limited integration of the Brazilian sector into global value chains when compared to other producing economies.

Table 3. Ranking of the main importing countries of non-coniferous sawnwood and their shares in the world market (1995–2024) [14].

Import				
	Country	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
1	Mainland China	182,220.88	27.12	27.12
2	Italy	35,640.58	5.30	32.42
3	United States of America	32,395.09	4.82	37.24
4	Thailand	27,559.30	4.10	41.34
5	Canada	26,959.58	4.01	45.35
6	Vietnam	21,494.18	3.20	48.55
7	Germany	16,816.55	2.50	51.05
8	Japan	16,735.58	2.49	53.54
9	United Kingdom of Great Britain and Northern Ireland	16,305.02	2.43	55.97
10	Spain	16,215.36	2.41	58.38
32	Brazil	3484.14	0.52	86.65

Country	Import		
	QUANTUM (1000 m ³)	P.R. (%)	P.C. (%)
World	672,017.54	100.00	100.00

Note: P.R. = relative participation; P.C. = accumulated participation; authors' calculations.

Analysis of the historical series reveals a watershed moment in the national trajectory. Until 2007, Brazilian production remained at robust levels, exceeding 14 million m³ annually, as observed in Figure 1. From 2008 onwards, a sharp and structural decline in production is observed, which stabilized at significantly lower levels in the last decade. According to Silva and Maciel (2022), the period between 2007 and 2009 corresponds to the only time when national and global production volumes showed similar behavior, reflecting the effects of the international financial crisis on the sector [15,16].

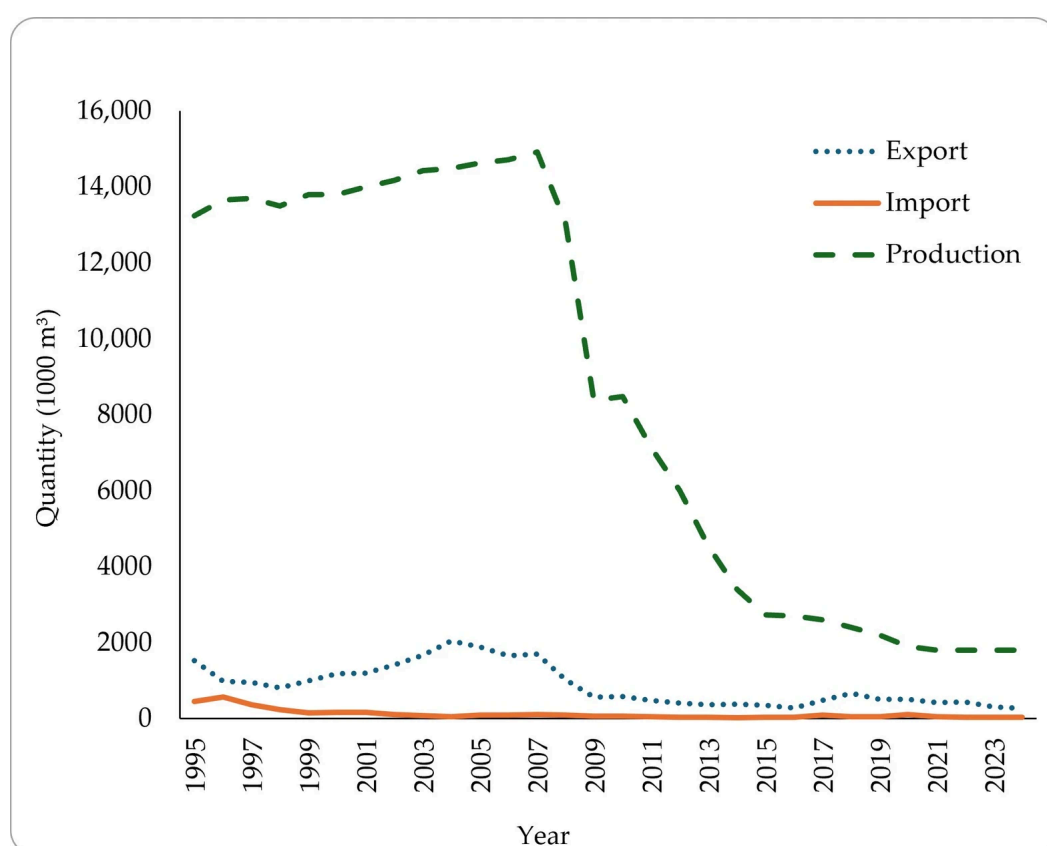


Figure 1. Temporal dynamics of the productive and commercial performance of non-coniferous sawnwood in Brazil (1995–2024).

Outside of this period, the trajectories proved to be distinct: in Brazil, production maintained a growth trend until 2007, followed by a period of contraction that extended until 2013. In contrast, world production showed a decreasing trend until 2003, registered a moderate recovery between 2003 and 2007, remained relatively stagnant until 2009, and then resumed continuous growth until 2013 [16]. Thus, the convergence observed between 2007 and 2009 constitutes an exception within a historical context marked by differentiated production dynamics between Brazil and the rest of the world.

As evidenced in Figure 1, regardless of the variations observed in production, the export and import curves remained relatively low and constant throughout the historical series. This behavior reinforces the strong link between the non-coniferous sawnwood sector and the domestic market, which absorbs approximately 90% of national produc-

tion and sustains segments such as civil construction, infrastructure, and the furniture industry.

In addition to the effects of the global economic crisis, the Brazilian sector faces structural limitations that affect its competitiveness, including deficiencies in logistics infrastructure, difficulty accessing forestry funding lines, regulatory bureaucracy, high interest rates, and a high tax burden [15,16]. Additionally, researchers highlight limitations related to productive modernization, the insufficiency of forest plantations in the South and Southeast regions, and the environmental impacts associated with predatory exploitation in the Amazon [17]. The increasing use of substitute materials, such as reconstituted wood panels, glass, steel, aluminum, and polyvinyl (used in the manufacture of PVC linings), has also increased competition in the market and imposed additional challenges to the expansion of the national sawnwood industry [15,16].

Internationally, Petrauski et al. (2012) identified Canada as the world's leading exporter of sawnwood between 2000 and 2007, benefiting from better technological and infrastructure conditions [15]. According to the study that assessed the competitiveness of Brazil and the main world exporters in the period from 1990 to 2020, Canada showed the highest level of competitiveness in the international trade of sawnwood, followed by Sweden, Finland, Russia, and Brazil [15]. Although the country has not reached the levels observed in the sector leaders, there has been positive evolution in average indicators and annual growth rates, demonstrating the gradual strengthening of Brazilian competitiveness in recent decades.

When analyzing the relationship between exports and production, it is observed that Brazil performs better than the world average, showing a relatively higher export orientation. While the share of Brazilian exports ranged from 4% to 14% of production, the world average ranged from 2% to 9% [16]. In short, the non-coniferous sawnwood sector is characterized by a solid production base in countries with tropical and temperate climates, where Brazil remains a strategic player, presenting a predominantly export-oriented profile and a low volume of imports [18].

3. Materials and Methods

3.1. Material

Sawnwood is defined as the solid product resulting from the longitudinal conversion of logs or bolts from broadleaved species (angiosperms), carried out through sawing processes or mechanized profiling, with a thickness greater than 6 mm [6,19]. This processing yields pieces with predominantly rectangular or square cross-sections, including, among others, boards, planks, beams, rafters, battens, and sleepers. The material may be marketed in rough (unplaned) or processed (planed) forms, with its classification established based on dimensional and finishing criteria. Excluded from this definition are wooden flooring, pieces with continuous profiles along their edges or faces, and wood obtained through the reprocessing of previously sawn pieces.

In the context of the International Tropical Timber Agreement, tropical timber is defined as all non-coniferous wood intended for industrial uses, originating from species that grow in countries located within the intertropical zone, between the Tropics of Cancer and Capricorn. This definition encompasses various forest products, including logs, sawnwood, veneers, and plywood panels [19].

For the purposes of this study, the analyzed product corresponds to non-coniferous sawnwood, classified in the database of the Food and Agriculture Organization of the United Nations (FAO) under item code 1633. Within this item code, all products listed in Table 4 are included, according to the categories and codes of the Harmonized System (HS), covering sawnwood of both tropical and non-tropical origin, differentiated by

species and degree of processing.

Table 4. Classification of non-coniferous sawnwood (item code 1633).

Category	HS Code	Description
44.06		Railway or tramway sleepers (cross-ties) of wood
		Not impregnated:
		Non-coniferous
		Other:
	4406.12	Non-coniferous
	4406.92	Non-coniferous
44.07		Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-jointed, of a thickness exceeding 6 mm.
		Of tropical wood:
		4407.21 Mahogany (<i>Swietenia</i> spp.)
		4407.22 Virola, Imbuia and Balsa
		4407.23 Teak
		4407.25 Dark Red Meranti, Light Red Meranti and Meranti Bakau
		4407.26 White Lauan, White Meranti, White Seraya, Yellow Meranti and Alan
		Other:
		4407.27 Of tropical wood: Sapelli
		4407.28 Of tropical wood: Iroko
		4407.29 Of tropical wood: Other
		4407.91 Of oak (<i>Quercus</i> spp.)
		4407.92 Of beech (<i>Fagus</i> spp.)
		4407.93 Of maple (<i>Acer</i> spp.)
		4407.94 Of cherry (<i>Prunus</i> spp.)
		4407.95 Of ash (<i>Fraxinus</i> spp.)
		4407.96 Of birch (<i>Betula</i> spp.)
		4407.97 Of poplar and aspen (<i>Populus</i> spp.)
		4407.99 Other

3.2. Formulation of the Model and Definition of Variables

The demand for Brazilian exports of non-coniferous sawnwood r is analyzed through an econometric model capable of capturing the relationship between the *exported quantum* and its main economic determinants. The proposed demand model is given by the following [2]:

$$\ln Q_t^D = \beta_0 + \beta_1 \ln PX_t^D + \beta_2 \ln PS_t + \beta_3 \ln PS_{s_t} + \beta_4 \ln PW_t + \beta_5 \ln YW + \beta_6 T + \varepsilon_t$$

where:

Q_t^d = the *quantum* demanded of Brazilian exports of non-coniferous sawnwood; PX^D = the FOB price of Brazilian exports of non-coniferous sawnwood; PS = the FOB price of the substitute product of coniferous sawnwood; PSs = the FOB price of the substitute product for engineered woods (plywood and veneered laminated timber—LVL); PW = the international FOB price of non-coniferous sawnwood; YW = a *proxy* of the global income of countries importing non-coniferous sawnwood; T = trend; ε_2 = stochastic term.

According to the fundamental law of demand, it is postulated that the FOB price of Brazilian exports of non-coniferous sawnwood (PX^D) presents an inverse relationship, i.e., has a negative sign ($\beta_1 < 0$). This implies that an increase in PX^D will result in a reduction in the quantity demanded (X) [20,21].

Regarding the prices of substitute products—coniferous sawnwood (PS) and engineered wood (PSs)—it is not possible to establish, a priori, the expected sign of the respective coefficients, since they can behave both as a substitute and a complementary good on the international market [21,22]. Still, this relationship indicates that an increase in PS and/or PSs tends to stimulate the displacement of consumer and importer demand towards Brazilian non-coniferous sawnwood, which becomes more competitive in relative terms [21,22].

The international FOB price of non-coniferous sawnwood (PW) is expected to be positive ($\beta_4 > 0$), indicating that an increase in the PW tends to raise the *quantum* demand for Brazilian exports (X), either by making the Brazilian product more competitive or by reflecting a strengthened global demand [21].

For the income of importing countries (YW), a positive relationship ($\beta_5 > 0$) is presumed, since the growth of the YW typically drives demand for forest products, which is a demand derived from final goods such as housing and manufactures [23].

It is not possible to establish, a priori, the expected signal of the trend variable (T), since it aims to capture structural shifts in the demand curve and the aggregate effects of unobservable factors over time [21]. The variable was operationalized in a linear manner, being defined as $T_{1995} = 1$, $T_{1996} = 2$, ..., $Q_{2024} = 30$.

3.3. Model Estimation and Evaluation

Econometric analysis has become an essential tool in modern economics for evaluating the short-run responses of economic systems to changes in market conditions and other external factors [17]. In the forestry sector, where quantitative studies on timber supply and demand remain relatively scarce and the behavior of market agents is not yet fully understood, econometric modeling provides an important framework for identifying the determinants of market dynamics and quantifying the relationships among economic variables [17].

The log-log functional specification was adopted, in which the estimated coefficients correspond directly to the elasticities of the dependent variable in relation to the explanatory variables [24,25]. This specification allows for direct interpretation of parameters and is suitable for modeling potentially nonlinear relationships, which become linear in parameters after logarithmic transformation [25,26].

The estimation of the parameters was performed using the Ordinary Least Squares (OLS) method, as it is the classic procedure for estimating linear models when the explanatory variables are considered exogenous to the system of equations, i.e., when there is no simultaneity between the determinants and the dependent variable, so that the covariates can be treated as coming “from outside the system” [24,25,27]. Under these con-

ditions, the MQO provides unbiased, consistent and efficient estimators, in addition to allowing for statistical inference based on the sample distribution of the estimators.

As a subsequent stage of the analysis, the classic hypotheses of the linear model were verified, including the absence of serial autocorrelation in the residuals. If the presence of first-order temporal dependence is identified, the Cochrane–Orcutt iterative procedure will be adopted, which assumes an autoregressive AR(1) structure, adapting the original equation, allowing for the re-estimation of the parameters in a manner consistent with the new stochastic structure [28]. This procedure aims to ensure greater efficiency of the estimators and validity of the hypothesis tests.

The statistical adequacy of the model was based on the F test and the t test to verify the hypotheses of nullity of the coefficients, the coefficient of determination (R^2) to measure the degree of fit of the model, and the d Durbin–Watson test for the detection of serial autocorrelation of residuals [29].

3.4. Database and Data Source

This study uses annual time series referring to the period from 1995 to 2024, adopted from the Brazilian economic stabilization framework following the implementation of the Real Plan in 1994. The information was obtained from the Food and Agriculture Organization of the United Nations (FAO) and the Institute of Applied Economic Research (IPEA) for the following variables:

- **Brazilian export quantity of non-coniferous sawnwood (X):** the *quantum* exported annually in cubic meters (m^3) [14].
- **Value of Brazilian exports of non-coniferous sawnwood (V):** the FOB price in US dollars converted to reais at the annual exchange rate (TC) [14].
- **FOB price of Brazilian non-coniferous sawnwood (PX):** the ratio between V and X, deflated by the Extended Producer Price Index (IPA) [14].
- **Brazilian exported quantity of coniferous sawnwood (XS):** the *quantum* exported annually of the substitute product, in cubic meters (m^3) [14].
- **Value of Brazilian exports of coniferous sawnwood (VS):** the FOB price in dollars converted to reais at the annual exchange rate (TC) [14].
- **FOB price of coniferous sawnwood (PS):** the ratio between VS and XS, deflated by IPA [14].
- **Brazilian exported quantity of engineered sawnwood (XSs):** the *quantum* exported annually of the substitute product, in cubic meters (m^3) [14].
- **Value of Brazilian exports of engineered sawnwood (VSs):** the FOB price in dollars converted to reais at the annual exchange rate (TC) [14].
- **FOB Engineered Wood Price (PSs):** the ratio between VSs and XSs, deflated by the IPA [14].
- **World quantity of non-coniferous sawnwood (XW):** the *quantum* exported globally, excluding Brazilian exports, in cubic meters (m^3) [14].
- **Value of world exports of non-coniferous sawnwood (VW):** the total value exported worldwide, excluding Brazil, converted to reais at the annual exchange rate (TC) [14].
- **FOB world price of non-coniferous sawnwood (PW):** the ratio between VW and XW, deflated by IPA [14].
- **World income (YW):** the *Proxy* of the income of importing countries, represented by the value of world imports of non-coniferous sawnwood, converted to reais by the annual exchange rate (TC) and deflated by the IPA [14].
- **Extended Producer Price Index—Domestic Availability (IPA):** the index used to deflate all nominal currency series [30].

- **Annual exchange rate (TC):** the average annual commercial sales rate, used to convert values in dollars to reais [30].

The annual exchange rate (TC), combined with domestic and international price indices, reflects the relative competitiveness of Brazilian exports in the global market, incorporating variations in domestic and foreign price levels, fluctuations in the currencies of Brazil's main trading partners against the U.S. dollar, and changes in the Brazilian exchange rate. In this context, the competitiveness of Brazilian tropical timber exports has historically been influenced by the appreciation of competitors' currencies relative to the U.S. dollar, as well as by the slower growth of Brazilian wholesale prices, measured in dollars, compared with those observed in the United States [31]. These factors affect the relative prices faced by international buyers and, consequently, the demand for Brazilian wood products.

To avoid duplication of data in the analysis and to ensure the correct representation of the impact of the international market, it is crucial to emphasize that the independent variables XW (World Quantity of Non-coniferous Sawnwood), VW (Value of World Exports of Non-coniferous Sawnwood) and, consequently, PW (FOB Price of World Exports of Non-coniferous Sawnwood), were constructed in order to exclude the respective values referring to the Brazilian exports. This approach ensures that the model captures the influence of the global market without contaminating the data already represented by the Brazilian variables (X , V and PX), allowing for a more accurate analysis of demand dynamics.

4. Results of Demand for Export

The results of the estimation of the demand model for exports of non-coniferous sawnwood indicate a good global fit of the regressions, as shown in Table 5. In the model estimated by Ordinary Least Squares (OQ), the adjusted coefficient of determination (adjusted R^2) was 0.86, showing that approximately 86% of the variation in the quantity demanded is explained by the variables included in the model. The F statistic confirms the overall significance of the regression ($F = 30.48$; $p < 0.01$). However, the Durbin–Watson test ($d = 1.01$) indicates the presence of positive autocorrelation in the residuals.

Table 5. Measures of adjustment and econometric validation of demand models.

	R^2 Adjusted	F	d
MQO	0.8591	30.4758	1.0069
CO	0.7543	13.2801	1.8840

Note: MQO = Ordinary least squares; CO = Cochrane–Orcutt; F = Snedecor's F test; d = Durbin–Watson test.

In view of this diagnosis, five interactions of the Cochrane–Orcutt method were applied, obtaining a d value close to 2 ($d = 1.88$), indicating the correction of serial dependence. After correction, the model maintained high explanatory power, with an adjusted R^2 of 0.75, and remained globally significant ($F = 13.28$; $p < 0.01$), ensuring the statistical consistency of the estimates.

Table 6 presents the estimated elasticities for the demand model. In the corrected model, it is observed that the FOB price of Brazilian non-coniferous sawnwood (PX^D) presented a negative and statistically significant coefficient at 10% (−0.52), in accordance with the demand theory. This result indicates that an increase of 1% in the price of the Brazilian product reduces, on average, the quantity demanded by approximately 0.52%, characterizing a relatively inelastic demand to the price.

Table 6. Export demand elasticities for non-coniferous sawnwood.

		Constant	PX^D	PS	PSs	PW	YW	T
MQO	Elasticity	−26.5630	−1.1953	−0.0559	−0.7395	−1.5022	2.6754	−0.0792
	T	−3.8321	−3.4684	−0.1704	−2.5275	−1.8099	5.9455 *	−7.5141
		*	*	ns	**	***		*
CO	Elasticity	−2.5679	−0.5196	0.2662	−0.1833	−0.9758	1.8020	−0.0128
	T	−2.8250	−1.9641	1.9372	−1.5107	−2.4710	5.5856 *	−3.6780
		*	***	***	ns	**		*

Note: * = significant at 1% probability; ** = significant at 5% probability; *** = significant at 10% probability; ns = not significant; PX^D = FOB price of non-coniferous sawnwood; PS = FOB price of coniferous sawnwood (substitute); PSs = FOB price of engineered wood (substitute); PW = world-wide FOB price of non-coniferous sawnwood; YW = world income; T = trend.

Regarding the prices of substitute products, coniferous sawnwood (PS) presented a positive and significant coefficient of 10% (0.27), suggesting a substitution relationship between the products. Thus, increases in the price of coniferous wood tend to shift demand towards Brazilian non-coniferous wood.

In turn, the price of engineered wood (PSs) showed a negative sign (−0.18), diverging from the initial expectation, indicating that this segment does not have a systematic influence on demand in the period analyzed. This result suggests that these products may have played a role closer to that of complementary goods than substitutes.

The world price of non-coniferous sawnwood (PW) showed a negative and significant elasticity at 5% (−0.98), contrary to the theoretical expectation of a positive sign. This result indicates that increases in international prices may be associated with the retraction of demand for the Brazilian product, possibly due to the intensification of competition between exporters, the search for alternative suppliers or the substitution by competing materials.

World income (YW) presented a positive coefficient, as predicted, and statistically significant at 1% (1.80), evidencing high income elasticity of demand. This result indicates that the growth of global economic activity exerts a strong influence on Brazilian exports, characterizing the product as a superior good and highly sensitive to the income level of importing countries.

The trend variable (T) presented a negative and significant coefficient at 1% (−0.013), suggesting the existence of a slight downward shift in demand over the period analyzed. This behavior may be associated with structural changes in the international market, such as technological substitution, changes in consumption patterns, or intensified competition.

5. Discussion

Prior to the discussion of the estimated elasticities, it should be noted that the results obtained are empirical in nature, being conditioned to the specification adopted, the quality of the data and the sample period considered. Each coefficient was estimated within the scope of the econometric model under the hypothesis of *ceteris paribus*, that is, assuming that the other variables are constant [32].

However, it is recognized that, in real contexts, this condition is hardly fully verified, since economic variables tend to interact simultaneously [32]. Thus, interpretation of the estimated parameters must be conducted with analytical prudence, understanding that the identified effects represent variations in the structure of the model and not necessarily isolated causal relationships in a dynamic environment.

The sharp drop in production observed from 2008 onwards, as evidenced in the historical series, shown in Figure 1, reflects a structural change that transcends purely economic variables. This decline can be attributed to restrictions in the supply of raw materials and the tightening of regulatory frameworks aimed at combating predatory and illegal exploitation in the Amazon. Although the region has a considerable timber resource, forest management activity still faces the challenge of unknown average production estimates at the species level and the concentration of exploitation in small areas [33]. In addition, environmental pressure and the rise of substitute products—such as reconstituted panels, glass, steel and aluminum—impose increasing risks to the sustainability of this market [32].

On the demand side, the results show that international consumption is fundamentally driven by external factors. The price elasticity of Brazilian exports (PX^D) presented the expected negative sign (-0.52 , $p < 0.10$) in the adjusted model, suggesting that the international demand for the Brazilian product is inelastic in relation to the FOB price, i.e., variations in the price do not generate drastic reductions in the volume demanded in the short term [24,32,34].

In addition, the positive coefficient of the price of coniferous sawnwood (0.26), statistically significant at the level of 10% probability, confirms that the product acts as a substitute good [24,35]. Thus, increases in the price of the substitute in the international market lead consumers to shift part of the demand to Brazilian non-coniferous wood. Therefore, it is observed that there is competition with coniferous wood in the global market, although the substitutability of non-coniferous wood is difficult to explain technically when considered only from the point of view of its physical characteristics [34,36].

This behavior is consistent with the interpretation of Ângelo (1998), according to which the demand for exports of Brazilian wood products does not result exclusively from the surplus of domestic production, but has its own characteristics in the international market [22]. According to the author, these products are not considered perfect substitutes for the goods offered by importing countries, being configured as imperfect substitutes. This condition is mainly due to differences in quality, technical standards, as well as different regulatory procedures, commercial legislation and customs requirements. These institutional and structural factors contribute to limiting the degree of substitutability between products, reinforcing the segmented nature of the demand for Brazilian non-coniferous wood in international trade.

In contrast to the behavior observed for coniferous sawnwood, the coefficient associated with the price of engineered wood (PSs) presented a negative (-0.18) and non-significant sign, indicating the absence of systematic influence on demand in the period analyzed. Considering that these products were selected because they represent, in certain segments of use, close substitutes for non-coniferous sawnwood—because they are part of the same production chain and perform similar functions—this result suggests that, in practice, the relationship between these goods can assume a complementary nature in which engineered wood does not fully replace non-coniferous sawnwood, but complements it in technical and structural applications.

World price elasticity showed a negative sign (-0.97) and statistical significance at 5% probability. The opposite signal to what is theoretically expected may indicate that the *quantum* demanded in Brazil responds specifically to niche markets or long-term contracts that do not linearly follow the average of world hardwood prices.

World income (YW) had the greatest impact (1.80), a significant variable also at 1% probability in the study by Calderon and Ângelo [32]. A 10% increase in the income of importing countries generates an expansion of approximately 18% in the demand for

Brazilian exports, reinforcing the sector's dependence on global economic growth. The product is characterized as a superior good, the same found for Brazilian plywood by Alexandre Brasil [34], and income-elastic, where the economic growth of importing countries directly boosts Brazilian exports [32,37].

The international demand for sawnwood is more sensitive to global economic conditions than to Brazil's internal factors, being strongly influenced by the GDP of importing countries, while the GDP of the exporter has less impact [38]. This behavior confirms the predominance of the theory of structural gravity in the trade of the product. In this context, after reaching record levels in 2021 and showing a retraction in the following two years, production stabilized in 2024, in a scenario of low supply flexibility, which reinforces the need for advances in forest governance and the transparency of production chains to ensure the sustainability and continuity of the sector [39].

6. Conclusions

Between 1995 and 2024, the Brazilian non-coniferous sawnwood sector consolidated itself as an activity predominantly focused on the domestic market, although it maintains relevance in the context of world production. In parallel, the international trade of this product is embedded in a complex regulatory framework composed of international norms, multilateral agreements, and national legislation, aimed at guaranteeing the legality of the timber, environmental sustainability, and the conservation of forest ecosystems. This set of instruments plays a fundamental role in combating illegal deforestation and the commercialization of forest products of unproven origin, directly influencing the dynamics and competitiveness of the export sector.

The structural models estimated for the export demand of non-coniferous sawnwood showed satisfactory explanatory capacity, demonstrating econometric consistency and adherence to the theoretical foundations that guide the analysis of international trade. In general, the selected variables proved relevant for understanding the behavior of demand in the external market, even though some coefficients presented statistical limitations after the autocorrelation correction procedures.

The price elasticity of demand showed a negative sign and reduced magnitude, characterizing inelastic behavior. This result indicates that variations in the FOB price of Brazilian sawnwood tend to cause proportionally smaller reductions in the volume demanded, allowing price increases to be accompanied by an increase in export revenue, even in the face of contractions in the quantities traded.

The results show that international demand for Brazilian non-coniferous sawnwood is strongly conditioned by the level of world income and relative prices, especially the price of the product itself and the price of coniferous wood. The significance and magnitude of the estimated coefficients reinforce the importance of external factors in determining the sector's export performance, demonstrating a high sensitivity of demand to international macroeconomic conditions.

Finally, the findings confirm the heterogeneity of consumption patterns in different importing markets and the complexity of the existing substitution relationships in the timber sector. These results highlight the need for commercial and production strategies capable of simultaneously responding to global economic fluctuations and the increasing regulatory demands related to the legality, traceability, and sustainability of internationally traded forest products.

Author Contributions: J.d.O.C., H.A. and A.N.d.A.; methodology: J.d.O.C. and H.A.; software: J.d.O.C.; validation: J.d.O.C. and H.A.; formal analysis: J.d.O.C.; investigation: J.d.O.C.; resources: J.d.O.C. and A.N.d.A.; data curation: J.d.O.C.; writing—preparation of the original draft: J.d.O.C.; writing—revision and editing: H.A., A.N.d.A., E.A.T.M., E.B.A.V. and L.d.C.S.; visualization:

J.d.O.C.; supervision: H.A.; project management: J.d.O.C. and H.A.; funding acquisition: H.A., A.N.d.A. and E.A.T.M. All authors have read and agreed to the published version of the manuscript.

Funding: The lead author received funding from the Coordination for the Improvement of Higher Education Personnel—CAPES, grant number 88887.164271/2025-00.

Data Availability Statement: The data are available in a publicly accessible repository, specifically the FAO Statistical Database and Ipeadata.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Export demand database.

Year	IPA	TC	X (m ³)	V (1000 USD)	XS (m ³)	VS (1000 USD)	XW (m ³)	VW (1000 USD)	YW (1000 USD)
1995	111.92	0.92	1,526,000	384,845	402,000	133,324	15,820,296	6,391,435	8,694,505
1996	119.00	1.01	975,000	238,383	474,000	106,363	15,443,319	6,191,170	7,699,063
1997	128.67	1.08	953,000	265,398	634,000	145,602	15,355,993	6,037,224	8,299,365
1998	133.26	1.16	806,000	249,322	783,000	160,588	14,681,521	5,209,975	6,536,991
1999	155.33	1.81	999,000	273,427	1,175,000	223,981	17,407,014	5,897,759	7,177,876
2000	183.47	1.83	1,188,000	277,525	1,276,000	212,669	19,630,069	6,512,293	8,018,776
2001	206.59	2.35	1,192,000	283,449	1,328,000	228,714	19,901,501	6,328,856	7,458,166
2002	241.01	2.92	1,416,000	321,854	1,499,000	227,087	21,635,221	6,527,422	7,498,593
2003	307.43	3.08	1,674,000	390,885	1,700,176	254,999	22,546,959	7,157,028	8,065,960
2004	339.58	2.93	2,038,000	541,619	1,619,000	294,748	24,270,316	8,475,184	9,528,178
2005	358.49	2.44	1,887,000	578,846	1,761,365	303,866	22,102,933	8,188,320	9,652,826
2006	361.39	2.18	1,662,000	571,000	1,505,000	275,314	21,021,482	8,543,615	9,949,203
2007	381.62	1.95	1,699,000	667,612	1,468,000	254,888	20,731,661	8,948,054	11,145,011
2008	433.93	1.83	1,031,000	476,904	1,090,000	202,645	18,955,890	8,795,984	9,967,975
2009	433.03	2.00	570,700	257,333	823,437	141,589	15,421,475	6,483,658	7,210,728
2010	457.80	1.76	578,000	264,042	690,000	153,870	18,828,059	7,910,514	8,866,195
2011	501.04	1.67	486,679	238,215	741,000	169,689	19,678,348	8,799,076	9,978,946
2012	530.54	1.95	408,743	193,813	719,000	157,461	19,453,114	8,720,968	9,640,735
2013	561.98	2.16	364,349	184,691	746,000	168,596	19,908,738	9,879,910	10,202,371
2014	587.44	2.35	376,093	194,016	993,000	230,376	22,473,303	11,369,820	12,056,381
2015	623.15	3.33	354,930	166,488	1,304,000	288,184	23,182,798	10,851,699	11,276,021
2016	694.49	3.49	284,297	175,994	1,812,821	361,193	24,113,424	10,834,371	11,064,801
2017	689.34	3.19	481,000	323,232	2,282,044	463,911	26,978,382	11,836,533	12,550,791
2018	737.15	3.65	664,000	373,832	3,078,043	549,556	26,110,278	12,002,029	13,202,551
2019	788.73	3.95	512,791	208,469	2,790,920	349,412	24,325,976	10,315,087	11,674,401
2020	930.42	5.16	512,791	168,182	2,219,096	481,076	22,538,609	9,303,382	10,353,781
2021	1,259.93	5.40	428,938	166,600	3,432,616	778,646	24,755,967	11,091,632	11,841,571
2022	1,396.51	5.16	438,185	203,895	2,726,663	817,637	24,775,529	11,587,649	12,846,561
2023	1,305.26	4.99	301,196	153,762	2,542,305	611,668	22,532,906	9,921,992	10,530,001
2024	1,316.43	5.39	274,017	120,949	2,242,053	643,576	22,313,005	10,020,121	10,460,881

Appendix B

Equation (A1). Dollar (USD) to Real (R\$) Conversion.

$$V_t^{R\$} = V_t^{USD} \times TC_t \quad (A1)$$

Equation (A2). FOB price with deflation of monetary variables.

$$P_t^{real} = \frac{\frac{V_t^{R\$}}{X_t}}{IPA_t} \times 100 \quad (A2)$$

Equation (A3). Quantity World.

$$XW_t = XW_t^{gloal} - X_t^{Brazil} \quad (A3)$$

Equation (A4). Quantity World.

$$VW_t = VW_t^{gloal} - V_t^{Brazil} \quad (A4)$$

References

- Kim, D.H.; Ahn, B.I.; Shim, G. Analyzing the Impact of EU's Legality Requirements Policies on Sustainable Timber and Sawnwood Trade—Focusing on Tropical Wood Trade. *Forests* **2024**, *15*, 1879. [Google Scholar] [CrossRef]
- Hu, J.; Jåstad, E.O.; Bolkesjø, T.F.; Rørstad, P.K. The Quantification and Tracing of Leakage in the Forest Sector in Nordic Countries. *Forests* **2024**, *15*, 254. [Google Scholar] [CrossRef]
- Masiero, M.; Pettenella, D.; Cerutti, P.O. Legality Constraints: The Emergence of a Dual Market for Tropical Timber Products? *Forests* **2015**, *6*, 3452–3482. [Google Scholar] [CrossRef]
- Brasil, P.d.R. *Lei N° 12.651, de 25 de Maio de 2012*; 2012. Available online: <https://ninho.inca.gov.br/jspui/bitstream/123456789/13541/1/LEI%20N%C2%BA%209.294%20DE%2015%20DE%20JULHO%20DE%201996.pdf> (accessed on 13 July 2025). [Google Scholar]
- Brasil, P.d.R. *Lei N° 11.284, de 2 de Março de 2006*; 2006. Available online: https://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11284.htm (accessed on 13 July 2025). [Google Scholar]
- MMA, M. do M.A. e M. do C.; IBAMA, I.B. do M.A. e dos R.N.R. *Instrução Normativa 21, de 23 de Dezembro de 2014*; 2014. Available online: <https://www.ibama.gov.br/component/legislacao/?view=legislacao&legislacao=134547> (accessed on 12 July 2025). [Google Scholar]
- MMA, M. do M.A. e M. do C.; IBAMA, I.B. do M.A. e dos R.N.R. *Instrução Normativa 82, de 25 de Março de 2022*; 2022; Volume 59, p. 103. [Google Scholar]
- MAPA, M. da A. Pecuária e Abastecimento/Gabinete do Ministro. *Portaria MAPA N° 514, de 8 de Novembro de 2022*; 2022; Volume 212, p. 3. [Google Scholar]
- Brasil, P.d.R. *Decreto N° 8.330, de 5 de Novembro de 2014*; 2014. [Google Scholar]
- MMA, M. do M.A. e M. do C.; IBAMA, I.B. do M.A. e dos R.N.R. *Instrução Normativa 28, de 11 de Dezembro de 2024*; 2024; Volume 240, p. 134. [Google Scholar]
- CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora Appendices I, II and III. Available online: <https://cites.org/eng/app/appendices.php> (accessed on 3 February 2025).
- Daly-Hassen, H.; Khalfaoui, M.; Sliti, H.; Chebil, A.; Jebari, S. Demand and Net Import Modeling and Forecasting for Wood Products in a Country with Limited Forest Resources (Tunisia). *Forests* **2026**, *17*, 202. [Google Scholar] [CrossRef]
- Brainer, M.S.d.C.P. Produtos Florestais. *Cad. Setorial ETENE* **2022**, *7*. Available online: <https://www.bnb.gov.br/revista/cse/articulo/view/2836/1938> [Google Scholar]
- FAO, F.A.A.O. FAO Statistical Database. Available online: <https://www.fao.org/faostat/en/#data/FO> (accessed on 11 July 2025).
- Hoisel, T.F.N.; Danilevicz, V.M.; Soares, N.S.; Profice, C.C. Competitividade do Brasil e dos Principais Exportadores Mundiais no Mercado de Madeira Serrada. *Desenvolv. Em Questão* **2023**, *21*, e13251. [Google Scholar] [CrossRef]
- Kloczko, C.; Zaque, L.; Tavares, S.; Melo, R.; Machado Neto, A.; Pedrosa, T. Análise Da Produção e Comercialização Brasileira de Madeira Serrada (1993–2013). *Nativa* **2017**, *5*, 563–567. [Google Scholar] [CrossRef]

17. Castro, R.V.O.; Castro, A.F.N.M.; Ataíde, G.d.M.; Júnior, C.A.A.; Marcatti, G.E.; Silveira, D.d.P.; Costa, C.B. Análise econométrica da produção de madeira serrada no Brasil. *Floresta* **2012**, *42*, 661–670. [Google Scholar] [CrossRef]
18. da Silva, L.F.; da Silva, M.L.; Cordeiro, S.A. Análise do mercado mundial de madeiras tropicais. *Rev. De Política Agrícola* **2012**, *21*, 48–54. [Google Scholar]
19. FAO, F.A.A.O. *Classification of Forest Products 2022*; FAO: Rome, Italy, 2022; ISBN 978-92-5-135594-7. [Google Scholar]
20. Krugman, P.R.; Obstfeld, M.; Melitz, M.J. *International Economics: Theory & Policy*; Pearson: London, UK, 2018; ISBN 978-0-13-451957-9. [Google Scholar]
21. Angelo, H.; Hosokawa, T.; Berger, R. Brasil No Mercado Internacional de Madeiras Tropicais. *Rev. Árvore* **1998**, *22*, 483–494. [Google Scholar]
22. Brasil, A.; Angelo, H.; Santos, A.; Berger, R.; Da Silva, J.C. Demanda de exportação de painéis de madeira do Brasil. *Floresta* **2004**, *33*, 135–146. [Google Scholar] [CrossRef]
23. Sills, E.O.; Abt, K.L. *Forests in a Market Economy*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2013; Volume 72, pp. 1–360. ISBN 978-94-017-0219-5. [Google Scholar]
24. Gujarati, D.N. *Econometria Basica*; Elsevier: Rio de Janeiro, Brazil, 2006; Volume 4, ISBN 978-85-352-1664-6. [Google Scholar]
25. de Matos, O.C. *Econometria Basica: Teoria e Aplicacoes*; Atlas: Raleigh, NC, USA, 2000; Volume 2, pp. 1–246. ISBN 978-85-224-2394-1. [Google Scholar]
26. Pedace, R. *Econometrics For Dummies*; John Wiley & Sons: Hoboken, NJ, USA, 2013; ISBN 978-1-118-53384-0. [Google Scholar]
27. Wooldridge, J.M. *Introductory Econometrics: A Modern Approach*, 4th ed.; student ed.; South-Western: Mason, Ohio, 2009; ISBN 978-0-324-58162-1. [Google Scholar]
28. Cochrane, D.; Orcutt, G.H. Application of Least Squares Regression to Relationships Containing Auto- Correlated Error Terms. *J. Am. Stat. Assoc.* **1949**, *44*, 32–61. [Google Scholar] [CrossRef] [PubMed]
29. Durbin, J.; Watson, G.S. Testing for Serial Correlation in Least Squares Regression: I. *Biometrika* **1950**, *37*, 409–428. [Google Scholar] [CrossRef] [PubMed]
30. IPEA, I. de P.E.A. Ipeadata. Available online: <https://www.ipeadata.gov.br/Default.aspx> (accessed on 11 July 2025).
31. Angelo, H.; Hosokawa, R.; Berger, R.; Castro, L. Rentabilidade das exportações brasileiras de madeira tropical. *Floresta* **2005**, *33*(1), 63–69. [Google Scholar] [CrossRef]
32. Calderon, R.d.A.; Ângelo, H. As exportações brasileiras de manufaturados de madeira. *Ciênc. Florest.* **2006**, *16*, 99–105. [Google Scholar] [CrossRef]
33. Lima, R.; Luiz, R.; Silva, J.A.A.D.; Guedes, M.C. Produção volumétrica bruta, rendimento e modelagem de madeira serrada de espécies comerciais da Amazônia 2018. Available online: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/191320/1/CPAF-AP-2018-Tese-Producao-volumetrica.pdf> (accessed on 15 July 2025). [Google Scholar]
34. Brasil, A.A. As Exportações Brasileiras de Painéis de Madeira. Master's Thesis, Universidade Federal do Paraná, Setor de Ciências Agrárias, 2002. [Google Scholar]
35. Greene, W. *Econometric Analysis*, 8th ed.; Pearson: New York, NY, USA, 2018; ISBN 978-0-13-446136-6. [Google Scholar]
36. de Almeida, A.N.; Angelo, H.; da Silva, J.C.G.L.; Hoeflich, V.A. Mercado de madeiras tropicais: Substituição na demanda de exportação. *Acta Amaz.* **2010**, *40*, 119–126. [Google Scholar] [CrossRef]
37. Raimundo, Y.M. *Análise das Exportações Brasileiras de Madeira Serrada e Painéis à Base de Madeira no Período de 1961 a 1999*; Mestrado em Economia Aplicada, Universidade de São Paulo: Piracicaba, Brazil, 2018. [Google Scholar]
38. Morland, C.; Schier, F.; Weimar, H. The Structural Gravity Model and Its Implications on Global Forest Product Trade. *Forests* **2020**, *11*, 178. [Google Scholar] [CrossRef]
39. FAO. *Global Forest Products Facts and Figures 2024. Industrial Roundwood, Sawnwood, Wood-Based Panels, Fibre Furnish, Paper and Paperboard, Wood Fuel, Charcoal and Pellets, Export and Import Value of Wood and Paper Products and Non-Wood Forest Products*; FAO: Rome, Italy, 2025; ISBN 978-92-5-140408-9. [Google Scholar]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.