forests

Article

The Legal Roundwood Market in the Amazon and Its Impact on Deforestation in the Region between 2009–2015

Fernando Wallase Carvalho Andrade [1], Tatiane Inácio Pinto [2], Letícia da Silva Moreira [3], Márcio José Moutinho da Ponte [4], Tarcísio da Costa Lobato [5], João Thiago Rodrigues de Sousa [1] and Victor Hugo Pereira Moutinho [1,*]

[1] Laboratory of Timber Technology, Forest and Biodiversity Institute, Federal University of Western Pará (UFOPA), Santarém 68035-110, Brazil; engenheiro.fernandoandrade@gmail.com (F.W.C.A.); thiagronomo@gmail.com (J.T.R.d.S.)
[2] Postgraduate Program of Wood Science and Technology, Federal University of Lavras (UFLA), Lavras 37200-000, Brazil; tatianepintostm@gmail.com
[3] Postgraduate Program in Society, Nature and Development, Federal University of Western Pará (UFOPA), Santarém 68035-110, Brazil; moreira.leticia94@gmail.com
[4] Program of Computer Science, Federal University of Western Pará (UFOPA), Santarém 68035-110, Brazil; mjmponte@gmail.com
[5] Program of Economy, Federal University of Western Pará (UFOPA), Santarém 68035-110, Brazil; tarcisiolobato@yahoo.com.br
* Correspondence: victor.moutinho@ufopa.edu.br

Citation: Andrade, F.W.C.; Pinto, T.I.; Moreira, L.d.S.; da Ponte, M.J.M.; Lobato, T.d.C.; de Sousa, J.T.R.; Moutinho, V.H.P. The Legal Roundwood Market in the Amazon and Its Impact on Deforestation in the Region between 2009–2015. *Forests* **2022**, *13*, 558. https://doi.org/10.3390/f13040558

Academic Editors: Paraskevi Karanikola, Thomas Panagopoulos, Thiago Almeida Vieira and Angelos Tsikas

Received: 23 February 2022
Accepted: 28 March 2022
Published: 31 March 2022

Abstract: Brazil is one of the largest producers of tropical wood in the world. Much of this wood is extracted from the Amazon region, especially in the state of Pará. Despite empirical knowledge, there is little information in the literature about the selectivity of trade and how this production has been behaving in recent years. Is there any relationship between this legal timber trade and deforestation? In this work, we compile data reports from control agencies and analyze the dynamics of the legal timber market in the state of Pará between 2009 and 2015 in terms of species, volume, and monetary value. We also correlate changes in volume m^{-3} and value m^{-3} with deforestation increase in the same period and region. We find that only ten groups of species represent almost 50% of the total timber volume marketed in the State, mainly from the Massaranduba (*Manilkara*) group. According to our models, the supply of a species of wood on the market is defined by its monetary value and not by its availability or characteristics, which hinders the insertion of new species and increases selectivity. Since 2011 the volume of legally traded logs has been decreasing sharply. Traditional forest regions in the state already demonstrate depletion in forested areas. While others, such as the lower Amazon region, have been increasing production, showing that new forestry operations areas are being used for harvesting in the function of the lower availability in traditional areas. Our models show that the legal reduced impact logging timber volume has an inverse relationship with the deforestation increase. Otherwise, preference for a small group of timber types still predominates, which may lead local woods to the danger of extinction.

Keywords: Amazon woods; Massaranduba; sustainable forest management; SISFLORA; timber species

1. Introduction

The Amazon region encompasses a large extension of tropical forest (~6 million km^2), and a high diversity of vegetal species (16 thousand tree species), many of which have demonstrated some timber potential (170–300 species) [1–3]. From this group, few timber species are known by consumers, focusing the demand on a reduced group (1–70 species), which leads to a decrease or even to a sub-regional demographic collapse of this select population over time [1,4,5].

Brazil is one of the largest producers of neotropical wood in the world, being the state of Pará responsible for more than 50% of the Brazilian Amazon logs production [5,6]. Due to this, mechanisms that assure legal harvesting and control of legally marketed timber are essential for sustainable forest management. In 2006, the Department of Environment and Sustainability of Pará—SEMAS implemented the Forest Products Trade and Transportation System—SISFLORA. Both these systems allow the inflow and outflow of roundwood credits and forest products in the state. At the federal level, the Brazilian Institute of Environment and Renewable Natural Resources—IBAMA requires the Forest Origin Document—DOF. Both of those are necessary tools to minimize deforestation and illegal timber trade, ensuring production in areas with a sustainable forest management plan.

The timber market in Pará has suffered great changes during recent years, both in terms of supervision of harvesting activities and timber demand [7,8]. Several authors have studied logging sustainability in the Brazilian Amazon [4,5,9,10]. Nonetheless, despite the importance for the economy, little is currently known about the dynamics of the timber market across the entire State, such as the insertion and/or exclusion of specific timber into the market during the last few years, and changes in species' monetary value, which could affect the economic viability of forest management. Moreover, it is important to define what are the most valuable timber species, aiming to replace and increase the number of managed species in the cutting cycle. Changes such as the increase in average pricing for timber combined with the lower supply of this material may influence illegal activities such as deforestation. In Brazil, the mismatch between the legal supplies of timber and the demands of the domestic processing industry has been a major driver of illegal logging for many years [11]. It is important to highlight whether or not the use of tropical wood is related to deforestation in the Amazon region, as this is a widespread prejudgment.

This paper aimed to quantify changes in the trade of legal timber from native forests in the state of Pará, Brazil. Specifically, we summarize a series of data sets from governmental agencies to (i) describe the timber market by micro-regions and cities, (ii) analyze the production dynamics and the pressure on determined groups of species, and measure deforestation increase for (iii) testing if the legal logging trade has been related to deforestation between the years of 2009 and 2015, for the studied regions.

2. Materials and Methods

2.1. Timber Market and Data Collection

Data for timber commercialization were subdivided into six mesoregions of the state of Pará, Brazil: Lower Amazon, Marajó, Metropolitan region of Belém, Northeast, Southeast, and Southern Pará (Figure 1).

We obtained the timber market data through annual reports issued by SISFLORA from the SEMAS [12]. The reports contained information on the extraction and trade of logs, per municipality, between the years 2009 and 2015. Those reports were also used to sum up the information contained in required documents for the transportation of wood logs (GF1), sawn timber (GF2), and final products (GF3) in the state, referred to as "Guia Florestal".

These documents are composed of information about which species were being transported, the municipality of origin, the species' popular name, its volume in cubic meters, and the commercial value (free of taxes), allowing, therefore, the calculation of the commercialized volume, the value per cubic meter (dividing the total value by total volume commercialized) and which species were marketed during the evaluated period. All information contained in GF1 was filled in by the forest companies and confirmed by the local inspection agency.

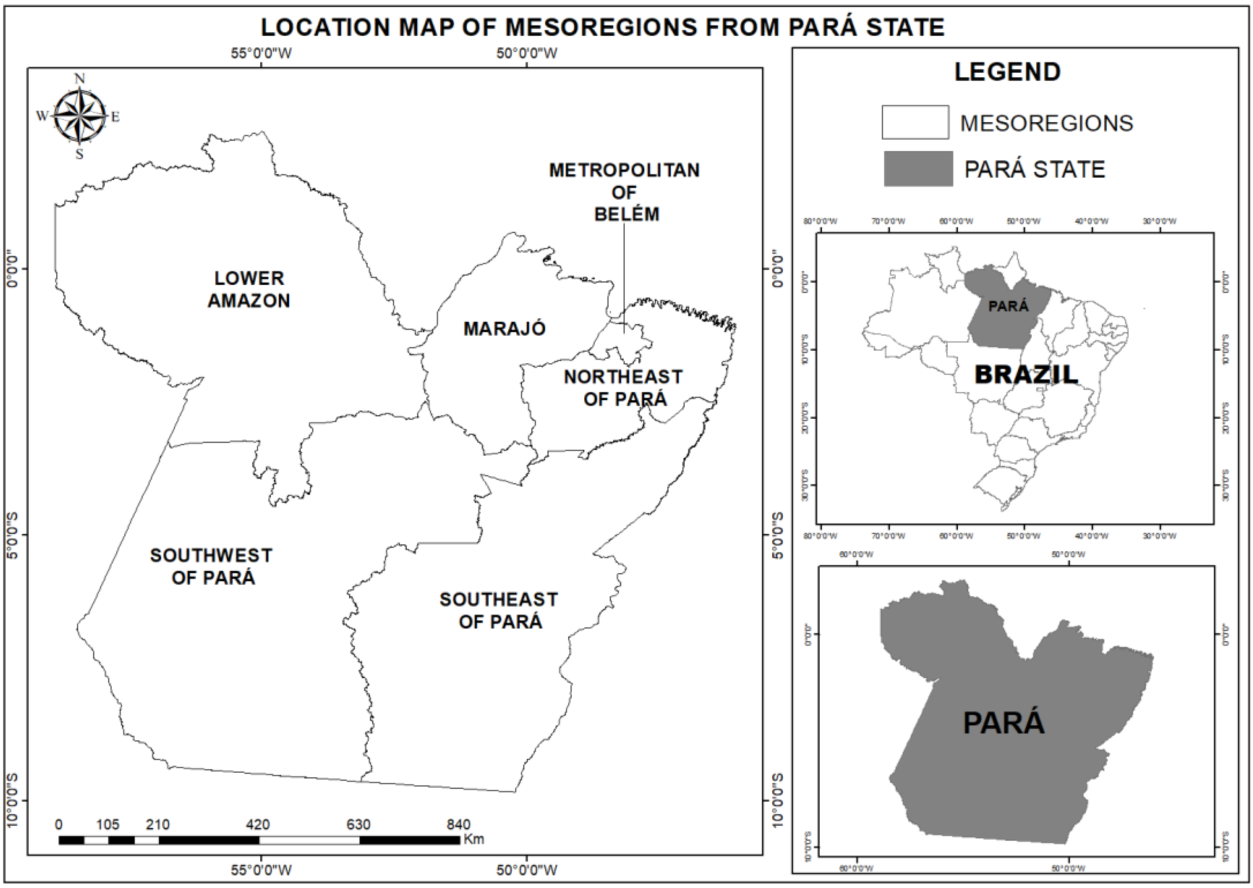

Figure 1. Mesoregions of state of Pará.

In order to better organize the data, the species were grouped accordingly to their popular names. For different species with the same popular name, the species were grouped out by cities and then into their respective mesoregions. In addition, forest essences were not botanically identified, so the scientific names described in it are only for protocol. At the time of data collection, the reports for 2016, 2017, 2018, and 2019 were not yet published.

In addition, the timber monetary value was converted and deflated in dollars, taking as reference the value of the currency on the date of 31 December for each year (2009–2015).

2.2. Empirical Estimation with Econometric Models

To investigate the relationship between deforestation increase and changes in volume m^{-3} and value m^{-3} we applied three static panel data estimators [pooled, fixed effect (FE) and random effect (RE)] [13,14] for the two most important timbers species of our study *Handroanthus* spp. (Yellow Ipê) and *Manilkara* spp. (Massaranduba). These models contain one or more lagged dependent variables, allowing the model to be a partial adjustment mechanism. Models 1 and 2 relate the increase in deforestation as a function of volume and the marketed value per cubic meter, respectively; while model 3 relates the volume per cubic meter as a function of its marketed value for the timbers of *Handroanthus* spp. and *Manilkara* spp. Data used in models were logarithmically transformed to correct bias effects on correlation or regression or to correct the heteroscedasticity effects on model residuals.

The models are shown as follows:

$$lnID_{it} = \beta_{it} + \beta_1 lnVolume_{it} + \varepsilon_{it} \tag{1}$$

$$lnID_{it} = \alpha_{it} + \alpha_1 lnValm^3{}_{it} + \varepsilon_{it} \tag{2}$$

$$lnVolume_{it} = \gamma_{it} + \gamma_1 lnValue_{it} + \varepsilon_{it} \tag{3}$$

where i represents municipality index, t represents the time index, α and β are the parameters to be estimated, *IDit* represents the increased deforestation, $Volume_{it}$ represents the volume per cubic meter, $Valm^3{}_{it}$ represents the value per cubic meter (estimate of the value per cubic meter for each species), $Value_{it}$ represents the marketed value (total value generated in the commercialization of each species), and ε_{it} represents the usual error term.

We have assumed that variations in deforestation may be caused by other factors, which were not predicted in the model, thus it was included lagged variables for constructing more efficient estimates using a model of dynamic panel data applying a generalized method of moments (GMM), by each difference (GMM-AB) [15] and System GMM (GMM-BB) [16].

For the selection of the most appropriate static model, we have used Chow, Breusch–Pagan, and Hausman tests [13]. The Chow test was used for analyzing the null hypothesis: is the pooled model preferable to fixed effects? Already, with the Breusch–Pagan test, we analyzed if the pooled model was preferable to the random effect. Lastly, the Hausman test was used to verify if the random effect model is preferable to the use of fixed effects.

To test whether the selected instruments are independent of the error or not, we performed the Sargan test [17]. Finally, to test the hypothesis that all coefficients, except the constant, are equal to zero, we have applied the Wald test [13].

The data used to measure deforestation were obtained by PRODES [18], which uses the deforestation measured increase from one year to the next, to analyze the variation of the affected area. The concept of deforestation, in this case, consists of the complete removal of primary forest cover by clear-cutting in an area above 6.25 hectares, regardless of the future use of these areas. It is important to cite that in the studied area, between 2009–2015, it was deforested a total area of 19,182 km^2 [18].

Regarding the database, due to the lack of information in the years of the research, a base was consolidated, taking in accordance with the available data for the variables of interest of the species with the highest volume and the highest marketed value. It is important to note that among these municipalities, there are those that most trade timber.

3. Results and Discussion

The forestry production in the state of Pará, when evaluating the annual volume (m^3) of marketed logs, shows us that from 2009 to 2011 the volume of commercialized timber has grown. This increase is about 57%, with a sharp decrease in the following years, as presented in Table 1.

Table 1. Volume and annual rates of increase and decrease in wood marketed in the state of Pará.

Year	Volume		Annual Rate
	(m^3)	(%)	(%)
2009	2,662,679.3	12	-
2010	3,725,647.5	17	40
2011	4,370,883.8	20	17
2012	3,395,182.8	15	−22
2013	2,913,447.3	13	−14
2014	2,946,764.5	13	1
2015	1,947,652.6	9	−33
Average	3,137,465.4	100%	-

Source: SISFLORA, adapted by the author.

According to Santana [4], the Brazilian timber market had had an increase of 5% from 2009 to 2011. This is due to the Brazilian Growth Acceleration Program (PAC—acronym in Brazilian Portuguese), which has been emphasizing growths in infrastructure and construction industries. PAC has also increased credit to the poorest part of the population, thus increasing the demand for natural materials, such as timber from native species of managed forests, this reaffirms the results found in our study wherein a peak in timber commercialization was observed in 2011.

The timber trade in the state of Pará has been estimated at an average of 3.1 million cubic meters per year, with a decreasing tendency during the sampling period (Figure 2). The Lower Amazon mesoregion has shown the highest volume of commercialized timber, while the volume of commercialized timber in Southwest and Southeast mesoregions has declined from 2011 to 2015, which indicates a reduction in the forested areas of the cities that compose these mesoregions. The Northeast mesoregion had a high volume of commercialized timber in the years 2010 and 2011, while strongly decreasing from 2013 to 2015. In contrast, the Marajó mesoregion has shown a constant volume of commercialized timber, with an increase in 2012 and a strong decrease in 2015.

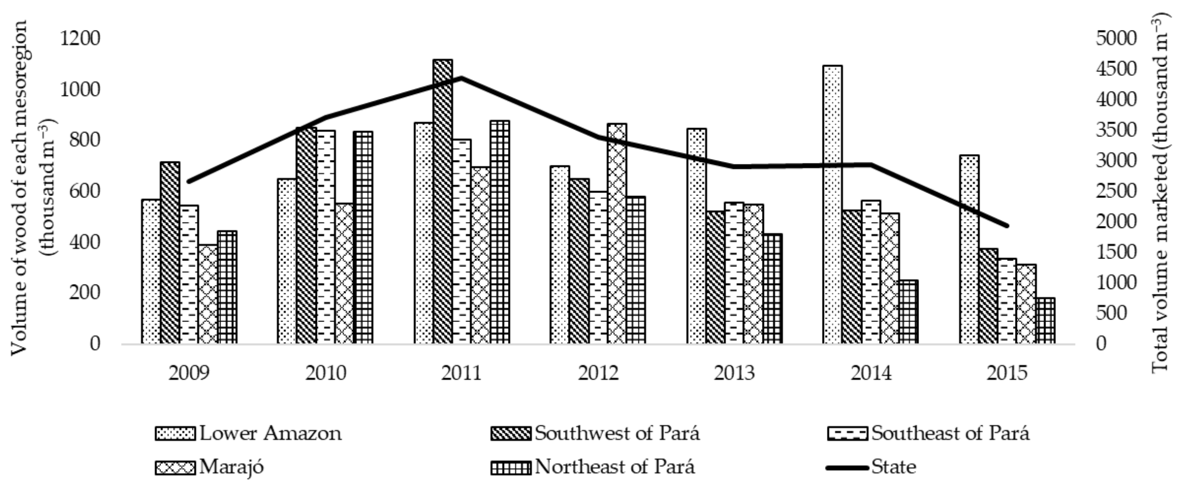

Figure 2. Volume of native wood of each mesoregion in relation to the total volume marketed in the state of Pará between the years 2009 and 2015.

On the other hand, we have seen that the Lower Amazon mesoregion has demonstrated an increased tendency in timber production when compared to the other mesoregions. In this mesoregion, there are large areas of public forests that are available for forest concessions, such as the National Forest of Tapajós, the National Forest of Saraca-Taquera, and the area of Mamuru-Arapiuns [8,19]. The most precious woods are becoming increasingly restricted to unlogged old-growth forests in the Northeast and Southeast mesoregions. In the last 45 years, the forest has been explored two or three times, which is exhausting for the environment [2]. The quality of timber of this species is historically attractive for the markets in the state of Pará [19].

The municipalities of Santarém and Prainha, which are part of the Lower Amazon mesoregion, have presented a large growth in marketed timber volumes during the period of evaluation (Table 2), indicating that these municipalities will very likely assume the first position in timber commercialization in the state in a near future, especially because these areas still retain trees with high-valued wood.

During the period of evaluation, we observed 923 species' names in the guides, which were divided into 640 different groups of timber species based on their popular name (Table 3). In both low-impact and conventional forest management, the species identification is uncertain, manipulable, and difficult to control by the responsible government agencies, especially those of low timber value [20].

Plumptre [21] recommends that timber should be sold by grouping or by lots, rather than individually as it is made nowadays, this would allow multiple uses for more species, including those species of less valuable timber. Richardson and Peres [5], studying forest management in areas under forest concession in the state of Pará, state that the winner companies were authorized by the government, to manage 314 species of 153 different genera. However, the number of harvested species was at most 70, which may lead to a depletion of the Amazon's timber species in a near future.

Table 2. Volume of log (1000 m^3) marketed in the ten most productive municipalities—SISFLORA-PA.

Municipality	Volume ($m^3 \times 10^3$) Year^{-1}						
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Portel	318.4	456.2	475.5	406.9	321.2	226.3	176.7
Paragominas	179.5	307.7	312.1	239.6	318.6	298.4	205.2
Santarém	136.9	201.7	296.3	227.8	249.6	266.2	266.1
Almeirim	103.3	211.6	284.5	214.8	218.9	280.9	91.6
Pacajá	281.6	286.2	454.9	91.0	56.8	28.0	40.2
Anapu	226.3	278.2	305.8	170.2	67.9	123.0	36.5
Tomé-Açu	168.5	280.3	320.1	156.9	138.8	55.7	53.9
Prainha	97.0	42.6	93.3	81.2	209.4	254.1	162.0
Rondon	125.6	122.2	134.3	143.9	100.4	92.6	46.5
Ipixuna	96.4	204.6	109.3	70.6	130.4	94.4	54.5

Table 3. List of the most marketed species in the state between 2009 and 2015.

Group	Genus	Total Volume		Total Value	
		Cubic Meter	**%**	**(USD) ***	**%**
Massaranduba/Iron wood	*Manilkara*	3,376,471.80	15%	270,948,071.88	16%
Jatoba/Tiger wood	*Hymenaea*	1,152,297.30	5%	90,625,791.26	6%
Guajara	*Chrysophyllum*, *Micropholis* and *Pouteria*	1,023,178.30	5%	65,211,073.01	4%
Cupiuba	*Goupia* and *Eschweilera*	987,720.40	4%	64,339,353.81	4%
Angelim	*Andira*, *Dimorphandra Dinizia*, *Hymenolobium*, *Marmaroxylon*, *Parkia*, *Sweetia*, *Vatairea* and *Vataireopsis*	893,742.40	4%	70,121,593.46	4%
Yellow Ipê	*Handroanthus* and *Macrolobium*	749,902.80	3%	135,612,950.95	8%
Tauari	*Allantoma*, *Cariniana*, *Coupeia* and *Couratari*	731,728.00	3%	48,172,273.47	3%
Red Angelim	*Andira* and *Dinizia*	664,321.00	3%	54,352,780.99	3%
Timborana	*Enterolobium*	648,751.50	3%	42,192,851.33	3%
Faveira	*Albizia*, *Andira*, *Dimorphandra*, *Dinizia*, *Enterolobium*, *Hymenolobium*, *Parkia*, *Piptadenia*, *Pithecellobium*, *Samanea*, *Schizolobium*, *Stryphnodendron*, *Tipuana*, *Vatairea*, *Vaitereopsis*, *Vochysia*	567,240.90	3%	37,139,678.96	2%
Others (630)	-	11,166,903.51	51%	765,050,358.14	47%
Total		21,962,257.90	100%	1,643,766,777.27	100%

* Updated monetary value with Historical Exchange rate for 2009 (BRL 1 = 0.5741 USD), 2010 (0.6018), 2011 (0.5367), 2012 (0.4887), 2013 (0.4236), 2014 (0.3756) and 2015 (0.2533).

The group of Massaranduba species (*Manilkara*) accounts for 15% of the total volume of the marketed timber in the state of Pará (Table 3), which indicates a strong pressure on this group. The other species add up to 51% of the total value, demonstrating that the introduction of new species in the market is relatively low, despite the diversity of woody forest species with potential uses in the region.

The pressure on specific groups such as *Manilkara* could result in the local extinction of the species of this genus if no monitoring and harvesting restrictions are applied and strongly supervised [22]. According to Castro and Carvalho [23], the characteristics of *Manilkara*'s wood make it highly valued, with this species being one of the most used for wooden structures [24], and also because of its high natural durability, lending great technological potential to this group. Future studies that can identify non-traditional timbers with characteristics such as those in *Manilkara* spp. are essential to reduce the pressure on this group. Using more timber species in addition to reducing pressure on the most valuable ones can increase the value of the overall forest and decrease the need for expansion to other areas [21].

Although *Manilkara* timber is the most marketed, the species does not possess the highest economic value, which would lead us to species such as Cedar, Yellow Ipê, Freijó, Yellow Itauba, and others (Table 4). Costa et al. [25] explain that *Manilkara* spp. has a high frequency and is abundant in the Amazon rainforest, increasing its timber supply, thus decreasing the final price.

Table 4. Ten species with highest commercial value in the state of Pará.

Species	Scientific Name	USD m^{-3} *						
		2009	2010	2011	2012	2013	2014	2015
Cedar	*Cedrela* spp.	249.3	261.3	233.1	212.2	183.9	163.1	110.0
Yellow Ipê	*Handroanthus* spp.	205.4	215.3	192.0	174.8	151.5	134.4	90.6
Freijó	*Cordia* spp.	172.2	180.5	161.0	146.6	127.1	112.7	76.0
Purple Ipê	*Handroanthus* spp.	48.1	50.4	45.0	41.0	35.5	31.5	21.2
Tatajuba	*Bagassa* spp.	107.1	112.2	100.1	91.1	79.0	70.0	47.2
Angelim	*Hymenolobium* spp.	-	-	82.9	75.5	65.4	58.0	39.1
Cumaru	*Dipteryx* spp.	86.4	90.6	80.8	73.5	63.7	56.5	38.1
Yellow Itauba	*Mezilaurus* spp.	143.5	150.5	134.2	122.2	105.9	93.9	63.3
Paraju	*Manilkara* spp.	-	111.2	116.6	104.0	94.7	-	-
Massaranduba	*Manilkara* spp.	88.9	93.2	83.1	75.7	65.1	57.7	38.9

* Updated monetary value with Historical Exchange rate for 2009 (BRL 1 = 0.5741 USD), 2010 (0.6018), 2011 (0.5367), 2012 (0.4887), 2013 (0.4236), 2014 (0.3756) and 2015 (0.2533).

For Suchomel et al. [26], the price of timber can be influenced by factors such as the global economic recession, rising oil prices, climate change, and stagnation of the building industry. According to Ribeiro [27], the higher timber price of a species is related to its lower availability in the forest, as in the case of Cedar, Yellow Ipê, and Freijó, demonstrating the high potential of hardwood species in this region. In other studies, conducted by the same author, Ipê and Cumaru are currently highly demanded species in both the construction and furniture industries. ITTO [28] reported a value of USD 147 m^{-3} for Ipê wood in 2009 and USD 136 m^{-3} in 2014, those values are in accordance with our results (Table 4).

Econometric Models

For Piketty et al. [7] and Hummel et al. [29], there is a tendency of harvesting activities of native forest areas to decrease, as a consequence of the increasingly governmental forces to combat illegal deforestation and a more rigorous posture on the approval of harvest management plans. However, according to Tollefson [30], deforestation in the Brazilian Amazonia has increased from 2012 to 2016.

To test the hypothesis that there has not been a relationship between deforestation trends and legally harvested timber, we have applied different econometric models. According to the static model, the relationship between the increase in deforestation and the value per cubic meter is significant and inversely proportional to all timbers. However, the same relationship was not observed for the dynamic models, except for the estimated coefficient of the lagged variable in the GMM-BB model for *Manilkara* spp. (Table 5).

Table 5. Results of panel models of the increase in deforestation in relation to the value per m^3 for *Handroanthus* spp. and *Manilkara* spp. in the municipalities of Pará, from 2009 to 2015.

Dependent Variable	Increasing Deforestation									
	Handroanthus spp. (Yellow Ipê)					*Manilkara* spp. (Massaranduba)				
Variables	Pooled	FE	RE	GMM-AB	GMM-BB	Pooled	FE	RE	GMM-AB	GMM-BB
$ID_{(t-1)}$	-	-	-	0.121 ***	0.499 ***	-	-	-	0.057	0.434 ***
	-	-	-	(0.036)	(0.009)	-	-	-	(0.057)	(0.034)
Value m^{-3}	−0.589 **	−0.368 **	−0.390 ***	−0.061	−0.029	−0.590 **	−0.633 ***	−0.628 ***	0.068	−0.209 **
	(0.261)	(0.131)	(0.145)	(0.046)	(0.048)	(0.283)	(0.185)	(0.156)	(0.200)	(0.092)
Constant	7.521 ***	6.057 ***	6.202 ***	−0.056 ***	1.974 ***	6.544 ***	6.795 ***	6.769 ***	−0.130 ***	3.000 ***
	(1.711)	(0.872)	(0.983)	(0.016)	(0.253)	(1.621)	(1.075)	(0.930)	(0.035)	(0.604)
Obs. numbers	147	147	147	105	126	224	224	224	160	192
Mun. numbers	21	21	21	21	21	32	32	32	32	32
Specification Tests	-	-	-	-	-	-	-	-	-	-
Chow	16.178 ***	-	-	-	-	18.949 ***	-	-	-	-
Breusch–Pagan	197.437 ***	-	-	-	-	342.228 ***	-	-	-	-
Hausman	0.532	-	-	-	-	0.014	-	-	-	-
Sargan	-	-	-	15.784	18.935	-	-	-	22.221 *	23.999
Wald	-	-	-	16.244 ***	14,918.8 ***	-	-	-	1.010	414.94 ***
Instruments	-	-	-	17	22	-	-	-	17	22

Note: Values in parentheses are robust standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The Chow, Breusch–Pagan, and Hausman tests have demonstrated that the random effect model was the most appropriate for our study. This model shows a negative relationship between the increase in deforestation and the value per cubic meter (Table 5). Thus, the legal timber commerce in the state of Pará does not negatively affect forest preservation. The increment in the value of different timbers turns the forest more attractive for companies [21] to invest in large areas, in order to perform long-term management of existing timber, and thus protect this area from inherent illegal activities, such as land invasion and land grabbing, among others, which will consequently lead to deforestation.

For Darrigo et al. [9] and Pokorny and Pacheco [10], areas of logging management under legal reduced impact can help the fight against forest deforestation and may be a useful tool for forest conservation. Moreover, the same authors state that deforestation occurs primarily for economic reasons and, in the case of forest loss value, the forest will continue to be transformed into other land uses.

The analysis of model 2 (Table 6) reveals that in static models, the observed relationship is not significant, but in dynamic models, it becomes significant at 1% for both species. Tests for adequacy of the use of dynamic models were met, with a non-significant Sargan test and a significant 1% Wald test.

Table 6. Results of panel models of deforestation increase in relation to volume (m^3) for *Handroanthus* spp. and *Manilkara* spp. in the municipalities of Pará, from 2009 to 2015.

Dependent Variable	Increasing Deforestation									
	Handroanthus spp. (Yellow Ipê)					*Manilkara* spp. (Massaranduba)				
Variables	Pooled	FE	RE	GMM-AB	GMM-BB	Pooled	FE	RE	GMM-AB	GMM-BB
$ID_{(t-1)}$	-	-	-	0.198 ***	0.462 ***	-	-	-	0.030	0.435 ***
	-	-	-	(0.037)	(0.015)	-	-	-	(0.068)	(0.030)
Volume	0.136	0.04	0.053	0.111 ***	0.084 ***	0.088	0.095	0.094	0.121 ***	0.064 ***
	(0.116)	(0.051)	(0.051)	(0.037)	(0.016)	(0.101)	(0.067)	(0.067)	(0.026)	(0.026)
Constant	2.605 **	3.320 ***	3.223 ***	−0.018	1.262 ***	2.384 **	2.325 ***	2.333 ***	−0.113 ***	1.234 ***
	(0.993)	(0.380)	(0.463)	(0.023)	(0.146)	(0.973)	(0.566)	(0.625)	(0.025)	(0.213)
Obs. numbers	147	147	147	105	126	224	224	224	160	192
Mun. numbers	21	21	21	21	21	32	32	32	32	32
Specification tests	-	-	-	-	-	-	-	-	-	-
Chow	15.786 ***	-	-	-	-	18.142 ***	-	-	-	-
Breusch–Pagan	192.735 ***	-	-	-	-	333.23 ***	-	-	-	-
Hausman	0.717	-	-	-	-	0.005	-	-	-	-
Sargan	-	-	-	18.838	19.752	-	-	-	21.008	23.618
Wald	-	-	-	33.058 ***	886.616 ***	-	-	-	22.492 ***	291.84 ***
Instruments	-	-	-	17	22	-	-	-	17	22

Note: Values in parentheses are robust standard errors. *** $p < 0.01$, ** $p < 0.05$.

In the GMM-AB and GMM-BB models for *Handroanthus* spp., the lagged variable shows reasonable temporal dynamics of deforestation influence over time. We observed that the legal reduced impact on logging timber volume has a low impact on increasing deforestation. Moraes et al. [31] and Pinagé et al. [32] have demonstrated that in the process of legal logging, there is minimal vegetation suppression in activities such as road opening and stockpiling, while Schwartz et al. [33] has demonstrated that changes caused by reduced management combined with post-harvest silvicultural treatment have a positive effect on the height and diameter growth rate of all species in managed areas of the Amazon rainforest.

However, it should be noted that in the second cutting cycle most species with cutting volume will not be the same ones as those of the first cycle [22,33]. Thus, it is necessary to characterize the wood of these new species, allowing a more appropriate use and pricing for these species at cutting time.

To analyze the timber harvest market supply (Model 4), we estimated static and dynamic models (Table 7).

Table 7. Results of the volume panel models (m^3) in relation to the value (BRL) for *Handroanthus* spp. and *Manilkara* spp. in the municipalities of Pará, from 2009 to 2015.

Dependent Variable	**Volume (m^3)**									
	***Handroanthus* spp. (Yellow Ipê)**					***Manilkara* spp. (Massaranduba)**				
Variables	**Pooled**	**FE**	**RE**	**GMM-AB**	**GMM-BB**	**Pooled**	**FE**	**RE**	**GMM-AB**	**GMM-BB**
$Volume_{(t-1)}$	-	-	-	0.032 **	0.098***	-	-	-	0.053 ***	0.227 ***
	-	-	-	(0.008)	(0.008)	-	-	-	(0.014)	(0.011)
Value	0.922 ***	0.932 ***	0.927 ***	0.899 ***	0.871***	0.938 ***	0.994 ***	0.971 ***	0.991 ***	0.836 ***
	(0.033)	(0.030)	(0.027)	(0.013)	(0.003)	(0.036)	(0.034)	(0.025)	(0.006)	(0.013)
Constant	−5.526 ***	95.667 ***	95.606 ***	90.142 ***	95.566***	94.918 ***	95.718 ***	95.397 ***	90.150 ***	95.381 ***
	(0.509)	(0.423)	(0.389)	(0.004)	(0.050)	(0.55)	(0.486)	(0.385)	(0.003)	(0.127)
Obs. numbers	147	147	147	105	126	224	224	224	160	192
Mun. numbers	21	21	21	21	21	32	32	32	32	32
Specification Tests	-	-	-	-	-	-	-	-	-	-
Chow	4.152 ***	-	-	-	-	6.084 ***	-	-	-	-
Breusch–Pagan	39.279 ***	-	-	-	-	101.953 ***	-	-	-	-
Hausman	0.071	-	-	-	-	4.464 **	-	-	-	-
Sargan	-	-	-	17.758	20.754	-	-	-	22.054 *	31.456 **
Wald	-	-	-	4558.99 ***	49,495.7 ***	-	-	-	144,905 ***	14,990.8 ***
Instrumentos	-	-	-	17	22	-	-	-	17	22

Note: Values in parentheses are robust standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Sargan's test showed us that using dynamic models for *Manilkara* spp. is compromising and it can be performed by statistical analysis. The random effect model is most suitable for *Handroanthus* spp. and the fixed effect model for *Manilkara*, with an elasticity of 0.927, and 0.994, respectively, showing that these variables have a strong relationship. When analyzing the dynamics of the model for *Handroanthus* spp., the estimated elasticities demonstrated small values, which may indicate that this market is not much influenced by the increase in the traded volume over time.

We also observed that the supply of a particular wood species in the market is defined by its market value and not by its availability or characteristics, with a low impact of other factors. As an example, Steege et al. [34] and Oliveira et al. [35] found that the *Eschweilera* Mart. ex DC. is one of the most abundant genres in the Amazon Forest of Pará state; however, despite its timber having many different potentials [36,37], its commercialization in the evaluated period was not sufficient to be among the ten most commercialized species, corroborating with the hypothesis which the species is not selected by the criteria of abundance/density in the forest inventory, but mainly in the market demand.

4. Conclusions

Our paper shows that the supply of legal timber decreased after 2011, and this has no relationship with the deforestation index in the Amazon rainforest. Moreover, this consequently leads to an increase in average prices of traditional timbers, highlighting the Cedar group. Overall, the timber market was still restricted to a small group of timbers, especially *Manilkara* spp., even with the introduction and use of new species. The Lower Amazon mesoregion, including the municipality of Santarém, emerged as a new center of timber commercialization in the State.

Furthermore, we have seen that between 2009 and 2015 the modus operandi of forest management in the region remains restrictive to the entry of new species, this increases the pressure on groups such as *Manilkara* spp. From these results, we propose the replacement of the most harvested species, and that government agencies come up with actions for controlling and enforcing the currently most productive areas, such as the Lower Amazon, and also urging forest recovery actions in areas that have been depleted.

Lastly, our analysis shows that the use of legal timber from the Amazon has an inverse relationship to deforestation in the region, and enforcement actions should focus on illegal logging from the Amazon rainforest.

Author Contributions: Conceptualization, V.H.P.M., F.W.C.A. and T.I.P.; methodology, T.I.P. and L.d.S.M.; formal analysis, T.I.P., M.J.M.d.P. and T.d.C.L.; data curation, T.I.P. and L.d.S.M.; visualization, J.T.R.d.S.; writing—original draft preparation, T.I.P.; writing—review and editing, all authors. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available from the corresponding author upon reasonable request.

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

References

1. Richardson, V.A. The Economic and Ecological Sustainability of the Amazonian Timber Industry. Ph.D. Thesis, University of East Anglia, Norwich, UK, 2015. Available online: https://ueaeprints.uea.ac.uk/id/eprint/59386 (accessed on 11 February 2021).
2. Ter Steege, H.; Pitman, N.C.A.; Sabatier, D.; Baraloto, C.; Salomão, R.P.; Guevara, J.E.; Phillips, O.L.; Castilho, C.V.; Magnusson, W.E.; Molino, J.-F.; et al. Hyperdominance in the Amazonian tree flora. *Science* **2013**, *342*, 1243092. [CrossRef]
3. Fauset, S.; Johnson, M.O.; Gloor, M.; Baker, T.R.; Monteagudo, M.A.; Brienen, R.J.W.; Feldpausch, T.R.; Lopez-Gonzalez, G.; Malhi, Y.; Ter Steege, H.; et al. Hyperdominance in Amazonian forest carbon cycling. *Nat. Commun.* **2015**, *6*, 6857. [CrossRef] [PubMed]
4. Bicknell, J.E.; Struebig, M.J.; Edwards, D.P.; Davies, Z.G. Improved timber harvest techniques maintain biodiversity in tropical forests. *Curr. Biol.* **2014**, *24*, R1119–R1120. [CrossRef]
5. Richardson, V.A.; Peres, C.A. Temporal decay in timber species composition and value in amazonian logging concessions. *PLoS ONE* **2016**, *11*, e0159035. [CrossRef] [PubMed]
6. Instituto Brasileiro de Geografia e Estatística I. Produção da Extração Vegetal SIDRA. 2016. Available online: http://www.sidra.ibge.gov.br/bda/pesquisas/pevs/default.asp (accessed on 12 September 2019).
7. Piketty, M.-G.; Poccard-Chapuis, R.; Drigo, I.; Coudel, E.; Plassin, S.; Laurent, F.; Thâles, M. Multi-level Governance of land use changes in the Brazilian Amazon: Lessons from Paragominas, State of Pará. *Forests* **2015**, *6*, 1516–1536. [CrossRef]
8. Santana, A.C.; dos Santos, M.A.S.; de Santana, Á.L.; Yared, J.A.G. O valor econômico da extração manejada de madeira no Baixo Amazonas, Estado do Pará. *Rev. Árvore* **2012**, *36*, 527–536. [CrossRef]
9. Darrigo, M.R.; Venticinque, E.M.; dos Santos, F.A.M. Effects of reduced impact logging on the forest regeneration in the central Amazonia. *For. Ecol. Manag.* **2016**, *360*, 52–59. [CrossRef]
10. Pokorny, B.; Pacheco, P. Money from and for forests: A critical reflection on the feasibility of market approaches for the conservation of Amazonian forests. *J. Rural Stud.* **2014**, *36*, 441–452. [CrossRef]
11. Lawson, S.; MacFaul, L. *Illegal Logging and Related Trade: Indicators of the Global Response*; Royal Institute of International Affairs: London, UK, 2010.
12. Sistema de Comercialização e Transporte de Produtos Florestais S. Extração e Comercialização de toras de Madeira Nativa por Município. 2016. Available online: http://monitoramento.sema.pa.gov.br/sisflora/index.php/relatorio (accessed on 10 June 2017).
13. Wooldrige, J.M. *Econometric Analysis of Cross Section and Panel Data*; The MIT Press: Cambridge, MA, USA, 2002.
14. Greene, W.H. *Econometric Analysis*, 4th ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2006.
15. Arellano, M.; Bond, S. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Rev. Econ. Stud.* **1991**, *58*, 277. [CrossRef]
16. Blundell, R.; Bond, S. Initial conditions and moment restrictions in dynamic panel data models. *J. Econ.* **1998**, *87*, 115–143. [CrossRef]

17. Sargan, J.T. The Estimation of Economic Relationships using Instrumental Variables. *Econometrica* **2016**, *26*, 393–415. [CrossRef]
18. PRODES—Projeto de Monitoramento da Floresta Amazônica Brasileira por Satélite. Available online: http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php (accessed on 7 August 2019).
19. De Santana, A.C.; de Santana, Á.L.; dos Santos, M.A.S.; Yaredm, J.A.G. Determinação dos preços da madeira em pé para as áreas de florestas públicas da região do Baixo Amazonas, no Estado do Pará. *Rev. Estud. Sociais* **2011**, *13*, 40–51. [CrossRef]
20. Macpherson, A.J.; Carter, D.R.; Schulze, M.D.; Vidal, E.; Lentini, M.W. The sustainability of timber production from Eastern Amazonian forests. *Land Use Policy* **2012**, *29*, 339–350. [CrossRef]
21. Plumptre, R.A. Links between utilisation, product marketing and forest management in tropical moist forest. *Commonw. For. Rev.* **2019**, *75*, 316–324.
22. Dionisio, L.F.S.; Schwartz, G.; do Lopes, J.C.; de Oliveira, F.A. Growth, mortality, and recruitment of tree species in an Amazonian rainforest over 13 years of reduced impact logging. *For. Ecol. Manag.* **2018**, *430*, 150–156. [CrossRef]
23. da Castro, T.C.; de Carvalho, J.O.P. Dinâmica da população de Manilkara huberi (Ducke) A. Chev. durante 26 anos após a exploração florestal em uma área de terra firme na Amazônia brasileira. *Ciência Florest.* **2014**, *24*, 161–169. [CrossRef]
24. Nahuz, M.A.R.; De, M.J.; Miranda, A.C.; Ielo, P.K.Y.; Pigozzo, R.J.B.; Yojo, T. *Catálogo de Madeiras Brasileiras para Construção Civil*; IPT—Instituto de Pesquisas Tecnológicas: São Paulo, Brazil, 2013.
25. Costa, D.H.M.; de Carvalho, J.O.P.; Van Den Berg, E. Crescimento diamétrico de Maçaranduba (Manilkara huberi chevalier) após a Colheita da Madeira. Amaz. *Ciênc. Desenvolv.* **1997**, *3*, 65–76.
26. Suchomel, J.; Gejdoš, M.; Ambrušová, L.; Šulek, R. Analysis of price changes of selected roundwood assortments in some Central Europe countries. *J. For. Sci.* **2012**, *58*, 483–491. [CrossRef]
27. Ribeiro, J. Desafios e Oportunidades para a Oferta de Madeira Sustentável de Origem Nativa da Amazônia Brasileira. Master's Thesis, Universidade de São Paulo, São Paulo, Brazil, 2014. Available online: http://www.florestal.gov.br/documentos/informacoes-florestais/premio-sfb/ii-premio/monografias-ii-premio/profissional-2/562-profissionais-9-monografia-1/file (accessed on 27 September 2020).
28. ITTO. Tropical Timber Market Report. 16–31 October 2010; Volume 15, pp. 1–15. Available online: http://search.ebscohost.com/login.aspx?direct=true&db=c8h&AN=2009675429&site=ehost-live (accessed on 23 October 2019).
29. Hummel, A.C.; da Alves, M.V.S.; Pereira, D.; Veríssimo, A.; Santos, D. *A Atividade Madeireira na Amazônia Brasileira: Produção, Receita e Mercados*; Imazon: Belém, Brazil, 2010; Volume 32.
30. Tollefson, J. Deforestation rates spike in Brazil. *Nature* **2016**, *540*, 182–183. [CrossRef]
31. Moraes, I.S.; Lima, A.M.M.; Adami, M.; Andrade, M.T.V.S. Canopy Opening Monitoring by Hemispherical Photographs with NDVI and LSMM, in Forest Concession Area: Mamuru-Arapiuns/PA. *Rev. Bras. Cartogr.* **2016**, *68*, 1303–1315.
32. Pinagé, E.R.; Matricardi, E.A.T.; Osako, L.S.; Gomes, A.R. Gap fraction estimates over selectively logged forests in western Amazon. *Nat. Resour.* **2014**, *5*, 969–980. [CrossRef]
33. Schwartz, G.; Peña-Claros, M.; Lopes, J.C.A.; Mohren, G.M.J.; Kanashiro, M. Mid-term effects of reduced-impact logging on the regeneration of seven tree commercial species in the Eastern Amazon. *For. Ecol. Manag.* **2012**, *274*, 116–125. [CrossRef]
34. Ter Steege, H.; Pitman, N.; Phillips, O.; Chave, J.; Sabatier, D.; Duque, A.; Molino, J.-F.; Prévost, M.-F.; Spichiger, R.; Castellanos, H.; et al. Continental-scale patterns of canopy tree composition and function across Amazonia. *Nature* **2006**, *443*, 444–447. [CrossRef] [PubMed]
35. Oliveira, L.M.; Sousa, L.K.V.; Moutinho, V.H.P.; Silva, U.C.S.; Aguiar, J.O.R.; Carvalho, J.O.P.; Melo, M.S. *Estudo Fitossiológico e Tecnológico de Novas Espécies Madeireiras em três áreas de Manejo Florestal Sustentável em Assentamentos Agrários na Região de Santarém, PA*; Relatório Técnico; CNPq: Brasília, Brazil, 2011.
36. Moutinho, V.H.P.; Couto, A.M.; Lima, J.T.; Aguiar, O.J.R.; de Nogueira, M.O.G. Energetic characterization of Matá-Matá wood from the brazilian rainforest (Eschweilera Mart Ex Dc). *Sci. For.* **2011**, *39*, 457–461.
37. Moutinho, V.H.P.; Lima, J.T.; Águiar, J.O.R.; de Nogueira, M.G.O. Scientific determination and wood anatomical features of species know in Brazilian Amazonia as matá-matá (*Eschweilera* spp.). *Rev. Cienc. Agrár.* **2012**, *55*, 134–141. [CrossRef]