REVISTA CONTRIBUCIONES A LAS CIENCIAS SOCIALES

Impacts of natural rubber export trajectories on the regional development of the Brazilian Amazon Region between 1827 and 2021

Impactos da trajetória das exportações de borracha natural sobre o desenvolvimento da Região Amazônica Brasileira entre 1827 e 2021

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ABSTRACT
This study has the following objectives: a - to estimate the instabilities and behavior of the trajectories of prices and exports of Brazilian natural rubber in each of the periods; b - to estimate forecast models of prices and exports of natural rubber from 1827 to 2021; c - to estimate the impacts of price forecast errors on the forecast errors of Brazilian rubber exports in the three periods that classify the trajectory of natural rubber exports. The research used data from the Brazilian Institute of Geography and the Brazilian Ministry of Industry and Trade. ARIMA models are estimated to predict the series of exports and prices of Brazilian natural rubber. From these models the forecast errors are generated and the influence of price forecast errors on the forecast errors of natural rubber exports is evaluated. Growth rates of exports and prices in the three periods studied were estimated, as well as the levels of instability of exports and prices. The results showed that both prices and exports of Brazilian natural rubber were quite unstable in the three periods evaluated and that the forecast errors of prices, as was one of the hypotheses of the research, interfered differently in the forecast errors of natural rubber exports and that exports had positive growth rates before and during the rubber cycle, while prices only had positive growth rates before and during the rubber cycle.

Keywords: rubber cycle, Amazon, natural rubber, synthetic rubber.

RESUMO
Este estudo tem os seguintes objetivos: a - estimar as instabilidades e o comportamento das trajetórias dos preços e das exportações de borracha natural brasileira em cada um dos períodos; b - estimar modelos de previsão dos preços e das exportações de borracha natural de 1827 a 2021; c - estimar os impactos dos erros de previsão dos preços sobre os erros de previsão das exportações brasileiras de borracha nos três períodos que classificam a trajetória das exportações de borracha natural. A pesquisa utilizou dados do Instituto Brasileiro de Geografia e do Ministério da Indústria e Comércio do Brasil. São estimados modelos ARIMA para prever as séries de exportações e preços da borracha natural brasileira. A partir desses modelos são gerados os erros de previsão e é avaliada a influência dos erros de previsão dos preços nos erros de previsão das exportações de borracha natural. Foram estimadas as taxas de crescimento das

exportações e dos preços nos três períodos estudados, bem como os níveis de instabilidade das exportações e dos preços. Os resultados mostraram que tanto os preços quanto as exportações de borracha natural brasileira foram bastante instáveis nos três períodos avaliados e que os erros de previsão dos preços, como era uma das hipóteses da pesquisa, interferiram de forma diferente nos erros de previsão das exportações de borracha natural e que as exportações tiveram taxas de crescimento positivas antes e durante o ciclo da borracha, enquanto os preços só tiveram taxas de crescimento positivas antes e durante o ciclo da borracha.

Palavras-chave: ciclo da borracha, Amazonia, borracha natural, borracha sintetica.

1 INTRODUCTION

Natural rubber is an important raw material in the world and has great relevance, especially since the period of industrial development at the end of the nineteenth century. This development, mainly of the automobile industry, caused the international demand for natural rubber to grow rapidly. According to Weinstein (1993), the result of this confluence of economic forces generated unprecedented commercial and demographic growth in the Amazon region, and made this part of Brazil one of the most promising trade centers in the country. Also according to this author, in the early 1900s, demand continued to grow, and by 1910 the price of the commodity reached its highest level.

The rubber tree (Hevea brasiliensis), from which natural rubber is extracted, is native to the Amazon region in South America, where it is found mainly in its native form. From the end of the second decade of the 19th century, when the first records appeared, and the first decade of the 20th century, natural rubber was a product of great importance for Brazilian international trade. In this period, its exports reached the same importance as those resulting from coffee. Moreover, this activity was an important source of employment and a driver of the Brazilian Amazon Region, in the various stages of preparation of natural rubber: from the bleeding of the trees, through the collection and smoking of latex, to the first processing that occurred within the areas of exploitation. (AKERS, 1912; SANTOS, 1980; LEMOS, 1983; PINTO, 1984; SILVA, 2022).

As labor was scarce in that region, the extraction of latex from rubber trees also served as a work alternative for people devastated by the frequent droughts that occurred in the semi-arid region of the Brazilian Northeast, who were recruited or migrated there spontaneously. This

contributed to increase the occupation of the Brazilian Amazon, with Brazilians coming from that region (WEINSTEIN, 1993).

Until the end of the 19th century, Brazil was the only exporter of natural rubber. In this condition of monopoly of the market, the Brazilian exporters practically defined the price that the product would be traded on the world market. With the entry into the market of natural rubber produced in Southeast Asia, at the end of the nineteenth century and the beginning of the twentieth century, and synthetic rubber, also at the beginning of that century, Brazilian exports of natural rubber from native rubber plantations, went into decline. Still, they remained at high levels until the year 1912 and, after that year, went into decline (LEMOS, 1983).

Thus, it is likely that natural rubber extracted from rubber trees in the Amazon, including those in neighboring countries, has followed the economic cycle that Homma (2014) described for extractive products. According to this author, this cycle manifests itself in three stages. In the first stage there is an expansion of production, with an increase in extraction, when natural resources are transformed into economic resources driven by the growth in demand. In the second stage stabilization will occur, because the extractive natural resource will reach the limit of its production capacity. At this stage the domestication process should already take place to also have cultivated species that should replace the extractive ones. In the third stage is the decline, which is characterized by the exhaustion of reserves caused by increased external demand. In this phase the process of domestication and cultivation should already be underway, which did not happen with the rubber produced in the native rubber trees of the Brazilian Amazon. In the case of this extractivism the situation worsened due to competition from the production of countries of southwest Asia (HOMMA, 2014; LEMOS, 1983. WEINSTEIN, 1993).

This research seeks to describe the trajectories of exports and prices of natural rubber by Brazil between the years 1827 (when records begin) and 2021. The research starts from the premise that this long period was not homogeneous with respect to both price and export variations. For this reason the export and price series of natural rubber are subdivided into three periods that follow, in some way, the trajectory described in the work of Homma (2014). The first period develops between the years 1827 until the year 1878, when the rubber produced in the rubber plantations cultivated in countries of Southwest Asia began to enter. The second period begins in 1879 and extends to 1912, a period that became known as the "Rubber Cycle"

(GONÇALVES et all, 2021). The last period of the study begins in 2013 and extends to the present day, which is characterized by the collapse of Brazilian natural rubber exports.

Thus, it is believed that the errors in the formation of expectations of natural rubber prices, in each of these stages, motivated by their instability, must have influenced the instability and the formation of expectations of demand for the commodity.

Anchored in these scenarios this study has the following objectives: a - to estimate the instabilities and behavior of the trajectories of prices and exports of Brazilian natural rubber in each of the periods; b - to estimate forecast models of prices and exports of natural rubber from 1827 to 2021; c - to estimate the impacts of price forecast errors on the forecast errors of Brazilian rubber exports in the three periods that classify the trajectory of Brazilian natural rubber exports

2 BRIEF HISTORY AND PROSPECTS

Brazil led the production of natural rubber, probably starting in the late 1700s, but the first record of its exports occurred in 1827, when Brazil exported 31 tons of the commodity. Until the late 1870s, natural rubber exports were totally dominated by Brazilian production from the native Amazonian rubber trees. This period was characterized by low levels of production, productivity, labor shortages, and high production costs. This translated into the high prices at which natural rubber was sold until the year 1910. (AKERS. 1912; COLLIER, 1968; SANTOS, 1980; DEAN, 1987; SUDHEVEA, 1983; WEINSTEIN, 1993; BARHAM & COOMES, 1994: FRANK & MUSACCHIO, 2022; SILVA, 2022;).

In 1879/1880 the production of natural rubber produced from rubber plantations grown in Southeast Asia, with higher productivity, and lower costs, began to enter the market, stimulated by the nascent automobile industry. In this phase the world production grew quite significantly and the Brazilian production also participated in this phase with a growing expansion of exports, although already with evident loss of competitiveness in terms of productivity per worker and per trees harvested. However, exports in this period had a great contribution to the accumulation of foreign exchange and the formation of wealth in the country. The exportation of natural rubber extracted from the native rubber trees in the Amazon region transformed small cities of the time, such as Belém and Manaus, into major centers, which were even compared, in the early 1900s, to European cities like Paris. It was due to this generation of

wealth that the years from 1879 to 2012 became known as the "rubber cycle" (CAETANO, 2021; CARDOSO *et al.*, 2021; SANTOS, 1980; WEINSTEIN, 1993).

In 1913, natural rubber production in Southeast Asia surpassed rubber production in Brazil. Also in 1913 natural rubber prices began to fall, initially quite rapidly (from 1913 to 1947), and then remained low from 1948 to the present day (AKERS. 1912; CARDOSO *et al*., 2021; COLLIER, 1968; SANTOS, 1980; LEMOS, 1983; WEINSTEIN, 1983; DEAN 1987; PANDOLFO, 1994; MORALES, 2002; OLIVEIRA *et al*., 2012).

The abolition of slaves in 1888 did not have much influence on rubber production, since slaves in the Amazon, according to Santos (1980), were used more for domestic services and food production. Furthermore, because no new slaves had entered the Amazon since 1834, due to the intense surveillance of the English navy in the Atlantic.

However, the fall of the monarchy in 1889 had a great influence on the collection of taxes on rubber exports. With the decentralization resulting from the federalism implanted in the Republic, the Brazilian states were able to keep part of the taxes collected, which previously went directly to the central government. This provided greater freedom for the local governments of the Amazon Region states to apply internally (WEINSTEIN, 1993).

It was also during this period that there was a search for new areas of native rubber. This caused explorers from the Brazilian Amazon, the so-called "rubber soldiers", to enter the Amazonian part neighboring the territory of Bolivia, causing a conflict that was only resolved with the signing of the Treaty of Petropolis in 1903, which gave rise to the current state of Acre (HOMMA, 2014; JORNAL DO BRASIL, 1904).

As noted by Machado *et al*. (2012), the amount of rubber exported only increased at the beginning of the 20th century. In 1901, the product already had a relevant participation in Brazilian exports (21%) and, in the following years, it only increased in such a way that, in 1910, it came to represent 40% of everything that was exported by the country. It was also important in the colonization process of the Amazon region, both at the end of the Empire and the beginning of the Republic (1889), and in the colonization policies adopted for the Amazon, by recruiting workers from the Northeast region, especially in periods of drought (BABCOCK, 1966; HOMMA, 2014; MACHADO *et al*. 2012 PINTO, 1984; SANTOS, 1980).

With the imminence of the outbreak of World War I (1914-1918), Russia and Germany adopted the strategy of investing in research to develop synthetic rubber and stop depending on

the production coming from Southwest Asia. Between the First and Second World War there were many advances in the production of synthetic rubber, and the technique was already mastered for large scale production. The advent of World War II (1939 to 1945) forced the American government to invest massively in the production of synthetic rubber. Germany, for the same reasons, also increased the production of synthetic rubber (SANTOS, 1980; MORALES, 2002; FURTADO, 2005).

The demand for rubber in World War II was enormous and the product became a strategic material. The United States, in 1939, was already working with steel, oil and rubber as strategic inputs. In 1940, with the advance of the Germans, the president of the United States, Franklin Roosevelt, drew up a defense plan, where rubber played a key role. At first, the country began to buy and stock rubber and rationalize its use. However, when Japan closed the borders of Southeast Asia, cutting off the supply of natural rubber to the Americans, the country put the rubber plan into execution. One of the plan's measures was to accelerate the production of synthetic rubber. Another was to encourage the production of natural rubber in regions where the warring countries had no dominion, and the Brazilian Amazon was chosen to fulfill this role (PAULA, 1980; MORALES, 2002; PINIZZOTTO & JIANFENG 2021).

The rubber produced from native trees of the Brazilian Amazon, using low technology, with high production cost, lost its ability to compete in the international market, already at the end of the nineteenth century, with the entry of rubber grown in southwest Asia. Even so the Brazilian government, as well as businessmen, did not immediately take any initiative to try to cultivate the tree in Brazil, even with the evident worldwide increase in demand for rubber. Perhaps because they believed, according to Morales (2002) and Fonseca (1970), that it would be impossible to overproduce the commodity to the point where the supply of rubber would grow to the point of causing a collapse in prices. Or perhaps because it takes 30-35 years for a rubber tree to reach the stage of full production. This may have been the cause of the discouragement of its cultivation at that time (ESPERANTE, 2018; FRANK & MUSACCHIO, 2022).

According to Gonçalves *et al*. (2021), it was in Bahia, in 1908, at the Escola Agrícola de São Bento das Lages, located in the Recôncavo Baiano, that the first rubber planting was done without much success. Later, in 1917, in São Paulo, on the Gavião Peixoto farm, another attempt was made to grow rubber trees. However, the greatest experience with cultivated rubber was Ford's, between 1927 and 1945, with "Fordlândia" in Pará. However, the project was not

successful, due to the "rubber leaf disease", caused by the fungus "Pseudocercospora ulei". As there was no technology to combat the fungus, the rubber trees showed great losses in estimated production. For this reason, the project failed.

After Ford's failure, the Fordlândia project was transferred to the Brazilian government. Years later a new attempt was made to cultivate natural rubber in the Amazon. This time at the then Instituto Agronômico do Norte (IAN), created in 1939 in Belém, PA, which began its research work in 1941 (HOMMA, 2014; GONÇALVES *et al*. , 2021).

According to Martin and Arruda (1993) the production of cultivated rubber in Brazil began to take momentum from the year 1975. In that year Brazil produced 19,348 tons of rubber, of which 12% came from cultivated trees. Only in 1990 did the production of cultivated rubber exceeded in percentage the production of rubber from native rubber trees. In that year, Brazil's natural rubber production of 30,827 tons, 54%, came from cultivated areas.

Currently, the following institutions, among others, stand out in research with the cultivation of natural rubber in Brazil: Rural University of the Amazon (UFRA), located in Belém in the state of Pará. The Brazilian Agricultural Research Corporation (EMBRAPA), mainly at the National Rubber Tree Research Center located in Manaus in the state of Amazonas; and the Campinas Agronomic Institute (IAC) located in the city of Campinas, São Paulo. (HOMMA, 2014).

According to the IBGE, in 2021 Brazil produced 376,000 tons of coagulated latex on 163,000 hectares in 2020, therefore with a productivity of 2,306 kg/hectare, predominantly from cultivated rubber plantations. The State of São Paulo had the highest production (66.3%). The states of Minas Gerais, Goiás, Bahia, Mato Grosso do Sul, Mato Grosso, and Espírito Santo together produced 31.3%. The remaining 2.4% came from the states of the Amazon Region (EMBRAPA, 2021; IBGE, 2021; SANTANA *et al*, 2018).

In summary, the trajectory of exports and prices of natural rubber produced in the Brazilian Amazon can be described in three periods: Before the rubber cycle, in which the country was hegemonic in the production and export of the commodity. The Rubber Cycle which began in 1879 and lasted until 1912. The third period, which will be identified in this research as the post-rubber cycle, begins in 1913 and extends to the present day. During this long period, in the early 1950s, Brazil became a net importer of natural rubber (SANTOS, 1980; LEMOS, 1983;

JACKS, 2019; HOMMA, 2003; ESPERANTE, 2020, CAETANO, 2021; CARDOSO *et al*, 2021).

3 METHODOLOGY

The variables used in the research were: quantities exported and prices of rubber in Brazil, between the years 1827 and 2021. The information for the years 1821 to 1987 were taken from IBGE (1990), while the information for the years 1988 to 2021 were extracted from COMEX STAT (2022). During this period, according to the Central Bank of Brazil (BACEN, 2007), there were nine (9) different types of currencies in Brazil. The prices were updated to 2021 Real, using the general price index, domestic availability (IGP-DI) of the Getúlio Vargas Foundation. Then the average exchange rate of the end of 2021 was taken and the whole price series was converted into 2021 US Dollars.

3.1 METHODOLOGIES TO REACH THE FIRST OBJECTIVE

The instabilities of natural rubber exports and prices were measured by the coefficient of variation (CV), which measures the percentage ratio between the standard deviation and the mean of a random variable. The larger the magnitude of the CV, the more unstable, or more heterogeneous, will be the distribution of the observed values of the random variable around its mean (SANTOS & DIAS, 2021).

To assess how the trajectories of natural rubber exports and prices have happened, we estimate instantaneous geometric rates of growth (GGR). In general, the GGR, or acceleration/deceleration rate of a continuous random variable (Y_t), by definition, is expressed by the following equation:

$$Y_t = \rho_0.e^{(\rho 1T + \lambda t)}$$

In the equation, "e" is the base of natural logarithms; $d[\log(Y_t)]/dT = \rho_1$ multiplied by 100 is the instantaneous GGR associated with the variable (Y_t); T = 0, 1, 2, ...,n). Its values will be defined in each of the periods in which the trajectories of exports and prices of natural rubber are studied. The random term (λ_t) assumes the assumptions of being white noise (WOOLDRIDGE, 2015).

3.2 METHODOLOGY TO ACHIEVE OBJECTIVE B: ESTIMATE FORECAST MODELS FOR NATURAL RUBBER PRICES AND EXPORTS FROM 1827 TO 2021

The predicted value (Y_P) of a random variable Y_t, will differ from its observed value due to the occurrence of random factors (ξ_t), which can be caused by exogenous variables. This information can be summarized by Equation (1):

$Y_t - Y_P = \xi_t$; or, similarly, $Y_t = Y_P + \xi_t$ (1)

For this study the random variable (Y_t) can be either the quantity exported annually in tons of natural rubber, or its price in USD per kilogram. It is for these variables that the forecasts will be created in this study, using the Box and Jenkins model. The formulations proposed by Box & Jenkins (1976) - ARIMA (Auto Regressive Integrated Moving Average) - are mathematical structures that aim to capture the behavior of a random variable that has values distributed over time series. It is considered that the time series Y_t can be represented as follows:

$$Y_t = \mu + \sum \psi_k . u_{t-k} = \mu + \psi(B).u_t \quad (2)$$

Where the linear filter ψ is defined by:

$\psi(B)=\theta(B)/\phi(B)$ (3)

The terms in equation (3) are defined by the following polynomials:

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots . - \theta_q B^q \text{ and } \phi(B) = 1 - \phi_1 B - \phi_2 B_2 - \ldots - \phi_p B^p$$

Defining $\tilde{Y}_t = Y_t - \mu_t$, where $\tilde{Y}_t$ is the expected value of Y_t, we obtain the following transformation:

$$\phi(B)\tilde{Y}_t = \theta(B)u_t \quad (4)$$

In equation (4), u_t is a generally Gaussian white noise. To do so, it must satisfy the following conditions: i) $E(u_t) = 0$; ii) $E(u_t^2) = \sigma(u_t)^2 < \infty$; e iii) $E(u_t, u_{t+k}) = 0$, para $k = \pm1, \pm2, ...$ (BOX, JENKINS, 1976; WOOLDRIDGE, 2015; CAMELO *et al*., 2018; BOX *et al*., 2015.)

According to Box, Jenkins, (1976), equation (4) is called ARMA(p,q) and can be rewritten as follows:

$$\tilde{Y}_t = \theta(B)\phi^{-1}.(B)u_t \qquad (5)$$

The types of Box and Jenkins models are:

(i) - moving average (MA) models: are those in which $\phi(B) = 1$ and are said to be MA(q).

ii) - autoregressive models (AR): are those where $\theta(B) = 1$ and are said to be AR(p). These models are so called because Y_t, at moment t, is a function of the values of this variable at moments prior to t.

iii) Autoregressive moving average models (ARMA): are those that have one part (AR) and one part MA and have the notation ARMA (p,q).

Before applying the ARMA model, it is necessary to evaluate whether the series being analyzed are stationary. This is done by looking at the graph of the series and analyzing the autocorrelation and partial autocorrelation functions (LIET *et al*., 2019). Another way to check whether the series is stationary is to estimate the first-order AR model over the original series and test whether the coefficient ϕ is less than 1. A stochastic process $Y_t = \psi(B)ut$ will be stationary if:

$\psi(B) = \Sigma_{k=0}^{\infty}\psi_k(B)^k$ converges to $|B| < 1$.

If the time series under study is not stationary, it must be transformed to become stationary. The autocorrelation function between the residuals is estimated. If the autocorrelation function stabilizes with the first difference, it can be assured that the series has become stationary. Otherwise, the second, third or more differences should be performed to search for stationarity. In general, series need no more than three lags to become stationary. In this case, the model is called an autoregressive moving average integrated model (ARIMA). "I" is the number of lags needed for the series to become stationary (LI *et al*., 2019).

3.2.1 Tests to assess the qualities of the fits

When choosing statistically appropriate models, one of the criteria was to look for the most parsimonious ones, from the perspective that the smaller the number of estimated parameters, the better the model fit. There are several tools to evaluate the quality of fit and performance of a predictive model, the most relevant measures to make this measurement, and which were used in this research, are: R-squared test (R2); Bayesian Information Criterion (BIC); Mean Absolute Percentage Error (MAPE); Ljung-Box test, and Pearson's correlation coefficient between the observed and the predicted series. All estimates in the paper were performed using Statistical Package for the Social Sciences (SPSS) software, version 27 (BOX & JENKINS, 1976; BOX *et al.*, 2015; WANG *et al.*, 2018; WOOLDRIDGE, 2015).

3.3 METHODOLOGY TO ACHIEVE THE THIRD OBJECTIVE: TO ESTIMATE THE IMPACTS OF PRICE FORECAST ERRORS ON THE FORECAST ERRORS OF BRAZILIAN RUBBER EXPORTS IN THE THREE PERIODS OF THE BRAZILIAN NATURAL RUBBER EXPORT TRAJECTORY

We define ϵ_t as the errors generated in the export forecast model and εt as the errors generated from the natural rubber price forecast model. To estimate the impact of the price forecast errors (ε_t) on the natural rubber export forecast errors (ϵ_t) the following exponential equation is used:

$$|\epsilon_t| = \beta_0.|\varepsilon_t|^{\beta 1} e^{\upsilon t} \qquad (6)$$

In equation (6), the random terms (ϵ_t; ε_t) are estimated in positive and negative values. The research seeks to assess the magnitudes of the impacts of these deviations on natural rubber exports and prices, regardless of the signs. Therefore, their absolute values are taken. The coefficient β_0 is the log-linear parameter of the equation; the constant "e" constitutes the base of natural logarithms; υ_t is the random term associated with equation (6); the coefficient β_1 is defined as follows:

$$\beta_1 = (\alpha_0 + \alpha_1 D1 + \alpha_2 D2) \qquad (7)$$

In equation (7), the variable D1 = 1 in the years before the natural rubber cycle (1827 to 1878) and D1 = 0 in the other periods. The variable D2 = 1 in the post rubber cycle period, from 1913 to 2021; D2 = 0 in all other years. When D1 = D2 = 0 was the rubber cycle period from 1879 to 1912. Thus, equation (7) can be rewritten as follows, already applying the natural logarithm operator:

$$\ln(|Є_t|) = \ln(\beta_0) + [(\alpha_0 + \alpha_1 D1 + \alpha_2 D2)]\ln(|\varepsilon_t|) + \upsilon_t \quad (7a)$$

In equation (7a), the coefficients α_0, α_1 and α_2, respectively, measure the sensitivities (elasticities) of the forecast errors of Brazilian natural rubber exports in response to the forecast errors of their prices: during, before and after the cycle of Brazilian natural rubber exports.

4 RESULTS AND DISCUSSIONS

The results found to achieve the first objective show, as expected, that exports and prices of natural rubber were quite unstable in the three periods in which the trajectories of these variables were divided in this research. In the period before the rubber cycle, from 1827 to 1878, the average exports were 2130.27 tons of natural rubber with a CV=100.07%. The prices in this period had an average of USD30.25/kg with a CV = 20.20%, showing the lower instability of prices. This is the period when only Brazil exported the product.

In the period called rubber cycle, the average of Brazilian exports reached 21,140.15 tons at an average price of USD24.72/kg. The exports of this period had a CV=53.32%, high, but the lowest observed in the three periods. The prices had a CV=27.97%.

In the post rubber cycle, from 1913 to 2021, both exports and prices of natural rubber had the highest instability CV=122.76% and CV = 60.68%, respectively. Average exports for this period fell to 8141.52 tons and average prices stood at USD4.78/kg. Estimates of the GGRs for exports and for natural rubber prices in each of the periods studied are shown in Table 1:

Table 1 - Estimates of geometric growth rates (GGR) for exports and prices of Brazilian natural rubber before the cycle, during the cycle, and after the rubber cycle.

	Natural rubber exports (tons)				
	Adj. R^2	Constant		Regression Coef.	
Periods	Value	Value	Sign	Value	Sign
Before the cycle (1827 – 1878)	0,938	4,441	0,000	0,095	0,000
During the cycle (1879 – 1912)	0,914	8,783	0,000	0,061	0,000
After the cycle (1913 – 2021)	0,397	10,498	0,000	-0,059	0,000
	Natural rubber prices (USD/kg)				
	R^2	Constant		Regression Coef.	
Periods	Value	Value	Sign	Value	Sign
Before the cycle (1827 – 1878)	0,031	3,468	0,000	-0,003	0,110
During the cycle (1879 – 1912)	0,350	2,877	0,000	0,018	0,000
After the cycle (1913 – 2021)	0,284	1,907	0,000	-0,009	0,000

Sources of the original data: IBGE, 1990; MIC, 2022.

From resuls shown in Table 1, Brazilian natural rubber exports experience the highest GGR in the years before the rubber cycle, when Brazil was the sole exporter of the product. In those years exports expanded at a GGR of 9.5% annualy and prices were practically stable, since the GGR was not statistically different from zero.

During the rubber cycle, the GGR of Brazilian natural rubber exports was also high (6.1% p.year.). In this period, as already discussed in this paper, Brazilian exports of the commodity experienced competition from natural rubber grown in Southeast Asian countries, which had higher productivity per rubber tree and per worker, but still expanded at a significant rate. During this period, prices grew at an average rate of 1.8% per year, which peaked in 2010. These 32 years were called the rubber cycle, because it was and classified by authors like HOMMA (2003) as "Bele Epoque". There the cities of Belém and Manaus were consolidated and still today keep signs of the progress caused by the "golden age" for exports and prices of Brazilian natural rubber (Table 1).

During the long period from 1913 to 2021, some facts occurred that interfered with the world market for natural rubber, among them: a greater and increasing participation of natural rubber grown in Southeast Asia; two world wars; the emergence of synthetic rubber. Brazilian natural rubber continued to be produced mainly from raw material extracted from native trees in the Amazon region until the early 1970s, with low productivity.

The decadence of Brazilian naural rubber exports manifests itself in an evident and continuous way, which seems irreversible. Over this long period the production and productivity of rubber grown in Asia have made Brazil's position in this market unsustainable. This

contributed to the fact that the prices of natural rubber exported by Brazil showed an average annual decline of 0.9%, while exports also had an average annual decline of 5.9% (Table 1).

4.1 THE RESULTS FOUND TO ACHIEVE THE SECOND OBJECTIVE: ESTIMATION OF THE MODELS FOR THE FORECASTS OF EXPORTS AND PRICES

In Table 2 are presented the results found in the creation of the models used for the forecasts of exports and prices of natural rubber between the years 1827 and 2021. These results showed that both the export and price series were not stationary and needed a difference to make them stationary. Both estimated models were ARIMA(0,1,1) at their original values, without the constant terms.

Table 2 - Models fitted to Brazilian export (EX) and natural rubber price (PR) forecasts from 1827 to 2020

Fitted model	ARIMA(0,1,1) (EX in ton)	ARIMA(0,1,1) (PR in USD2020/kg)
Direrence	1,0	1,0
MA lag1	0,189*	0,224*
R^2	0,945	0,923
MAPE	53,740	20,230
Normalized BIC	15,709	2,537
Ljung Box	36,169^{NS}	25,569 ^{NS}
$r_{Pearson}$	0,997	0,998

Original data sources: IBGE, 1990; MIC, 2022.*Significant to less than 1% error; NS: Not significant to at least 25% error,

As can be seen in the evidence shown in Table 2, the adjustments found were parsimonious and proved robust from the statistical point of view, which allows the projections to be made and the analyses proposed in this research to be performed. The adjusted coefficients of determination were 0.945 and 0.923, respectively, for the forecast models of exports and prices of natural rubber produced in Brazil, for the period 1827 to 2021. The other statistics associated with the adjustments such as MAPE, Normalized BIC and the Pearson correlation coefficients estimated to evaluate the adequacy of the predicted values to the observed ones, were also robust, from a statistical point of view (BOX *et al*., 2015; NASCIMENTO CAMELO *et al*, 2018; GUJARATI, PORTER, 2011; PINHEIRO *et al*, 2021; VANDEPUT, 2021; WANG *et al.*, 2018; WOOLDRIDGE, 2015).

4.2 RESULTS FOUND TO MEET THE THIRD OBJECTIVE: TO ESTIMATE THE IMPACTS OF PRICE FORECAST ERRORS ON THE FORECAST ERRORS OF BRAZILIAN RUBBER EXPORTS IN THE THREE PERIODS OF THE BRAZILIAN NATURAL RUBBER PRODUCTION/EXPORT PATHWAY

The results found to find estimates of elasticities that assess the impacts of price forecast errors on those arising from rubber exports in each of the periods analyzed are shown in Table 3.

Table 3 - Estimates of the impacts of price forecast errors on natural rubber exports in Brazil between 1827 and 2020

Variables	Coefficient	Sign.	Elasticities
Constant	8,208	0,000	-
Period 1827 - 1878	0,979	0,011	0,578
Period 1879 - 1912	-0,401	0,100	-0,401
Period 1913-2021	0,858	0,006	0,457
Adjusted R^2	0,810		

Original data sources: IBGE, 1990; MIC, 2022.

The results shown in Table 3 confirm the assumptions that guided the construction of this research. One of these assumptions is that the forecast errors of prices interfered with the forecast errors of natural rubber exports. The other assumption was that these interferences were different.

This evidence suggests that when Brazil was hegemonic in natural rubber exports in the years before the rubber cycle, price forecast errors had the largest impact on export forecast errors as measured by the elasticity of 0.578 (Table 3).

Throughout the rubber cycle, when prices of the product became competitive with the entry of the product grown in the rubber plantations of Southwest Asia, the elasticity was negative and with the smallest magnitude among the three periods. Because of this competition, prices grew at a lower rate than they did in the period before the cycle (Table 2) and, probably, exporters captured this phenomenon and overestimated exports, motivated by a slower expansion of these prices (Table 3).

In the post-rubber cycle phase, as seen in the discussion, the export capacity of Brazilian natural rubber became unsustainable, due to historical factors that occurred in the period, among them, the most relevant were the emergence of rubber grown in the countries of Southwest Asia and the emergence of synthetic rubber. The conjunction of facts of this period must have contributed to the forecast errors of exports due to the forecast errors of natural rubber prices had a positive magnitude of 0.457.

This evidence also suggests that there has been a kind of accommodation, both of natural rubber producers and policy makers, since for over a century the situation of rubber production in Brazil has only deteriorated.

5 CONCLUSIONS

The production and export of natural rubber extracted from native rubber trees was of great importance for the economic and social development and for the occupation of Brazilians from cities and states in the Amazon Region, especially in the 19th and early 20th centuries.

There are reports that in the 1700s and early 1800s the extraction of natural rubber in that region already occupied people. However, it was only after 1827 that Brazilian exports of this commodity began to be recorded. It generated enough wealth to transform cities like Belém (now the capital of the state of Pará) and Manaus (now the capital of the state of Amazonas), which in the rubber cycle, between 1879 and 2012, were even compared to already exuberant cities in Europe, like Paris.

The production of natural rubber in the Amazon also played an important role in the occupation of the population of the Northeast that was always hit by periodic droughts. Mainly northeastern men were recruited or attracted to work in the Amazon region in all phases of natural rubber production.

One can characterize the Brazilian rubber production in three periods, from the time when the first record of export was obtained: 1 - Before the Rubber Cycle, which occurred between 1827 and 1878. In this period Brazil had a monopoly on the export of the commodity, all of it extracted from rubber trees in the Amazon. 2 - During the Rubber Cycle, which occurred between 1879 and 1912. In this period natural rubber grown in Asian countries entered into the market. This period was also characterized as a phase of sharp growth in commodity prices that peaked in 2010. This phase ended in 2012 when Brazil recorded its highest volume of natural rubber exports. 3 - Post natural rubber cycle phase that began in 2013 and extends to the present days. This long period saw two world wars, the emergence of synthetic rubber, the increasing advance of cultivated rubber in Southwest Asia, and the first attempts to cultivate rubber in Brazil, still in the Amazon. However, the producers were faced with a disease known as "rubber leaf disease" which was unknown to researchers and therefore had no way to control. In this post-rubber cycle

phase there was an evident decline in Brazil's participation in this market, so that, in the early 1950s the country became an importer of natural rubber.

The research sought and succeeded in building parsimonious models to capture the trajectories of exports and prices of natural rubber as well as generate the forecast errors of prices and forecast errors of exports of natural rubber during all these years (1827-2021). In this part the research attempted to prove the assumption that price forecast errors differentially affected the three periods in which the research was constructed.

The overall conclusion of the research is that probably the decline in the export of natural rubber produced in the Brazilian Amazon was mainly due to four reasons: 1 - the low production and productivity of the native rubber trees of that region, from which rubber was extracted in Brazil; 2 - the entry into the market of rubber grown in Southeast Asia from the end of the 19th century; 3 - the entry of synthetic rubber, mainly during the first and second world wars; 4 - the negligence with which the producers/exporters, as well as the Brazilian policy makers, observed the evident advance of natural rubber production from Asian plantations.

The question that can be asked is : Why didn't they take consistent measures for Brazil to start cultivating the native Amazonian tree, as soon as the Asian production of natural rubber started competing with the Brazilian one?

The attempts that were made when the market dominance of rubber produced in rubber plantations in Asia was already widespread, seemed to political decision makers that the situantio was not to be anchored on a sustainable technical basis. To complicate the process, the cultivation of rubber trees in the Amazon proved to be unviable in the first attempts, due to the appearance of "leaf spot disease" caused by a fungus that producers and policy makers did not know about, and it seems that researchers at the time had no incentive to advance their knowledge of the problem and, for these reasons, could not control it.

More recently, rubber plantations have developed in states outside the Amazon region. Currently, the states of Sao Paulo, Minas Gerais, Goias, Bahia, Mato Grosso, Mato Grosso do Sul and Espirito Santo, are the states that cultivate the rubber tree successfully.

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