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Pine Log Price Changes in South America: A Comparison of Argentina, Brazil, and Uruguay Markets

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ABSTRACT

We analysed the degree of price cointegration among pine log markets in northeast Argentina, Paraná State of Brazil, and Uruguay by examining price series over the period 2008–2020. We evaluated the cointegration of price series of the same product through the study regions. In the same way, we analysed the cointegration of price series of different products within the same zone. We found market cointegration for medium sawlogs and export logs, between Paraná and Uruguay and between Misiones and Uruguay. In addition, pairwise groups of sawlogs, pulpwood and woodchips were cointegrated in sawmill and pulp mill-markets. In regions without pulp mills, the prices of sawlogs and veneer logs of similar size and quality were cointegrated. These results reveal the existence of a dynamic of substitution. Usually, veneer logs are delivered to sawmills. However, in some situations, small sawlogs may be downgraded and sold to pulp mills.

Keywords: Southern Cone, cointegration, sawmills, pulp mills, sawlogs, pulpwood

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1 Introduction

In the last few decades, new investments increased the area of forest plantations and the number of sawmills and pulp mills in the Southern Cone. The area that comprises Uruguay, three states of South Brazil, and two provinces in the northeast of Argentina contains 2.55 million hectares (ha) of *Pinus* spp., and 7.54 million ha of Eucalyptus (Sistema Nacional de Informações Florestais, 2017). Cubbage *et al.* (2020) reported that for *Pinus* spp. and *Eucalyptus* spp., pulpwood stumpage prices ranged from \$5 to \$30 USD/m^3 in the Southern Cone. The prices of the largest diameter *Pinus* spp. sawlogs ranged from \$16 USD/m^3 in Uruguay to \$53 USD/m^3 for good markets in Chile. Brazil and Argentina sawtimber prices were \$30 USD/m^3.

The fast-growing pine plantations in the Southern Cone produce logs for sawtimber, veneer, pulp, MDF (Medium Density Fibreboard), and energy. However, industry composition evidences differences among forest markets. In Uruguay and Corrientes, a province in Argentina, sawmills and log exports demand pine logs. On the other hand, there is no market for pulpwood logs because of the lack of pulp mills. Nevertheless, in Paraná State of Brazil and Misiones province of Argentina, the demand is diversified by sawmills, pulp mills, fibreboard mills, and biomass energy companies.

Analysing the degree of cointegration of the pine log markets in these three countries is important to understand how the characteristics of each economy, the regulations on the trade of logs, and the different industrial sectors determined the prices of pine logs over the last decade. In addition, investigating the cointegration relations within the same region will help understand the differences in the prices of sawlogs and pulpwood.

Broz and Viego (2014) analysed the evolution of log prices in the Northeast Argentinean pine market. They used ARIMA models with a good prediction capacity for nine months, but with a limited capacity to explain small variations. Kanieski da Silva *et al.* (2020) found different levels of market cointegration in the south of Brazil for pine stumpage prices, including pulpwood, sawlogs and veneer logs. Also, they found a fast adjustment to a new market equilibrium after a shock, explained by the intensive nature of planted forests in Brazil. In this situation, fast growth caused diameter class to change faster than in other countries.

There are two main forest markets according to their industry composition and market efficiency. When the price series are non-stationary, the market would be efficient. Yet when they are stationary, the market is inconsistent with the weak form of efficient market hypothesis, where future prices cannot be predicted by analyzing prices from the past. This inefficiency allows for profitable arbitrage and implies a sub-optimal economic outcome (Murray and Prestemon, 2003). The pine log market in Uruguay and Corrientes comprises mainly sawmills, with competition for goods and prices, thus it is likely associated with an efficient market.

Instead, when the forest sector is composed of only a few pulp mills and medium and small sawmills, it is likely associated with an oligopsony market, as in Paraná State of Brazil and Misiones Province of Argentina. In this type of market, the cellulose industries have a dominant position, controlling most of the demand side for price and consumption of pulpwood logs and influencing the prices of all sawlogs products. Murray and Prestemon (2003), Kanieski da Silva *et al.* (2020), and Chudy and Hagler (2020) stated that this pattern could change over time, even in the same region. One of the most widely used tests for measuring market efficiency in time series analysis is the ADF (Augmented Dickey-Fuller). The ADF test evaluates the null hypothesis that the series has a unit root, and therefore is non-stationary. If the hypothesis is rejected, the price series is stationary and may be consistent with an inefficient market.

Markets with non-stationary price series could be cointegrated. In these cointegrated markets, the Law of One Price (LOP) may be satisfied. The LOP implies that a product price should be the same in different markets, even throughout different production facilities, if the same currency is considered (Murray and Prestemon, 2003; Morales Olmos and Siry, 2018). When a market meets these conditions, the price differences should be associated only with the transaction and transport costs from production companies to consumption points. The fulfilment of the LOP between the log markets of a group of forest countries would indicate that the log prices in these countries move together (Shahi *et al.*, 2006). Violating the LOP implies an opportunity for arbitrage profits. Transportation of goods from low-priced to high-priced regions results in a sub-optimal market performance (Murray and Prestemon, 2003; Kanieski da Silva *et al.*, 2020). This theory presumes that there are relatively free markets and free trade, which we examine in part in this research.

We analyze the price series dynamics of pine sawlogs and pine pulp logs in the northeast of Argentina, Paraná State of Brazil, and Uruguay forest markets. In particular, we seek to determine the degree of price cointegration between these markets and for different products within each market.

2 Materials and Methods

2.1 The Forest Markets

In Argentina, the provinces of Misiones and Corrientes concentrate 95% of the country's pine production (Figure 1). Plantations of *Pinus taeda* and *Pinus elliottii* were established from the 1980s onwards taking advantage of state

Figure 1: Map of the study area: Uruguay, the provinces of Misiones and Corrientes in Argentina, and the State of Paraná in Brazil.

incentive mechanisms for forestation and foreign capital investment. However, since 2008 the area of new forestation in Misiones and Corrientes has shown a rapid decline (Denegri *et al.*, 2017). There are two pulp mills and one MDF industry in Misiones province. These industries consume logs from 8 cm up to 18 cm in the small end diameter (SED). The log supply to these mills comes from their own plantations, but they also buy at the open market. In contrast, most of the sawmills and veneer companies are supplied from the log markets.

Paraná is the most important state in the Brazilian pine production sector, having 673,769 ha of pine plantations. Santa Catarina, Rio Grande do Sul, and São Paulo contain the rest of the pine forested area (Figure 1). Pine plantations produce logs for the pulp mills, sawmills, fibreboard mills, and veneer companies (Table 1). These pine plantations areas have decreased 2% per year in response to the growth of the area planted with eucalyptus (Indústria Brasileira de Arvores (IBÁ), 2019).

In Uruguay, pine log production supplies wood to sawmills, a plywood mill and chip energy factories. There are no long fibre pulp companies in Uruguay. The biggest sawmills have their plantations within a 100 km radius. Additionally, in the departments of Rivera, Tacuarembó, and Cerro Largo there are several small sawmills. In the last decade, new short fibre pulp mills

Table 1: Main Southern Cone Pine Forest Market Description.

Characteristics	Argentina	Brazil	Uruguay
Coniferous plantation area [ha]	800,000	1,570,000	180,000
Harvested volume [m^3/year]	7,500,000	45,000,000	2,444,000
Sawmill logs demand [t/year]	4,868,849	–	1,185,723
Cellulose logs demand [t/year]	4,300,000	9,250,000	0

Source: Own elaboration from Ministerio de Agroindustria (2015), Sistema Nacional de Informações Florestais (2017), Associação Paranaense de Empresas de Base Florestal (2018), Uruguay XXI (2019), and Indústria Brasileira de Arvores (IBÁ) (2019).

and sawmills drove forest demand. They caused a noticeable decline in the area planted with pine in favour of eucalyptus plantations. In addition, northern Uruguay exports a large proportion of their production as roundwood. In 2018 pine log exports reached 2 million tons and USD 178 million, and the destinations of the logs export are China (90%), Vietnam, India, and Portugal. Export to China has increased by 42% between 2017 and 2018 (Uruguay XXI, 2019).

2.2 Data

In Argentina, we obtained the series of log prices in nominal Pesos from the Misiones Forest Engineer Association monthly bulletin (Colegio de Ingenieros Forestales de Misiones, 2021). These data are collected from the voluntary contributions of the forest companies of Misiones and Corrientes and show the prices of different forest products in both provinces. For this research, we used prices at the mill yard of pulpwood, woodchips and sawlogs by product class and log size. These monthly price series cover the period between January 2008 and December 2020.

In Brazil, we obtained sawlog nominal prices in Reales at the mill yard from the Secretaria da Agricultura e do Abastecimento (2021) semi-annual bulletin. These price series were derived from the records of prices received by producers when selling their wood. The values used correspond to the state average, weighted by the production for each department. The report includes biannual data from May-September and October-April between 2008 and 2020. The price series include only sawlogs and veneer logs from 8 up to 45 cm SED. We estimated monthly data by a linear interpolation.

In Uruguay, the Dirección General Forestal (Ministerio de Ganadería, Agricultura y Pesca, 2021) contributed with export records between 2010 and 2020, compiled by trade consultants Descartes-Datamyne Latam (https://www.datamynelatam.com/). These data contain monthly records of logs shipped to overseas destinations. They also include shipments to sawmills located in the Rivera free-trade zone. The data indicated the volume and price of the sawlogs involved in every transaction. We systematized the data to obtain the monthly average price, weighted by the transaction volume of each destination. This price series does not discriminate products by diameter class. However, all logs were more than 18 cm in diameter and between 4.95 and 5.9 m in length.

We used the prices of logs loaded on a truck at the roadside as the basis for comparison among the three countries. Log prices at the roadside include stumpage prices for timber in the woods and harvesting costs. There are substantial differences in forest stand returns in the woods (Cubbage *et al.*, 2020) and harvesting costs (Mac Donagh *et al.*, 2019) among the three countries. But, the metric of log prices is best measured as the sum of stumpage and harvesting costs, which we used.

To correct the effects of inflation, we deflated the Argentinean nominal price series, setting December 2016 as the base period (Consumer Price Index CPI, December 2016 = 845.2; Cavallo and Bertolotto, 2016). This CPI series comes from independent researchers and is considered more accurate than the official CPI series. Then, we converted real prices to USD considering the exchange rate of the Central Bank of Argentina for the base period (16.04 $ ARS/USD). This period was free of exchange rate distortions caused by government controls. To estimate the price of the logs loaded on the truck at the roadside, we subtracted transportation costs from the price paid for at the mill yards. The transport cost was estimated using the official Road Cost Model, using an assumed 100 km transport average distance for all products (Ministerio de Transporte, 2019).

Similarly, Paraná State log prices were deflated by a price index with base period December 2016 (National Consumer Price Index INPC December 2016 = 4940.8; Instituto Brasileiro de Geografia e Estatística, 2021). We consider the exchange rate of the base period (3.34 R$/USD, Banco Central do Brazil) to convert this series to USD. To estimate the prices of logs on the truck, we substracted the transport cost, 0.18 R$/t.km, assuming a distance of 100 km (Silva Lopes *et al.*, 2016).

The price series from Uruguay comes from reports in USD. We deflated them by the US average urban consumer price index (U.S. Bureau of Labor Statistics, 2021). The prices of the logs loaded on the truck were obtained by subtracting the port operation fees and transport cost from the FOB prices series. In Montevideo port the average operation fee was $22 USD/t. The transport cost from the Tacuarembó forest area to Montevideo port was $22.5 USD/t, and to Rivera free-trade zone was $5.5 USD/t.

The price series analysed contain sawlogs, pulpwood, and veneer logs. The diameter of a sawlog product determines its price. Table 2 presents the characteristics of the products analysed and the names used to identify them in this article.

Table 2: Characteristics of the Products Included in the Price Series.

Product	Use	Small end diameter (cm)
Veneer logs	Veneer production for plywood boards.	>35
Sawlog 4	Timber production in sawmills	30–45
Sawlog 3		25–30
Sawlog 2		18–25
Sawlog 1		<18
Pulpwood	Cellulosic pulp and fibre board production.	8–18
Woodchips	Fuel for biomass energy production.	–

2.3 Cointegration Analysis

Timber price series do not have a well-defined mean or variance and tend to drift randomly. Usually, they are non-stationary. Therefore, market shocks generate a persistent effect in price series, and then they do not return to their previous long-run trend. An initial condition for two cointegrated price series is that they are non-stationary series (Engle and Grange, 1987). There may be a linear combination of these series, and then they could be cointegrated (Chudy and Hagler, 2020). Cointegration is the existence of a long-run relationship among two or more non-stationary price series.

One precondition to the evaluation of price series cointegration is that all the series must be non-stationary, or integrated of first order in the levels and stationary in the first difference (Shahi *et al.*, 2006). We verified the non-stationarity condition in three ways: the Dickey-Fuller test (ADF), the Phillips-Perron test (PP) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS). The ADF test has been the most widely used in the literature (Morales Olmos and Siry, 2018). The ADF method tests the null hypothesis of the existence of a unit root and that the series is non-stationary (Dickey and Fuller, 1979). The ADF test is available in the package "tseries" of R (Trapletti and Hornik, 2020). Two variants of this test were evaluated: the model with an intercept, and the model with both: intercept and slope of the trend. In addition, we ran the Phillips-Perron (PP) supplementary test because this is more appropriate for short time series (Morales Olmos and Siry, 2018).

As verification, we performed the complementary test of Kwiatkowski-Phillips-Schmidt-Shin (KPSS). The null hypothesis of this test is that the series is stationary around a deterministic trend (H0), against the alternative of the existence of a unit root (Kwiatkowski *et al.*, 1992; Chudy and Hagler, 2020). For this reason, this test is more conservative when rejecting the null hypothesis of stationarity, since it also considers series that have a trend with a constant slope. To remove possible stochastic trends, we applied these tests for the series in first differences. The unit root hypothesis was tested to significance levels of 1%, 5%, and 10%. In the ADF test, we used the Bayesian Information Criteria (BIC) to select the number of lags used in the regression. For PP and KPSS tests, the lag parameter was set to $4 * (T/100)^{(1/4)}$ (Kwiatkowski *et al.*, 1992).

We tested the presence of cointegration relationships only among non-stationary series. Then there were two questions to be answered: (1) if the price series of the same product among the regions are cointegrated; and (2) if prices series are cointegrated within the same area. We tested the cointegration between price series by pairwise comparisons using Johansen's estimation (Johansen, 1988; Chudy and Hagler, 2020). This test tells if two or more series can form a cointegration relationship. This test includes a Vector Error Correction Model with the differenced series. The rank of the coefficient matrix of this model is given by r, and the Johansen test sequentially tests whether this rank r is equal to zero and through to $r = n - 1$, where n is the number of time series tested. The null hypothesis of $r = 0$ indicates that there is no cointegration at all. A rank $r > 0$ implies a cointegrating relationship between two or more time series. Johansen's pairwise test concludes that a pair of price series are cointegrated when the Lambda Trace value is greater than a critical value defined for each confidence level. In this situation, the result rejects the null hypothesis of the absence of cointegration between the series. We implemented Johansen's test present in the package "*urca*" of R (Pfaff, 2008).

3 Results

Table 3 presents the average and deviation of the price series for products and countries. Products with different diameters showed price variations among regions. Misiones and Corrientes had 19% greater prices for sawlog 3 than sawlog 2. Instead, in Paraná (Brazil), this difference was 28%. For larger logs, both in Misiones and Paraná, sawlog 4 presented a price at the mill 43% greater than sawlog 2. Moreover, in the smaller sawlogs, sawlog 2 prices in Argentina were only 6% more than sawlog 1. Instead, in Paraná, this difference reaches 47%. Paraná has a greater price difference between the smallest sawlog class and slightly higher prices than the Argentinean sawlog market.

3.1 Price Trends

During the study period, the price series showed relevant variations. Figure 2 shows the evolution of log prices loaded on a truck between 2008 and 2020. In Paraná State, the real prices of sawlog 4 and veneer logs showed a decline of 20% between 2008 and 2012. Nevertheless, by 2014 these prices fully recovered. Instead, sawlogs 1 and 2 showed a declining trend, with an accumulated loss of

Table 3: Forest Products Log Mean Prices.

Region	Product	Time frame (Months)	Nominal price at the mill USD/t		Real price at the mill (1) USD/t		Real price on the truck (1) USD/t	
			Av.	Var. (CV%)	Av.	Var. (CV%)	Av.	Var. (CV%)
Misiones Province of Argentina	Sawlog 4	2008–2020 (156)	42.8	231.5 (36)	46.2	155.4 (27)	38.1	154.8 (33)
	Sawlog 3	2008–2020 (156)	36.4	167.9 (36)	38.1	103.9 (27)	30.1	104 (34)
	Sawlog 2	2008–2020 (156)	30.3	139.2 (39)	32.2	85.8 (29)	24.2	86 (38)
	Sawlog 1	2008–2020 (150)	29.5	62.3 (27)	30.4	52.7 (24)	22.5	52 (32)
	Pulpwood	2008–2020 (156)	18.4	18.1 (23)	19.9	5.8 (12)	11.8	6 (21)
	Woodchips	2008–2020 (156)	11.8	8.6 (25)	12.7	5.7 (19)	4.7	6.1 (53)
Corrientes Province of Argentina	Sawlog 4	2018–2014 (73)	14.0	17.6 (30)	51.5	34.7 (11)	43.4	32.8 (13)
	Sawlog 3	2008–2020 (156)	28.6	554.8 (82)	37.5	80.7 (24)	29.5	77.6 (30)
	Sawlog 2	2008–2020 (156)	22.8	361 (83)	31.2	64.4 (26)	23.2	62 (34)
	Sawlog 1	2008–2012 (58)	6.3	1.7 (21)	29.9	10.5 (11)	21.7	8.5 (13)
Paraná State of Brazil	Veneer log	2008–2020 (156)[a]	58.9	71.6 (14)	55.6	21.1 (8)	50.2	21.1 (9)
	Sawlog 4	2008–2020 (156)[a]	54.2	53.6 (14)	51.2	15.4 (8)	45.8	15.4 (9)
	Sawlog 3	2012–2020 (100)[a]	45.1	72.3 (19)	45.4	3.4 (4)	40.0	3.4 (5)
	Sawlog 2	2008–2020 (156)[a]	38.0	65.1 (21)	35.4	8.2 (8)	30.0	8.2 (10)
	Sawlog 1	2008–2020 (156)[a]	26.0	34.3 (23)	24.1	5.1 (9)	18.7	5.1 (12)
Uruguay (Sawmills)	Sawlogs	2010–2018 (102)	23.8	5.8 (10)	24.7	6.1 (10)	19.2	6.1 (13)
Uruguay Exports	Sawlogs	2010–2020 (130)	75.7	268.5 (22)	78.0	387.6 (25)	55.3	387.4 (36)

Source: Av.: average; Var.: variance; CV: coefficient of variation; (1): base period December 2016.
[a]Biannual data interpolated to monthly frequency, reported in April and September; Sawlogs for Uruguay comprise logs over 18 cm in the small end diameter.

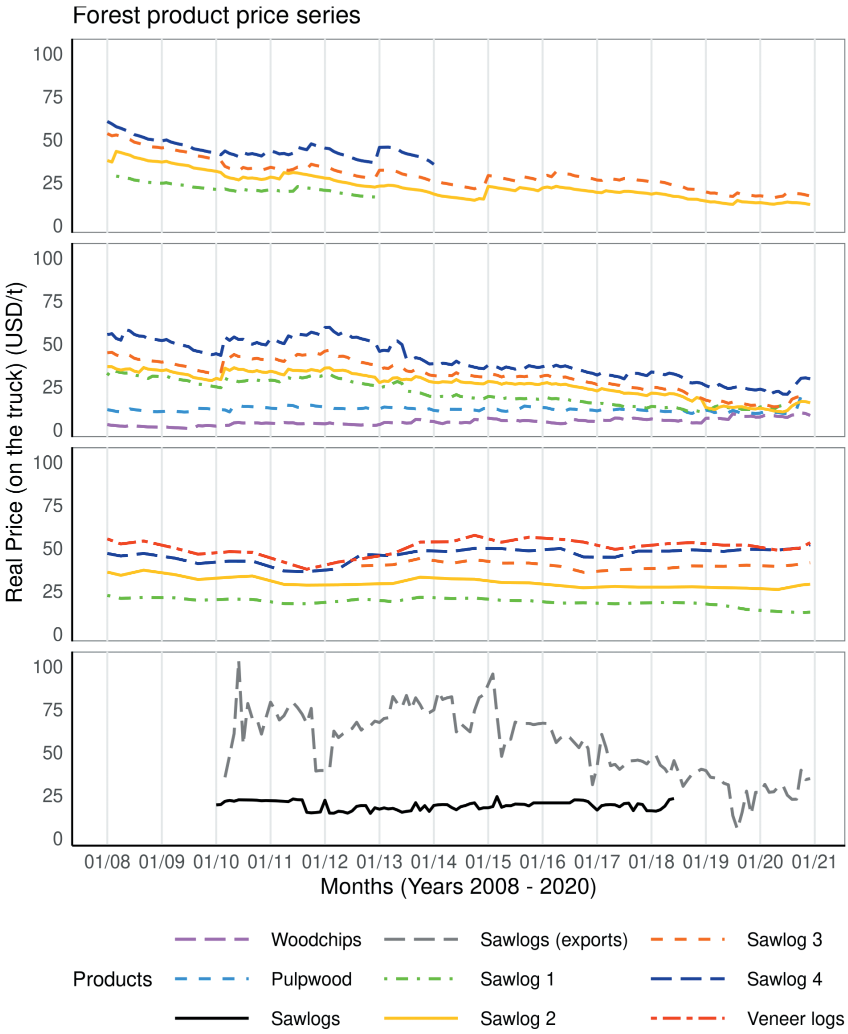

Figure 2: Forest products prices in the selected regions (monthly data, 2008–2019).

30% between 2008 and 2019. During 2020 we observed a change in the trend, with a 10% increase in prices of sawlog 1 and 2.

In the Argentinean provinces, the sawlog prices showed a constant decline. In Corrientes, sawlog 3 presented a real price reduction of 68% from 2008 to 2020. In Misiones, sawlogs lost 53% in value until 2019, whereas the real price of the pulp logs decreased by only 6%, and the energy chips increased their price by 42%. However, during 2020 the real price of sawlogs showed a recovery of 25%, associated with the increasing international lumber prices and a larger production rate in sawmills. Until 2019, the smallest sawlogs and cellulose products reduced the price gap between them. Small sawlogs can substitute the pulpwood logs, but this is not the case in the opposite direction. In this scenario, some forest operations near cellulose mills can choose to downgrade the smallest sawlogs and sell this as pulpwood. This improves the forest company's net profit through the reduction of the harvesting costs, although at the expense of the forest producer, within or outside the company.

In the province of Corrientes, this product substitution did not occur because of the absence of cellulose industries. For this reason, forest producers had problems selling wood with less than 18 cm in the small end. The decline in prices throughout the last decade influenced this substitution dynamic. In 2008, the average real price of sawlog 2 in Misiones was \$35.3 USD/t, close to the price of sawlog 1 (\$32.2 USD/t), and higher than \$11.1 USD/t for the pulpwood. On the other hand, in 2019 the prices of these three products took close values (12.9 USD/t for sawlog 2, \$12.6 USD/t for sawlog 1 and 10.4 USD/t for pulpwood). This situation might have motivated the product substitution based on the harvesting costs, the transport distance, and the volume of the supply contracts.

In Uruguay, it is important to highlight the differences between the prices of the sawlogs for local sawmills and the export prices to China. During the last decade, prices in the domestic market declined 11%, whereas the exports prices decreased 35%. The average log price on the truck was \$55.5 USD/t for export logs and \$19.2 USD/t for logs delivered to Zona Franca Rivera. The real price of logs exported to China showed a 30% increase during 2020.

Table 4 presents the stationarity analyses. The results of the ADF and PP test performed with an intercept did not provided evidence to reject the null hypothesis of non-stationarity for most of the price series. Only the prices of sawlogs from Uruguay delivered to local sawmills were stationary at a significance level of 1%. For sawlogs 3 and 4 in Corrientes, the PP test showed only low significant evidence to reject the null hypothesis of non-stationarity. For the woodchips in Misiones and the exports in Uruguay, the ADF and PP tests with a trend term rejected the null hypothesis of non-stationarity, indicating that these price series fluctuated around a deterministic trend. In Figure 2 it can be seen that the series of prices of exports from Uruguay were apparently non-stationary. On the other hand, for woodchips in Misiones a constant upward slope is observed, associated with the increase in the importance of this product in the region.

As a confirmation test, the KPSS test rejected the null hypothesis of stationarity in all price series, except the sawlogs from the domestic market in Uruguay. These results show that all series can be considered non-stationary, except the domestic market in Uruguay. Non-stationary price series can be cointegrated with other series. On the other hand, all series became stationary when running the tests in first differences.

Table 4: Stationarity Test for the Time Series of the Log Price Loaded on the Truck.

		Levels						First differences		
Region	Product	ADF (intercept)	ADF (intercept and trend)	PP (intercept)	PP (intercept and trend)	KPSS (intercept)	KPSS (intercept and trend)	ADF	PP	KPSS
Misiones Province of Argentina	Sawlog 4	−1.25	−2.42	−1.16	−2.44	2.86*	0.23*	−9.53***	−13.09***	0.07
	Sawlog 3	−0.90	−1.97	−0.87	−2.03	2.82*	0.40*	−7.75***	−10.72***	0.07
	Sawlog 2	−0.79	−2.36	−7.78	−2.50	2.86*	0.50*	−8.98***	−13.46***	0.05
	Sawlog 1	−1.56	−1.67	−1.01	−2.08	2.92*	0.20*	−8.91***	−14.31***	0.10
	Pulpwood	−2.26	−2.04	−2.53	−2.31	0.57*	0.25*	−9.36***	−13.43***	0.18
	Woodchips	−1.50	−4.25***	−1.26	−4.26***	2.59*	0.09	−10.37***	−13.00***	0.05
Corrientes Province of Argentina	Sawlog 4	−2.33	−2.72	−2.61*	−2.80	1.19*	0.28*	−4.70***	−6.29***	0.21
	Sawlog 3	−2.44	−2.74	−2.59*	−2.89	2.58*	0.38*	−7.95***	−12.27***	0.28
	Sawlog 2	−2.51	−2.55	−2.36	−2.43	2.69*	0.44*	−6.87***	−10.85***	0.28
	Sawlog 1	−1.66	−2.17	−1.85	−2.22	1.29*	0.23*	−4.40***	−5.65***	0.29
Paraná State of Brazil	Veneer log	−2.02	−2.47	−1.54	−2.06	0.79*	0.29*	−3.66***	−3.85***	0.25
	Sawlog 4	−1.75	−2.89	−0.98	−2.14	1.54*	0.21*	−4.15***	−4.33***	0.19
	Sawlog 3	−2.24	−2.20	−1.25	−1.19	0.74*	0.29*	−2.94**	−3.45***	0.19
	Sawlog 2	−2.54	−3.08	−1.93	−1.65	2.20*	0.19*	−3.59***	−4.24***	0.18
	Sawlog 1	−0.74	−2.28	0.1	−0.93	1.93*	0.43*	−4.70***	−4.86***	0.21
Uruguay (Sawmills)	Sawlog	−3.49***	−3.44**	−4.67***	−4.63***	0.23	0.24*	−8.87***	−15.88***	0.07
Uruguay Exports	Sawlog	−2.17	−4.05***	−2.26	−4.43***	1.79*	0.43*	−10.33***	−13.08***	0.14

Source: ADF: Augmented Dickey-Fuller unit root test; H0: non-stationarity; PP: Phillips-Perron unit root test; H0: non-stationarity; KPSS test; H0: stationary; *significant at 10%; **significant at 5%; ***significant at 1%; Sawlogs for Uruguay comprise logs over 18 cm in the small end diameter.

3.2 Regional Cointegration

We found evidence of price series cointegrated among regions with the Johansen test. For sawlog 2, the Johansen test indicated the presence of at least one pair of price series cointegrated (H0: $r = 0$ rejected with a significance level of 1%). There were no cointegrated pairs between the Paraná, Misiones and Corrientes series (Table 5). Instead, we found a cointegration relationship between the price series of sawlog 2 from Paraná and the export logs from Uruguay ($r = 0$ rejected with a significance level of 1%). Also, we found cointegration between the price series of sawlog 2 from Misiones and export logs from Uruguay ($r = 0$ rejected with a significance level of 5%). There was no evidence of cointegration between regions for other products.

3.3 Product Cointegration

In Misiones, the pairwise Johansen's cointegration analysis indicated multiple pairs of cointegrated price series. Markets of sawlog 4 and woodchips have cointegrated price series, with a significance level of 5%. Also, the woodchips price series are cointegrated with sawlog 3, 2 and 1, and with pulpwood. In these instances, the significance level is only 10%, but if a Johansen test including a trend term is considered, the significance level of these cointegration relationships increases to 10%. Markets of pulpwood and sawlog 1 have price series cointegrated with a significance level of 10%.

In Corrientes, we rejected the non-cointegration hypothesis for the price of sawlogs 3 and 2 (significant at 1%). Further, we found a cointegration relationship between the prices of sawlog 4 and sawlog 2, present in the series until 2014. Because of several possible pairwise combinations, Table 6 only shows results when the Johansen test rejected the null hypothesis. The results of other pairwise comparisons are available on request. The cointegration of log prices for medium and large sawlogs is an expected result. All these logs are processed by the same group of sawmills, in the same region. Therefore there is a regional market.

In Paraná, two pairs of sawlog markets had cointegrated price series (significant at 5%): veneer logs and sawlog 4, and veneer logs and sawlog 3. These cointegration relations may be because these products are similar in size. Both have a high industrial value and respond to the same market variations. Forest owners can decide which to produce to increase the total value harvested. Substitution of one product for another may also be because of differences in sawing technology and efficiency of each mill.

4 Discussion

We examined the cointegration relationships between the price series of three pine log producing countries in the Southern Cone of South America. The

Table 5: Johansen Cointegration Test for Log Prices between Regions.

Product	Regions and period	λ Trace	Result
Sawlog 4	Misiones, Corrientes, and Paraná (01-2008 – 01-2014)	26.98	Not cointegrated
	Misiones – Paraná (01-2008 – 12-2020)	13.98	Not cointegrated
Sawlog 3	Misiones – Paraná (09-2012 – 12-2020)	9.43	Not cointegrated
	Paraná – Corrientes (09-2012 – 12-2020)	6.16	Not cointegrated
	Misiones – Corrientes (01-2008 – 12-2020)	10.25	Not cointegrated
Sawlog 2 and sawlogs (export)	Misiones, Corrientes, Paraná, and Uruguay Exports (03-2010 – 12-2020)	H0: $r \leq 1$	
		24.18	Price series cointegrated
		68.04***	At least one pair cointegrated
	Misiones, Corrientes and Paraná (01-2008 – 12-2020)	18.76	Not cointegrated
	Paraná – Uruguay Exports (03-2010 – 12-2020)	35.5***	Cointegrated
	Corrientes – Uruguay Exports (03-2010 – 12-2020)	13.10	Not cointegrated
	Misiones – Uruguay Exports (03-2010 – 12-2020)	18.48**	Cointegrated
Sawlog 1	Misiones, Corrientes and Paraná (03-2008 – 12-2012)	21.84	Not cointegrated
	Misiones – Paraná (01-2008 – 06-2020)	7.79	Not cointegrated

Source: For Johansen's trace test the null hypothesis is that $r = 0$, there is no cointegration relations. If the null hypothesis is rejected, at least a pair of price series are cointegrated. The second test is for $r \leq 1$ and the alternative hypothesis ($r > 1$) indicate there is $r + 1$ price series cointegrated. *Significant at 10%; **significant at 5%; ***significant at 1%.

Table 6: Johansen Cointegration Test Products for Log Prices within Regions.

Region	Products tested	λ Trace	Result
Misiones Province of Argentina	Sawlog 4, sawlog 3, sawlog 2, sawlog 1, pulpwood, and woodchips (01-2008 – 06-2020)	(H0: $r \leq 1$) 62.75	Price series cointegrated
		110.3***	At least one pair cointegrated
	Sawlog 4 – woodchips (01-2008 – 12-2020)	19.19**	Cointegrated
	Sawlog 3 – woodchips (01-2008 – 12-2020)	15.79*	Cointegrated
	Sawlog 2 – woodchips (01-2008 – 12-2020)	16.40*	Cointegrated
	Sawlog 1 – pulpwood (01-2008 – 06-2020)	17.11*	Cointegrated
	Sawlog 1 – woodchips (01-2008 – 06-2020)	16.92*	Cointegrated
	Pulpwood – woodchips (01-2008 – 12-2020)	16.55*	Cointegrated
Corrientes Province of Argentina	Sawlog 4, sawlog 3, sawlog 2, and sawlog 1 (03-2008 – 01-2012)	41.52	Not cointegrated
	Sawlog 4, sawlog 3, and sawlog 2 (01-2008 – 01-2014)	(H0: $r \leq 1$) 7.28	Price series cointegrated
		29.69*	At least one pair cointegrated
	Sawlog 4 – sawlog 2 (01-2008 – 01-2014)	19.62**	Cointegrated
	Sawlog 3 – sawlog 2 (01-2008 – 12-2020)	32.74***	Cointegrated
Paraná State of Brazil	Veneer log, sawlog 4, sawlog 2, and sawlog 1 (01-2008 – 01-2020)	43.38	Not cointegrated
	Veneer log, sawlog 4, sawlog 3, sawlog 2, and sawlog 1 (09-2012 – 12-2020)	67.22*	At least one pair cointegrated
	Veneer log – sawlog 4 (01-2008 – 12-2020)	20.16**	Cointegrated
	Veneer log – sawlog 3 (09-2012 – 12-2020)	19.29**	Cointegrated

Source: For Johansen's trace test the null hypothesis is that $r = 0$, there is no cointegration relations. If the null hypothesis is rejected, at least a pair of price series are cointegrated. The second test is for $r \leq 1$ and the alternative hypothesis ($r > 1$) indicate there is $r + 1$ price series cointegrated. *Significant at 10%; **significant at 5%; ***significant at 1%.

cointegration relationships in this market were not previously evaluated. Combining monthly and bi-annual prices of sawlogs and pulpwood, we describe the evolution and market integration of prices between 2008 and 2020. In brief, we found that with some exceptions, (1) delivered and loaded at roadside real log prices decreased for most products from 2008 to 2019, showing a slight increase throughout 2020; (2) log markets were not cointegrated among the three regions; (3) log markets for different products were cointegrated within each region.

We collected time series for different periods and with a different time span. In Paraná, the interpolation of the bi-annual reports resulted in a lower variance than in the series of the other regions (Table 2). The stationarity tests carried out made it possible to establish that the sawlog price series of Paraná have a unit root and therefore can present cointegration relationships. In Misiones and Corrientes, the smaller time span of these log price series would favour the detection of slightly significant cointegration relationships. The incorporation of a trend term in the ADF and PP models made it possible to observe that the price of woodchips fluctuates around a constant slope trend.

The global decrease in stumpage prices for timber since 2008 has occurred in the three regions analysed (Cubbage *et al.*, 2020). This trend is reflected in the log prices loaded at the truck. Also, timber harvesting costs in the same regions decreased (Mac Donagh *et al.*, 2019). Lowered roadside log prices may have increased comparative advantage for the three countries, making them more competitive, but this depends on trends in other parts of the world. In summary, the decreased prices certainly benefit forest products manufacturing facilities and employment. However, this trend probably decreases investment returns for forest landowners and has uncertain outcomes for timber loggers.

The establishment of new short fibre industries and sawmills has led to an increase in the area planted with Eucalyptus in Brazil and Uruguay, often replacing pine forests (Indústria Brasileira de Arvores (IBÁ), 2019; Uruguay XXI, 2019). In Uruguay, this process discourages the installation of new factories that consume pine logs. In this scenario, exports of logs to Southeast Asia are increasing as an alternative to selling the timber generated in forests that are not associated with an industrial project. In the period analysed, these exports consisted mainly of individual business opportunities. For this reason, the series of average prices for Uruguay's exports shows changes in dynamics throughout the entire period studied. Also, this export modality has been occurring in the province of Corrientes, prominently during 2020. In both regions, log exports respond to better prices but are associated with a timber supply excess in the local market.

The analyses indicated that most log markets among the three countries were not cointegrated. The only exception was medium-sized sawlogs, for which the price series for Paraná and Misiones formed pairs cointegrated with Uruguay. The lack of trade relations between the three countries analysed, together with the differences in their economies, maybe the cause of the different evolution of prices for the same product (Chudy and Hagler, 2020). Protesters closed the main bridge between Argentina and Uruguay, and Argentina banned log trade with Uruguay for part of this period.

In the markets analysed in this study, sawlogs, pulpwood and manufactured products are not exchanged among regions, except a small proportion of sawlogs between Misiones and Corrientes. Therefore, log price fluctuations could be more related to micro markets than export-import relations (Zhang *et al.*, 2017; Kanieski da Silva *et al.*, 2019).

Within each region, some sawlog products of similar dimensions show cointegrated price series. This occurs for the most valuable products (large sawlogs and veneer logs in Paraná), and the least valuable products (sawlog 3 and 2 in Corrientes, and sawlog 1 and pulpwood in Misiones). These relationships imply that sawmills or pulp mills with flexible input requirements may motivate the substitution of similar size timber products. This may occur for various reasons, including the challenge of sorting and trucking wood to different locations; the location of timber and the processing mill with the appropriate technology; and the ability of low tech to high tech mills to process different products from the same size of logs.

In Misiones, the cointegration found between each sawlog product and the woodchips is associated with a market in which sawmills and pulp mills complement each other. Pulp mills also consume woodchips for power generation. Therefore, market shocks generate a persistent effect in this non-stationary price series, that then they do not return to their previous long-run trend. The medium pulp mills found in this region drive the evolution of the price of sawlogs through the products substitution relations. In some situations, sawlogs 1 can also be processed as pulpwood, or even as woodchips. Also, pulpwood can be transformed into woodchips.

From 2014 to 2019, sawlog prices showed a constant decline in the three countries. This trend led to a reduction in the price differences between various types of sawlogs. This situation affects the decisions that determine forest management planning. In Misiones and Corrientes, this trend led to a shortening of the rotation. This reduction implies fewer thinning's, increasing the proportion of medium logs at the lowest cost. These changes were related to changes in sawmill technology. This trend could change after the increase in the price difference between products observed during 2020.

Finally, this study has used information collected by public institutions and professional associations of the Southern Cone. In Argentina and Brazil, this information is publicly available, supporting the assumption about the availability of the information needed to assume a perfect market. However, the updated information and the level of detail in product classification is required for the cointegration analyses of negotiations between the different participants in the forest products markets.

5 Conclusions

We found that pine log markets in three Southern Cone countries moved in the same direction and that within each country sawlog markets were usually cointegrated. These results do confirm our *a priori* expectations. However, despite their relative proximity, markets for logs among the countries analysed were generally not cointegrated, suggesting that various political or social factors limit the application of the law of one price in the Southern Cone. We can attribute this result to a variety of factors, such as the large expense of the transport of cheap logs; the substantial increase in costs due the relatively bad roads among the countries; some financial and political friction; hidden exchange rate differences between official rates and actual rates among countries; and periodic outright bridge blockages and log trade bans from Argentina to Uruguay.

Although global trends affect local prices, the interaction among the three regions is not the primary cause of similar trends. Their primary log markets and even log export and forest product markets are relatively independent. This suggests that there is less of a broad regional timber free market within the Southern Cone, with each country seeking its comparative advantages with much more distant partners, and receiving lower rents due to higher transport and transaction costs. This probably would decrease aggregate regional economic social welfare, but the local manufacturing firms in each country have adapted and fared well enough to succeed in their proximal markets. However, it may limit industry expansion, and probably harm timber producers and investments due to more constrained markets. The implications and net benefits and costs of these factors for each country and potential forest sector investments certainly could be an opportunity for further research, as well as policy debates.

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