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Are prices converging in the global sawnwood market?

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ABSTRACT

This paper aims at addressing if the increasing globalization in the international sawnwood markets has caused export prices to converge to a single reference price or, alternatively, certain restrictions remain to generate a segmented market where different reference prices for each market segment co-exist. Annual price series for the top-10 exporting countries are considered for that purpose. Results show that the data cannot support the null hypothesis of convergence. Instead, the global sawnwood market appears to be segmented into two convergence clubs (Chile-USA-Latvia-New Zealand and Canada-Germany-Austria-Finland-Sweden), while the Russian Federation exhibits an independent pathway. Causality tests are conducted to analyze the price dynamics in the global sawnwood products indicating that international price relationships are demand-driven. Finally, results suggest that the inclusion of a country in a particular convergence club is mainly determined by the price differential between countries (competition factors), and to a lesser extent, by the countries' combined market share in the global market (catching-up factors).

1. Introduction

The global coniferous sawnwood market has been steadily growing in value over the past 25 years (FAO, 2019); however, it experienced significant fluctuations associated with the 2008 global financial crisis, when the price of raw materials, specifically sawnwood, significantly increased. Global production of coniferous sawnwood increased from 272 million m^3 in 1992 to 353 million m^3 in 2018, representing a remarkable increase of 29.5%. One of the most dynamic factors in this market has been the irruption of China, which has become the second largest global importer after the United States (USA). From the supply perspective, several factors have facilitated a significant increase in the production of forest resources and contributed to this growth. These include the resurgence of the Russian Federation and other developing countries, the use of fast-growing tree plantations, and genetic and technological improvements. This increase in production has transmitted to international trade; moreover, between 1992 and 2018, global exports of coniferous sawnwood more than doubled, growing from 66 million m^3 in 1992 to 134 m^3 in 2018.

Previous literature (Morales Olmos and Siry, 2018; among others) has suggested that, despite different price levels and pricing systems worldwide, the increased globalization and competition in international forest-based product markets could cause export prices to move together, contributing to market integration. This paper addresses this issue by focusing on the global coniferous sawnwood market. Furthermore, we test whether the increasing trade has led to a process of price convergence toward a single reference price or if certain restrictions remain to generate a segmented market where different reference prices for each market segment co-exist.

The theoretical background to achieve tis objective relies on the “law of one price” (LOP). The LOP postulates that in the presence of efficient arbitrage activities and perfect competition, a good's price tends to equalize in two distant geographical areas after adjusting for the exchange rate (if necessary). The only difference lies in the so-called transaction costs, among which the most relevant is transport cost. If the LOP holds, it is said that markets are integrated. Since the pioneering works of Ardeni (1989) and Goodwin (1992), the methodological approach primarily adopted in the literature to test for the LOP is based on the explicit consideration of the stochastic properties of the series (nonstationarity and cointegration).

This approach has been applied to many products and markets, including forest-based products. A significant share of the studies focuses on the integration of regional markets into a single national market, such as the USA (Nagubadi et al., 2001; Yin et al., 2002; Yin and

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Xu, 2003), Finland (Toppinen, 1998; and Toppinen and Toivonen, 1998), Norway (Størdal and Nyrud, 2003), Sweden (Jaunky and Lundmark, 2015), Canada (Nanang, 2000), Austria (Fuhrmann et al., 2021), and New Zealand (Niquidet and Manley, 2008). In an international context, the literature is divided into two main groups. On the one hand, some studies refer to a well-defined geographical area, such as Scandinavia (Toivonen et al., 2002), the Baltic Rim (Mäki-Hakola, 2002; Mutanen and Toppinen, 2007), Canada–USA (Tang and Laaksonen-Craig, 2007), the USA and its central purchasing countries (Buongiorno and Uusivuori, 1992), or the European Union (Hänninen et al., 2007). More recently, literature, such as Morales Olmos and Siry (2018) and Chudy and Hagler (2020), has increasingly focused on market integration in more countries, generally including the most relevant producer or exporter countries in a specific forest-based product.

The literature mentioned above suggests that, despite the increasing trade globalization, in forest-based product markets the LOP does not hold. The presence of convergence clubs better characterizes the price dynamics in such markets. However, the literature does not provide information about such segments, merely assuming their existence based on the rejection of the LOP. Moreover, except for Chudy and Hagler (2020), there is limited research analyzing price relationships among the leading exporters. The extant literature primarily focuses on regional markets within a single country or among countries belonging to a specific world region, as in Morales-Olmos and Siry (2015); Morales Olmos and Siry (2018).

Furthermore, concerning the methodological framework, all mentioned studies are based on the cointegration analysis; however, some heterogeneity seems to exist. For instance, in some cases, even adopting a multivariate approach, cointegration tests are applied to different pairs of prices (Nanang, 2000; Chudy and Hagler, 2020; Fuhrmann et al., 2021; among others) when this approach only offers a partial picture. To some extent, these studies disregard the fact that all markets are interconnected. Although the previous literature refers to the LOP, most studies merely test the LOP through the implementation of causality tests among prices (Yin and Xu, 2003; Jaunky and Lundmark, 2015). Only a few studies identify the long-run relationships (cointegration vectors) to test for the LOP (Tang and Laaksonen-Craig, 2007).

Against this background, the contribution of this study is twofold. First, we adopt a methodological approach capable of jointly analyzing a large number of series, allowing us to identify the different market segments in case the LOP is not fulfilled. Our approach is based on a convergence analysis, where prices converging in a given market can be interpreted as validating the LOP since an "attractor" is guiding the evolution of all prices. Conversely, if prices diverge, no such attractor is evident, and the LOP does not hold, indicating that the market is segmented. In the latter case, several attractors may co-exist, with countries being grouped around them (segments or convergence clubs). This approach is related to the seminal work of Barro and Sala-i-Martin (1991, 1992), who defined the concepts of β-convergence and σ-convergence. Later, Carlino and Mills (1996) and Bernard and Durlauf (1995) considered the stochastic properties of the series, generating the stochastic convergence approach, which is widely used in methodological and empirical studies. This study analyzes the convergence in the global sawnwood markets following Phillips and Sul (2007, 2009). Their approach allows us to identify the possible existing convergence clubs in case the null hypothesis of price convergence toward a single or reference price does not hold. This approach was originally used to analyze the dynamics of macroeconomic variables in a set of countries, such as inflation; however, its field of application has been notably extended to other markets, such as housing in the USA (Montañés and Olmos, 2013), energy in China (Zhu et al., 2016), and water in the USA (Tzeremes and Tzeremes, 2018), among others.

Our second contribution to the existing literature is that apart from testing the LOP—or, in case it does not hold, identifying convergence clubs—we generate additional information to characterize the convergence clubs. More precisely, we provide 1) information about the key determinants of price dynamics among convergence clubs and 2) empirical evidence about the main factors explaining the inclusion of a country in a given convergence club.

The remainder of this paper is structured into six additional sections. Section 2 highlights some structural characteristics of the global coniferous sawnwood markets. Section 3 introduces the methodological approach adopted in this research and Section 4 presents the results of applying the convergence analysis to the prices of the leading global exporters of sawnwood. Section 5 analyzes the primary determinants of the evolution of prices within each estimated convergence club through a battery of causality tests, whilst Section 6 analyzes the characteristics that determine whether a country belongs to a particular convergence club. The study ends with some concluding remarks and some recommendations for future research.

2. The global coniferous sawnwood market

The global coniferous sawnwood production reached 353 million m^3 in 2018, and international trade accounted for around 38% of global production (134 million m^3). Fig. 1 presents the evolution of both magnitudes during the 1992–2018 period. This figure shows that global production and trade have grown consistently since 1992, except for the financial crisis period (2008–2009), as the demand for housing decreased significantly. The figure also indicates that international trade has been more dynamic than global production. While global production increased by 29.5% from 1992 to 2018, total exports more than doubled (103%). This growth occurred mainly before the financial crisis, as from 2009, total production and exports grew by 41% and 58%, respectively.

Five countries (USA, China, Canada, the Russian Federation, and Germany) concentrate amost 60% of global production. Fig. 2 shows the evolution of coniferous sawnwood production in these countries, indicating that their relative positions have kept stable during the analyzed period. The only exception is the Russian Federation, where sawnwood production decreased by the end of the 1990s before recovering; the Russian Federation was the second largest producer in 1992, while in 2018, it occupied the fourth position. Three of the five largest producers (the Russian Federation, Canada, and Germany) are also among the five most important exporting countries; the other two are Sweden and Finland. These five countries concentrate 66% of the global exports in value (billion USD). The other five countries to complete the top 10 (USA, Austria, Chile, Latvia, and New Zealand) represent a market share of 16%.

Table 1 shows the main characteristics of the 10 most relevant exporting countries. Canada is by far the leading exporter, doubling the market share of the second (the Russian Federation). Additionally, USA exports only represent 4% of global exports in value, despite being the more prominent producer. Regarding the geographical destination of exports, some significant patterns arise, being distance one of the key determinants. The USA and Canada concentrate their exports to North America and Asia (China and Japan). European countries show more intense trade flows within Europe, except Finland, which shows more intense trade flows with Asian countries, and Germany with China, being its second largest customer. New Zealand concentrates its exports on Asia, while Chile looks to the USA and Asia.

Fig. 3 illustrates the evolution of the export price of coniferous sawnwood from the 10 central exporting countries (in real USD), revealing no clear pattern in price behavior; however, the USA price remains the highest throughout the considered period, while the lowest price corresponds to the Russian Federation. The reduction in price dispersion in the analysis period could indicate a potential price convergence process related to increased global trade, which we analyze in the following sections.

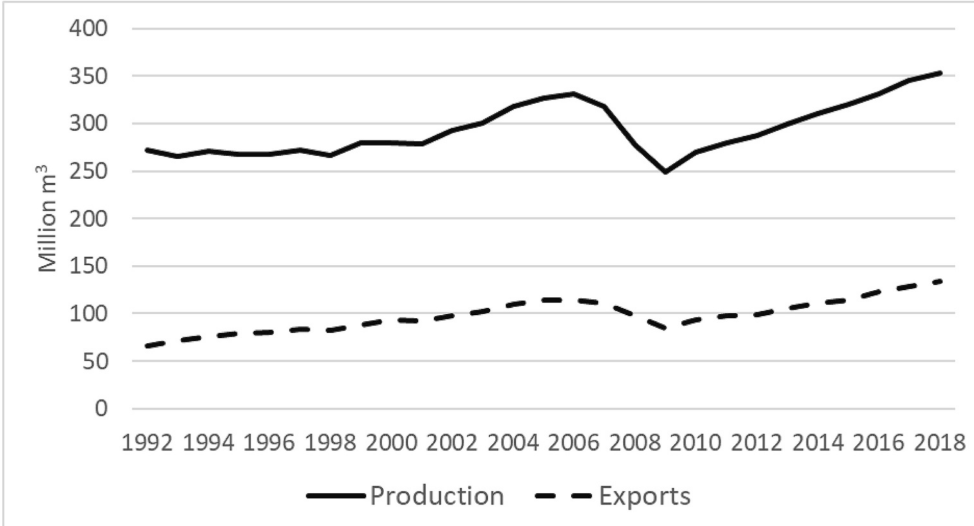

Fig. 1. Evolution of global production and exports (1992–2018) (million m^3).
This Figure presents the evolution of global sawnwood production and exprts (million m^3).
Source: FAOSTAT: Forest Product Statistics.

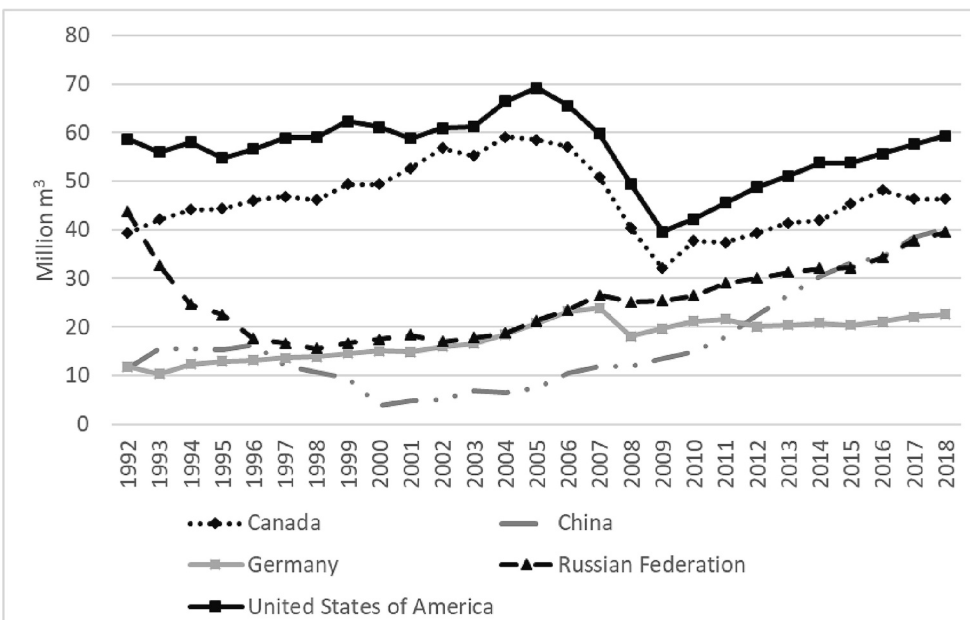

Fig. 2. Evolution of sawnwood production (million m^3).
This Figure presents the evolution of the production (million m^3) of the Top 5 exporting countries.
Source: FAOSTAT: Forest Product Statistics.

3. Methodological approach to convergence analysis

As noted in the introduction, convergence analysis dates back to the seminal works of Barro and Sala-i-Martin (1991, 1992). Their analyses were based on the simple concepts of β-convergence and σ-convergence, which are used to measure whether macroeconomic reference variables demonstrate an equilibrium path that the set of countries is approaching. If the standard deviation of the variable under study decreases over time, there is evidence of σ-convergence; β-convergence is evident if countries with the lowest values of the variable at the beginning of the sample exhibit higher growth rates than the rest.

Quah (1993a, 1993b) criticized these techniques, showing that the evidence favoring β-convergence may be spurious. Subsequently, researchers sought to construct alternative methods to examine the existence of convergence, such as the contributions of Evans and Karras (1996), Loewy and Papell (1996), Nahar and Inder (2002), Strazicich et al. (2004), and Carrion-i-Silvestre and German-Soto (2007). These studies are based on the concept of stochastic convergence developed by Bernard and Durlauf (1995) and Carlino and Mills (1993, 1996).

In this approach, convergence analysis is based on the following relationship:

$$\lim_{t\to\infty}\left(y_{i,t}-y_t^*\right)=\delta_i \; i=1,2,\ldots N \; t=1,\ldots,T. \quad (1)$$

where, $y_{i,t}$ represents the value (in logs) of the variable in time t in the i-th geographical area in which we seek to measure the existence of a convergence process. y_t^* is the target value to which that variable should

Table 1
Some characteristics of the ten main sawnwood exporting countries (2018).

	Exports		Destination countries					
	Billion USD	Global market share (%)	First	%	Second	%	Third	%
Canada	7932.1	27	USA	68	China	9	Japan	6
Russian Feder.	4208.5	14	China	32	South Korea	14	Japan	10
Sweden	3338.2	11	United Kingdom	15	Egypt	14	Germany	11
Finland	2158.6	7	China	26	United Kingdom	13	Japan	10
Germany	2069.0	7	France	23	China	18	Netherlands	14
Austria	1483.4	5	Germany	57	Italy	12	France	7
USA	1148.2	4	Canada	33	Mexico	23	China	16
Chile	799.2	3	USA	30	China	22	Japan	12
Latvia	712.5	2	United Kingdom	28	Germany	18	Denmark	10
New Zealand	650.1	2	China	40	South Korea	11	Japan	9

This table shows some characteristics of the ten main sawnwood exporting countries: market shares, main destination countries and the percentage of exports generated from pinewood.
Source: FAOSTAT: Forest Product Statistics.

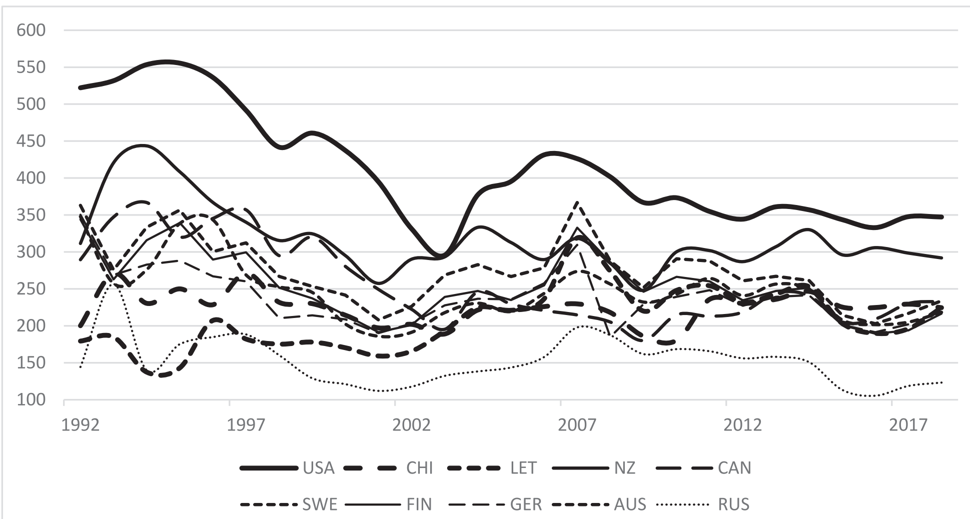

Fig. 3. Evolution of sawnwood prices.
This figure presents the evolution of the sawnwood prices. Prices are measured in real USD (2010).

converge. In eq. (1), absolute convergence is evident if $\delta_i = 0$, while conditional convergence is evident when δ_i differs from 0. Moreover, stochastic convergence refers to the phenomenon in which differences among countries or regions are not persistent, and some common factors subsequently occur within the long-run effects. Under such assumptions, we examine the stochastic properties of δ_I to determine whether convergence is evident. Carlino and Mills (1993) propose estimating the following model:

$$\delta_{it} = \mu_i + \beta_i\, t + u_{it}\ i = 1, \ldots, N\ t = 1, \ldots, \mathrm{T}. \tag{2}$$

Here, the values of the parameters μ and β characterize the whole typology of convergent/divergent cases. If $\mu < 0$ and $\beta > 0$, the variable under study in a region or country is growing from a worse circumstance than in the comparison area; thus, convergence is apparent. Similarly, $\mu > 0$ and $\beta < 0$ indicates a convergence process, as the variable under study in the country/region is above the reference value and decreases toward it. Conversely, $\mu < 0$ and $\beta < 0$ or $\mu > 0$ and $\beta > 0$ indicate divergence, as the country/region is below/above the reference values and the path is moving toward widening this distance. Finally, if $\beta = 0$, then the distance between regions or countries remains constant, which can be interpreted as weak convergence.

The framework presented above is not free from criticism, particularly regarding the lack of an appropriate statistic for testing the null hypothesis of convergence. Phillips and Sul (2007, 2009) (hereafter, PS) construct a new framework to navigate this issue. The method allows direct testing of the null hypothesis of convergence, and if we reject this hypothesis, we can determine the presence of convergence clubs, following Barro and Sala-i-Martin (1991). Moreover, this methodology has the advantage of allowing the inclusion of variables with differing stochastic properties, including the presence of nonlinear trends.

Following PS (2007), let X_{it} represent the variable of interest (sawnwood export prices, in our case), where i represents the cross-sectional dimension (the number of countries included in the study), while t represents the time dimension. The individual price can be stated as $X_{it} = g_{it} + a_{it}$, with g_{it} encompassing the systematic components and a_{it} representing the transitory ones. This formula can be transformed with some simple algebra into the following time-varying factor model, $X_{it} = \delta_{it}\,\mu_t$, with μ_t being the common component and δ_{it} is the idiosyncratic one. In our particular case, μ_t reflects the common price for the countries included in our sample, and δ_{it} provides a measure of the economic distance between the price of the i-th country and the common price. Then, PS proposed to test the convergence hypothesis by analyzing that the idiosyncratic element moves toward a common element in all countries. This examination involves determining whether δ_{it} converges toward δ. To do so, PS first defines the relative transition path as follows:

$$h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}} \tag{3}$$

This path eliminates the common element μ_t. If the convergence hypothesis holds, then δ_{it} goes toward δ; therefore, h_{it} converges to 1. At the same time, the cross-sectional variation H_{it} goes toward 0 when T grows asymptotically:

$$H_{it} = N^{-1} \sum_{i=1}^{N} (h_{it} - 1)^2 \xrightarrow{As} 0, \text{as } T \xrightarrow{As} \infty \quad (4)$$

Consequently, PS proposes testing for the convergence hypothesis using the following equation:

$$log\frac{H_1}{H_t} - 2log[log(t)] = \alpha + \beta log(t) + u_t, t = [rT] + 1, \dots, T. \quad (5)$$

where, r usually takes the value 1/3, as PS suggests. Eq. (5) is usually referred to as the log-t regression. The use of robust-variance estimates allows controlling for the possibility of autocorrelation or heteroskedasticity in the disturbance term u_t, ensuring that the t-ratio for testing the hypothesis $\beta = 0$ converges to a normal distribution. Given that only negative values of β confirm rejection, the left-hand side of the distribution is generally used, so the null hypothesis of convergence is rejected whenever the t-ratio is lower than −1.65. If this occurs, we can analyze the presence of convergence clubs by applying the clustering algorithm proposed by PS (2009).[1]

4. Price convergence or a segmented market?

As noted in the introduction, this study primarily aims to determine whether a convergence process exists among the prices of the 10 leading coniferous sawnwood exporting countries. Annual data from 1992 to 2018 are obtained from the United Nations Food and Agricultural Organization's FAOSTAT database. As the database only provides data on trade values and volumes, this study uses unit values as a proxy for export prices. Unit values are obtained by dividing each country's export value and volume. All prices (unit values) are expressed in real USD (base 2010).

Before implementing the PS approach, we begin with a simple σ-convergence analysis. Fig. 4 presents the evolution of the cross-section coefficient of variation (CV) of the different sawnwood prices, revealing that the value at the beginning of the sample period (36.0) is generally the same as in 2000 (35.2). From 2000, the CV shows a clear declining trend, ending in 2011 with a value of 19.7. This decline represents a considerable reduction from its value in 2000; however, the dispersion rose from 2011 onward, reaching values near 30 in 2016 before falling to 24.5 in 2018. It is not easy to draw a robust conclusion about convergence from Fig. 4; however, the final dispersion is approximately one-third of that observed at the beginning of the sample, suggesting evidence in favor of the existence of σ-convergence. Nevertheless, the CV also increases after 2011, limiting the evidence of such convergence. Then, it seems sensible to use an alternative approach, such as the PS mentioned above methodology, to better analyze the null hypothesis of convergence.

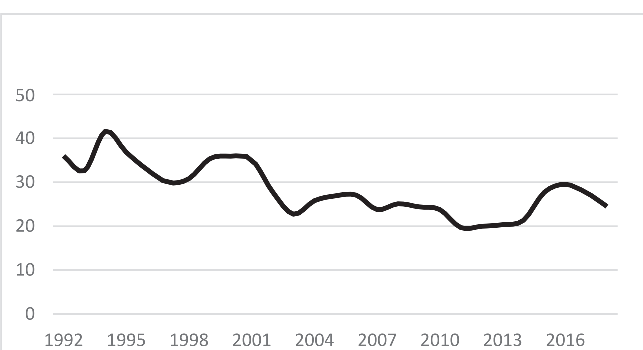

Fig. 4. Coefficient of Variation of the global prices of sawnwood (σ-convergence).
This figure presents the evolution of the cross-section coefficient of variation.

Table 2 (Panel I) presents the results after applying the PS methodology to test the null hypothesis of price convergence in the global coniferous sawnwood market. The value of the statistic is −12.1, which is lower than the critical value at a 5% significance level (−1.65). Consequently, we can find evidence against the null hypothesis of convergence, implying the absence of a single reference price in the market.

As the null of convergence is rejected, let us examine whether different convergence clubs exist. The results of applying the PS convergence algorithm are presented in Panel II of Table 2, reveal the existence of two statistically different convergence clubs. Club 1 includes the prices of the USA, Chile, Latvia, and New Zealand, while the estimated convergence club 2 includes those of Germany, Austria, Canada, Finland, and Sweden. Finally, the prices of the Russian Federation cannot be included in any group as they show a divergent pattern of behavior. Table 2 shows that the estimated convergence clubs do not correspond to specific geographic areas; however, considering the information shown in Table 1, we can see that convergence club 2 includes the five relevant sawnwood exporting countries (except the Russian Federation), while convergence club 1 includes countries with the lowest market share among the top 10. Figs. 5 and 6 illustrate the evolution of the prices for the countries included in the estimated convergence clubs 1 and 2, respectively.

To better understand the formation of these clubs, Fig. 7 plots the different values of the relative transition paths, defined in eq. (3), for the period 1992–2018. The figure shows that the coniferous sawnwood prices are grouped into three differentiated levels. The USA and New Zealand prices represent the upper limit, while Russian Federation prices mark the lower limit. The remaining countries show h values converging around 1. The rationale for including these countries in clubs 1 or 2 depends on the trend demonstrated by the h value. Chilean and Latvian prices were relatively low in 1992, with their relative transition paths taking values of 0.7 and 0.6, respectively; however, they are clearly at the market average (h = 1) at the end of the sample. In the case of Canada, h values have remained relatively constant at around 1, while there was a negative deviation from the initial values in the remaining countries (Austria, Germany, Finland, and Sweden).

Finally, Fig. 8 shows the evolution of average prices corresponding to

Table 2
Testing for convergence.

Panel I. Convergence test	
PS convergence test	−0.60 (−12.1)*
Panel II. Convergence Clubs	
Estimated convergence clubs	
Club 1: Chile, USA, Latvia, New Zealand	0.37 (15.9)
Club 2: Germany, Austria, Canada, Finland, Sweden	0.53 (2.4)
Divergent: Russian Federation	

This table presents the results of using the methodology designed in Phillips and Sul (2007). Panel I report the convergence analysis, with the log t-ratios reported in parenthesis and the value above it corresponds to the estimation of the parameter β in (5). Panel II reports the use of the clustering algorithm employed to determine the existence of convergence clubs.

* means the rejection of the null hypothesis of convergence (critical value: -1.65).

[1] Phillips and Sul (2007, 2009) and Panopoulou and Pantelidis (2013) provide detailed descriptions of the aforementioned algorithm.

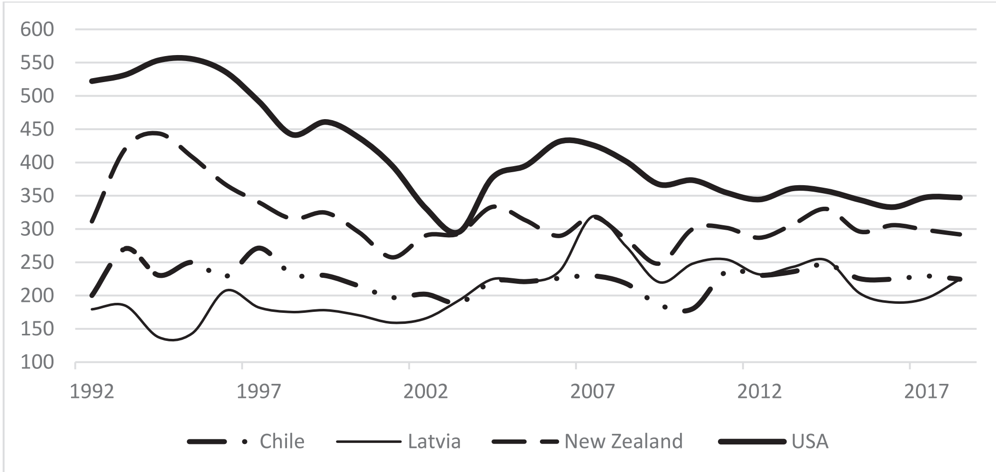

Fig. 5. Price evolution. Estimated Convergence Club 1.
This Figure presents the evolution of the prices included in the estimated convergence club 1. Prices are measured in real USD (2010).

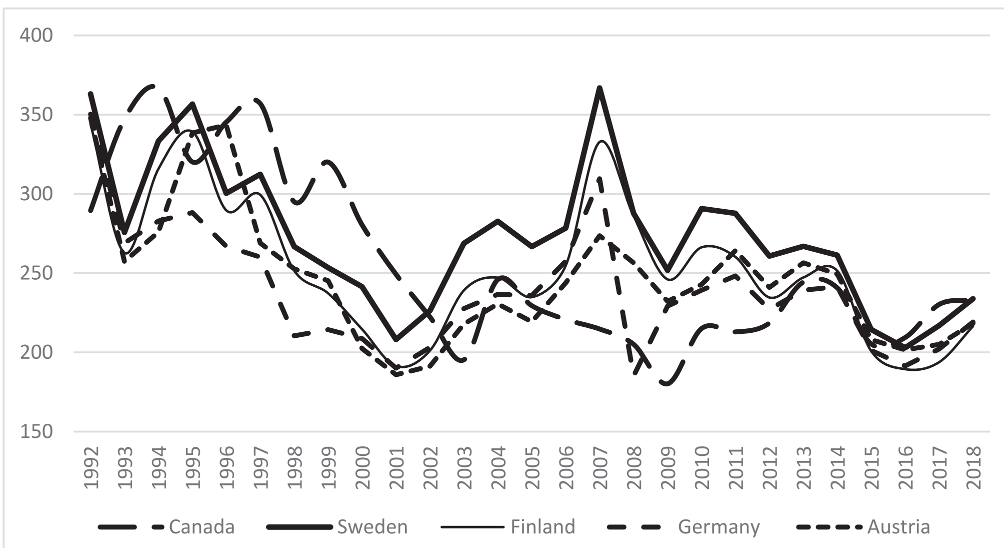

Fig. 6. Price evolution. Estimated Convergence Club 2.
This Figure presents the evolution of the prices included in the estimated convergence club 2. Prices are measured in real USD (2010).

the two convergence clubs plus those of the Russian Federation. Average prices corresponding to convergence club 1 are higher than those of the other two regions, except in the first year of our sample period. The average prices in club 1 were 20% higher than in club 2. Second, Fig. 8 shows similar price dynamics in both clubs and the Russian Federation, except at the beginning of the period under analysis. Third, during the 2009–2013 period, associated with the global financial crisis that affected global prices of raw materials, club 2 prices were close to those of club 1. Following that period, the distance between the prices of the two clubs widened again. Finally, comparing the average prices in club 1 to those of the Russian Federation, a reasonably stable relationship is found in which the former has remained twice as high as the latter, with slight downward deviations from 2007 to 2013.

As mentioned, it seems that the dynamics of global coniferous sawnwood prices were affected during higher volatility in global commodity markets (2009–2013). To analyze this issue, we recursively estimate eq. (5) for the samples 1992–m, with m = 2007, 2008, …, 2018. Fig. 9 presents the evolution of the estimated parameter β, showing an estimated coefficient of -0.3 for the period before the global price volatility crisis (1992–2007), with a t-ratio of -7.6, indicating a strong rejection of the null of convergence. However, when increasing the analysis period, the magnitude of the coefficient decreases in absolute values, arriving at a positive value in 2014. Consequently, we cannot reject the null convergence hypothesis for the three years from 2012 to 2014. The end of the crisis caused international prices to resume their inertia, and the evidence against the null hypothesis of convergence has grown, generating a highly segmented market.

5. Determinants of price evolution in each convergence club

This Section is devoted to determine the factors that drive the price evolution in the global coniferous sawnwood marke. To achieve this objective, causality tests among a set of price series are carried out. First, we examine whether there is a causal relationship between the average prices of each convergence club. Second, we extend the analysis by including the import prices of the two main importing countries (the USA and China), as price dynamics in international markets used to be demand–pull driven.

Causality is analyzed following the methodological approach of Toda and Yamamoto (1995). Following these authors, we estimate the

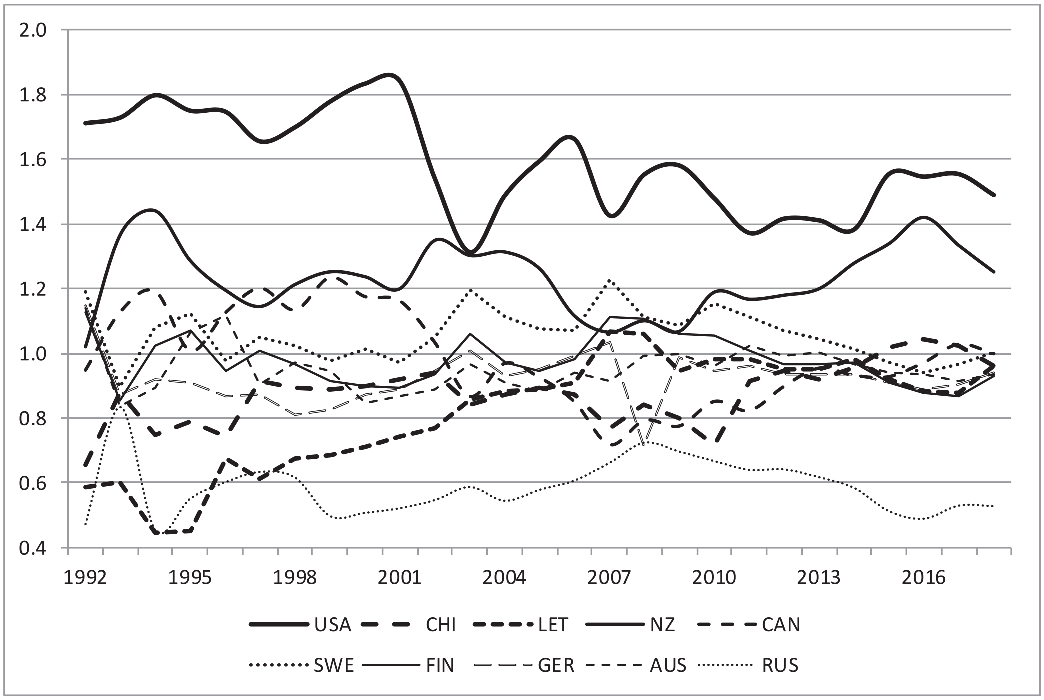

Fig. 7. Evolution of the relative transition paths for the different countries (1992–2018).
This figure presents the relative transition path, which is defined in (3).

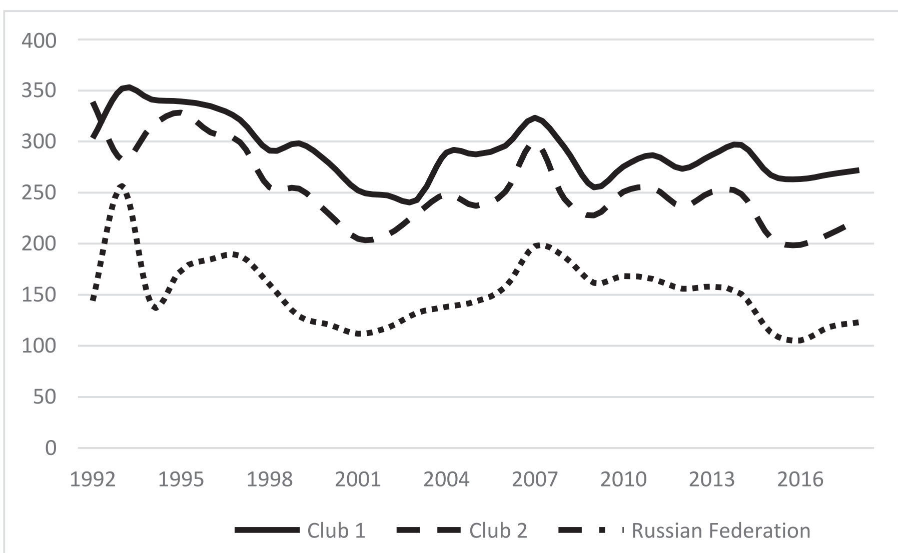

Fig. 8. Average prices of each convergence club.
This figure presents the evolution of the average prices of each estimated convergence club.

following model for each pair of prices:

$$x_t = \mu + \sum_{j=1}^{p+d_{max}} \alpha_j x_{t-j} + \sum_{j=1}^{p+d_{max}} \beta_j y_{t-j} + u_t. \quad (6)$$

Here, d_{max} is the highest order of integration of the two variables analyzed. We should note that the standard Granger causality model is slightly modified by increasing the optimum lag order p by d_{max} extra lags. Analyzing the null hypothesis that y causes x is equivalent to testing the null hypothesis that H_o: $\beta_1 = \beta_2 = \ldots = \beta_p = 0$.

To determine the order of integration of the variables, the statistic proposed by Elliott et al. (1996) is used, which is based on the generalized least squares estimation of the augmented Dickey–Fuller regression. The number of lags was chosen following the modified Akaike information criterion (AIC) proposed by Ng and Perron (2001). Table 3 presents the results of the unit root analysis. The analysis of these tables leads us to conclude that the presence of a unit root in prices cannot be rejected, except for the case of Chinese prices. This rejection might be due to the presence of some outliers, as Franses and Haldrup (1994) show. Regardless, this result would not affect the causality analysis, as the value of d_{max} would always be 1.

Once the maximum order of integration is determined, the optimal lag is selected using the Schwarz (1978) Bayesian information criterion to estimate eq. (6). In most cases, the optimal lag is set to one period; the only exception is the relationship between the Chinese and the Russian

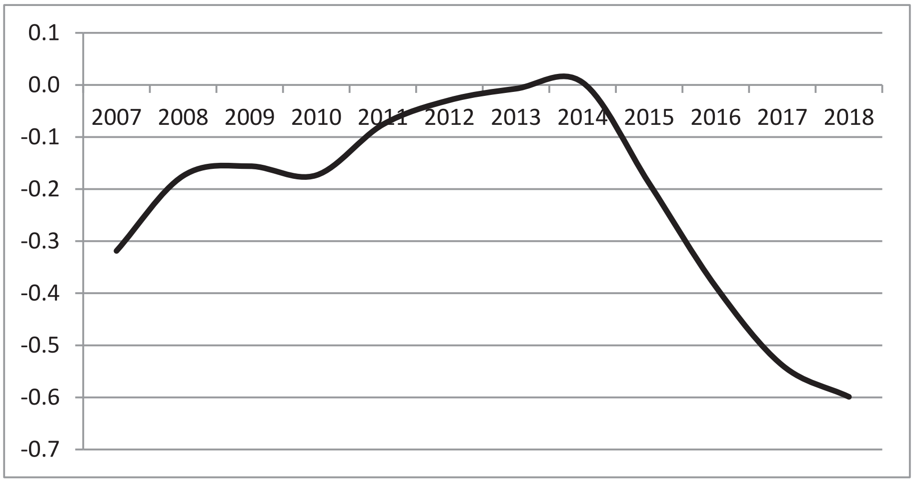

Fig. 9. Recursive estimation of the Phillips-Sul log-t equation.
This figure presents the evolution of the recursive estimation of the parameter in (5), when the sample size goes from 1992 to m, with m = 2007, …, 2018.

Table 3
Testing for unit roots.

Variables	ADF-GLS
Average price Club1 (Chile, Latvia, New Zealand and the United States)	−2.31
Average price Club 2 (Canada, Sweden, Finland, Germany and Austria)	−1.67
Russian Federation	−1.98
United States	−1.68
China	−6.11*

This table presents the values of the statistic proposed in Elliott et al. (1996) for testing the null hypothesis of unit root, with the number of lags selected by using the MIC statistics presented in Ng and Perron (2001), considering a maximum number of lags of 5.
* Indicates rejection of the null hypothesis of unit root at 5%.

Federation prices, where the optimal lag is three periods. Table 4 presents the results of the causality tests.

This table shows that the average prices of the estimated convergence club 1 exhibit an independent behavior. In contrast, the average prices of the estimated convergence club 2 reject the null hypothesis of non-causality concerning Russia and China. Finally, the relationships between Russian, Chinese, and USA prices are much stronger than the previous ones; we can reject the null hypothesis of non-causality in five out of the six potential combinations among the three price series (the only exception is that the USA prices do not appear to cause Russian Federation prices). Therefore, the interdependencies of these countries are significantly higher than those observed between the average prices of estimated convergence clubs 1 and 2. The results indicate that the emergence of China as one of the main importing countries has significantly influenced price dynamics in the international sawnwood market. Indeed, China's price affected the prices of the other countries and clubs, except for those of club 1; furthermore, China's price was caused by the export price of the Russian Federation, its leading supplier.

Table 4
Granger causality tests.

	Convergence Club 1 (Chile, Latvia, New Zealand and United States)	Convergence Club 2 (Canada, Sweden, Finland, Germany and Austria)	Russian Federation	USA	China
Club 1	–	0.07	0.26	1.76	2.32
Club 2	2.85*	–	12.83**	0.11	18.53**
Russia	0.06	0.00	–	6.15	10.15**
USA	0.00	0.38	0.16	–	8.07**
China	3.23*	0.41	9.90**	9.84	–

This table presents the results of testing the null hypothesis of Granger non-causality. To that end, we have followed the results of Toda and Yamamoto (1995) and have estimated eq. (6) with p determined by the SBIC statistic.
* the null hypothesis of Granger non-causality is rejected at 10%;
** the null hypothesis of Granger non-causality is rejected at 5%.

6. Factor conditioning club formation

This final section attempts to answer the third question raised in the introduction by determining the factors determining countries' membership in a particular convergence club. For this purpose, a logit model is estimated where the dependent variable takes a value of one if two countries belong to the same club, and zero otherwise. Since we are investigating 10 countries, the total number of observations is 45. The literature does not provide a sound theoretical background to select variables that explain the inclusion of countries in specific convergence clubs. In macroeconomics, two main factors explain inflation convergence: 1) increased competitiveness, which pushes down prices, and 2) catching-up effects that push prices upwards as income levels in different countries also increase. Moreover, in the context of international trade, gravity models (Isard, 1954) have been widely used to explain bilateral trade flows for a specific good. In such models, main explanatory variables are the distance between countries plus some additional geographical location variables. Finally, we have also considered the results of Blanco et al. (2016), who estimated a logit model in the housing market to analyze the key determinants of regional housing price convergence in Spain.

Considering this literature, we organized the potential explanatory variables to explain price convergence in the global coniferous sawnwood market into four groups, each examining three variables. The first group refers to the geographical location of the two countries considered in each relationship. The second is related to the bilateral trade between the two countries. The third group is related to the combined relative importance of the two countries concerning global exports, and the fourth group considers the price differences between each pair of countries. In each group, one of the variables measures the changes along the sample period to capture catching effects. The 12 explanatory variables are defined as follows:

- Distance is measured in kilometers between the capitals of the two countries considered in each observation (DISTANCE).

- The shared border is a dichotomous variable that takes the value of one if the two countries share a border and zero otherwise (BORDER).
- Continent is a dichotomous variable that takes a value of one if both countries are located on the same continent and zero otherwise (CONTINENT).
- The trade volume between the two countries is measured at the beginning of the study period (average 1997–1999) (TRADE 1997–1999).
- The trade volume between the two countries is measured at the end of the study period (average 2015–2018) (TRADE 2015–2018).
- Changes in trade volume between the two countries are measured between 1997 and 2018 (TRADE VARIATION).
- The combined market share of the two countries is determined at the beginning of the study period (AVERAGE 1992–1994) (QUOTA 1992–1994).
- The combined market share of the two countries is established at the end of the study period (average 2015–2018) (QUOTA 2015–2018).
- Changes in the combined market share of the two countries are measured between 1992 and 2018 (SHARE VARIATION).
- The price differential between the two countries at the beginning of the study period (average 1992–1994) (PRICE DIFFERENCE 1992–1994).
- The price differential between the two countries is determined at the end of the study period (average 2015–2018) (PRICE DIFFERENCE 2015–2018).
- Changes in the price differential between the two countries are measured between 1992 and 2018 (PRICE DIFFERENTIAL VARIATION).

Table 5 presents the logit model's estimated coefficients. The first column (Model 1) corresponds to the estimation of the complete model (including all explanatory variables), revealing that only two variables related to price differentials were significant at a 5% level. This result was expected due to the high multicollinearity among the included variables. Different tests were then conducted to examine the combined significance of the variables included in each of the four variable groups (location, volume of trade between countries, combined market share, and price differential). The results of these tests indicate that the variables associated with the volume of trade between countries were not jointly significant, those of location were only significant at a 10% level, and those of the remaining two groups were jointly significant at a 5% level.

Based on these results, Model 2 includes only the variables related to market share and price differential, while Model 3 also includes the location variables. These two models are estimated sequentially by introducing the more significant variable in each step. Model 2 fits better than Model 3 (lower AIC), indicating that the location variables do not influence the probability of membership in a particular convergence club; furthermore, the combined market share and differential price variables determine this probability. The greater the price differential at the end of the study period, the lower the probability of belonging to the same club. We can also see that market share variables are not individually significant; however, they are jointly significant, so we have kept these variables in the model. These results are interesting because while at the beginning of the study period, greater participation of the two countries in the global trade raised the probability of belonging to the same club, precisely the opposite took place at the end. This result can be explained by the remarkable growth of the Russian Federation in global trade, which belongs to neither of the two identified convergence clubs.

One of the limitations of this model's estimation is the sample size (45 observations). To validate the consistency of the data obtained, we next re-estimate the model using bootstrapping techniques (100

Table 6
Percentage of times that the variable was selected in the Logit model estimated by bootstrapping (%).

Variables	%
Quota 2015–18	76
Price Differential 2015–18	76
Quota 1992–94	73
Price differential 1992–94	62
Trade 1997–99	62
Continent	57
Distance	51
Variation Quota	51
Variation Trade	47
Trade 2015–18	39
Border	29

This Table shows the estimated coefficients of the Logit model shown in Table 5 but using bootstrapping techniques. Values represent the proportion of cases where each covariate was selected, that is, the covariate's importance in explaining the probability of the inclusion of a country in the estimated convergence club.

Table 5
Estimated coefficients from the logit model.

Dependent variable	Estimated Parameters (Standard Error)					
	Model 1		Model 2		Model 3	
Distance	0.00001	(0.0001)			−0.00004	(0.0001)
Border	0.906	(−2.322)			0.894	(−1.303)
Continent	0.279	(−1.350)			−0.482	(−1.181)
Trade 1997–99	−0.00001	(0.00001)				
Trade 2015–18	0.00001	(0.00001)				
Variation Trade	−0.0004	(0.0003)				
Quota 1992–94	0.154	(0.118)	0.105	(0.073)	0.108	(0.076)
Quota 2015–18	−0.257	(0.181)	−0.170	(0.123)	−0.182	(0.129)
Variation Quota	0.002	(0.166)				
Price differential 1992–94	−0.002	(0.011)				
Price Differential 2015–18	−0.020*	(0.011)	−0.016**	(0.008)	−0.019**	(0.009)
Price Differential Variation	−1.153**	(0.011)				
Intercept	2.824	(−2.431)	1.147	(0.974)	1.726	−1647
Sensitivity	0.862		0.828		0.862	
McFadden R square	0.29		0.188		0.212	
Observations	45		45		45	
Log Likelihood	−22.059		−24.910		−24.633	
Akaike information criterion	70.118		57.821		63.267	

This table shows the estimated parameters of the logit model to explain the inclusion of countries in the same convergence club.
Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

different samples are generated from the original sample, and Model 2 is sequentially re-estimated). Table 6 presents the proportion of cases where each covariate was selected, which can be interpreted as each covariate's importance in explaining the probability of the inclusion of a country in the estimated convergence clubs. Of the 100 simulations performed, QUOTA 2015–2018 and PRICE DIFFERENTIAL 2015–2018 were selected in 76% of cases, followed by QUOTA 1992–1994 with 73%.

Finally, sampling error can change the estimated parameter signs depending on the number of variables introduced in a model. Therefore, Table 7 shows the results obtained using the same simulation exercise to determine the percentage of cases in which each parameter appears with a positive or negative sign. This table reveals that the parameter associated with the QUOTA 1992–1994 variable has a positive sign in 83% of the simulations, coinciding with the sign with which it appears in the selected model. Similarly, the variables PRICE DIFFERENTIAL 2015–2018 and QUOTA 2015–2018 appear with a negative sign in >90% of the simulations.

7. Concluding remarks

This study analyzed the price dynamics of the global coniferous sawnwood market. More precisely, we tested for potential price convergence by considering export prices from the 10 most relevant exporting countries using annual data from 1992 to 2018. We followed the methodological framework suggested by Phillips and Sul (2007, 2009), and our results show that the data cannot support the null hypothesis of convergence. Instead, the global coniferous sawnwood market appears to be segmented into two convergence clubs, while the Russian Federation exhibits an independent pathway. The estimated convergence club 1 is composed of prices from Chile, the USA, Latvia, and New Zealand (countries with the lowest market share in total global exports). In contrast, the estimated convergence club 2 includes prices from Germany, Austria, Canada, Finland, and Sweden (countries traditionally playing a significant role in the global exports).

Causality tests were conducted to analyze the price dynamics in global coniferous sawnwood products. Average prices for the two convergence clubs, Russian Federation prices, and those for the top two importing countries (the USA and China) were included in the analysis. The results indicate that international price relationships are demand-driven, indicating that central importing countries are responsible for price dynamics in the sawnwood market. The only exception is for convergence club 1, for which internal relationships primarily drove price dynamics. This finding is consistent with the fact that this convergence club includes the countries with the lowest market share, playing a more limited role in international trade. Second, the irruption of China in the international market as one of the most significant importing countries has reinforced the demand-driven price relationships in the global coniferous sawnwood market. Moreover, price dynamics in China are mainly driven by its leading supplier, the Russian Federation.

Finally, our results suggest that the inclusion of a country in a particular convergence club is mainly determined by the price differential between countries (competition factors), and to a lesser extent, by the countries' combined market share in the global market (catching-up factors). Countries with smaller price differentials tend to show similar evolution and are more likely to have convergence processes. Likewise, countries with a higher combined market share in global trade at the beginning of the study period were more likely to belong to the same segment; however, this relationship has changed over time due to the strong growth of Russia as an exporting country and China as an importing country, leading to a substantial change in trade flows.

Our study contributes to the current literature on price dynamics in the international forest products markets as we present a methodological framework for simultaneously considering three issues. First, this study does not depend on the stochastic properties of the series. Second, it included a large set of countries. Third, it allows for testing the potential existence of convergence and, in case of rejection, can also identify potential market segments and variables to explain the probability of a country belonging to a specific market segment. Finally, our methodological framework can analyze the primary drives of price dynamics among segments.

Nonetheless, this study is not free from limitations, among which data availability is the most relevant. The data used correspond to the annual averages; more frequent data (i.e., monthly) would be more appropriate for this type of analysis and would enable a more in-depth examination of convergence mechanisms. When using aggregated data, a loss of information occurs that can mask the true convergence mechanism, such as the different seasonality or growth patterns of plantations and climates, which can influence the quality of the final product and, subsequently, its price. Finally, using unit values as a proxy for export prices entails some challenges as sometimes such values cannot capture price changes in products subject to significant quality changes over time. In this study, we have used a single average per country for the HS-4 digit code (4407). This approach means that the primary sources of heterogeneity are the origin of the wood (pine, etc.) and the export destination countries; however, we do not think that using unit values has biased our results, as most commodities are not significantly affected by quality changes, as Miao and Wegner (2022) also reflect.

Apart from considering the above mentioned limitations, future research could take two main directions. First, it would be interesting to extend this methodological framework to other forest-based products to determine if international markets are also segmented and if similar variables can explain the characteristics of the different convergence clubs. A second area of interest would be to measure the extent to which, in each convergence club, the reference price is a vital determinant of domestic prices. That is, future research can determine the extent to which the international reference price determines the price dynamics along the coniferous sawnwood supply chain in each country or, conversely, if domestic prices influence international reference prices.

Table 7
Results of the simulations on the sign of the coefficients in the logit model estimated by bootstrapping (%).

	Percentage of times the variable appears with positive sign	Percentage of times the variable appears with negative sign
Quota 1992–94	83.56	16.44
Trade 1997–99	72.58	27.42
Border	62.07	37.93
Price differential 1992–94	61.29	38.71
Trade 2015–18	51.28	48.72
Variation Quota	49.02	50.98
Distance	41.18	58.82
Continent	38.60	61.40
Price Differential Variation	6.90	93.10
Quota 2015–18	6.58	93.42
Price Differential 2015–18	6.58	93.42
Variation Trade	4.26	95.74

This table shows the results obtained using the same simulation exercise than in Table 6 to determine the percentage of cases in which each parameter appears with a positive or negative sign.

CRediT authorship contribution statement

Jose M. Gil: Conceptualization, Visualization, Supervision, Writing - original draft, Writing - review & editing. **Antonio Montañés:** Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Bernardo Vásquez-González:** Data curation, Methodology, Formal analysis, Writing - original draft, Writing - review

& editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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