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COINTEGRATION ANALYSIS IN THE CENTRAL EUROPEAN SPRUCE TIMBER MARKET

The oversupply of spruce timber in Central Europe reduces softwood prices, compromising the profitability of forest holdings. To date, relationships between Central European timber markets have been relatively little studied; the same is true of the factors affecting roundwood price variability and fluctuations in that region. An understanding of changes in those markets and linkages between them is important not only for forest owners and managers, but also for companies in the wood sector.

The present work describes market analysis in terms of long-term correlations between the Austrian, Czech, Polish, and Slovak markets (cointegration analysis). Cause-and-effect relationships between the analyzed markets were verified using the Granger causality test.

The Engle-Granger and Johansen cointegration tests revealed a long-term equilibrium between the analyzed spruce sawlog markets, except for Slovakia. Bidirectional causality was found between the Austrian, Czech, and Polish markets. However, there was no evidence for the integration of pulpwood markets, which indicates their independence.

Keywords: wood economics, timber market, timber price, market co-integration

Introduction

The functioning of the timber market and trade is vital for timber producers and the wood industry. Globalization processes have increased the importance of the international timber market, while the rational management of forest resources requires the monitoring of timber price changes not only on the national level, but also on the European or even global level. The resulting knowledge is indispensable for developing optimum market strategies. It is widely believed that there are strong linkages between European markets, and that they influence each other [Toivonen et al. 2002; Ratajczak 2003; Olmos 2014]. If markets in

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different countries are competitive and efficient, then prices in those countries should be identical after adjusting for transportation costs (according to the law of one price) [Mäki-Hakola 2002].

The situation in the timber market (including timber prices) in a given country depends on timber supply, which is determined by biological and silvicultural factors, as well as the forest ownership structure, sustainable forestry practices, environmental policies, market organization, and national and global economic trends. In addition to economic variables, timber prices are also indirectly affected by climatic and biotic factors and by natural disasters (hurricanes, droughts, etc.) [Zając 1999; Adamowicz 2010; Hanewinkel et al. 2013; Wysocka-Fijorek and Lachowicz 2018; Banaś and Kożuch 2019; Adamowicz and Górna 2020].

Market linkages have been the subject of research for many years. Initially, market integration was investigated in terms of correlation, with one equation and regression analysis. The difficulty with such models is that they may fail to identify a correlation between two price time series characterized by the same type of trend [Mäki-Hakola 2002]. Currently, price relationships are analyzed using the concept of cointegration to eliminate the problem of spurious regression. The Engle-Granger procedure may be applied when all variables are integrated of order one, I(1).

Markets are integrated when prices are similar irrespective of the seller and buyer of a given product. There is a considerable body of research on the vertical and horizontal integration of roundwood and wood product markets in Europe and the USA. In a US study encompassing the years 1977-2011, Zhuo and Changyou [2014] showed that market integration at the first stage of the supply chain (timber prices) is stronger than at further stages (processed timber). Parajuli et al. [2016], who analyzed linkages among timber prices in the south-central United States for 1981-2014, reported that while timber prices were intercorrelated, the effects differed depending on product type. The Granger test suggested a unidirectional causality from pulpwood markets to respective sawtimber markets. While there is a rich literature on price linkages in the Scandinavian markets [Toppienen and Toivonen 1998; Jukany and Lundmark 2015], there are few papers analyzing relationships between individual Central European and Scandinavian countries. Examples include a study by Toivonen et al. [2002], who did not find any relationships between spruce and pine roundwood prices in Scandinavian countries (Finland and Sweden) and Austria. Mäki-Hakola [2002], who investigated linkages between timber prices in Finland, Estonia, Germany, and Lithuania in the years 1994-2001, reported partial integration of the spruce pulpwood markets and full integration of the pine pulpwood markets. On the other hand, the sawlog markets were fully endogenous and did not form a single market. Also Olmos and Siry [2018] showed that in the years 1995-2012 sawlog prices in Finland and Germany were not cointegrated. On the other hand, there is a scarcity of research on the integration of Central European markets.

Due to the changing situation of the forestry and wood industry in Europe, as well as the evolution of trade relations between countries, there is a need to study and understand the mechanisms governing the regional and national timber markets. Over the past decades, and especially in the last several years, the supply of spruce timber has abruptly increased as a result of the spruce dieback in Europe due to bark beetle outbreaks (especially *Ips typographus* (L.)) and abnormal weather conditions leading to droughts and hurricanes (which, in particular, resulted in a drop in prices locally). The current situation in the spruce timber market shows that after large-scale incidental fellings in previous years and due to the increasing demand for timber in China and the USA, there is a significant shortage of softwood timber, which is driving up its prices.

Data on exports and imports of unprocessed spruce softwood suggest the presence of market linkages between Central European countries. Nevertheless, the degree of integration of geographic markets can be best understood by analyzing price correlations rather than trade flows.

Relatively little is known about linkages between Central European timber markets. There is a need to expand our knowledge about long-term linkages between markets (by cointegration analysis). An understanding of changes in wood markets and relationships between them is important not only for forest owners who wish to optimize timber supply management. It is also crucial for commercial decision-making by other entities in the supply chain, as well as by potential investors in the forest and wood industry.

The objective of the present work is to analyze the prices of spruce sawlogs and pulpwood in selected primary timber markets of Central Europe – Austria, Czechia, Poland, and Slovakia – in 2005-2019, and in particular, to analyze the long-term (cause-and-effect) relationships between spruce timber prices in European markets.

Materials and methods

Econometric and statistical methods are designed to reveal the effects of causal mechanisms, but not their nature. The main objective of the current analysis was to determine cause-and-effect relationships between the analyzed markets using the concept of Granger causality, where X is understood to cause Y when X is useful in forecasting Y [Granger 1969]. This can be assessed using the Granger causality test [Granger 1980]; the following formula was applied in the study:

$$y_t = a_0 + \sum_{i=1}^{k} a_i\, y_{t-1} + \sum_{i=1}^{k} b_i\, x_{t-i} + \varepsilon_t$$

The combined significance of the parameters b_i means that the values of the X series significantly affect the forecasts of the Y series, which is taken to mean that X is the Granger cause of Y. The null hypothesis of the test, according to which X is not a Granger cause of Y, is as follows:

$$H_0: b_1 = b_2 = \cdots = b_k = 0$$

Before performing the test, the Akaike information criterion (AIC) [Akaike 1974] was used to determine the number of prior observations in the time series X and Y that should be considered (designated by k). The parameters of the model were estimated by the ordinary least squares (OLS) method to make sure that the X and Y series meet certain conditions, such as the stationarity of both series and their integration of order one (the stationarity of the first differences if the series itself is nonstationary) combined with cointegration (there is a linear combination of these series which is stationary – the coefficients of such a combination were determined with a cointegrating vector). A violation of these conditions may result in spurious regressions, which, while showing statistically significant results, do not correspond to actual relationships in reality. A price time series cointegration test is performed after determining the stationarity of an individual time series. In this study, the stationarity of time series was examined using the augmented Dickey-Fuller (ADF) test [Said and Dickey 1984], the Phillips-Perron (PP) test [Phillips and Perron 1988], and the Kwiatkowski--Phillips-Schmidt-Shin (KPSS) test [Kwiatkowski et al. 1992]. In contrast to ADF and PP, in KPSS the null hypothesis assumes series stationarity, and so the interpretation of its results is different from the other tests: a low p-value indicates nonstationarity. The three tests often provided inconclusive results (with some indicating stationarity, and some nonstationarity). In the case of series which were integrated of order one, I(1), cointegration was evaluated using the Johansen test [Johansen 1991], which involves analysis of the vector autoregressive model (VAR):

$$Y_t = \mu + \sum_{i=1}^{t} A_i Y_{t-i} + \varepsilon_t \tag{1}$$

where Y designates the vector of the analyzed time series [MacKinnon et al. 1999].

Analysis of differences in the above model leads to two possible versions of a vector error correction model (VECM):

$$\Delta X_t = \mu + \Pi X_{t-k} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-1} + \varepsilon_t \tag{2}$$

or

$$\Delta X_t = \mu + \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-1} + \varepsilon_t \tag{3}$$

Inferences are identical in the two cases, as they are based on the matrix Π, which has the same form in both VECM versions:

$$\Pi=\sum_{i=1}^{k} A_i-1 \tag{4}$$

The rank of this matrix (designated as *r*) is equal to the number of vectors cointegrating the series comprising *Y*, with $r = 0$ indicating the absence of such vectors (no cointegration). Any higher number indicates cointegration. Johansen proposed two test statistics for determining *r*: the trace statistic and the maximum eigenvalue statistic in a sequential procedure. The first step involves testing the null hypothesis (the same for both statistics):

$$H_0: r=0$$

in the next step

$$H_0: r \leqslant 1$$

then

$$H_0: r \leqslant 2$$

and analogously up to

$$H_0: r \leqslant n-1$$

where *n* stands for the number of tested series. The procedure was terminated upon the first statistically non-significant result, and the *r* value from the first non-rejection of the null hypothesis was taken as an estimator of *r*. Similarly to Granger causality, the Johansen test requires the determination of *k*, or the number of lags considered (this time in the VAR model), which was done using the AIC. Analysis was performed using R software ver. 4.0.3.

The study materials consisted of time series of net nominal prices of spruce roundwood and pulpwood for the years 2005-2019 on a quarterly basis. In the case of Austria and Slovakia, data for 2005-2018 were obtained from the FAO Database, and data for 2019 from the websites of statistical agencies in those countries [www.fao.org/forestry/statistics]. Data for Slovakia were taken from the Forest Portal Market Information System [www.forestportal.sk], and those for Poland from reports of the State Forest Information System.

Price comparisons between countries are difficult and challenging because of disparities in timber size and grade classifications, and also due to different trade terms. However, differences between the most important types of timber (sawlogs, pulpwood, and firewood) are negligible; indeed, the studied assortments are very similar in terms of quality specifications, and so they can be meaningfully compared [Malinen and Kilpelainen 2013; Gejdos et al. 2019]. The present study focused on the prices of spruce sawlogs and pulpwood on a quarterly basis (as sold at the forest road, roadside landing, or timber storage parity – Slovakia).

It should be noted that in Austria and Slovakia the prices of spruce and fir softwood were available only for the two species together. For Austria, the mean net prices of spruce/fir were given in €/m^3, while for Czechia, Poland, and

Slovakia, prices expressed in the local currencies were converted into euros at the quarterly exchange rates published by the Czech National Bank, the Polish National Bank, and the Bank of Slovakia, respectively.

Results

The nominal prices of spruce roundwood in the years 2005-2019 differed considerably between the analyzed countries (Fig. 1), with the highest prices for spruce sawlogs recorded in Austria (101.24 €·m^{-3}), and the lowest in Poland (69.45 €·m^{-3}) (Table 1). The lowest minimum price was found in Slovakia (39 €·m^{-3}), and the highest minimum price in Austria (68.34 €·m^{-3}).

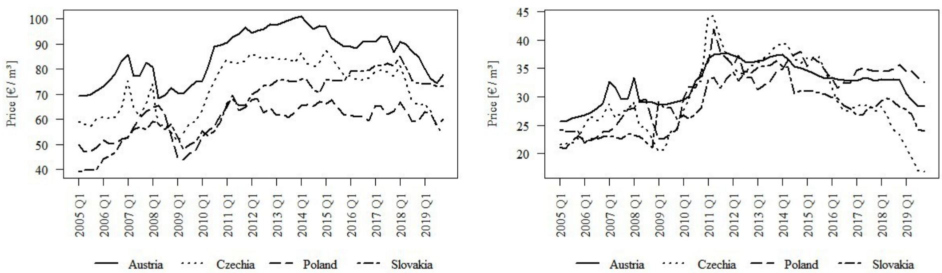

Fig. 1. Nominal prices of spruce sawlogs and pulpwood in selected Central European countries in the years 2005-2019

Table 1. Descriptive statistics of quarterly price time series for spruce sawlogs and pulpwood (Czechia, Poland) and spruce/fir sawlogs and pulpwood (Austria, Slovakia)

	Unit	Austria		Czechia		Poland		Slovakia	
		sawlog	pulpwood	sawlog	pulpwood	sawlog	pulpwood	sawlog	pulpwood
Mean	€/m^3	85.46	32.27	72.08	29.53	59.55	31.16	65.46	28.27
Median	€/m^3	88.61	32.95	75.53	28.31	61.68	32.87	70.92	28.11
Maximum	€/m^3	101.24	37.72	87.35	44.23	69.45	41.92	85.06	36.35
Minimum	€/m^3	68.34	25.61	51.27	16.80	43.93	20.87	39.00	21.00
Max/min	–	1.50	1.50	1.70	2.60	1.60	2.00	2.20	1.70
Standard deviation	–	10.10	3.50	11.00	6.70	6.70	5.40	13.10	4.30
Coefficient of variation	%	11.80	11.00	15.20	22.70	11.30	17.30	20.10	15.20

The Polish and Austrian markets revealed the greatest stability of sawlog prices, while the highest volatility was recorded for Czechia and Slovakia, with the lowest prices since 2011 (Table 1). The highest and lowest pulpwood prices were found in Czechia (44.23 €·m^{-3} and 16.80 €·m^{-3}, respectively). In that country, wood prices dropped significantly in 2019 due to massive outbreaks of the spruce bark beetle, hindering the planning of harvesting and limited local demand.

Stationarity of time series of timber prices and their differences

Tests for Austria, Czechia, and Slovakia consistently indicate price nonstationarity for sawlogs. In the case of price differences, the tests are inconclusive, but since two out of the three tests applied (PP and KPSS) suggest stationarity, it is assumed that time series in those countries are integrated of order one. Tests for Poland were inconclusive both for timber prices and price changes; in terms of prices, two tests (ADF and PP) suggested nonstationarity (Table 2), while in terms of price differences two tests (PP and KPSS) indicated stationarity, which is taken to mean that the price series is integrated of order I(1).

Table 2. Results of ADF, PP, and KPSS stationarity tests for spruce roundwood prices and their first differences (with constant)

Country	Price series			First differences of price series		
	ADF	PP	KPSS	ADF	PP	KPSS
Austria	-1.346	-3.027	0.279**	-2.631	-45.777**	0.078
Czechia	-0.412	-1.656	0.277**	-2.652	-54.177**	0.103
Poland	-3.239	-13.009	0.145	-3.135	-42.224**	0.033
Slovakia	-1.618	-4.819	0.202*	-2.982	-46.676**	0.064

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

The tests consistently indicate the nonstationarity of pulpwood prices. While the results for price changes in the studied countries are inconclusive, both PP and KPSS suggest stationarity (Table 3), and so the time series are taken to be integrated of order I(1).

Cointegration tests

Since all four time series are of order I(1), their cointegration was evaluated using the Johansen test. Both versions of this test showed a cointegration relationship of r=1 in the sawlog market (Table 4).

Table 3. Results of ADF, PP and KPSS stationarity tests for spruce pulpwood prices and their first differences (with constant)

Country	Price series			First differences of price series		
	ADF	PP	KPSS	ADF	PP	KPSS
Austria	-1.164	-2.856	0.318**	-2.816	-60.779**	0.056
Czechia	-1.157	-2.781	0.314**	-3.465	-45.534**	0.059
Poland	-2.122	-9.005	0.244**	-3.302	-55.804**	0.036
Slovakia	-0.574	-2.769	0.332**	-4.04*	-62.314**	0.097

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

Table 4. Results of the Johansen test for cointegration among spruce sawlog prices

Country	H0	Maximum eigenvalue test statistic	Trace test statistic
Austria-Czechia- -Poland-Slovakia (*k*=3)	$R = 0$	30.24*	53.37*
	$r \leq 1$	15.32	23.13
	$r \leq 2$	6.05	7.81
	$r \leq 3$	1.76	1.76

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

Subsequently, pairwise comparisons were performed to test for market cointegration. Both versions of the Johansen test revealed the cointegration of the Polish, Austrian, and Czech markets (Table 5).

Also in the case of pulpwood prices (where all time series are of order I(1)), cointegration was evaluated using the Johansen test. Both versions of this test suggest the absence of cointegrating relationships (Table 6).

Granger causality test

The integrated markets were tested in terms of causality using the Granger test, in order to examine how they influence each other. The analysis showed that the Czech market affects the Polish and Austrian markets (Table 7). In turn, the Polish and Austrian markets influence the Czech market (consequently, there are linkages between Poland and Czechia and between Austria and Czechia). Furthermore, the Austrian market affects the Polish market. Taking into consideration *k*, or the lags in the model, it was found that Austrian prices have an impact on Czech prices at $k = 2$ (with a lag of two quarters). For the other analyzed relationships, $k = 5$, which means that the identified effects are considerably extended over time.

Table 5. Results of pairwise cointegration comparisons using the Johansen test

Country	H_0	Maximum eigenvalue test statistic	Trace test statistic
Austria-Czechia (k=2)	r = 0	18.58 *	20.89 *
	r ≤ 1	2.31	2.31
Austria-Poland (k=5)	r = 0	29.26 **	32.99 **
	r ≤ 1	3.73	3.73
Austria-Slovakia (k=2)	r = 0	8.14	11.85
	r ≤ 1	3.71	3.71
Czechia-Poland (k=5)	r = 0	26.01 **	27.66 **
	r ≤ 1	1.65	1.65
Czechia-Slovakia (k=2)	r = 0	8.09	10.01
	r ≤ 1	1.92	1.92
Poland-Slovakia (k=2)	r = 0	12.52	16.81
	r ≤ 1	4.3	4.3

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

Table 6. Johansen test checking for cointegrating vector among spruce pulpwood prices

Countries	H_0	Maximum eigenvalue test statistic	Trace test statistic
Austria-Czechia-Poland-Slovakia (k=2)	$r = 0$	19.47	43.82
	$r \leq 1$	19.18	24.34
	$r \leq 2$	4.95	5.17
	$r \leq 3$	0.22	0.22

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

Discussion

Price variation in individual markets results from an interplay of numerous natural, economic, and political (legal) factors, as well as the processing potential, technological development, and innovation of the wood industry. In

Table 7. Results of Granger causality test evaluating the mutual effects of markets

Direction	*F*	*p*	*k*
Austria→Czechia	7.5	0.001**	2
Czechia→Austria	3.82	0.025*	2
Austria→Poland	5.95	<0.001**	5
Poland→Austria	0.83	0.532	5
Czechia→Poland	3.69	0.004**	5
Poland→Czechia	2.86	0.019*	5

* and ** indicate null hypothesis rejection at the 5% and 1% probability levels, respectively.

the years 2005–2008, spruce timber prices in the Central European market were on an increase, with 2008 marking the beginning of a downturn as the global financial crisis destabilized the timber market. The most pronounced drop in timber prices during the 2008 downturn affected large-sized softwood assortments [Suchomel et al. 2012; Gejdos and Potkány 2017]. Since 2015, there has been a decreasing trend in spruce and spruce/fir timber prices (except for the Slovak market), which is largely attributable to a dramatic increase in the supply of timber in the aftermath of major hurricanes (and especially Niklas in 2015), droughts, as well as bark beetle outbreaks (in 2018–2019 in Austria, Czechia, and Slovakia).

Recent years have shown the negative effects of abiotic and biotic factors on spruce stands, which disrupted the timber production policies in Czechia, Austria, and Slovakia. In 2019, in the Czech forests, a total of 32.58 million m^3 of timber was harvested (an increase of 6.89 million m^3 over 2018), with the proportion of incidental felling amounting to 95% (approx. 31 million m^3) in 2019 [MZ 2019]. The overall volume of timber harvested in Slovakia from forests under all forms of ownership was 9.22 million m^3 in 2019, with incidental cutting accounting for 56% (more than 5 million m^3 of softwood) [Ministry of Agriculture 2020]. In the same year, 18.90 million m^3 of timber was produced in Austria (85% softwood), which was 5.6% higher than the ten-year average. Toth et al. [2020] reported a strong correlation between salvage felling attributable to *Ips typographus* outbreaks and a decrease in timber prices in Czechia.

Analyses by many authors have revealed either the presence or absence of long-term relationships between prices in the global and European timber markets. Long-term linkages were more often found between markets for similar timber assortments located in the proximity of each other than in the case of distant markets. Certain studies [Olmos 2014; Olmos and Siry 2018] showed the absence of linkages among global pulpwood markets, but numerous long-term linkages were identified for sawlog prices (nevertheless, Europe was not defined as a single market for sawlogs). Chudy and Hagler [2020], who analyzed linkages between selected markets around the world, many of them distant, found moderate correlations and no integration between countries, which indicates the apparent independence of those markets.

Markets in one region are often interrelated and driven by similar market mechanisms and climatic factors. Moreover, investments in infrastructure and lower costs of transportation contribute to the integration of timber markets. The current analysis of neighboring Central European spruce timber markets revealed long-term relationships between sawlog prices, except in the case of Slovakia. This result may be explained by disturbances in the Slovak market after 2007. In 2010 the Slovak government implemented a new policy on timber trade involving long-term contracts with several entities, which led to a more than 20% surge in spruce/fir prices; furthermore the country's adoption of the euro currency in 2009 weakened its linkages with the neighboring markets. On the other hand, the present study did not find evidence for the cointegration of spruce pulpwood markets. It should be noted that these findings do not entirely preclude integration, as the results may be affected by the use of quarterly data (in the case of Slovakia and Czechia monthly data are not available).

The spruce sawlog markets of Central Europe may be deemed cointegrated, with mutual causality found for three market pairs (with a half-yearly lag between the Czech and Austrian markets). Consequently, a decrease (increase) in one of them is highly likely to result in a decrease (increase) of prices in the neighboring countries, which should be taken into consideration in designing timber sales policies. These results are convincing, as such linkages are also suggested by the patterns of spruce timber exports and imports between these countries. In contrast, other authors have reported the absence of integration for beech sawlog prices in Europe, which may be attributable to the small size of the beech timber market as compared to the spruce and pine markets [Toppinen et al. 2005].

According to Niquidet and Manley [2011], discrepancies in the findings obtained by different authors studying the integration of roundwood markets may be due to differences in the applied statistical methods and materials (data). Furthermore, the results of research on market integration also have some major policy consequences, as they may be used in defining the geographic scope of markets in the process of developing competitiveness strategies [Niquidet and Manley 2007].

However, market cointegration findings should be interpreted cautiously, especially if they are to be used as an input in defining trade policies, due to the increasing frequency of hard-to-predict external factors, which may distort and limit existing linkages between markets. Natural disasters as well as spruce dieback may be detrimental to timber producers due to their effects on timber production and prices. Some large-scale events may decrease both timber prices and standing stock resources, also exerting a negative influence on the owners of unaffected stands. Viewed with hindsight many years later, the actual effects of a natural disaster are generally inconsistent with expectations [Prestemon and Holmes 2004].

In the short term, timber oversupply leads to negative spikes in prices, while also reducing standing stock, which may lead to an increase in timber prices in the long term. This would mean that the owners of affected stands should delay harvesting, but some disturbances exhibit temporal and spatial autocorrelations influencing price risks, which complicates the picture [Prestemon and Holmes 2000]. In the case of beetle outbreaks, the catastrophic consequences usually last for several years, and so the owners of intact timber should consider the promise of future price increases, given increased production risk over time [Prestemon and Holmes 2000]. On the other hand, an oversupply of "cheap" spruce timber in the region offers an opportunity for the growth and development of the Central European wood industry. In particular, short-term benefits may be reaped by manufacturers of cellulose, particle boards, and sawn timber products.

The southern pine beetle epidemic in the southern United States in the years 1984-1985 reduced the growing stock by 18% in Louisiana and by 13% in Texas. Prices declined at a rate of 1.5% per percentage point of growing stock decrease [Holmes 1991]. In the case of Hurricane Hugo, the long-term price increase was approx. 0.5% to 1.0% per percentage point of growing stock decrease [Prestemon and Holmes 2004].

It is interesting whether and to what extent incidental spruce harvesting in Central Europe will affect the markets and distort existing trade relationships in raw and processed timber (mostly sawn products) in Europe. It seems that timber oversupply in Central Europe will affect the Scandinavian market, as a similar oversupply has been observed in Germany, which has been the most important market for Finland, accounting for 20-25% of Finnish exports of spruce sawn timber [Olmos and Siry 2018]. The Scandinavian (Finnish) market has already suffered because of increased timber supply from Eastern Europe and Russia, with the Finnish sawmilling industry having an uncertain future [Malaty et al. 2007].

Spruce dieback alters the age structure of stands and, over the coming decades, will cause problems with supply for the sawmill industry, which requires a predictable and stable input of timber. Thus, it is necessary to adjust forest management practices to the consequences of climate change, primarily by altering species composition (mixed forests), which would translate into a different structure of assortments supplied to the market and entail the need to modify technology in processing plants.

Conclusions

The nominal prices of spruce sawlogs and pulpwood in Central Europe in 2005--2019 differed between the analyzed markets. Sawlog prices commanded the highest prices in Austria in Q1 2014 (101.24 €/m^3) and in Czechia in Q1 2015 (87.35 €/m^3). The lowest and most stable prices occurred in the Polish market, peaking in 2011 at 69.45 €/m3. The growth trend was the longest in the Slovak market, lasting from 2005 (39 €/m^3) to 2018 (85.06 €/m^3). The sawlog and pulpwood markets were destabilized by the American financial crisis of 2008 and by the oversupply of timber resulting from spruce dieback in the region in the years 2015-2019. Downward trends were observed in all markets, with nominal prices in Czechia in 2019 being lower than in 2005.

Both the Johansen and Engle-Granger tests for the cointegration of price time series revealed a long-term equilibrium between the analyzed spruce roundwood markets, except for Slovakia (where prices were influenced by state interventionism). Bidirectional relationships and causality were found between the Austrian, Czech, and Polish markets. This is important information for companies from the wood sector. However, there was no evidence for integration in pulpwood markets, which indicates their independence.

There is a need to continue studies in this field and to monitor the influence of timber oversupply in Central Europe on markets in other regions. Attention should also be given to the long-term effects of this situation on timber prices and relationships between markets.

References

Adamowicz K. [2010]: Cenowa elastyczność popytu na drewno na pierwotnym lokalnym rynku drzewnym w Polsce (Price elasticity of demand for timber on primary local wood market in Poland). Sylwan 154 [2]: 130-138. DOI: https://doi.org/10.26202/sylwan.2009018

Adamowicz K., Górna A. [2020]: The application of trend estimation model in predicting the average selling price of timber. Drewno 63 [206]: 147-159. DOI: 10.12841/wood.1644-3985.350.07

Akaike H. [1974]: A new look at the statistical model identification. IEEE Transactions on Automatic Control 19 [16]: 716-723

Banaś J., Kożuch A. [2019]: The application of time series decomposition for the identification and analysis of fluctuation in timber supply and price: a case study from Poland. Forests 10 [990]: 1-18. DOI:10.3390/f10110990

Chudy R.P., Hagler R.W. [2020]: Dynamics of global roundwood prices Cointegration analysis. Forest Policy and Economics [115]: 1-14. DOI: 10.1016/j.forpol.2020.102155

FAO: www.fao.org/forestry/statistics [accessed: 4.12.2020]

Forest Portal: www.forestportal.sk [accessed 4.12.2020]

Gejdos M., Potkány M. [2017]: Prediction and analysis of Slovakian timber trade on global market conditions. Serbian Journal of Management [12]: 281-289. DOI: 10.5937/sjm12-11228

Gejdos M., Lieskovsky M., Giertliova B., Nemec M., Danihelova Z. [2019]: Prices of raw-wood assortments in selected markets of Central Europe and their development in the future. Bioresources [14]: 2995-3011

Granger C.W.J. [1969]: Investigating causal relations by econometric models and cross--spectral methods. Econometrica 37 [3]: 424-438

Granger C.W.J. [1980]: Testing for causality: A personal viewpoint. Journal of Economic Dynamics and Control [2]: 329-352

Hanewinkel M., Cullmann D., Schelhaas M.J. [2013]: Climate change may cause severe loss in the economic value of European forest land. Nature Clim Change [3]: 203-207

Holmes T.P. [1991]: Price and welfare effects of catastrophic forest damage from southern pine beetle epidemics. Forest Science 37 [2]: 500-516

Johansen S. [1991]: Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive model. Econometrica 59 [6]: 1551-1580

Junkany V.C., Lundmark R. [2015]: Dynamics of timber market integration in Sweden. Forests 6 [12]: 4617-4633. DOI: 10.3390/f6124391

Kwiatkowski D., Phillips P.C.B., Schmidt P., Shin Y. [1992]: Testing the null hypothesis of stationarity against the alternative of a unit root. Journal of Econometrics 54 [1-3]: 159--178

MacKinnon J., Haug A., Michelis L. [1999]: Numerical distribution functions of likelihood ratio tests for cointegration. Journal of Applied Econometrics 14 [5]: 563-577

Mäki-Hakola M. [2002]: Cointegration of the roundwood markets around the Baltic Sea: An empirical analysis of Roundwood markets in Finland, Estonia, Germany and Lithuania. Manuscript, Helsinki

Malaty R., Toppinen A., Viitanen J. [2007]: Modelling and forecasting Finnish pine sawlog stumpage prices using alternative time-series methods. Canadian Journal of Forest Research [37]: 178-187. DOI: 10.1139/x06-208

Malinen J., Kilpelainen H. [2013]: Price systems for standing sales of industrial roundwood in Finland. Baltic Forestry 19 [2]: 307-315

Ministry of Agriculture [2020]: Report on the forest sector of the Slovak Republic 2019. Green report. Ministry of Agriculture and Rural Development of the Slovak Republic, Bratislava [accessed 21.03.2021]. Avilable from: https://www.mpsr.sk/en/index.php?navlD=18id=75

MZ [2019]: Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2019. Ministerstvo zemědělství (Report on the state of forests and forest management in the Czech Republic in 2019. Ministry of Agriculture) [accessed 22.04.20121]. Available from: http://eagri.cz/public/web/mze/lesy/lesnictvi/zprava-o-stavu-lesa-a-lesniho/zprava-o-stavu-lesa-a-lesniho-2019.html

Niquidet K, Manley B. [2011]: Testing for nonlinear spatial integration in roundwood markets. Forest Science 57 [4]: 301-308

Niquidet K., Manley B. [2007]: Price dynamics in the New Zealand log market. NZ Journal of Forestry [11]: 4-9

Olmos V.M. [2014]: Global roundwood markets. Lic. en Economía, Uruguay

Olmos V.M., Siry J. [2018]: The Law of One Price in global coniferous. Silva Fennica 52 [1]: 1-19. DOI: 10.14214/sf.6999

Parajuli R., Tanger S., Joshi O., Henderson J. [2016]: Modeling prices for sawtimber stumpage in the South-Central United States. Forests [7]: 148. DOI: 10.3390/f7070148

Phillips P.C.B., Perron P. [1988]: Testing for a unit root in time series regression. Biometrika 75 [2]: 335-346

Prestemon J.P., Holmes T.P. [2000]: Timber price dynamics following a natural catastrophe. American Journal of Agricultural Economics 82 [1]: 145-160

Prestemon J.P., Holmes T.P. [2004]: Market dynamics and optimal timber salvage after a nature catastrophe. Forest Science 50 [4]: 495-511

Ratajczak E. [2003]: Rynek drzewny w Polsce w perspektywie integracji z Unią Europejską (The Wood Market in Poland in the Perspective of Integration With the European Union). Annals Universitatis Marie Curie-Skłodowska Lublin – Polonia. SECTIO H. Vol. XXXVII: 317-328

Said S.E., Dickey D.A. [1984]: Testing for unit roots in autoregressive-moving average models of unknown order. Biometrika [71]: 599-607

Suchomel J., Gejdos M., Ambrusova L., Sulek R. [2012]: Analysis of price changes of selected roundwood assortments in some Central Europe countries. Journal of Forest Science [58]: 483-491

Toivonen R., Toppinen A., Tilli T. [2002]: Integration of roundwood markets in Austria, Finland and Sweden. Forest Policy and Economics 4 [1]: 33–42. DOI: 10.1016/s1389-9341(01)00071-5

Toppinen A., Toivonen R. [1998]: Journal of Forest Economics [4]: 241-265

Toppinen A., Viltanen J., Leskien P., Toivonen R. [2005]: Dynamics of roundwood prices in Estonia, Finland and Lithuania. Baltic Forestry 11 [1]: 88-96

Toth D., Maitah M., Maitah K., Jarolinova V. [2020]: The impacts of calamity logging on the development of spruce wood prices in Czech forestry. Forests 11 [283]: 1-13. DOI: 10.3390/f11030283

Wysocka-Fijorek E., Lachowicz H. [2018]: Zmiany cen, ilości i wartości surowca drzewnego sprzedawanego w Lasach Państwowych (Changes in prices, volume and value of wood raw material sold by the State Forests). Sylwan 162 [1]: 12-21. DOI: https://doi.org/10.26202/sylwan.2017043

Zając S. [1999]: Analiza ekonometryczna i prognozowanie zjawisk i procesów rynku surowca drzewnego w Polsce. Prace Instytutu Badawczego Leśnictwa A [886]: 1-133

Zhuo N., Changyou S. [2014]: Vertical price transmission in timber and lumber markets. Journal of Forest Economics [20]: 17-32

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