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Intervention analysis of COVID-19 pandemic impact on timber price in selected markets

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ABSTRACT

Using intervention analysis and time series of roundwood prices from ten European and North American countries, we analyzed the impact of the COVID-19 pandemic on the movement of timber prices. The study material consists of forty-six quarterly time series prices of logs and pulp, both softwood and hardwood, covering the period 2005–2022. During the Covid-19 pandemic period (2020:Q1-2020:Q4), softwood log prices mostly underwent declines, with the changes being the largest in Slovakia (−35%), the Czech Republic (−24%) and Austria (−24%), slightly smaller in the United States (−19%), Poland (−17%), Slovenia (−12%) and Germany (−11%) while no significant price changes were recorded in Finland and Sweden. In Canada and the United States, sharp price declines occurred earlier (2020:Q1 and 2020:Q2, respectively), while in Europe, significant price declines occurred later and lasted longer. In the post-pandemic COVID-19 period, prices increased, but in most cases, the shift was not statistically significant compared to the pre-pandemic period. Softwood pulp prices were subject to much less change, with a significant increase only in Slovakia and Poland. In contrast, no significant changes were observed in the price of both log and pulpwood hardwood during the COVID-19 pandemic.

1. Introduction

The COVID-19 pandemic has caused enormous disruption to human lives, livelihoods, and economic systems around the world (Attah, 2022). According to Golar et al. (2020), the COVID-19 pandemic had a global impact, affecting >200 countries. Researchers are intensively engaged in assessing the impacts of COVID-19 on health and well-being, gender equality, food production and supply, the stock market, and the overall economy (Maraseni et al., 2022). According to the Organization for Economic Co-operation and Development (OECD, 2021) Economic Outlook report released in September 2021, global economic growth declined by 3.4% in 2020, yet global economic growth is estimated to be 5.7% per year in 2021 and 4.5% in 2022 (Blaser et al., 2022). The economic impact of COVID-19 was modest in countries with high vaccination rates, but this option increased pressure on global supply chains and costs. The EU report by de Vet et al. (2021) also looks at the impact of Covid-19 on the European industry as a whole.

The COVID-19 pandemic has affected forests and the people dependent on them around the world in many ways and many areas (Stanturf and Mansuy, 2021). The pandemic has also directly affected the market for forest products and indirectly the demand for end products (Muhammad et al., 2022). The COVID-19 pandemic initially caused short-term disruptions in forest product supply chains and accelerated recent trends in consumer behavior (FAO, 2020; Attah, 2022). As in many other sectors, the disruption of forest-related supply chains has led to a sharp decline in exports and imports worldwide (ILO Sectoral Brief, 2020). Measures to limit the spread of the COVID-19 virus have delayed or postponed forest management and forest-wood-processing research, and increased visitation to forests near urban areas has increased vandalism, litter accumulation, and fire hazards (Stanturf and Mansuy, 2021).

The estimated impacts of the COVID-19 pandemic on the forestry-logging sector vary between regions and countries. Chirwa et al. (2021) report that in South Africa, due to the commercial nature of the forestry sector, the impact of COVID-19 on timber production, supply, demand, and prices was generally low. United Nations (2021a) reports that most Eastern Europe, Caucasus, and Central Asia countries reduced production and consumption of wood products as a result of government

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restrictions during the COVID-19 pandemic, but in the last quarter of 2020, there was a return to normal rhythm and an increase in production activity. In contrast, Basnyat et al. (2020) or Maraseni et al. (2022) considered the impacts of COVID-19 on the forestry sector in Nepal to be severe, as do Khan et al. (2022) in Pakistan or Komut (2022) and Bayram (2021) in Turkey. The Chinese timber industry was also vulnerable to the COVID-19 pandemic because of its dependence on the international market for timber raw materials and product sales (Thao et al., 2021). As far as the United Nations Economic Commission for Europe (UNECE) region is concerned, the COVID-19 pandemic brought uncertainty to forest product markets in 2020, with production and consumption subject to rapid and extreme fluctuations. However, by the end of 2020, there was only a slight overall decline in the sector and this trend continued in 2021 (United Nations, 2021b).

In the United States, the COVID-19 pandemic has led to unprecedented changes in conifer lumber prices of >300% between 2020 and 2022 (Zanello et al., 2023). The reasons for this increase have been attributed to supply constraints caused by pandemic-induced labor shortages and increased demand for lumber caused by the country's real estate and home improvement boom related to COVID-19 (van Kooten and Schmitz, 2022). State and local governments have implemented various measures related to COVID-19 to contain the virus, which has disrupted production and manufacturing industry supply chains (Bruck et al., 2023). Lamichhane et al. (2023) forecasted stumpage prices for post-pandemic period and stated that finding relevant exogenous variables that match the trend and direction of changes in pine saw timber prices in the US South has become more difficult after the market developments following the COVID-19 pandemic.

In Europe, the situation was different. As noted by the United Nations (2021b), the COVID-19 pandemic brought uncertainty to forest product markets in 2020. Basic statistics for measuring the impact of the COVID-19 crisis in the European Union are provided on the Eurostat website (Eurostat., 2023a). Timber production and consumption were subject to rapid and extreme fluctuations (United Nations., 2021b). The impacts of COVID-19 on forest products are caused by supply and demand disruptions in both the markets for finished wood products (e.g. furniture) and the interlinked market for raw materials and inputs (e.g. logs and sawn timber) (Muhammad et al., 2022). The impact of COVID-19 in Central and South-Eastern European countries on downstream forestry industries was investigated by Kuzman et al. (2003) where the pandemic severely affected the supply chain. In most EU member states, the pandemic and the subsequent lockdown led to a slowdown in the forest industry and forest management across the continent (ProPopulus, 2020). Among the various activities within the forestry sector, nature tourism (Wunderlich et al., 2023), manufacturing and the furniture industry have been the most affected by the pandemic, mainly due to supply chain disruptions.

The objective of the work was to analyze the impact of the COVID-19 pandemic on timber prices using intervention analysis, structural shift analysis and time series of softwood and hardwood prices from selected European and North American countries. The paper is organized as follows. First, the basic information about forestry and timber price series in selected countries are presented. Next, we introduce the methods utilized in this article: testing for a structural break in time series and the concept of intervention analysis. Then we present our empirical result and discussion. Finally, we make some concluding remarks.

2. Materials and methods

2.1. Basic information on selected countries

Eight European countries that are members of the European Union were selected for the analysis. These are Austria, Czech Republic, Germany, Poland, Slovakia and Slovenia. Among the Scandinavian countries, Finland and Sweden were selected. Table 1 shows the characteristics of each country from a forestry perspective.

USA and Canada were chosen from North America. The Table 2 shows the characteristics of these countries from a forestry perspective.

The economic importance of forestry and logging to the country's economy can be expressed in terms of gross value added (GVA) relative to gross domestic product (GDP). The development of this value over time will also indicate the development of the sector's economy. The value added of forestry and logging in economic terms is shown for the countries assessed in Table 3.

The gross value added represents the effect of the forestry and logging sector as measured by the difference between the final output of the sector and the intermediate consumption of the sector.

2.2. Data

The study material consisted of nominal delivery roundwood prices

Table 2
Forestry characteristics of American countries in 2020.

Item/country	USA	Canada
Area of forest and OWL* (thous. ha)	914,742	397,982
Forest cover (%)	33.9	34.8
Forest and OWL per capita (ha)	2.76	10.4
Share of coniferous forests (%)	78.0	70.0
GPD total (1000 mil. USdolar)**	17,143	1341
Density rural (people per km^2)	16.92	18.4
Roundwood production (thous. m^3)	429,700	132,180
Roundwood production coniferous (thous. m^3)	293,023	107,661

Source: FAO, 2022; Trading Economics, 2023; World Bank, 2023; Canadian Council of Forest Ministers, 2023; CNB, 2023.

Table 1
Forestry characteristics of European countries in 2020.

Item/country	Austria	Czechia	Germany	Poland	Slovakia	Slovenia	Finland	Sweden
Area of forest and OWL* (thous. ha)	4029	2677	11,419	9483	1946	1238	23,155	30,344
Forest cover (%)	48.8	34.7	32.1	31.0	40.5	58.5	76.2	74.5
Forest and OWL per capita (ha)	0.45	0.25	0.14	0.25	0.36	0.6	4.19	3.14
Share of coniferous forests (%)	63.5	75.8	60.0	68.7	36.5	46.5	70.0	83.0
GPD total (1000 mil. Eur)**	446.9	276.6	3869.9	659.9	109.7	59.0	223.8	475.3
Density rural (people per km^2)	44.7	36.1	53.9	49.5	52.3	48.0	2.7	3.2
Roundwood production (thous. m^3)	16,789.57	32,586***	78,673.44	40,572.78	7447.86	3890.78	60,127.94	74,100.00
Roundwood production coniferous (thous. m^3)	13,946.29	31,313***	63,063.63	30,906.32	4034.92	2105.57	47,232.72	65,100.00

Sources: Eurostat., 2023b; Ministry of Agriculture of the Czech Republic, 2021; Ministry of Agriculture and Rulal Development of the Slovak Republic, 2021; Quadt et al., 2013; Forest Europe, 2020; Federal Ministry of Food, Agriculture and Consumer Protection, 2011; FAO, 2020; Ministry of Agriculture, Forestry and Food of the Slovenia, 2023; Statista, 2023; FAO, 2022; CNB, 2023.

* OWL – other wood land.
** Year 2022.
*** Year 2019.

Table 3
Economic indicators for forestry and logging in 2000 and 2020.

Country	Gross value added (mil. €, current prices)		Gross value added/ forest area (€/ha)		Gross value added/ forest area as a % of GDP	
	2000	2020	2000	2020	2000	2020
Austria	784	756	204	194	0.4	0.2
Czechia	388	912	147	341	0.6	0.4
Germany	1501	1227	141	107	0.1	0.0
Poland	706	1716	78	181	0.4	0.3
Slovakia	129	575	68	295	0.6	0.6
Slovenia	93	269	75	227	0.4	0.6
Finland	2239	4046	100	181	1.6	1.7
Sweden	3021	3202	107	114	1.1	0.7
USA	10,707	17,428*	1170	1905	1.1	1.1
Canada	746	1452**	203	365	2.5	2.7

Source: Eurostat., 2023b; Trading Economics, 2023; World Bank, 2023.
* Year 2018.
** Year 2019.

time series from eight European countries, as well as Canada, and the United States. Forty-six price series of different species, both logs and pulpwood, were included. The time series covers the period from 2005: Q1 to 2022:Q4 and comprises 72 items. The sources of data are different and described in Table 4. The monthly time series from Austria, Germany, Finland, the USA and Canada were converted into quarterly series by using price series of the last month of the quarter.

Due to the significantly different magnitude of inflation between the countries analyzed all series were adjusted to real prices using a country-specific inflation index given by OECD (2023). Source prices were reported in different currencies. To make the data comparable between countries, all prices were converted into price indexes assuming 2015 = 100. The detailed description of prices time series is presented in Appendix A.

2.3. Testing for stationarity and structural break

Based on Box and Jenkins (1970) framework, time series analysis requires the system to be stationary. The stationarity of the time series was evaluated using the augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests. In the former, the null hypothesis is that the process is not stationary, which is rejected only if evidence to the contrary is strong enough, so it conservatively supports nonstationary. In contrast, the null hypothesis of the KPSS test states that the time series is nonstationary, so it conservatively supports data stationarity.

A structural break in time series significantly influenced analysis results. A shift in a structural break refers to a change in the underlying structure of a time series data, where the data suddenly deviates from its previous pattern.The shape of the timber price series (Fig. 1) indicated structural changes around 2020, coinciding with the Covid-19 pandemic outbreak. To confirm or exclude the occurrence of structural changes during the pandemic COVID-19, Zivot and Andrews (1992) (*Z*-A) non-stationarity test with the presence of one endogenous structural break was performed. This test indicated a point in the time series of a potential structural break but did not state if such a break is significant. To confirm or reject the significance of the breakpoint occurrence indicated by the Z-A test, we applied the Chow test Chow (1960).

Table 4
Description of timber price sources.

Country	Acronym	Price unit	Logs	Pulp	Source
Austria	AT	Euro/ m^3	Sp, Pi, Be	Sp, Pi, Be	STATcube, Austria (2023)
Czechia	CZ	Price index	Sp, Pi, Be	Sp, Pi	Czech Statistical Office (2023)
Germany	GE	Price index	Sp, Pi, Be	Sp, Pi, Be	Federal Statistical Office, Germany (2023)
Finland	FI	Euro/ m^3	Sp, Pi, Br	Sp, Pi, Br	Luke Forest Statistic (2023)
Slovenia	SLO	Euro/ m^3	Con., Be	–	UNECE/FAO (2023)
Slovakia	SK	Euro/ m^3	Sp, Pi, Be	Sp, Pi, Be	Forest Portal o Lesoch Slovenska (2023)
Sweden	SE	SEK/m^3	Sp, Pi	Sp	UNECE/FAO (2023)
Poland	PL	PLN/m^3	Sp, Pi, Be	Sp, Pi, Be	State Forest Poland (2023)
Canada	CA	CDN $/$m^3$	Con	Con	UNECE/FAO (2023)
USA	USA	USA $/b.feet	Dg, He, Ro, Hm	–	UNECE/FAO (2023)

Sp – Spruce, Pi – Pine, Be – Beech, Br – Birch, Dg – Douglas fir, He – Hemlock, Ro –Red oak, Hm – Hard maple, Con – coniferous.

2.4. Intervention analysis model

Consider a set of t time-sequenced timber price observations (y_1, y_2, …, y_t), which represents the realization of a particular ARIMA process. Although we do not have exact knowledge of this stochastic process, employing Box and Jenkins (1970) method, we can describe its generating mechanism. ARIMA models combining AR and MA are defined as ARIMA (p, d, q), where p and q are the orders of AR and MA models, respectively, and d represents the degree of series integration (differencing) (Yin, 1999):

$$y_t = \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \ldots + \varphi_p y_{t-p} + e_t + \theta_1 e_{t-1} + \theta_2 e_{t-2} + \ldots + \theta_q e_{t-q} \quad (1)$$

where: y_t is the value observed at time t in the time series, δ is a constant term, φ_i is the i-th autoregressive coefficient, θ_j is the j-th moving average coefficient, and et represents residues uncorrelated with any previous ones.

Seasonal time series can be analyzed by incorporating seasonal fluctuations in classical ARIMA models in the form of parameters (P, D, Q) S describing seasonal lags. Such models are denoted as SARIMA (p, d, q) (P, D, QS), where P – order of seasonal autoregression, D – degree of seasonal integration, Q – order of seasonal moving average, and S – length of seasonal cycle (Banaś and Utnik-Banaś, 2021).

Pure ARIMA models include only lagged value of prices (AR component) and their errors (MA component). Occurrence of certain events, such as environmental accidents, introducing new policies, pandemic periods, and intervention in the normal evolution of the response series. In the intervention model, the response series (in our case, timber prices evolvement since the occurrence of the COVID-19 pandemic) is characterized by an ARIMA process and the effect of the input series. An input series is an indicator variable that identifies the occurrence of the event affecting the response series. Changes in time series caused by such events can be investigated by employing intervention analysis (Box and Tiao, 1975; Pankratz, 1991). Conducting such an analysis requires a proper definition of the type of intervention and the transfer function. There is a wide variety of intervention effects that may be observed. Here, we focus on two main types: pulse and step (Schaffer et al., 2021). Pulse impact (P_t) is a sudden, temporary change in time series, observed for one or more time points immediately after the event and then returns to the baseline level, described as:

$$P_t = \left\{ \begin{matrix} 1, if\ t = T_0 \\ 0, if\ t \neq T_0 \end{matrix} \right\} \quad (2)$$

Step impact (S_t) is a sudden, sustained change where the time series is shifted either up or down by a given value immediately following the intervention, described as:

$$S_t = \left\{ \begin{matrix} 1, if\ t \geq T_0 \\ 0, if\ t < T_0 \end{matrix} \right\} \quad (3)$$

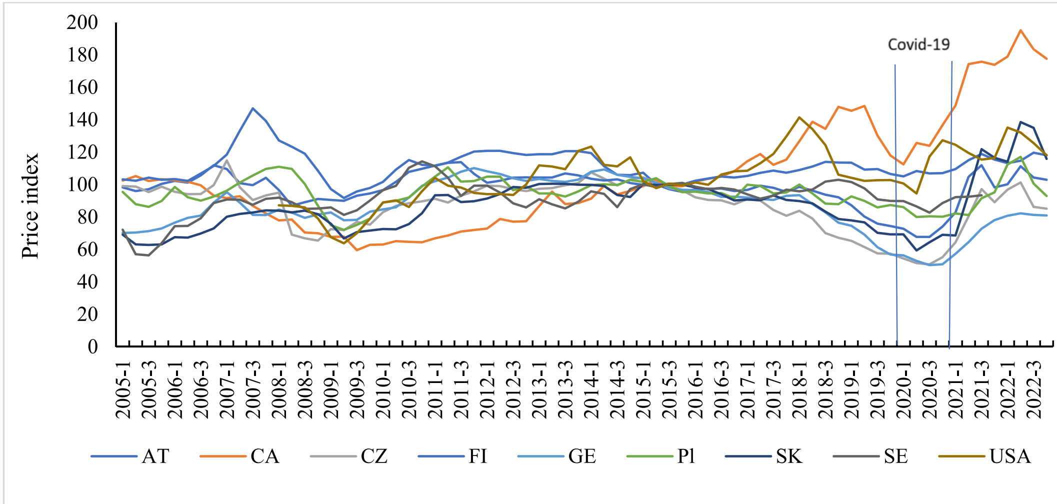

Fig. 1. Price movement of spruce logs in selected markets in 2005–2022.
AT – Austria, CA – Canada, CZ – Czechia, FI – Finland, GE – Germany, PL – Poland, SE – Sweden.

The price changes during the Covid and post-Covid periods represent a multi-period response. The specific patterns of price movement and the significant price volatility cause the usual dummy variable treatment that defines the input X_t as $X_t = 0$ for $t < j$ and $X_t = 1$ for $t \geq j$ may not be appropriate (Yin and Newman, 1999). The better solution can be to detect the response in different periods separately by defining multiple transfer functions. We adopted pulse impact for the direct COVID-19 period and step impact for the post-COVID-19 period. Without a priori knowledge, the number of periods n within which significant responses occur must be determined empirically. Analyzing the time series of timber prices (see Fig. 1), we assumed the COVID-19 period from the first (2020:Q1) to the fourth quarter (2020:Q4) of 2020 yr. That is, we use $P_{2020:Q1} \cdot \omega_1$ to capture the rise or fall Y_t (timber price) during 2020: Q1. Similarly, $\omega_{2,}$ $\omega_{3,}$ $_{and}$ ω_4 are the coefficients evaluated for price changes in the second, third, and fourth quarters of 2020. To assess the price movement in the post-COVID-19 period, we use $S_T \cdot \omega_T$ for $t >$ 2020: Q4. The following formula describes our intervention model:

$$y_t = \sum\nolimits_{t=2020:1}^{2020:4} \omega_t p_t + \omega_{t>2020:4} p_{t>2020:4} + n_t \tag{4}$$

where $p_t = 1$ for 2020Q:1 $\leq t \leq$ 2020Q:4 and 0 otherwise, $s_t = 1$ for $t >$ 2020Q:4 and 0 otherwise, n_t represents an ARIMA process as described by Formula 1.

Intervention analysis was conducted in the following steps: 1) testing time series for stationarity using the augmented Dickey–Fuller (ADF), Kwiatkowski–Phillips–Schmidt–Shin (KPSS), and Zivot-Andrew (ZA) tests, 2) identifying a tentative ARIMA model, 3) estimating and evaluating the significance of tentative models parameters, 4) identified pure ARIMA model best fit the data using the Akaike information criterion (AIC), 5) diagnostic checking of the model residuals in terms of their normality and autocorrelation (ACF and PACF), 6) identify time of intervention event and chose proper transfer function, 7) estimating and evaluating coefficient significance of intervention model.

3. Results

Conducted ADF and KPPS tests for stationarity showed that most of the analyzed time series (35) of prices are non-stationary, and 11 of the series (mainly in Finland, Poland, and Slovakia) are stationary (Appendix B). The first differences of all price time series are stationary (results of testing are not shown).

The shape of softwood prices time series indicated structural changes around 2020 (for spruce see Fig. 1). Results of the Zivot-Andrew test indicated the occurrence of potential structural changes at different points in time depending on the time series (Table 5, Appendix C). The results of the Chow test confirm that the detected structural breaks are statistically significant for most in the price series, except for: Sweden spruce log, Slovakia beech log and USA logs of Douglas fir, hemlock and red oak.

Generally, shifts in trend occurred mostly 2–3 quarters earlier than changes in intercept. In the softwood series, structural shifts are mostly coincident with the COVID-19 pandemic period (2020 logs, 2021 pulp) with the exception of Finland and Sweden, where structural changes occurred between 2011 and 2015. In hardwood series structural changes do not coincide with Covid-19 pandemic period, breaks in intercept occurred before the pandemic (2013-2016) while shifts in trend after it (2022).

Optimal ARIMA models selected from among tentative models based on the lowest value of AIC are shown in Appendix B. Most of them are integrated in first order only in the case of the spruce and pine price series in Poland, the degree of model integration is zero. Most of the optimal models turned out to be SARIMA, including the seasonal MA part with the first order, indicating significant seasonality fluctuation of timber prices in these series. In general, the length of lags of AR or MA components is mostly one or two, except for pine pulpwood price in Slovakia, with three significant lags. The modeled process is white noise for a series of spruce pulpwood prices in Poland.

Intervention models for the analyzed series are presented in Table 6 and Appendix D. A negative sign at the intervention coefficient indicates a price decline in each quarter. In the case of spruce log in Austria, the values of coefficients $\omega_2 = -21.78$ and $\omega_3 = -24.20$ indicate that spruce log prices in the second and third quarters of 2020 fell by 21.78% and 24.20%, respectively, with a significance level of $p < 0.001$.

The significantly lower value of AIC = 393.9 for the intervention model compared to the AIC = 402.5 for the pure ARIMA model of the same series (Appendix B) confirms that incorporating the transfer function of intervention improved the model describing timber prices in the period, including the Covid-19 event. In Czechia, the price of spruce logs period decreased the most in the third and fourth quarters by −24.12% and − 23.85%, respectively ($p < 0.001$). In Slovakia, the price of spruce logs decreased the most by 34.9% and 29.71% in the second and third quarters, respectively, with p-value <0.001. In Poland, a decrease in spruce log price appeared later, in the third and fourth quarter, by 13.25% and 16.86%, respectively, and was less significant ($p < 0.05$). In Germany, the price decrease was smaller and more significant ($p < 0.05$) only in the fourth quarter (−11.16%). Similarly, a

Table 5
Zivot-Andrew test and Chow test for structural break in spruce price series.

Series	Shifts in intercept			Shifts in trend		
	Z-A test	PSB	Chow test	Z-A test	PSB	Chow test
AT-Sp-lo	−4.071	2020:4	12.396***	−3.278	2020:2	14.772***
CZ-Sp-lo	−3.284	2021:1	7.932***	−2.5725	2020:1	13.700***
CA-con-lo	−4.887**	2021:1	21.662***	−3.4784	2020:1	22.186***
Fi-Sp-lo	−4.031	2011:3	14.026***	−3.858	2014:4	10.278***
GE-Sp-lo	−3.266	2021:2	3.315*	−3.0507	2020:3	7.9730**
PL-Sp-lo	−4.443	2021:2	4.938*	−3.7887	2020:3	7.644**
SE-Sp-lo	−3.975	2014:3	2.505	−3.4413	2012:4	1.141
SLO-con-lo	−5.021**	2021:1	48.429***	−3.439	2020:2	45.265***
SK-Sp-lo	−4.433	2021:1	21.485***	−3.0426	2020:2	30.017***
USA-Dg-lo	−3.802	2018:2	3.420	−3.1051	2009:3	0.175
AT-Sp-pu	−3.058	2022:2	19.120***	−3.6467	2021:4	20.567***
CZ-Sp-pu	−2.872	2021:4	19.587***	−3.0315	2021:2	19.534***
CA-con-pu	−5.226**	2020:2	9.2083***	−4.698	2019:3	7.787**
Fi-Sp-pu	−2.823	2013:1	15.890***	−2.753	2015:1	18.013***
GE-Sp-pu	−3.377	2021:3	8.138***	−3.4647	2021:1	10.970**
PL-Sp-pu	−6.544***	2021:4	31.394***	−4.5521**	2021:2	32.439***
SE Sp-pu	−3.307	2011:4	10.445***	−2.5077	2013:2	6.951**
SK-Sp-pu	−3.393	2021:2	12.497***	−3.8009	2020:4	16.09***

*, **, *** – significance at 0.05, 0.01, and 0.001 level respectively; lo – logs; pu – pulp.

Table 6
Intervention models of COVID-19 event for spruce price in selected markets.

Country	ω_{q1} (2020:1)	ω_{q2} (2020:2)	ω_{q3} (2020:3)	ω_{q4}4 (2020:4)	ω_{pc} (>2020:4)	AIC
Logs						
Austria	−8.11**	−21.78***	−24.20***	−15.01**	8.56*	393.9
Czechia	−13.09**	−21.78***	−24.12***	−23.85***	17.67	447.4
Finland	1.03	5.64	1.57	2.17	0.10	388.6
Germany	−0.01	−3.83	−7.74	−11.16*	15.50	335.2
Poland	−2.71	−10.90*	−13.25*	−16.86**	16.04***	417.1
Slovakia	−12.33**	−34.90***	−29.71***	−21.90**	24.73***	441.7
Slovenia[1)]	−8.04	−11.77*	−5.33	9.61	17.73**	418.5
Sweden	−0.92	−1.95	−5.68	−4.37	2.63	380.7
Canada[1)]	−10.04*	−8.42	−9.42	−1.41	6.99	417.8
USA [2)]	−11.4*	−19.9**	2.35	10.80	3.58	382.1
Pulp						
Austria	0.92	0.37	−1.24	0.04	2.69	332.3
Czechia	−7.50	−5.79	−2.77	−1.50	2.17	437.3
Germany	1.45	2.08	3.13	3.44	0.86	389.6
Finland	−1.88	2.36	−0.13	−1.34	2.61	349.1
Poland	−3.70	−6.16	−0.60	5.04	9.68*	474.2
Slovakia	−8.79	−9.66	−7.50	−3.54	14.50**	426.9
Sweden	4.94	3.38	−1.37	−3.12	0.14	352.6
Canada[1)]	0.14	4.20	−3.19	−2.17	−6.89	463.5

ω_t – coeficients of intervention model; *, **, *** - significance at 0.05, 0.01, and 0.001 level respectively; [1)] coniferous, [2)] Douglas fir; AIC – Aikaike Information Criterion.

less significant decrease was in Slovenia but appeared earlier in the second quarter (−11.77%). In Scandinavian countries, prices of spruce logs do not decrease in 2020 year. In Sweden, intervention coefficients have negative signs but are not statistically significant ($p > 0.05$). In Finland, analyzed coefficients have even positive signs but are also statistically insignificant. Price decreases were recorded earlier in North America than in Europe. A significant decrease ($p < 0.05$) of coniferous logs in Canada by −10.04% appeared in the first quarter and in the USA (Douglas fir) by −11.45 and − 19.9% in the first and second quarters. Respectively. The movement of pine log price in the Covid period in analyzed countries was mostly like the price of spruce log (Appendix D).

Conifer pulpwood prices fluctuated much less during the pandemic period. In most of the countries, intervention coefficients had negative signs, but the price decrease was statistically significant only in Slovakia ($p < 0.001$) and Poland (only Pine pulpwood, $p < 0.05$) (Table 6, Appendix C).

Unlike softwood, hardwood prices, both logs and pulp, have not been subject to significant changes. COVID-19 intervention coefficients had both positive and negative signs but were statistically insignificant in all cases (see Appendix C).

4. Discussion

In this study, we analyzed the impact of the COVID-19 pandemic on timber price changes in selected markets in Europe and North America. To confirm or reject significant changes in timber prices we employed two methods of time series analysis: intervention, and structural break. Both of them were used in forestry to identify particular events and assess their impact on timber or sawn wood prices (Chudy and Hagler, 2020; Eriksson and Lundmark, 2020). Yin and Newman (1999) used an intervention analysis to investigate Hurricane Hugo's effect on South Carolina's stumpage prices. They detected a downfall in timber prices four months after hurricane occurrence followed by a price increase. In the hardwood pulpwood market, the changes were insignificant. Our findings are similar: we detected a decrease in softwood prices in most of the analyzed markets during the COVID-19 pandemic, followed by a price increase in the recovery period, but we did not find significant changes in hardwood prices.

Bruck et al. (2023) quantified the effect of various COVID-19 policies on standing timber prices in the Southern United States. Similarly, as in our study, they found an overall significant decrease in prices across all timber products (7%–30%) soon after COVID-19 lockdowns in early 2020. After determining fixed effect estimators they found that lockdown had a decreasing price effect on pine pulpwood but an increasing effect on hardwood saw timber. Yin (2001) employed an intervention analysis framework to assess the impacts of the federal policy shifts and the booming housing market on Douglas fir log price changes in the Pacific Northwest, USA. He found the significant impact of both events and assessed that 70% of log price movement and 70% of log price movement might have been caused by policy shifts induced by spotted owl protection and remained by lumber price shifts driven by the booming housing market.

Structural break analysis is often used to analyze the impact of sudden events (such as an economic crisis, occurrence of hurricane or pandemic outbreak) on price movement (Yin, 2001; Yin and Baek, 2005). Detecting a breakpoint and assessing a structural shift is important in time series analysis as it can help identify significant changes in a system. Similar to Parajuli and Chang (2015) we performed the Zivot-Andrew test and Chow test, allowing us to detect structural shifts in intercept and in trend. The results of our study confirm the presence of structural breaks in most series. However, breakpoints vary from market to market. In general results of structural break analysis detected significant shifts during COVID-19 in the same price series as intervention analysis did. The exception are USA log price series of Douglas fir and Hemlock, for which intervention analysis revealed a significant price decrease in the first and second quarter of 2020 but the Zivot-Andrev test indicated structural breaks in different times (2018:Q2 in intercept and 2009:Q3 in trend) which after performing Chow test occurred insignificant. We additionally tested for these series occurrences of hypothetical structural breaks during 2020:Q1–2020Q4 but results indicated that they are statistically insignificant both in intercept and trend. The lack of structured shifts in the USA softwood log prices may be due to the implementation of COVID-19-related policies by state and local governments to limit the virus outbreak (Bruck et al., 2023).

The findings of our study indicated a significant impact of COVID-19 on softwood prices and an insignificant influence on hardwood prices. It can be explained by the different intensities of supply chain disruptions and the relationship between supply and demand (Asada et al., 2023). The COVID-19 pandemic caused a lockdown of the economy during which there was a significant reduction in the construction industry (the main consumer of softwood) and light demand for sawnwood. The COVID period was followed by rapid growth in housing, resulting in a surge in demand for sawn wood with limited softwood supply (Zanello et al., 2023; van Kooten and Schmitz, 2022). Hardwood is generally used in much smaller quantities, with a much higher degree of processing (furniture), and the relationship between supply and demand of this kind of timber was not significantly disturbed during the COVID-19 pandemic.

The results of our study indicated that the changes in softwood prices during the COVID-19 pandemic depended on the geographical location of the market. While price fluctuations were significant in Central Europe, no significant price changes were observed in Scandinavian markets. These findings can be partially explained by differences in market cointegration. Banaś et al. (2022) analyzed relationships in European Union softwood markets and stated that these markets are not fully integrated. They detected a long cointegration relationship between Austria, Czechia, Germany, and Slovakia markets, but not with Sweden or Finland markets. Scandinavian softwood markets are large compared to Central European markets (production: Sweden 74 million m^3, Finland 60 million m^3). The lack of significant price changes during the COVID-19 period can therefore be explained by better timber market resilience on external shocks. Structural break analysis revealed that in Scandinavian markets changes in softwood prices between 2011 and 2015 had a much greater impact than during the COVID-19 pandemic.

The economic importance of forestry and logging to a country's economy can be estimated in terms of gross value added (GVA) to gross domestic product. The highest GVA per forest area of the European countries assessed was estimated for the Czech Republic in 2020 (341 € ha, see Table 2). As stated by Eurostat. (2023b) this indicator should be interpreted with caution as it may be affected by activities that are not part of the forestry and logging sector. Nevertheless, this indicator is indicative of economic developments in these sectors. From the above findings, it can be concluded that in states dependent on rural agriculture and forestry, the impact of the pandemic was greater than in states where the share of forestry in gross domestic product is lower than for other sectors.

A significant limitation of our study is the short time series after the Covid-19 event. The results of the study indicate that price declines occurred mainly in the first half of 2020, however, in some cases, a particularly pulpwood period of low prices also affected the first two quarters of 2021. The period of price declines was followed by an equally sharp rise in prices and then a gradual decline. The short recovery period after COVID-19 (less than two years) does not allow a clear statement on what level prices will stabilize in the long term.

5. Conclusions

Analysis conducted in this study revealed that changes in roundwood prices during the COVID-19 pandemic period depended on the geographical location of the timber market. The most significant changes (price decreases) were observed in Slovakia, the Czech Republic, and Austria, less pronounced changes occurred in Poland and Germany. No significant price changes were observed in the Scandinavian markets (Finland and Sweden). In the North American countries (USA and Canada) the decline in roundwood prices occurred earlier (in the first quarter of 2020) and was short-lived, followed by rapid price increases. Similar changes but to a slightly lesser extent involved softwood pulp prices In contrast, no significant changes in hardwood prices were observed for either roundwood or pulpwood.

The intervention analysis and structural break analysis proved to be a good tool to study the impact of external shocks like the COVID-19 pandemic on the movement of wood prices. Incorporating events into a time series described by the ARIMA model allows for quantification (how much) and direction of change (decrease, increase, neutral) influence of such events on price movement in the more extended period. Detecting break points in time series and testing for structural shifts allows us to assess the significance of changes over a longer time horizon.

The results of the study indicate that the COVID-19 pandemic caused softwood prices to fall during the period of lockdown of the economy and then rise in price, which influenced a significant increase in timber price volatility. However, the short time series availability after the occurrence of the COVID-19 pandemic does not make it possible to say clearly at what level timber prices will develop in the long term.

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CRediT authorship contribution statement

Petra Hlaváčková: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing, Funding acquisition. **Jan Banaś:** Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Katarzyna Utnik-Banaś:** Conceptualization, Investigation, Methodology, Supervision, Validation, 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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Appendix A. Statistic description of the timber prices for selected roundwood markets in 2005–2022

Series	Unit	Mean	Median	Minimum	Maximum	Standard deviation	Variability coeficient
AT-Sp-lo	€/ m^3	46.8	46.9	33.7	65.9	7.3	15.7
AT-Pi-lo	€/ m^3	63.7	64.9	45.8	78.0	8.8	13.8
AT-Be-lo	€/ m^3	78.6	77.8	73.9	89.3	3.4	4.3
AT-Sp-pu	€/ m^3	32.2	32.8	25.6	47.9	4.4	13.7
AT-Pi-pu	€/ m^3	34.6	36.5	25.5	56.4	5.9	17.1
AT-Be-pu	€/ m^3	43.9	45.7	30.2	77.9	7.7	17.6
CZ-Sp-lo	CK/m^3	1887.4	1865.5	1254.0	2954.0	361.3	19.1
CZ-Pi-lo	CK/m^3	1569.4	1621.0	918.0	2194.0	246.8	15.7
CZ-Sp-pu	CK/m^3	768.4	747.0	365.0	1542.0	224.3	29.2
CZ-Pi-pu	CK/m^3	778.9	755.0	409.0	1574.0	225.3	28.9
CZ-Be-lo	CK/m^3	166.5	1683.0	1311.0	1991.0	163.9	9.9
Fi-Pi-lo	€/ m^3	57.7	57.6	46.1	71.8	5.6	9.8
Fi-Sp-lo	€/ m^3	58.5	58.0	46.7	77.0	6.7	11.5
Fi-Br-lo	€/ m^3	48.0	47.2	39.7	63.5	4.3	8.9
Fi-Pi-pu	€/ m^3	29.7	29.6	24.3	40.2	3.2	10.9
Fi-Sp-pu	€/ m^3	32.0	31.3	27.8	42.0	2.8	8.8
Fi-Br-pu	€/ m^3	30.2	30.1	23.7	41.9	3.5	11.5
GE-Sp-lo	Price index	84.6	87.45	51.2	108.6	15.6	18.5
GE-Pi-lo	Price index	80.3	83.25	52.1	102.8	15.9	19.7
GE-Be-lo	Price index	95.4	97.15	71.2	136.6	11.4	11.9
GE-Sp-pu	Price index	81.4	85.15	46.5	112.2	17.2	21.1
GE-Pi-pu	Price index	87.5	89.7	47.8	115.1	16.6	19.0
GE-Be-pu	Price index	90.3	93.85	51.7	124.8	13.8	15.3
PL-Pi-lo	€/ m^3	57.4	57.3	41.0	95.8	9.9	17.2
PL-Sp-lo	€/ m^3	61.2	61.5	42.4	98.7	10.6	17.3
PL-Be-lo	€/ m^3	50.7	49.3	34.2	100.9	10.8	21.3
PL-Pi-pu	€/ m^3	34.0	34.0	21.2	65.6	9.2	26.9
PL-Sp-pu	€/ m^3	34.0	33.8	20.9	67.7	9.7	28.7
PL-Be-pu	€/ m^3	35.3	35.5	22.2	89.4	10.2	28.9
SK-Sp-lo	€/ m^3	53.1	52.9	30.6	105.8	15.2	28.6
SK-Pi-lo	€/ m^3	43.7	42.6	29.3	77.7	9.6	22.0
SK-Be-lo	€/ m^3	48.5	47.3	31.6	95.7	9.0	18.5
SK-Sp-pu	€/ m^3	28.5	28.1	17.2	60.6	7.1	24.9
SK-Pi-pu	€/ m^3	29.3	28.9	18.3	61.6	7.2	24.7
SK-Be-pu	€/ m^3	40.0	38.0	26.1	91.0	9.4	23.6
SLO-con_lo	€/ m^3	63.4	60.9	38.0	104.6	12.1	19.1
SLO-Be-lo	€/ m^3	62.7	60.3	54.5	98.8	7.6	12.1
SE-Pi-lo	SEK/m^3	460.8	468.0	265.0	567.0	52.5	11.4
SE-Sp-lo	SEK/m^4	476.1	500.0	264.0	584.0	68.7	14.4
SE-Sp-pu	SEK/m^5	286.9	285.0	175.0	354.0	41.7	14.5
CA-con-lo	CDN$/m3	69.4	58.7	35.3	156.3	29.5	42.5
CA-con_pu	CDN$/m3	38.3	36.3	24.9	59.1	9.1	23.9
USA-Dg_lo	USA $/b. feet	593.5	599.6	316.3	894.3	135.8	22.9
USE-He-lo	USA $/b. feet	473.7	484.5	243.3	638.5	98.7	20.8
USA-Dg_lo	USA $/b. feet	596.7	592.0	329.0	933.0	136.0	22.8
USE-He-lo	USA $/b. feet	477.7	489.0	233.0	667.0	103.3	21.6
USA-Ro-lo	USA $/b. feet	443.9	451.0	250.0	602.0	78.2	17.6
USA-Hm-lo	USA $/b. feet	486.7	475.5	266.0	936.0	153.5	31.5

Sp – Spruce, Pi – Pine, Be – Beech, Br – Birch; lo – log, pu – pulp.

Appendix B. Results of unit root tests and optimal ARIMA models for selected roundwood markets

Series	ADF test	KPPS test	ARIMA	AIC
AT-Sp-lo	−0.113	0.194*	(0,1,1)(0,1,1)	402.5
AT-Pi-lo	−0.455	0.298**	(0,1,1)(0,1,1)	353.8
AT-Be-lo	−1.49	0.28**	(0,1,2)(0,1,1)	288.2
Cz-Sp-lo	−2.47	0.42*	(0,1,0)(0,1,1)	449.4
Cz-Pi-lo	−1.76	0.39*	(0,1,0)(0,1,1)	328.4
Cz-Be-lo	−1.46	1.02**	(2,1,0)(0,1,1)	452.7

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(*continued*)

Series	ADF test	KPPS test	ARIMA	AIC
Fi-Sp-lo	−0.47	0.13*	(0,1,2)	389.1
FI-Pi-lo	−1.08	0.22*	(0,1,2)	391.1
Fi-Br-lo	−0.40	0.58*	(2,1,1)	355.1
Ge-Sp-lo	−1.53	0.45*	(1,1,1)(0,1,1)	332.5
Ge-Pi-lo	−1.22	0.41**	(2,1,2)(1,0,0)	328.1
Ge-Be-lo	−3.52**	0.13	(0,1,1)(0,1,1)	342.4
Pl-Sp-log	−4.00**	0.09	(2,0,1)(0,1,1)	419.6
Pl-Pi-log	−4.72***	0.07	2,0,1)(0,1,1)	439.2
PL-Be-lo	−2.27	0.27**	(0,1,1)(0,1,1)	445.8
SK-Sp-lo	−3.90*	0.13	(2,1,2)	353.8
SK-Pi-lo	−2.41	0.11	(2,1,3)(0,0,1)	381.9
SK-Be-lo	−2.59	0.82**	(0,1,0)(0,1,1)	400.9
AT-Sp-pu	−2.37	0.29**	(1,1,0)(0,1,1)	326.1
AT-Pi-pu	0.55	0.28	(1,1,0)(0,1,1)	350.6
AT-Be-pu	1.46	0.23**	(1,1,0) (0,1,1)	363.7
Cz-Sp-pu	−2.63	0.22**	(0.1,0)(0,1,1)	431.3
Cz-Pi-pu	−2.48	0.57*	(2,1,0)(0,0,1)	445.4
Ge-Sp-pu	−2.22	0.50*	(1,1,0)(0,1,1)	381.5
Ge-Pi-pu	−2.37	0.53*	(1,1,0)(0,1,1)	374.4
Ge-Be-pu	−1.49	0.28**	(1,1,0)(0,1,1)	348.3
Fi-Sp-pu	−1.41	0.83**	(2,1,1)(1,0,0)	354.8
FI-Pi-pu	−4.02**	0.27	(0,1,2)(0,0,1)	355.2
Fi-Br-pu	−4.09**	0.16	(2,1,1)	352.9
PL-Sp-pu	−2.62	0.59*	(0,1,0)(0,1,1)	467.4
PL-So-pu	−3.11*	0.42	(1,1,0)(0,1,1)	448.8
PL-Be-Pu	−1.52	0.54*	(1,1,0)(0,1,1)	417.6
SK-Sp-pu	−2.97	0.30	(2,1,2)(0,1,1)	433.9
SK-Pi-pu	−2.94*	0.29	(2,1,2) (0,1,1)	457.1
SK-Be-pu	1.13	1.19**	(1,1,2)	468.1
SW-sp-lo	−3.86**	0.55*	(1,1,0)(0,1,1)	371.9
SW-Pi-lo	−2.14	0.13	(1,1,0)(0,1,1)	346.3
SW-Sp-pu	−3.77**	0.18*	(0,1,1)(0,1,1)	353.6
SL-con-lo	−3.45**	0.19	(1,1,2)(0,1,1)	419.3
SL-Be-lo	−1.32	0.46*	(2,1,1)(0,1,1)	346.8
CA-con-log	−0.65	1.33**	(2,1,2)(0,1,1)	421.3
CA-con-pu	−0.79	1.42**	(1,1,2)(1,1,2)	455.6
USA-Dg-lo	−1.57	0.99**	(1,1,2)(0,1,1)	385.3
USA-He-lo	−2.81	0.73**	(1,1,2)(0,1,1)	380.6
USA-Ro-lo	−2.34	0.74**	(1,1,2)(0,1,1)	615.5
USA-Hm-lo	−2.33	1.17**	(0,1,0)(1,1,2)	637.7

*, ** null hypothesis rejected at the 5% or 1% probability levels, respectively; the null hypothesis assumed time series stationarity in KPSS and nonstationarity in ADF.

Appendix C. Table Zivot-Andrew test and Chow test for structural break for pine and hardwood price series (for spruce see Table 4)

Series	Shifts in intercept			Shifts in trend		
	Z-A test	PSB	Chow test	Z-A test	PSB	Chow test
AT-Pi-lo	−3.173	2021:1	7.067**	−2.732	2020:2	10.348***
AT Be-lo	−4.309	2014:1	5.437**	−4.135*	2020:3	6.957**
AT-Pi-pu	−3.382	2022:2	4.009*	−3.521	2021:4	20.405***
AT-Be-pu	−5.925***	2022:2	34.659***	−4.269*	2022:1	33.268***
CZ-Pi-lo	−3.345	2018:1	10.390***	−2.934	2020:3	11.2905***
CZ-Pi-pu	−2.567	2021:4	19.973	−3.419	2021:2	20.066***
CZ-Be-lo	−5.422***	2015:3	3.190/0.05	−5.618***	2019:3	10.098***
Fi-Pi-lo	−4.423	2011:4	19.496	−4.167*	2015:2	4.699*
Fi-Br-lo	−5.875***	2022:2	8.707	−5.281***	2022:1	8.783***
Fi-Pi-pu	−2.654	2018:1	28.598	−3.386	2014:4	25.107***
Fi-Br-pu	−3.298	2022:1	11.062	−3.729	2016:4	20.392***
GE-Pi-lo	−3.124	2018:1	21.031	−2.865	2010:3	20.859***
GE-Be-lo	−6.235***	2022:2	11.640	−6.097***	2022:2	11.640***
GE-Pi-pu	−3.361	2021:4	6.329	−3.681	2021:2	6.479*
GE-Be-pu	−2.835	2016:1	13.952	−2.724	2021:4	4.881*
PL-Pi-lo	−4.270	2021:2	6.725**	−3.371	2020:3	8.416**
PL-Be-lo	−5.053**	2021:4	23.954	−4.211**	2021:3	24.631***
PL-Pi-pu	−6.283***	2021:4	25.927	−5.147***	2021:2	27.373***
PL-Be-pu	−3.001	2021:4	84.865	−4.734**	2021:4	84.865
SK-Pi-lo	−2.899	2021:2	15.594	−2.530	2020:4	19.414
SK-Be-lo	−3.691	2016:4	6.815**	−3.105	2022:3	2.171
SK-Pi-pu	−2.302	2021:2	16.985	−2.915	2021:1	18.978***
SK-Be-pu	−2.694	2022:3	4.617*	−2.694	2022:3	4.617*
SLO-Be-lo	−5.014**	2013:2	16.941	−6.045	2015:3	26.033***
SE-Pi-lo	−5.043**	2011:4	22.964	−4.541**	2012:4	11.284***
USA-He-lo ns	−3.900	2018:2	7.405**	−3.147	2020:4	2.514

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(*continued*)

Series	Shifts in intercept			Shifts in trend		
	Z-A test	PSB	Chow test	Z-A test	PSB	Chow test
USA-Ro-lo	−5.736***	2020:4	0.369	−7.392	2019:4	0.936
USA-Hm-lo	−6.931	2013:4	23.327	−4.328	2015:1	13.788***

*, **, *** - significance at 0.05, 0.01, and 0.001 level respectively.

Appendix D. Intervention models of COVID-19 event for roundwood price in selected markets (for spruce see Table 5)

Series	ω_{q1} (2020:1)	ω_{q2} (2020:2)	ω_{q3} (2020:3)	ω_{q4} (2020:4)	ω_{pc} (>2020:4)	AIC
AT-Pi-lo	−2.39	−7.32*	−5.93	2.80	2.08	342.2
AT-Be-lo	−0.01	−0.32	−0.20	0.68	−0.26	297.1
CZ-Pi-lo	−0.14	−9.2*	−17.0***	−14.8***	2.72	323.9
CZ-Be-lo	−7.20	−4.10	5.39	−2.83	5.83	455.7
FI-Pi-lo	1.92	1.86	−0.57	−0.23	0.05	354.6
FI-Br-lo	0.38	1.73	−1.04	−0.59	4.75	353.0
GE-Pi-lo	0.82	0.04	0.12	−3.30	5.96	336.3
GE-Be-lo	3.28	4.10	−1.06	−0.58	0.73	345.6
PL-Pi-lo	−0.98	−2.66	2.64	3.04	2.42	439.2
Pl-Be-lo	6.0	3.28	5.42	1.54	0.67	353.2
SK-Pi-lo	1.34	−4.26	−7.28*	−5.49	11.98*	386.2
SK-Be-lo	0.73	0.34	−0.79	−1.48	−6.13	408.9
SLO-Be-lo	0.38	−1.07	0.80	−5.89	1.04	349.7
SE-Pi-lo	0.47	0.72	−1.14	−3.51	1.04	354.2
USA-He-lo	−6.19	−11.65*	7.40	13.14*	9.43	377.7
USA-Ro-lo	−0.35	1.94	20.23	−14.09	23.55	621.5
USA-Hm-lo	0.06	−12.14	−5.85	−24.05	29.08	644.7
AT-Pi-pu	0.57	−0.78	−1.03	0.01	1.99	359.1
AT-Be-pu	−2.02	0.48	−1.76	−1.84	7.11	367.4
CZ-Pi-pu	2.10	2.38	3.38	3.86	−1.99	454.1
GE-Pi-pu	−0.46	−0.49	−4.08	−4.98	0.98	381.1
GE-Be-pu	−0.57	0.93	−1.48	0.36	−1.12	354.1
FI-Pi-pu	−1.26	1.49	0.91	1.05	−0.24	356.1
FI-Br-pu	1.34	1.87	0.86	−0.03	0.55	357.7
PL-Pi-pu	−1.89	−5.12	−1.84	3.42	2.76	446.8
Pl-Be-pu	0.54	−0.29	2.89	2.10	−0.96	426.7
SK-Pi-pu	−8.83	−7.11	−9.03*	−9.21*	0.14	458.3
SK-Be-pu	−3.50	−1.83	−1.92	−0.34	−1.91	392.6

*, **, *** - significance at 0.05, 0.01, and 0.001 level respectively.

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