forests

MDPI

Article

The Application of Time Series Decomposition for the Identification and Analysis of Fluctuations in Timber Supply and Price: A Case Study from Poland

Jan Banaś *[ID] and **Anna Kożuch**

Department of Forest Management, Geomatics and Forest Economics, University of Agriculture in Krakow, avenue 29, Listopada 46, 31−425 Kraków, Poland; anna.janusz@urk.edu.pl
* Correspondence: jan.banas@urk.edu.pl; Tel.: +48-696-726-154; Fax: +12-4119715

check for updates

Abstract: The objective of the study was to verify the applicability and usefulness of time series decomposition in analyzing the variability of timber prices and supply in Poland. The employed multiplicative model was the product of four components: cyclical, seasonal, and irregular fluctuations and the long-term trend. The elements of the time series were determined by means of the Census X11 method, while cyclicality was separated from the trend employing the Hodrick–Prescott filter. Data included quarterly information about the supply (volume) and prices (value) of the timber sold by the State Forests in the years 2005–2018. Analyses were performed for tree species with the greatest economic significance, that is, pine, oak, spruce, beech, birch, and alder, and for their most popular assortments: general purpose large-diameter timber (W0) and medium-diameter timber (S2A). Time series decomposition of quarterly timber production volume and prices revealed irregular, seasonal, and cyclic fluctuations. Within an annual time horizon, irregular fluctuations accounted on average for 6.7% and 28% of overall variability in timber prices and supply, respectively; they exhibited low amplitudes (+5%, −25%, respectively). Cyclical fluctuations were primarily found for prices and were characterized by substantial variations in cycle length (2–4 years) and change amplitude (3–27 Euros). Cyclical fluctuations in timber prices and supply were usually negatively correlated with each other: the upper turning points of price cycles fell near the lower turning points of supply cycles (with a shift of 1 to 3 quarters). The seasonality of prices was also inversely correlated with supply: quarters with low supply exhibited higher prices and vice versa. Seasonal fluctuations were more pronounced for timber supply (36%) as compared to timber prices (20.3%). Different seasonality patterns were found for hardwood and softwood. The lowest supply of softwood was found in the first quarter and the highest in the third quarter (spruce) or fourth quarter (pine). The supply of hardwood was the highest in the first quarter and the lowest in the third quarter.

Keywords: timber market; timber price variability; price seasonality; supply seasonality; cyclical fluctuation; sawtimber; pulpwood

1. Introduction

In the process of forest resource management, the volume of timber harvested and its assortment structure should be optimized for the primary market according to the changing economic conditions, taking into account developments in the European economy and climate change in long-term strategies [1]. Empirical studies on the timber sector tend to focus on designing long-term scenarios, while globalization has given rise to interconnections between distant timber markets, which means that national and local markets must promptly react to macroeconomic conditions [2]. As a result, of increasing importance to the timber market are short-term economic analyses and forecasts [3,4].

Analysis of the situation in timber markets is challenging, amongst others, due to uncertainty of supplies associated with climate change and the risk of disasters. Other factors that need to be taken into account are technological advancements in timber harvesting as well as political programs and economically motivated legal constraints [5]. Furthermore, environmental aspects are playing an increasingly important role, while timber production may be also limited by the rising awareness of the social functions of forests [6–8]. Last but not least, timber availability is a major problem at the stage of designing forestry development strategies due to the ongoing discussions concerning climate change and the role that forests play in the process of carbon sequestration [9].

The market prices, volume, and assortment structure of timber change as a result of numerous factors [10–12]. The prices depend, amongst other factors, on the demand from the timber product sector, which is in turn affected by domestic and global economic circumstances [13,14], as well as by the supply of the raw material—the various timber assortment/species groups offered by the State Forests National Forest Holding (hereinafter referred to as "the State Forests" or SFNFH) and the adopted timber sale rules determined by legal regulations setting out specific sale procedures and minimum prices.

The State Forests National Forest Holding is an organization without legal personality, managing state-owned forests in Poland. It has its own independent budget with 90% of its revenues derived from the sale of timber. In Poland, coniferous sites account for more than half of the total forest area (50.4%) and conifers are dominant on 68.4% of that area. The Scots pine is the most abundant species on 60.2% of the area managed by the State Forests, with spruce, fir, and beech being more abundant in the mountainous areas. Other tree species of economic importance include Norway spruce and silver fir (accounting for 6.1% and 3.1% of the total forested area, respectively), and, among broadleaved trees, pedunculate and sessile oaks (7.7%), silver birch (7.3%), European beech (5.9%), and alder (5.7%) [15]. Almost 50% of forests managed by the SFNFH has a protective function (mostly water and soil protection). Natura 2000 sites occupy as much as 38% of the area managed by the SFNFH. Furthermore, numerous other forms of nature conservation include reserves (1282) and restricted zones around protected animal and plant species (3655) [16].

The operations of the State Forests fall under numerous legal regulations, especially in terms of developing and implementing annual financial and management plans, which are in turn based on the general assumptions laid out in 10-year forest management plans concerning timber harvesting from different stands as part of various silvicultural procedures. In Poland, timber is sold on a free market, but the State Forests also follows some detailed procedures set forth by its Director-General. At the beginning of the period under consideration, the rules of timber sale to companies and individual customers evolved as a result of a series of decisions issued of the Director-General. The State Forests also launched the Wood & Timber Portal, which offers an information technology—tool for marking timber for sale. Each year, the harvested timber is divided into assortment/species groups and is offered via several procedures: Internet sales through the Wood & Timber Portal, the "e-drewno" ("e-wood") application, auctions, special auctions of valuable timber assortments, trade negotiations, and based on the retail price list. The Director-General also makes decisions on the initial prices and conversion coefficients for the various assortment/species groups. In 2005, timber sales were regulated by Decision 51/2005, according to which sales contracts were to be signed with enterprises which had a history of purchasing timber from the State Forests, while other enterprises faced a minimum annual threshold of 40,000 m^3 [17]. Also, the bid criteria for auctions have evolved. While the most important criteria are still price and purchase history (quantity of timber purchased over the past 3 years), another factor taken into consideration is geography, that is, the principle of reducing the distance from the timber harvesting site to the processing facility in order to lower the amount of greenhouse gas emissions [18].

The assortments with the greatest shares in the overall volume of timber sold by the State Forests over the past years were general purpose large-diameter timber grades: W0 softwood (33%) and W0 hardwood (6.4%) as well as medium-diameter S2A softwood (25%), S2A hardwood (8.8%), and S4 fuelwood (approximately 8%). The number of enterprises purchasing timber based on contracts from

the State Forests is approximately 7300. Furthermore, the number of foreign companies buying wood from the State Forests has been on an increase: from 1200 in 2010 to 1869 in 2017; their purchases accounted for 3.6% and 4.6% of the total timber volume sold by the State Forests, respectively. As much as 89% of that timber was sold to the German market, 4.5% to the Czech Republic, and 4.2% to Slovakia, with smaller amounts sold to Sweden and Austria [16].

In accordance with the legislation, timber prices do not constitute the basic criterion regulating the volume of timber available in the market [19], but are of great importance in optimizing forestry planning [20,21]. To maximize benefits from price fluctuations, supply adjustments may be considered [19,22]. Information about timber prices is a valuable source of knowledge used in marketing and in strategic forest management planning. Therefore, comprehensive analyses explaining primary timber market mechanisms, including changes in timber prices over time, have been the subject of numerous studies both in Poland and abroad [23–31]. The stochastic nature of timber prices has been under scrutiny for some time now [32,33], and the functioning of the timber market has been addressed using time series [34,35]. A variety of methods have been deployed to predict changes in timber prices [36–41], with a focus on (structural) changes in stochastic seasonality or trends in time series and their role in forecasting market prices [42] Timber price and supply forecasting has a long history in forestry economics, with most research being based on models of supply and demand in different geographic regions [43].

A good understanding of price mechanisms and price predictability in the timber market would be very useful for forest owners and managers as well as investors and is crucial for the correct functioning of the timber sector [43–47]. Elasticity in timber planning and sales is particularly important in the face of random events, such as windthrows or sudden economic changes, while ensuring sufficient and stable timber supply is critical at times of intensive economic growth. Although the amount of timber harvested is determined by forest management plans, actual timber supply is marked by frequent deviations from the planned levels, which vary in amplitude and time horizon. Depending on their underlying cause and nature, those changes may be classified into: (1) irregular fluctuations (e.g., due to large-scale disasters), (2) long-term trends (systematic increase in forest resources), (3) cyclical fluctuations (e.g., periodic increases and decreases in demand associated with the economic cycle), and (4) seasonal variations (increased production of certain timber assortments in wintertime). Elucidation of the mechanisms underlying timber supply fluctuations and the related price changes is important for the revenues of State Forests districts (the economic aspect of forestry), for customers in the timber sector (stability of supply), and enterprises providing services to forest districts (organization and planning of work throughout the year, optimization of equipment use, management of human resources).

The objective of the present work was to apply time series decomposition to identify irregular, seasonal, and cyclical fluctuations as well as long-term trends in the supply and prices of timber offered by the State Forests in Poland.

2. Materials and Methods

2.1. Data

The study material consisted of data on the volume and price of timber sold in each quarter by the Polish State Forests in the years 2005–2018.

Calculations and analyses were performed for large-diameter sawtimber (W0) as well medium-size piled timber for industrial purposes (S2A), which have the greatest shares in timber sales. The average price of sawtimber (separately for each species) was calculated as a total sum of sawtimber value divided by the volume of that timber sold in a particular quarter. The average price of pulpwood was calculated in a similar way. Data taken for the calculation included 180.1 million m^3 and 164.8 million m^3 of sawtimber and pulpwood, respectively, sold by the State Forests in the years 2005–2018. In terms of species, conifers constituted 79% of the analyzed volume of timber, with pine accounting for

66% (Table 1). Prices of wood were converted from PLN (Polish currency) to Euros using the average monthly exchange rates according to the currency tables of the National Bank of Poland [48].

Table 1. Summary of data used for empirical estimation: 2005–2018.

Type of Timber	Sawtimber		Pulpwood		Total [1]	
	m³ 10³/quarter	€/m³	m³ 10³/quarter	€/m³	m³ 10⁶	%
Pine	2218.1 ± 387.5 [2]	59.7 ± 5.7	1823.5 ± 430.1	34.2 ± 4.6	226.3	66
Spruce	490.8 ± 105.6	63.9 ± 5.7	329.0 ± 114	33.7 ± 4.2	45.9	13
Birch	102.5 ± 12.8	46.0 ± 4.9	346.5 ± 35.5	33.5 ± 3.4	25.1	7
Beech	227.5 ± 47.3	51.9 ± 7.2	194.2 ± 38.8	35.1 ± 3.3	23.6	7
Oak	135.4 ± 14.8	128.3 ± 20.6	148.8 ± 37.4	34.2 ± 2.8	15.9	5
Alder	42.4 ± 9.7	49.3 ± 5.1	100.1 ± 18.1	29.7 ± 3.5	8.0	2

[1] Total amount of sawtimber and pulpwood sold in years 2005–2018; [2] ± Standard deviation values.

2.2. Calculations

Decomposition of the time series of prices was done for real prices obtained by multiplying nominal prices by a deflator (inflation coefficient) for a given year quarter (based on data from the Central Statistical Office [49]), with the reference being 2018 prices.

Timber supply and price time series were described using a multiplicative model representing a product of the identified component, having the following form [50]:

$$Y_t = T_t \cdot C_t \cdot S_t \cdot I_t \tag{1}$$

where Y_t—timber supply or price in period t, T_t—long-term trend, C_t—cyclical fluctuations, S_t—seasonal fluctuations, and I_t—irregular fluctuations.

The constituent components of the time series were determined using the Census X-11 method (Statistica package 13.1). Seasonality was eliminated from the original series dividing the empirical price values by the corresponding seasonality coefficients. The significance of seasonal fluctuations ($p < 0.01$) was evaluated using the F test—trend-cycle extracted from the time series as a Henderson mean. In turn, (I) was obtained by dividing the seasonally adjusted time series by the trend-cycle (TC).

The separation of the cyclical component from the trend was done using the Hodrick–Prescott filter to isolate a stochastic smoothly varying trend [51,52]. In the Hodrick–Prescott method, the value of the time series is represented as a sum of a long-term trend and a cyclical component:

$$Xt = Tt + Ct \tag{2}$$

where X_t—value of the time series, T_t—value of the long-term trend, and C_t—value of the cyclical component.

The smoothing parameter was set to a level of $\lambda = 1600$ as quarterly data were used.

In order to determine the effects of the studied types of fluctuations on overall price variability, the share of their variances in the overall variance was determined for different time horizons of change (one to four quarters) and mean values for each year were calculated.

Cycles in the analyzed time period were identified using upper and lower turning points as the maximum and minimum values of the model price levels, respectively. To determine whether directional price changes were random or perhaps had a long-term nature (forming the beginning of a new cycle), respective values quarters of cyclical dominance (QCD) were computed. That parameter reveals the number of quarters after which the variation in the random component is equal to the variation in the trend component and long-term fluctuations.

3. Results

3.1. Timber Price Fluctuations

Decomposition of the time series of the real prices of large-diameter timber confirmed the presence of irregular, seasonal, and cyclical fluctuations, as well as a long-term trend (Figure 1).
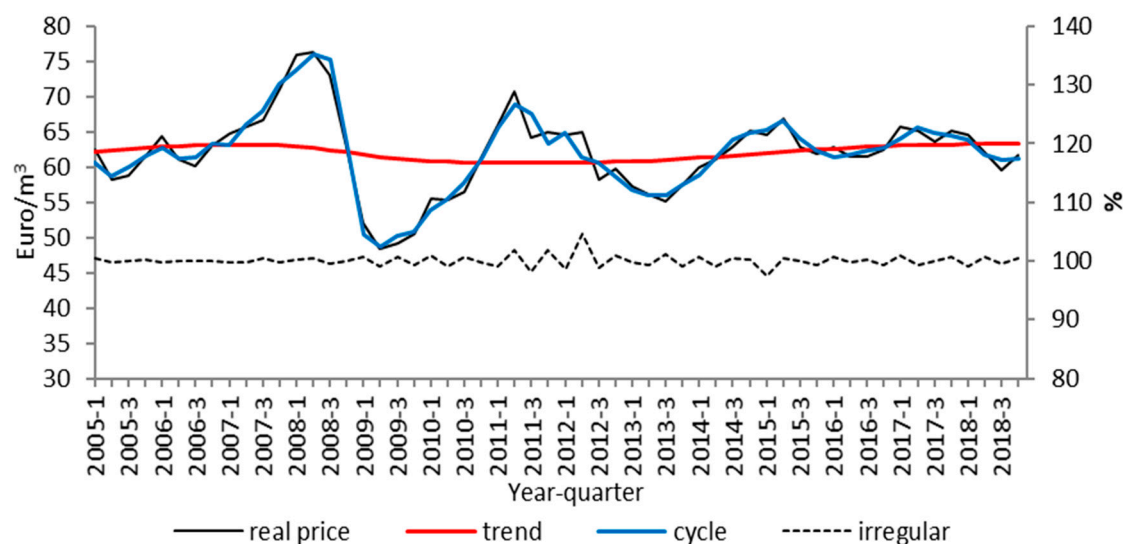

Figure 1. Decomposition of the time series of mean sawtimber prices (for all tree species taken together) in Poland in the years 2005–2018; left axis—cyclical fluctuations and long-term trend, right axis—irregular fluctuations.

The long-term trend was gradually decreasing in the years 2005–2009 and increasing in 2010–2018. Cyclical fluctuations were highly varied both in terms of amplitude of changes and cycle duration. A QCD of 2.29 indicates that three-quarters of changes in the same direction represented a pattern initiating a new cycle. In the analyzed period, the upper turning points fell in the following quarters (abbreviated as Q1, Q2, Q3, and Q4): Q1 2008, Q3 2011, Q4 2014, and Q2 2017, and the lower turning points in Q3 2009, Q2 2013, and Q4 2015. The amplitudes of cyclical fluctuations (differences between the upper and lower turning points) amounted to: €22, €12, and €3/m^3 in the first, second, and third cycles, respectively.

Irregular fluctuations of prices were characterized by a relatively low amplitude, usually not exceeding 1%. Higher irregular fluctuations occurred in the years 2011–2015 (up to 2%), with the highest price change attributable to them (+5%) found in Q2 2012.

Seasonal fluctuations differed between the studied timber assortments and tree species (Table 2). The seasonal amplitudes for W0 pine timber were small, but statistically significant at $p < 0.001$ and $F = 8.47$. The prices of pine timber usually peaked in Q1 (101.2%) and reached the lowest values in Q3 (98.3%). The highest seasonal price amplitude was found for spruce (8.8%), oak (5.1%), and alder (4.6%), also following the same pattern of peak prices in Q1 and the lowest ones in Q3. The F-test was 122.1, 36.2, and 35.6 for spruce, alder, and oak respectively, at a statistical significance of $p < 0.001$. The seasonal fluctuations of pulpwood were characterized by a much lower amplitude, while for pine and alder they were not statistically significant (at $p < 0.01$).

Table 2. Seasonal fluctuations in the prices of sawtimber (W0) and pulpwood (S2A).

| Assortments	Type of Timber	Price (quarters) (%)		F-Test	p-Level
		Maximum	**Minimum**		
Sawtimber W0	Pine	101.2 (Q1)	98.3 (Q3)	8.5	<0.001
	Spruce	105.2 (Q1)	96.4 (Q3)	122.1	<0.001
	Oak	102.5 (Q1)	97.4 (Q3)	35.6	<0.001
	Beech	101.6 (Q1)	98.7 (Q3)	10.0	<0.001
	Birch	101.5 (Q1)	98.5 (Q3)	12.2	<0.001
	Alder	102.1 (Q1)	97.5 (Q3)	36.2	<0.001
Pulpwood S2A	Pine	ns		3.0	0.038
	Spruce	101.8 (Q1)	98.6 (Q3)	16.5	<0.001
	Oak	103.3 (Q3)	97.6 (Q2)	5.7	<0.005
	Beech	101.2 (Q2)	98.3 (Q4)	14.4	<0.001
	Birch	101.7 (Q2)	94.4 (Q4)	16.6	<0.001
	Alder	ns		2.1	0.12

ns—not significant at $p < 0.01$.

Within a one-quarter horizon, seasonal, cyclical, and irregular fluctuations accounted for 44.4%, 36.8%, and 18.8% of overall variability in the prices of WC0 timber, respectively (Table 3). In horizons of two quarters and more, cyclical fluctuations explained from 72.8% (two quarters) to 98% (four quarters) of the variability. On average, cyclical, seasonal, and irregular fluctuations accounted for 73%, 20%, and 7% of that parameter, respectively.

Table 3. Shares of irregular, cyclical and seasonal fluctuations in overall variability of timber prices in Poland in 2005–2018.

Horizon of Change (Number of Quarters)	Fluctuations (%)		
	Irregular	**Cyclical**	**Seasonal**
1	18.8	36.8	44.4
2	2.6	72.8	24.6
3	3.2	84.4	12.4
4	2.0	98.0	0.0
Mean	6.7	73.0	20.3

Ranges of irregular and cyclical fluctuations as well as long-term trends identified for the major tree species are given in Figure 2 for large-diameter timber and in Figure 3 for pulpwood. Cyclical fluctuations were found to exert the greatest influence on the overall variability in all W0 and S2A assortments. The highest positive price dynamics characterized W0 oak timber (34%), with a marked rising trend since 2013 (Figure 2).
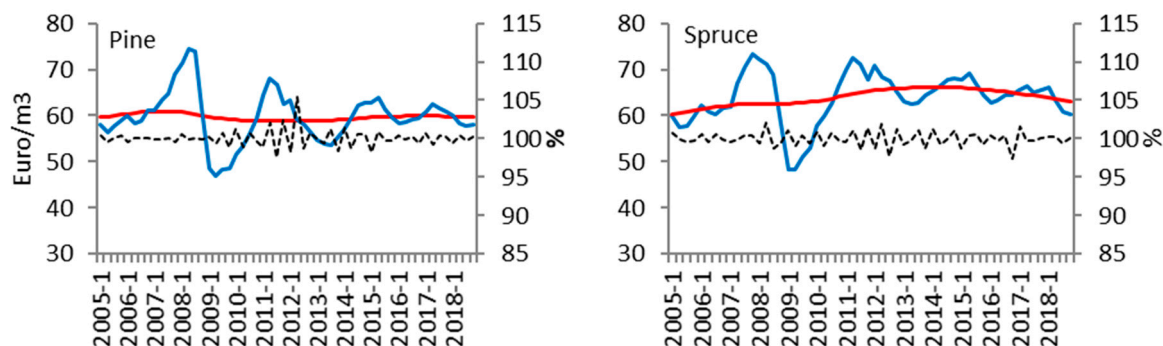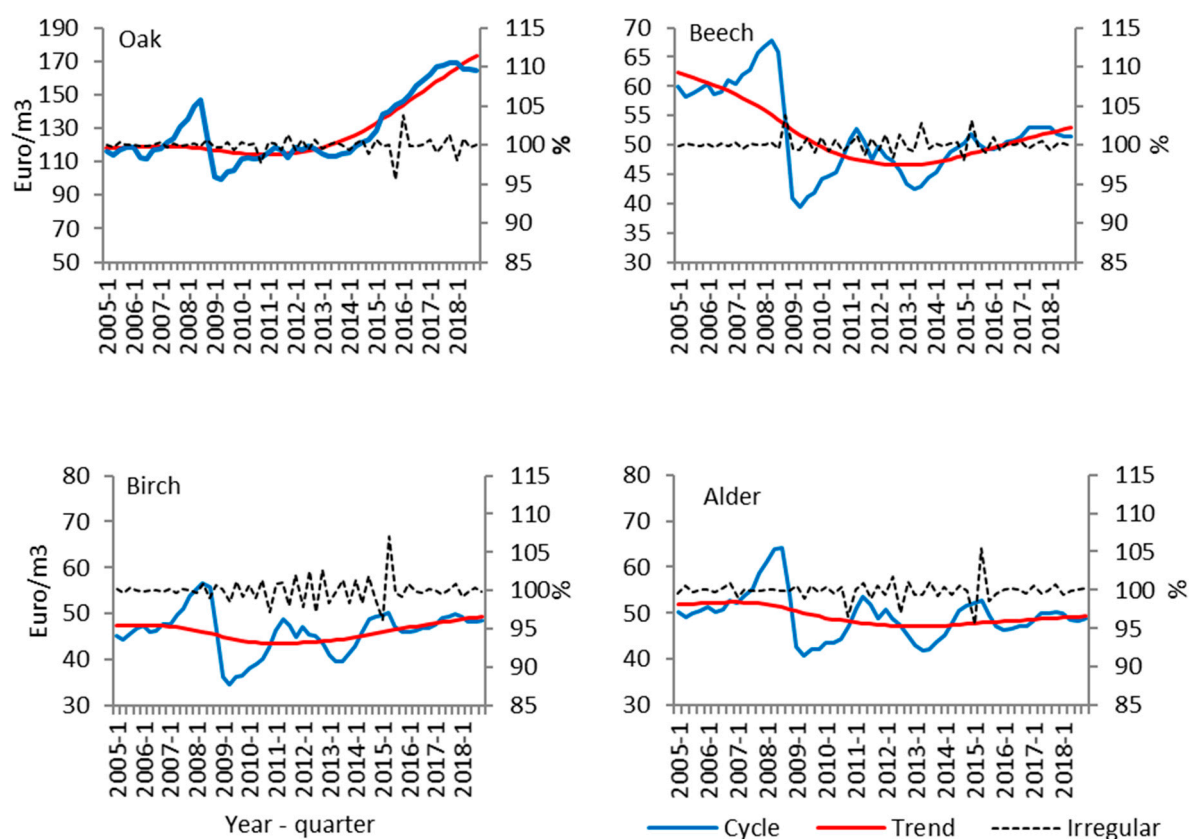

Figure 2. *Cont.*

Figure 2. Irregular and cyclical fluctuations and long term trends in the prices of large-diameter timber in Poland in 2005–2018; left axis—cyclical fluctuations and long-term trends, right trend—irregular fluctuations.

Beech timber was characterized by the largest amplitude of cyclical fluctuations between Q1 2008 and Q3 2009 (29%), and also a major decreasing trend up to 2013. The effects of irregular fluctuations were most pronounced for pine, birch, and alder timber. The prices of W0 birch and alder timber revealed similar cyclical fluctuations and seasonal variability. Birch exhibited a rising price trend, in contrast to alder, for which a declining trend was observed. The prices of medium-diameter timber (S2A) were characterized by a stable increasing trend (Figure 3), translating into a real rise of approximately 27% for pine, spruce, and beech, while price changes were the smallest in S2A oak timber (16%). The greatest deviations of cyclical fluctuations from the trend were noted in the years 2005–2013. The largest amplitudes of random fluctuations in S2A timber prices were found for pine (17%).
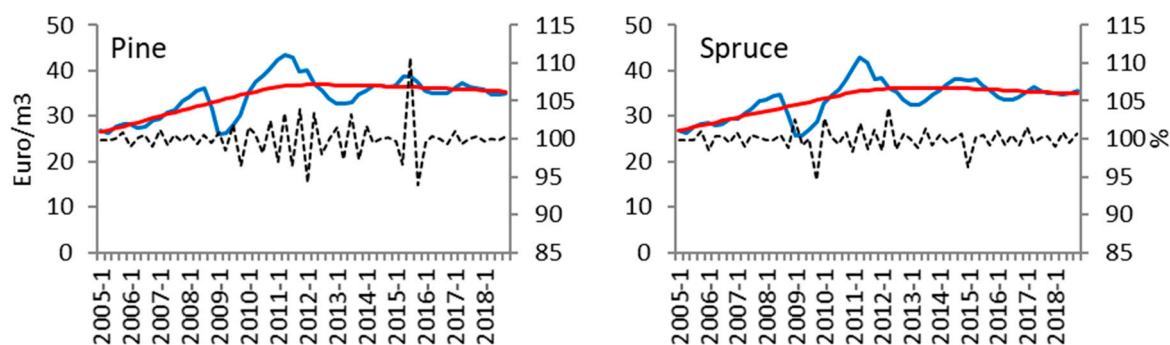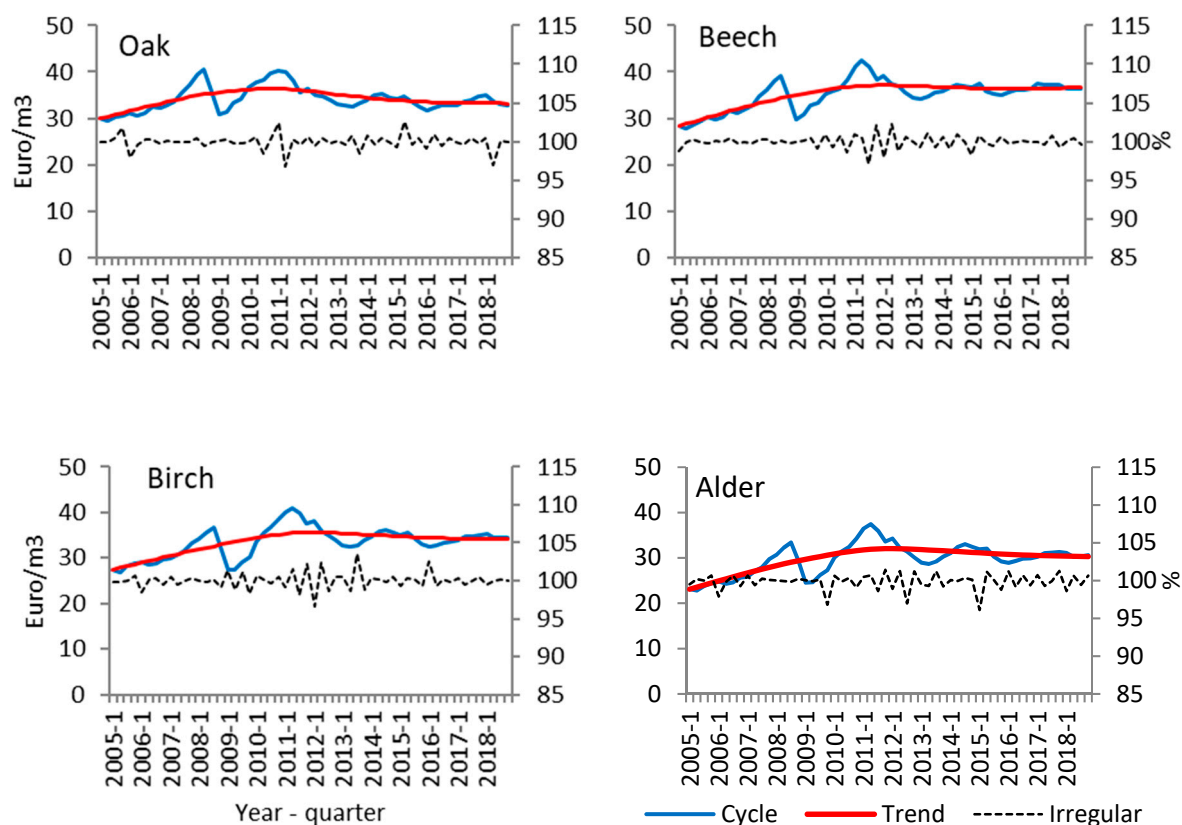

Figure 3. *Cont.*

Figure 3. Irregular and cyclical fluctuations and long term trends in the prices of medium-diameter timber in Poland in 2005–2018; left axis—cyclical fluctuations and long-term trends, right trend—irregular fluctuations.

3.2. Fluctuations in Timber Supply

Decomposition of the overall wood supply time series for the years 2005–2018 confirmed the presence of all the components of formula 1 (Figure 4). Wood supply was characterized by an increasing long-term trend with an average annual increment being 60,000 m^3 in the years 2005–2011 and 113,000 m^3 in 2012–2018.
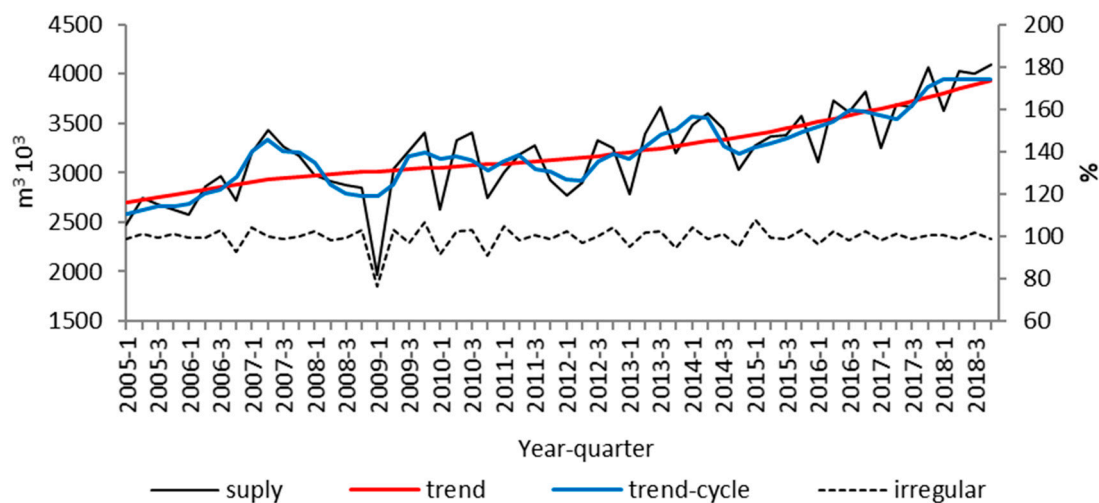

Figure 4. Time series decomposition for large-diameter timber supply (all species together) in Poland in 2005–2018; left axis: cyclical fluctuations and long-term trend; right axis: irregular fluctuations.

Cyclical fluctuations in timber supply and prices were negatively correlated with each other (Pearson's correlation coefficient of −0.607). The upper turning points of timber supply (maximum supply) occurred near the lower turning points of timber price cycles (minimum price), except for 2008–2009, when a decline in the volume of timber harvested was followed by a decline in prices after a two-quarter delay.

Seasonal fluctuations in timber supply varied between the studied tree species and were generally negatively correlated with seasonal changes in timber prices: for individual tree species, quarters with the highest volume harvested were characterized by the highest prices (Table 4). The smallest quantity of W0 softwood timber was sold in Q1 (pine—89.2%; spruce—85.2%), with the greatest quantities sold in Q4 (pine—105.8%) and Q3 (spruce—107.8%). In terms of hardwood, the smallest amount was sold in Q3 (from 82% for beech to 93% for birch), and the greatest in Q1 (from 110% for oak to 121.7% for alder), except for birch (the highest sales in Q4).

Table 4. Seasonal fluctuations in large-diameter timber (W0) and pulpwood (S2A).

9	Type of Timber	Supply (Quarters) in (%)		*F*-Test	*p*-Level
		Maximum	Minimum		
Sawtimber W0	Pine	105.8 (Q4)	89.2 (Q1)	15.7	<0.001
	Spruce	107.8 (Q3)	85.2 (Q1)	95.6	<0.001
	Oak	110 (Q1)	82.6 (Q3)	28.0	<0.001
	Beech	114.8 (Q1)	82.0 (Q3)	39.4	<0.001
	Birch	112.1 (Q4)	93.2 (Q3)	16.3	<0.001
	Alder	121.7 (Q1)	88.7 (Q3)	67.1	<0.001
Pulpwood S2A	Pine	105.9 (Q2)	94.1 (Q1)	2.1	0.11
	Spruce	108.1 (Q2)	85.5 (Q1)	41.4	<0.001
	Oak	113.3 (Q2)	88.1 (Q3)	48.5	<0.001
	Beech	116.9 (Q2)	87.4 (Q4)	72.1	<0.0010
	Birch	106.3 (Q2)	95.5 (Q3)	3.3	0.026
	Alder	112.4 (Q1)	91.5 (Q3)	28.1	<0.001

The seasonality of wood supply was statistically significant ($p < 0.001$; *F*-test from 15.7 for pine to 96.7 for spruce), except for pine and birch pulpwood, which did not reach statistical significance.

Changes in the volume of sales between consecutive quarters attributable to irregular fluctuations generally did not exceed 5%, except for 2009–2010, when irregular fluctuations in prices were much higher with the peak amplitude (27%) between Q4 2008 and Q1 2009.

Within a one-quarter horizon of change, seasonal, irregular, and cyclical fluctuations accounted for 47%, 44%, and 9% of the overall variability in timber supply, respectively (Table 5). The half-yearly horizon was also dominated by seasonal fluctuations (56%), with cyclical and irregular fluctuations explaining 24% and 20%, respectively. On an annual scale, seasonal, cyclical, and irregular fluctuations accounted for 36%, 36%, and 28%, respectively.

Table 5. Shares of irregular, cyclical and seasonal fluctuations in overall variability of timber supply in Poland in 2005–2018.

Horizon of Change (Number of Quarters)	Change (%)		
	Irregular	Cyclical	Seasonal
1	44	9	47
2	20	24	56
3	22	40	39
4	26	74	0
Mean	28	36	36

The ranges of irregular and cyclical fluctuations as well as long-term trends are shown in Figure 5 for large-diameter timber and in Figure 6 for pulpwood (for each tree species individually). Significant cyclical changes ($p < 0.01$) were found in the supply of large-diameter pine wood from 2014, with slight deviations from the increasing trend. The supply of large-diameter spruce timber was characterized by an increasing trend up to 2008, with a maximum deviation from the trend line in 2007, by 2,738,000 m³. The smallest amplitudes were found for cyclical fluctuations in the supply of W0 beech and oak timber. The effects of irregular fluctuations on supply was pronounced in the case of beech, birch, and alder assortments. W0 oak timber revealed a stable supply. In turn, the supply of birch wood exhibited a long-term decreasing trend, and was characterized by substantial irregularity and cyclical fluctuations. A downward trend was also found for alder wood supply, which declined from 187,000 m³ in 2005 to 157,000 m³ in 2018. The supply of this type of timber exhibited numerous irregular changes, with a maximum in Q1 (Figure 5). S2A assortments revealed an increasing price trend. It was the least pronounced for alder wood, which displayed the greatest amplitudes of cyclical fluctuations (Figure 6).
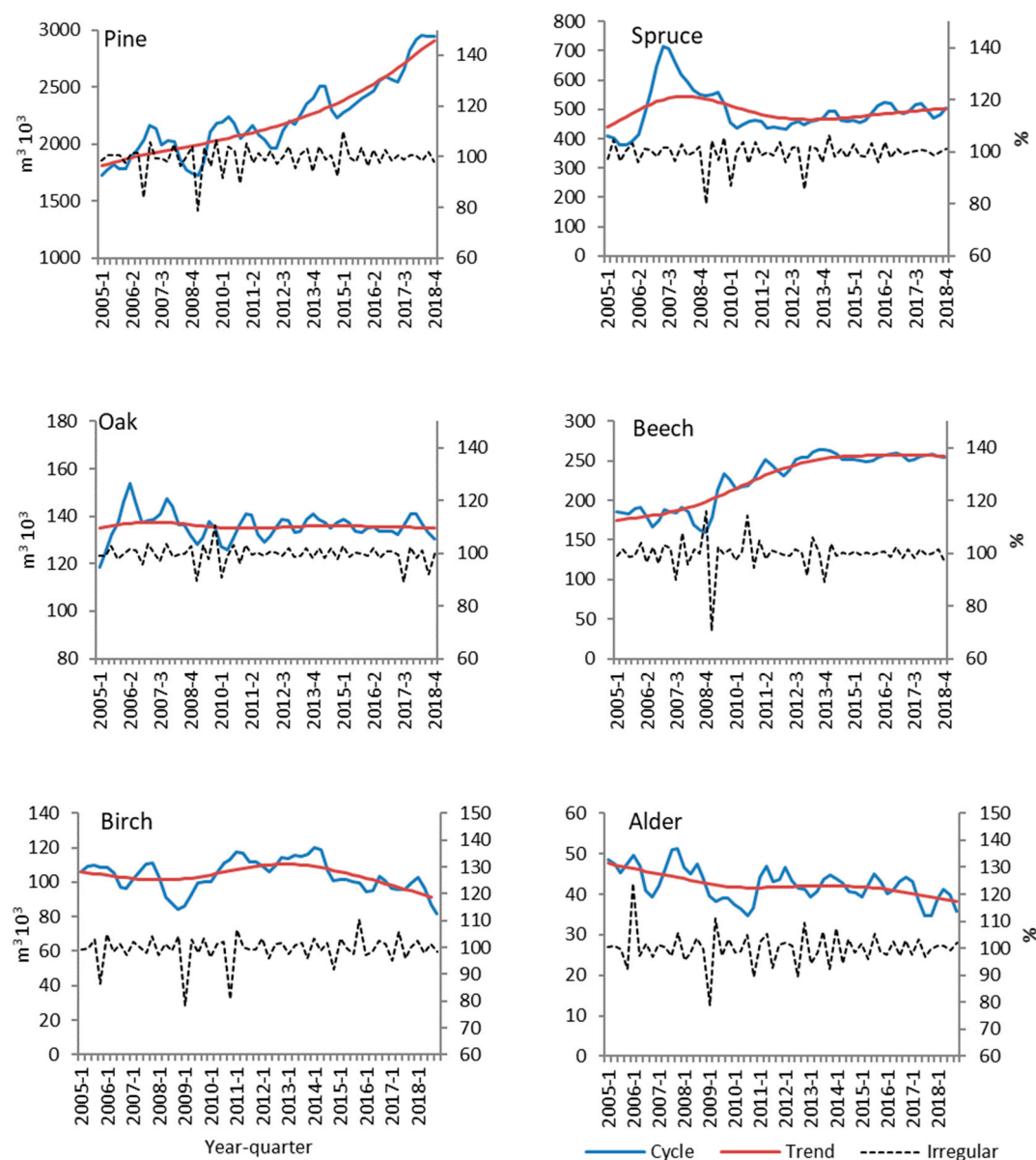

Figure 5. Irregular and cyclical fluctuations and long-term trends in sawtimber supply in Poland in the years 2005–2018.
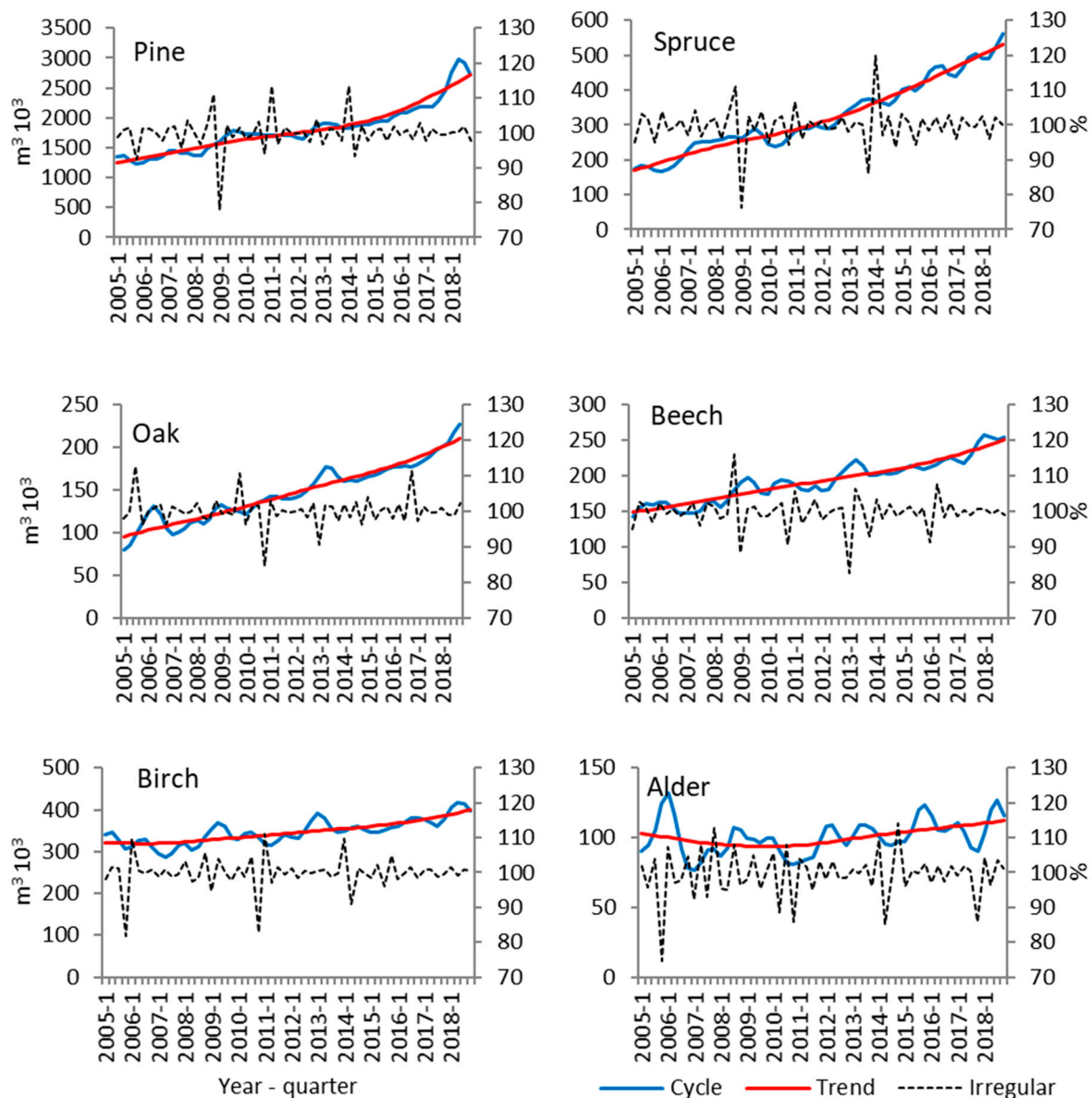
Figure 6. Irregular and cyclical fluctuations and the long-term trend of S2A timber supply in Poland in the years 2005–2018.

4. Discussion

The timber industry exhibits cyclical patterns [53] as a result of complex interactions between various market factors, which determine the business situation in the primary timber market (in terms of demand, prices, and timber supply). Petersen and Strongin attributed differences in cyclicality between different industries to product durability, with durable-good industries being three times more cyclical than non-durable-good industries [54]. It has also been suggested that technological progress and changes in consumer preferences are the determinants of long-term trends in the forest products sector [55].

The cyclical price patterns in the Polish market were largely associated with the condition of the domestic, European, and even global economy, and were the predominant factor responsible for the overall fluctuations in timber prices (73%). In the years 2005–2009, which saw dynamic economic changes arising from the final stage of the economic growth cycle (2007) and the global financial crisis initiated in 2008, there was a decreasing long-term trend, while cyclical fluctuations revealed large amplitudes in the real prices of timber (+€22/m^3, −€27/m^3). After two years of substantial price

increases, a slump in demand translated into a decrease in prices beginning in Q1 2008, while the change occurred in Q3 2009. The turning points of prices coincided with the turning points of Polish GDP growth (analyzed quarterly).

An increasing trend in the real prices of timber occurred from 2010 to 2017. Four cycles were identified in the analyzed period; they became shorter over time (from 4 to approximately 3 years) and their amplitudes gradually decreased. The price dynamics in consecutive cycles were as follows: +22%, −35%; +28%, −19%; +16%, −9%; and +8%, −4%. The situation in the European timber market was also to some extent associated with the stages of the global economic cycle. The decline in timber prices in European countries in 2008 was caused by the American financial crises [5,56]. Similarly, the downturn in the American housing market which lasted from Q4 2007 to Q2 2009, negatively influenced the forest products market [57] and in particular led to a decline in the prices of large-diameter timber [58]. In the years 1985–2010 in the American market, four 5–6-year-long cycles were identified in the forest product industry, of which three coincided with larger economic cycles and one resulted from developments in the trade dispute with Canada [53].

Timber supply (reflecting the volume of sales) was characterized by a smaller share of cyclical changes (36%) as compared to timber prices, in particular, as a result of the changes occurring in Q1, exhibiting the greatest seasonal and random fluctuations. The years 2005–2012 revealed a weak increasing trend in sales, which intensified in 2012–2018 (with a maximum of 4089 m^3 in Q4 2018). Cyclical fluctuations in supply were less pronounced than those in prices as four cycles were noted with gradually decreasing amplitudes. In the first cycle, the upper turning point in Q2 2007 coincided with the peak economic performance of the Polish economy (6.6% GDP growth) due to the growing demand from the industry, and especially the furniture and construction sectors. In turn, Q1 2009 saw a dramatic drop in sales (with an amplitude of −43% for the cycle). Similarly, following a set of faltering economic indicators (rising unemployment, negative GDP growth year-on-year, and decreasing sold production of the industry), supply also shrank in Q1 2013 and Q4 2014. However, in Poland the demand for timber assortments did not always reflect directions in GDP change [10], as a declining trend in timber sales was also observed at a time of slower GDP growth. A negative correlation was found between changes in timber price and supply cycles. Typically, a decline in supply coincided with increasing price cycles.

Timber supply (both quantity and assortment structure) primarily depends on the implementation of planned forest management procedures arising from the silvicultural needs of individual stands; at the same time it is necessary to optimize supply to achieve economic objectives. Under conditions of instability in the global markets and a considerable decrease in demand in the first half of 2009, the State Forests managed to implement its sales plan, but at somewhat reduced prices. In the same year timber sales in Finland amounted to as little as 16.5 million m^3 as compared to 33.2 million m^3 in 2010, at prices that were lower than in 2008 [59]. Toppinen and Kuuluvainen [60] reported high price elasticity for Finland pulpwood supply, in contrast to France [61]. According to studies from Europe and other continents, timber supply is affected by numerous market and non-market factors, depending on forest products and geographic region [62]. Moreover, pulpwood exhibits lower price elasticity than saw logs, which suggests that pulpwood supply is less affected by price changes than that of large-diameter sawtimber. As in the American market the prices of sawtimber were higher than those of pulpwood, the supply of softwood was affected by the sawtimber markets in the short term [63].

Seasonality in various markets, including the timber market, is attributable to institutional factors shaped by people, as well as to natural determinants [64]. Analyses confirmed the presence of timber price and supply seasonality at an overall level of 20.3% and 36%, respectively. The amplitudes of seasonal timber price fluctuations were small, especially as far as S2A softwood and W0 pine wood were concerned. The greatest seasonal fluctuations in prices were found for hardwood species, such as oak (W0—5.1%, S2A—5.7%), as well as birch and alder. Large-diameter timber prices peaked in Q1 and reached the lowest levels in Q3. The prices of S2A assortments differed depending on tree species;

the highest prices were: spruce in Q1, beech in Q2, and oak in Q3. Within an annual time horizon, seasonality of timber prices is of lesser importance than cyclical fluctuations due to the fact that the seasonal prices of timber harvesting and sales are planned almost a year ahead. Trade contracts with customers are finalized in Q1 of the year of sale. This ensures predictable revenues while limiting the possibility of making flexible, economically beneficial decisions during the year. Price seasonality was also affected by the results of auctions conducted on an ongoing basis on the "e-drewno" portal as well as demand from individual customers purchasing timber at higher prices as compared to large enterprises. The sale of timber from October to December commands higher prices than sales from April to June; and the volume of timber harvested in wintertime is the highest [39,65]. It has been reported from Turkey that in spring and summer timber prices are higher in those regions where harvesting and haul are possible only in summertime, while in other regions prices increase during winter [66].

The seasonality of hardwood harvesting and sales is attributable to natural circumstances. The sales of hardwood are the highest in Q1 (except for birch timber, which peaks in Q4) and the lowest in Q3, which is characterized by the most intensive activity of biological factors. In addition to the progression of the seasons of the year, seasonality is also determined by organizational factors, resulting from timber delivery schedules agreed with enterprises, and some economic factors, such as the seasonal nature of construction work, low wintertime activity in the wood industry, and enterprise stock levels.

The more stable the economy and the better the economic indicators (e.g., GDP year-on-year), the lower the frequency and amplitude of random (irregular) changes in timber prices. (max. amplitude Q2 2012) and timber supply (Q1/Q2 2009). Irregular fluctuations had the most pronounced effect in one quarter horizon and were associated with hard-to-predict natural and economic factors independent of the planned silvicultural treatments. The impact of irregular fluctuations on timber supply and prices was smaller than that of seasonal and cyclical fluctuations, on average amounting to 28% and 6.7% within an annual horizon. Natural disasters (windthrows, the disease affecting spruce stands in the Beskidy Mountains) and other unforeseeable events were of a local nature and did not affect timber supply at the nationwide scale except for pine wood in the years 2017–2018. The salvage harvesting of stands damaged by a hurricane that hit north-western Poland in August 2017, affecting 80,000 ha of forests led to an additional supply of approximately 3 million m^3 of timber.

Considerable differences in timber prices and supply were found between different types of timber. In the analyzed period, the sales of large-diameter pine timber increased by 40%, from 7,119,000 m^3 in 2005 to 11,735,000 m^3 in 2018. The prices of that timber type were stable; in 2005 it was approximately €49/m^3 and peaked at approximately €61 /m^3 in 2017 (the highest price was obtained in Q1, when the volume sold was the lowest). The greatest quantities of pine timber were sold in Q2 (S2A) and Q4 (W0), which may be attributable to the purchasing strategies of enterprises, their capacity to store and process timber, as well as their stock management policies. The spring and summer months are characterized by increased activity of insect pests, and especially wood staining fungi causing blue stain of pine timber. Thus, given the increasing use of multi-function harvesters and due to the risk of micro-wounds and penetration by pathological fungi, autumn and winter are the best periods for timber harvesting.

Comparing timber prices between countries is complicated due to different quality requirements for different assortment classes [13], but it can be done by analyzing the most important assortments, such as W0, S2A, and fuelwood [37]. Importantly, W0 pine timber prices in neighboring and nearby countries were similar (e.g., in Lithuania they ranged from €46/m^3 to €66/m^3), which suggests that there does not seem to be room for further increases in the Polish market, also due to the plans to adopt the Euro currency.

The high incidence of natural disasters throughout Central Europe (windthrows, *Ips typographus* outbreaks) adversely affected spruce timber prices. Southern Poland experienced an oversupply of spruce, with sales exceeding the planned volume many times over. The relatively low prices

in Poland as compared to Austria, acceptable transport costs, and favorable exchange rates led to increased interest of foreign companies, which protected the local market from a dramatic downturn and drastic price decreases [67]. The greatest volume of W0 spruce wood was harvested in Q2 and Q3 due to the limited access to harvesting sites located at high altitudes in wintertime, and especially due to the need to remedy *Ips typographus* outbreaks. This is confirmed by analysis of timber price seasonality (Q3 exhibited the lowest level of that parameter). Also, a Japanese study reported a correlation between lower monthly prices between June and August due to pest damage [68]. Spruce timber exhibited a dynamic change in assortment structure: since 2005 the supply of S2A spruce almost tripled (2073 m^3 in 2018), while that of W0 spruce remained within the range of 1500–2000 m^3/year. The prices of large-diameter timber were sensitive to negative data from the economy, and hence the substantial contribution of cyclical fluctuations, especially in the years 2007–2009. The most pronounced drop in timber prices in the period of economic crisis affected large-diameter softwood 69]. The prices of large-diameter assortments W0 peaked in Q2 of 2012 at €71.3/m^3. Much higher prices of those assortments were reported from Austria, at approximately €68–71/m^3 during the crisis depending on the region [69]. In 2003–2013, the average difference in the prices of spruce roundwood between the Czech Republic and Germany amounted to €15.03/m^3 and between the Czech Republic and Austria to €17.62/m^3 [5]. During the economic slowdown, greater price stability was exhibited by medium-diameter assortments (S2A). No seasonal fluctuations were found in the prices of this assortment, probably due to continuous harvesting.

In the period under consideration, there was a 7% decrease in the real prices of beech timber, with a 27% increase in sales. The prices of that beech assortment reflected a stagnation in the European market [69,70] attributable to a long-term decline in demand for beech timber. The prices of beech sawtimber peaked in the period preceding the financial crisis and so they may be expected to rise again over the next two years, except for beech in Austria [37]. In Poland the prices of W0 assortments revealed considerable seasonal and cyclical fluctuations, with beech timber exhibiting the strongest downwards trend since 2005, which intensified in 2008–2012 and ended in 2013. Despite that, the supply of beech timber increased, to remain at an approximate constant level of 1,000,000 m^3/year since 2013. The greater supply resulted from the need to conduct the necessary management treatments in mature (aging) beech stands. The nominal prices of W0 timber amounted to €52/m^3 in Q1 2005 and in Q4 2018, and so their real value declined. W0 timber was under a strong influence of market data, as reflected in the amplitudes of irregular and cyclical price fluctuations. In terms of seasonal variations, the largest volume was harvested in Q1 (which coincided with the highest prices commanded). Thus, timber was harvested during a period of rest, as processing in the spring and summer is difficult due to the high risk of defects, such as stains. Beech pulpwood (S2A) was more stable and exhibited an increasing trend in both prices and supply. That assortment exhibited a moderate price change, from €24/m^3 in 2005 to €36/m^3 in 2011 and 2019. In 2005 in Austria, beech timber W0 w 2005 cost slightly less than €80/m^3 with a downward trend up to 2014; nevertheless, it was much more expensive than in Poland.

As compared to other types of timber, the supply of oak remained stable at approximately 500,000 m^3/year. The prices of W0 oak timber in Poland were the least sensitive to adverse economic circumstances, being characterized by a systematic increase, especially after 2013. On the other hand, an increasing trend in the supply of S2A was accompanied by a decrease in prices. W0 oak timber is considered a valuable assortment, and similarly to beech timber it is harvested in wintertime due to its material requirements. In Q1 2005, that assortment was priced at approximately €105/m^3, as compared to €165/m^3 in 2018. The prices of S2A decreased in 2012, embarking on a downward trend. Interestingly, oak pulpwood exhibited lower prices than pine, beech, spruce, and birch (approximately €26/m^3 in 2005 and €33/m^3 in 2018). In Poland there has been a decline in the supply of large-diameter birch and alder timber, while the supply of S2A assortments, and especially alder, has exhibited the least marked increasing trend among all species. W0 timber cost €39/m^3 in 2005 and €48/m^3 in 2018; similar prices were reported from Finland. A comparison of data has revealed a substantial difference

in prices between the Polish and Ukrainian markets on the one hand, and the market of the Baltic countries on the other [27].

5. Conclusions

(1) Over a long time horizon, timber prices exhibit substantial variation in terms of both the direction and amplitude of changes. Time series decomposition was used to analyze overall variability into its components depending on the impulse causing the fluctuations and the time horizon of the change. The practical aspect of the study was to elucidate the factors shaping the timber market and their underlying causes.

(2) Irregular fluctuations occurred over short time horizons (1–2 quarters) and were caused by random events that are typically difficult to identify; consequently, such changes are hard to predict. Within a one-year horizon, irregular fluctuations contributed approximately 6.7% and 28% of the overall variation in timber prices and supply, respectively, and were characterized by small amplitudes (+5% and −25%, respectively). Their effects are more noticeable in local markets.

(3) Seasonal fluctuations occurring with an annual horizon are associated with the seasons of the year, weather conditions, and the seasonality of timber harvesting and timber demand. Seasonal fluctuations had a greater effect on timber sales (36%) than on prices (20.3%). Seasonality was negatively correlated with supply—prices were lower in quarters with high supply and vice versa. Seasonality patterns depend on the type of timber; in the case of softwood, the lowest supply was found in Q1, and the highest in Q3 (spruce) or Q4 (pine). The supply of hardwood was the highest in Q1, and the lowest in Q3.

(4) Cyclical fluctuations primarily affected timber prices and were characterized by considerable variations in cycle length (2–4 years) and change amplitude (3–27 Euros). During the economic downturn (2008/2009) the amplitudes were much higher than during periods of steady economic growth (e.g., 2014–2018). Cyclical fluctuations in timber prices were typically negatively correlated with fluctuations in timber supply: the upper turning points of price cycles fell near the lower turning points of supply cycles (with a shift of 1 to 3 quarters).

(5) Analysis of the overall variation in timber prices and supply may find applications in predicting timber prices and planning timber volumes to be harvested over longer time horizons, as well as in adjusting the timber assortment structure to changes in the market.

(6) Long-term price changes exhibited a slight upwards trend, while timber supply was characterized by a more pronounced increasing trend (the percentage increase in overall supply was greater than that of prices). In the long run, the growing demand for large-diameter oak timber, given its constant supply, led to higher prices, while beech timber became cheaper as a result of its oversupply.

Author Contributions: Conceptualization, J.B.; Methodology, J.B.; Software, J.B.; Validation, J.B. and A.K.; Investigation, J.B. and A.K.; Writing—Original draft preparation, J.B. and A.K.; Writing—Review and editing, J.B. and A.K.; Visualization, J.B.; Supervision, J.B. and A.K.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lundholm, A.; Corrigan, E.; Nieuwenhuis, M. Implementing Climate Change and Associated Future Timber Price Trends in a Decision Support System Designed for Irish Forest Management and Applied to Ireland's Western Peatland Forests. *Forests* **2019**, *10*, 270. [CrossRef]
2. Hetemäki, L.; Hänninen, R.; Toppinen, A. Short-Term Forecasting Models for the Finnish Forest Sector: Lumber Exports and Sawlog Demand. *For. Sci.* **2004**, *50*, 461–472.

3. Hetemäki, L.; Mikkola, J. Forecasting Germany's Printing and Writing Paper Imports. *For. Sci.* **2005**, *51*, 483–497.

4. Tzanova, P. Time Series Analysis for Short-Term Forest Sector Market Forecasting. *Austrian J. For. Sci.* **2017**, *134*, 2005–2230.

5. Hlavackova, P.; Brezina, D.; Sujova, A. The Price Formation of Raw Wood in the Czech Republic and a Comparison with the Neighbor States. *Procedia Econ. Financ.* **2015**, *26*, 389–395. [CrossRef]

6. Kostadinov, F.; Holm, S.; Steubing, B.; Thees, O.; Lemm, R. Simulation of a Swiss wood fuel and rundwood market: An expolorative study in agent-based modeling. *For. Policy Econ.* **2014**, *38*, 105–118. [CrossRef]

7. Kożuch, A.; Adamowicz, K. Wpływ kosztów realizacji pozaprodukcyjnych funkcji lasu na sytuację ekonomiczną nadleśnictw Regionalnej Dyrekcji Lasów Państwowych w Krakowie. *Sylwan* **2016**, *160*, 1010–1019. [CrossRef]

8. Niemelä, J.; Young, J.; Alard, D.; Askasibar, M.; Henle, K.; Johnson, R.; Kurttila, M.; Larsson, T.-B.; Matouch, S.; Nowicki, P.; et al. Identifying, managing and monitoring conflicts between forest biodiversity conservation and other human interests in Europe. *For. Policy Con.* **2005**, *7*, 877–890. [CrossRef]

9. Alberdi, I.; Michalak, R.; Fischer, C.; Gasparini, P.; Brändli, U.-B.; Tomter, S.M.; Kuliesis, A.; Snorrason, A.; Redmond, J.; Hernández, L.; et al. Towards harmonized assessment of European forest availability for wood supply in Europe. *For. Policy Econ.* **2016**, *70*, 20–29. [CrossRef]

10. Adamowicz, K. Cenowa elastyczność popytu na drewno na pierwotnym lokalnym rynku drzewnym w Polsce. *Sylwan* **2010**, *154*, 130–138.

11. Gejdoš, M.; Danihelová, Z. Valuation and Timber Market in the Slovak Republic. *Procedia Econ. Financ.* **2015**, *34*, 697–703. [CrossRef]

12. Wysocka-Fiorek, E.; Lachowicz, H. Changes in prices, volume and value of wood raw material sold by the State Forests. *Sylwan* **2018**, *162*, 12–21.

13. Malinen, J.; Kilpeläinen, H. Price systems for standing sales of industrial roudwood in Finland. *Balt. For.* **2013**, *19*, 307–315.

14. Malinen, J.; Haring, M.; Kilpeläinen, H.; Verkasalo, E. Comparison of alternative roundwood pricing systems—A simulation approach. *Silva Fenn.* **2015**, *49*. [CrossRef]

15. Directorate-General of State Forests. *Forests in Poland*; State Forest Information Center: Warszawa, Poland, 2018.

16. Directorate-General of State Forests. *The State Forests in Figures 2018*; State Forest Information Center: Warszawa, Poland, 2018.

17. *Zarządzenie Nr 51 Dyrektora Generalnego Lasów Państwowych z Dnia 16 Sierpnia 2005 r. Zmieniające Zarządzenie Nr 91 Dyrektora Generalnego Lasów Państwowych, z Dnia 30 Listopada 2001 r, Znak PA-80-121/2001, w Sprawie Prowadzenia Sprzedaży Drewna w Państwowym Gospodarstwie Leśnym Lasy Państwowe. (OM-906-1-107/05)*; State Forest Information Center: Warszawa, Poland, 2005.

18. *Zarządzenie nr 46 Dyrektora Generalnegp Lasów Państwowych z Dnia 24 Października 2016r. w Sprawie Sprzedaży Drewna Prowadzonej Przez Państwowe Gospodarstwo Lesne Lasy Państwowe. (ZM.800.2.2016)*; State Forest Information Center: Warszawa, Poland, 2016.

19. Adamowicz, K. Ocena wpływu zmian gospodarczych na ilościowe zmiany podaży surowca drzewnego. *Zarządzanie Ochr. Przyr. Lasach* **2011**, *5*, 189–200.

20. Leskinen, P.; Kangas, J. Modelling Future Timber Price Development by Using Expert Judgments and Time Series Analysis. *Silva Fenn.* **2001**, *35*, 93–102. [CrossRef]

21. Szramka, H.; Bieniaszewski, T.; Auguścik, Ł.; Bobek, J.; Adamowicz, K. Wpływ wad drewna wielkowymiarowego na przychody z jego sprzedaży. *Sylwan* **2017**, *161*, 238–246.

22. Suchodolski, P.; Idzik, M. Identyfikacja i ocena zmienności cen drewna w nadleśnictwie Płock. *Wiadomości Stat.* **2018**, *11*, 41–55.

23. Borzykowski, N. A supply-demand modeling of the Swiss roundwood market: Actors responsiveness and CO2 implications. *For. Policy Econ.* **2019**, *102*, 100–113. [CrossRef]

24. Holm, S.; Hilty, L.M.; Lemm, R.; Thees, O. Empirical validation of an agent-based model of wood markets in Switzerland. *PLoS ONE* **2018**, *13*, e0190605. [CrossRef]

25. Knauf, M. An Analysis of Wood Market Balance Modeling in Germany. *For. Policy Con.* **2015**, *50*, 319–326. [CrossRef]

26. Koskela, E.; Ollikainen, M. A game-theoretic model of timber prices with capital stock: An empirical application to the Finnish pulp and paper industry. *Can. J. For. Res.* **1998**, *28*, 1481–1493. [CrossRef]

27. Lachowicz, H.; Wysocka-Fijorek, E. Silver birch timber market in Poland in 2008−2012. *Sylwan* **2016**, *160*, 971–980.

28. Olsson, O.; Hillring, B. Price relationships and market integration in the Swedish wood fuel market. *Biomass Bioenergy* **2013**, *57*, 78–85. [CrossRef]

29. Paschalis−Jakubowicz, P.; Kulik, P.; Lachowicz, H. Obrót surowcem drzewnym najwyższych klas jakości w Polsce. *Sylwan* **2015**, *159*, 91–102.

30. Prestemon, J.P.; Holmes, T.P. Timber price dynamics following a natural catastrophe. *Am. J. Agric. Econ.* **2000**, *82*, 145–160. [CrossRef]

31. Zając, S. Analiza ekonometryczna i prognozowanie zjawisk i procesów rynku surowca drzewnego w Polsce. *Pr. IBL Ser. A* **1999**, *886*, 1–133.

32. Penttinen, M.J. Impact of stochastic price and growth processes on optimal rotation age. *Eur. J. Forest Res.* **2006**, *125*, 335–343. [CrossRef]

33. Khajuria, R.P.; Kant, S.; Laaksonen-Craig, S. Modeling of timber harvesting options using timber prices as a mean reverting process with stochastic trend. *Can. J. For. Res.* **2012**, *42*, 179–189. [CrossRef]

34. Gonzalez-Gomez, M.; Bergen, V. Berücksichtigung der Nichtstationärität von Zeitreihen bei empirischen Untersuchungen des deutschen Rohholzmarktes. *Allg. Forst J.-Ztg* **2014**, *186*, 53–62.

35. Kolo, H.; Tzanova, P. Forecasting the German forest products trade: A vector error correction model. *JFE* **2017**, *26*, 30–45. [CrossRef]

36. Buongiorno, J. Global modelling to predict timber production and prices: The GFPM approach. *Forestry* **2015**, *88*, 291–303. [CrossRef]

37. Gejdoš, M.; Lieskovský, M.; Giertliová, B.; Němec, M.; Danihelová, Z. Prices of Raw-Wood Assortments in Selected Markets of Central Europe and their Development in the Future. *Bioresources* **2019**, *14*, 2995–3011.

38. Leskinen, P.; Kangas, J. Modelling and simulation of timber prices for forest planning calculations. *Scand. J. For. Res.* **1998**, *13*, 469–476. [CrossRef]

39. Michinaka, T.; Kuboyama, H.; Tamura, K.; Oka, H.; Yamamoto, N. Forecasting Monthly Prices of Japanese Logs. *Forests* **2016**, *7*, 94. [CrossRef]

40. Prestemon, J.P. Evaluation of U.S. southern pine stumpage market informational efficiency. *Can. J. For. Res.* **2003**, *33*, 561–572. [CrossRef]

41. Zhou, M.; Buongiorno, J. Space-Time Modeling of Timber Prices. *J. Agric. Resour. Econ.* **2006**, *31*, 40–56.

42. Malaty, R.; Toppinen, A.; Viitanen, J. Modelling and forecasting Finnish pine sawlog stumpage prices using alternative time-series methods. *Can. J. For. Res.* **2007**, *37*, 178–187. [CrossRef]

43. Bolkesjø, T.F. Projecting pulpwood prices under different assumptions on future capacities in the pulp and paper industry. *Silva Fenn.* **2005**, *39*, 103–116. [CrossRef]

44. Dahal, P.; Mehmood, S. Determinants of timber bid prices in Arkansas. *For. Prod. J.* **2005**, *55*, 89–94.

45. Kallio, A. Analysing the Finnish pulpwood market under alternative hypotheses of competition. *Can. J. For. Res.* **2011**, *31*, 236–245. [CrossRef]

46. Sun, C.; Zhang, D. Assessing the financial performance of forestry related investment vehicles: Capital asset pricing model vs. arbitrage pricing theory. *Am. J. Agric. Econ.* **2001**, *83*, 617–628. [CrossRef]

47. Toppinen, A.; Kuuluvainen, J. Forest sector modelling in Europe—The state of the art and future research directions. *For. Policy Econ.* **2010**, *12*, 2–8. [CrossRef]

48. National Bank of Poland. Exchange Rate of the Polish National Bank. Available online: https://www.nbp.pl/home.aspx?f=/statystyka/kursy.html (accessed on 6 June 2019).

49. Central Statistical Office. Inflation Coeficients in Poland. Available online: https://stat.gov.pl/obszary-tematyczne/ceny-handel/wskazniki-cen/wskazniki-cen-towarow-i-uslug-konsumpcyjnych-pot-inflacja-/miesieczne-wskazniki-cen-towarow-i-uslug-konsumpcyjnych-od-1982-roku/ (accessed on 4 June 2019).

50. Shiskin, J.; Young, A.H.; Musgrave, J.C. *The X-11 Variant of the Census Method II Seasonal Adjustment Program*; Technical paper 15; US Government Printing Office: Washington, DC, USA, 1967.

51. Hodrick, R.; Prescott, E.C.; Postwar, U.S. Business Cycles: An Empirical Investigation. *J. Money Credit Bank.* **1997**, *29*, 1–16. [CrossRef]

52. Ravn, M.O.; Uhlig, H. On Adjusting the Hodrick-Prescott Filter for the Frequency of Observations. *Rev. Econ. Stat.* **2002**, *84*, 371–380. [CrossRef]

53. Mehrotra, S.N.; Kant, S.; Majumdar, I. Industry Cycles in the US Softwood Lumber Industry: 1985 through 2010. *For. Prod. J.* **2014**, *64*, 116–125. [CrossRef]

54. Petersen, B.; Strongin, S. Why are some industries more cyclical than others? *J. Bus. Econ. Stat.* **1996**, *14*, 189–198.

55. Wear, D.N.; Prestemon, J.P.; Foster, M.O. US Forest Products in the Global Economy. *J. For.* **2016**, *114*, 483–493. [CrossRef]

56. Gejdoš, M.; Potkány, M. Prediction and analysis of Slovakian timber trade on global market conditions. *Serb. J Manag.* **2017**, *12*, 281–289. [CrossRef]

57. Woodall, C.W.; Piva, R.J.; Luppold, W.G.; Skog, E.K.; Ince, J.P. An assessment of the downturn in the forest products sector in the northern region of the United States. *For. Prod. J.* **2011**, *61*, 604–613. [CrossRef]

58. Parajuli, R.; Chang, S.J.; Hill, R.C. How Effective Is the United States-Canada Softwood Lumber Agreement 2006? An Econometric Study. *For. Sci.* **2015**, *61*, 1041–1049. [CrossRef]

59. Kolis, K.; Hiironen, J.; Ärölä, E.; Vitikainen, A. Effects of sale-specific factors on stumpage prices in Finland. *Silva Fenn.* **2014**, *48*. [CrossRef]

60. Toppinen, A.; Kuuluvainen, J. Structural changes in sawlog and pulpwood markets in Finland. *Scand. J. Forest Res.* **1997**, *12*, 382–389. [CrossRef]

61. Solberg, B. *An Econometric Analysis of Timber Supply in Eight Northwestern European Countries*; EFI Technical Report No. 44; European Forest Institute: Joensuu, Finland, 2011; Available online: https://efi.int/publications-bank/econometric-analysis-timber-supply-eight-northwestern-european-countries (accessed on 10 June 2019).

62. Tian, N.; Poudyal, N.C.; Augé, R.M.; Hodges, D.G.; Young, T.M. Meta-Analysis of Price Responsiveness of Timber Supply. *For. Products J.* **2017**, *67*, 152–163. [CrossRef]

63. Polyakov, M.; Wear, D.N.; Huggett, R.N. Harvest Choice and Timber Supply Models for Forest Forecasting. *For. Science* **2010**, *56*, 344–355.

64. Zwirglmaier, K. Seasonality of Prices—The Example of German Timber Prices. *Technisce Universitat Munchen*. 2010. Available online: http://www.gipecofor.org/doc/drupal/liens_article/evenements/2010/ZWIRGLMAIER_IUFRO_Paris_Mai2010.pdf. (accessed on 15 July 2019).

65. Brown, R.N.; Kilgore, M.A.; Coggins, J.S.; Blinn, C.R. The impact of timber-sale tract, policy, and administrative characteristics on state stumpage prices: An econometric analysis. *For. Policy Econ.* **2012**, *21*, 71–80. [CrossRef]

66. Şen, G.; Güngör, E. Determination of the Seasonal Effect on the Auction Prices of Timbers and Prediction of Future Prices. *J. Bartin Fac. For.* **2018**, *20*, 266–277.

67. Sikora, A.T. The effect of natural disasters on the timber market. *For. Res. Papers* **2017**, *78*, 277–284. [CrossRef]

68. Kuboyama, H.; Tachibana, S. Statistical analysis on price trend of softwood roundwood. *Kanto J. For. Res* **2014**, *65*, 9–12.

69. Suchomel, J.; Gejdos, M.; Ambrusova, L.; Sulek, R. Analysis of price changes of selected roundwood assortments in some Central Europe countries. *J. For. Sci.* **2012**, *58*, 483–491. [CrossRef]

70. Kożuch, A.; Banaś, J.; Zięba, S.; Adamowicz, K. Analysis of the supply and price of beech wood in southern Poland. *Acta Sci. Pol. Silv.* **2016**, 87–96. [CrossRef]