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A COMPARISON OF PREDICTION EFFICIENCY FOR TIMBER PRICES IN POLAND IN TIMES OF ECONOMIC CRISIS WITH THE APPLICATION OF THE LINEAR APPROXIMATION METHOD AND BROWN'S EXPONENTIAL SMOOTHING MODEL

An analysis was made of two prediction methods: the Linear Approximation Method (LAM) and Brown's Exponential Smoothing Model (BESM). These two methods were investigated and compared in terms of their efficiency in timber price prediction. Models and price predictions were prepared based on three time series (5-, 7- and 9-year) for three years: 2015, 2016 and 2017. The analyses were conducted using data on mean annual timber prices from the period 2006-2017. This meant that the time series included the years of the 2007-2008 economic crisis. Prediction efficiency was evaluated by comparing the results obtained with actual timber prices in the years 2015-2017. It was found that the predictions generated by LAM were better than those produced by BESM. The smallest relative and absolute errors of prediction were obtained applying the linear function: y_t^ *= 5.277t + 161.70. This function was constructed based on a 5-year time series. Absolute error amounted to 1.59 PLN (€0.35). Relative error was below 1%. The results of this work suggest that further studies are desirable to investigate the applicability of trend analysis to the prediction of timber prices with the inclusion of analyses of nonlinear trends. The present results of timber price modelling may provide a basis to search for a homogeneous model of timber price prediction adapted to specific conditions of timber sales.*

Keywords: forest economics, market, price, prediction, raw wood

Introduction

In the contemporary, dynamically developing world the ability to predict socio-economic phenomena is becoming increasingly important. A key skill required

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of managers at present is to use available tools to prepare forecasts assisting the organisational management system. As a consequence, knowledge needed in the prediction development process is considered to be increasingly important. In the dynamically changing economic situation (the economic crisis of 2007-2008, the current economic crisis related to the pandemic) reliable prediction is a crucial element supporting the decision-making process. This is evidenced by the fact that in recent years many researchers have investigated prediction models, including also price prediction. For example, Mondal et al. [2014] and Du [2018] prepared predictions of share prices, McNally et al. [2018] conducted studies on future bitcoin prices, crude oil prices were predicted by Du Cao et al. [2015] and by Kowalik and Herczakowska [2010], while short-term predictions of electricity prices at the Polish Power Exchange (Towarowa Giełda Energii) were presented by Popławski [2006]. Literature on the subject also includes studies comparing various prediction models in terms of their capacity to predict price trends. Results of such studies have been presented by, for example, Chou and Ngo [2016], Omar et al. [2016], Du [2018], McNally et al. [2018], and Shao and Dai [2018]. There is a very limited number of papers concerning the timber market. The problem of forecasting timber prices has been investigated, for example, by Soares et al. [2010], who attempted to construct a model forecasting prices of eucalyptus (*Eucalyptus spp.* L.), while Koutroumanidis et al. [2009] presented forecasts of fuel wood prices in Greece using the ARIMA models, artificial neural networks and a hybrid ARIMA-ANN model, Cordeiro et al. [2010] developed a model forecasting export prices for pine lumber in Brazil. In turn, Malaty et al. [2007] attempted to compare the efficiency of forecasting of pine (*Pinus sylvestris* L.) timber prices in Finland using two models, the Autoregressive Integrated Moving Average Model (ARIMA) and Vector Autoregression (VAR). Among the conclusions presented by those authors is an indication of the need for further studies on innovative tools supporting the prediction of timber prices. They stress that timber products are subject to considerable price volatility and are strongly affected by local conditions in the forest economy. Adamowicz [2010] stated that in view of the need to take account of economic changes manifested in the business cycles of forestry administrative units, studies need to analyse changes in the timber market, including also studies based on prediction. These provide a basis for planning processes (not only in forestry) and support decision-making processes by incorporating actions to be conducted in the future, taking account of knowledge on past and present events. For this reason, research needs to be carried out in relation to the search for empirical evidence concerning stochastic properties of timber prices and development of methodological foundations for the prediction of changes in those prices. Due to the specific character of the forest economy, reliable prediction of timber prices requires consideration of the forest economy conditions in individual countries. In Poland, to date, no in-depth studies have been conducted in this regard. In view of the lack of methodological foundations for the development of predictions for changes in timber prices in Central Europe, particularly Poland, it is desirable that such research should be carried out. Considering the current state of knowledge on prediction methods, all studies in this area will contribute both to scientific theory and to the development of know-how.

For example, in Poland there is a lack of methodological foundations facilitating the preparation of reliable forecasts for the development of prices for individual timber assortments. It appears that results of Polish research on the subject may be used in comparative analyses concerning timber price predictions in other countries, particularly in Central Europe. It needs to be remembered that at present there are no uniform European guidelines for the utilisation of timber resources, and as a result various organisational and legal solutions are applied in timber trading. For this reason, it is necessary to develop a comparative database of prediction results obtained using diverse methods, which may be further verified under different legal and economic conditions. In the authors' view, studies on the prediction of changes in timber prices ought to begin with the testing of objective forecasting methods. It was thus decided to analyse the applicability of selected econometric methods in *ex ante* analysis to predict timber prices. The main aim of the study was to select one of two investigated methods, Brown's Exponential Smoothing Model (BESM) and the Linear Approximation Method (LAM), as a method providing a better fit for the forecasting of changes in timber prices in Poland. The study presented below did not take account of imports, exports and natural disasters, which may affect the results obtained. The study assumed that any inflation that occurred was included in the average annual wood prices. These factors may be a subject for continued research. The present research is of a pioneering nature; due to the lack of confirmed scientific tools for wood price prediction, the selected methods were investigated with the aim of providing a basis for comparing more complex methods or creating a hybrid statistical and mathematical model that would be of use in predicting wood prices in Europe.

Research methodology

The two methods selected for this study were LAM and BESM. The analysis was based on information on mean annual timber prices (PW) from the period 2006-2017. To determine which method best predicted PW changes, each of the analysed methods was used to obtain three forecasts for the years 2015, 2016 and 2017, and the results were compared with actual data on PW in those years. The data used in the study are average annual wood prices. The authors assumed that inflation was included in these prices, and therefore they have not been adjusted. The price information was obtained from the Announcements of the President of the Central Statistical Office, which are published annually.

Making the assumption that the length of the time series adopted in the construction of the trend model influences the result of the forecasts, the analysed methods were tested based on a system of three time series (5-, 7- and 9-year). As a result, a total of 27 predictions were obtained (with 9 for each tested method). On this basis the PW prediction methods were compared (with analysis of prediction errors) and the appropriate period for the construction of the PW prediction model was indicated.

First, PW prediction was performed using LAM. For this purpose, a PW growth trend model was constructed, which was further used to predict PW and to estimate the parameters of the linear function in the classical form $y_t = at + b$. This estimation of the PW function parameters was performed by solving the classical set of equations:

$$\begin{bmatrix} \sum_{t=1}^{n} y_t = & n \times b + a \times \sum_{t=1}^{n} t \\ \sum_{t=1}^{n} y_t \times t = & b \times \sum_{t=1}^{n} t + a \times \sum_{t=1}^{n} t^2 \end{bmatrix} \tag{1}$$

where y_t is the PW in period t, t denotes the period (1 year), n is the number of observations, a is the trend coefficient, and b is the absolute term of the trend function.

First, using the formula given above (formula 1), the value of the trend coefficient (a) was estimated:

$$a = \frac{\sum_{t=1}^{n} y_t t - \frac{\sum_{t=1}^{n} t \sum_{t=1}^{n} y_t}{n}}{\sum_{t=1}^{n} t^2 - \frac{\left(\sum_{t=1}^{n} t\right)^2}{n}} \tag{2}$$

where the symbols have the same meanings as in formula 1.

Based on this coefficient, the mean increase or decrease in PW between individual periods (t) was determined. The value of the absolute parameter of the analysed function (b) was estimated using information on the value of the PW trend coefficient (a), the arithmetic mean of the number of periods used in the simulation $(\bar{t})$ and the arithmetic mean of PW $(\bar{y}_t)$:

$$b = \bar{y}_t - a \times \bar{t} \tag{3}$$

Next, a prediction of PW changes was constructed using BESM:

$$y_t^* = \alpha y_{t-1} + (1 - \alpha) y_{t-1}^* \tag{4}$$

for $t = 2, 3, \ldots, n+1$, where y^*_{t-1} is the theoretical value from the previous period, y_{t-1} is the empirical value of the trend from the previous period, and α is the smoothing constant.

Remembering that this method is based on a combination of the weighted mean of the past value of the phenomenon and the future forecast, the value of α was selected based on the smallest error determined using the Root Mean Squared Error (RMSE), s^*:

$$s^* = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - y_t^{\alpha})^2} \quad (5)$$

where s^* is the mean square predictive error, n is the population size, y_t is the actual value in the present period, α is the smoothing constant, and y_t^{α} is the expired forecast.

It was assumed that the better model would have a lower RMSE value.

The effectiveness of the methods for constructing PW predictions was assessed by determining parameters of the stochastic structure for the results, namely the residual standard deviation, residual variation coefficient, convergence coefficient, coefficient of determination, and standard errors for the structural parameters of the trend equation.

The standard deviation of the residual ($S(e_t)$) was calculated from the formula:

$$S(e_t) = \sqrt{\frac{\sum_{i=1}^{n}(y_t - \hat{y}_t)^2}{n-k}} \quad (6)$$

where y_t and n are as in formula 1, $\hat{y}_t$ is the theoretical value in the present period, and k is the number of estimated parameters (in the case of the linear trend function, $k = 2$).

This indicates the degree to which the explained variable is influenced by random effects, established by estimation of the residual variation coefficient $(V_{S(e_t)})$ calculated from the following formula:

$$V_{S(e_t)} = \frac{S(e_t)}{y_t} \cdot 100\,\% \quad (7)$$

where $S(e_t)$ is as in formula 6, and y_t is as in formula 1.

It was assumed that the constructed model could be considered suitable for prediction when $(V_{S(e_t)}) < 20\%$. The convergence coefficient (φ^2) was calculated from the formula:

$$\varphi^2 = \frac{\sum_{i=1}^{n}(y_t - \hat{y}_t)^2}{\sum_{i=1}^{n}(y_t - \bar{y}_t)^2} \quad (8)$$

where y_t is as in formula 1, $\hat{y}_t$ is as in formula 6, and $\bar{y}_t$ is the mean weighted value of actual timber prices in period *t*.

The coefficient of determination (R^2) was calculated from the formula:

$$R^2 = 1 - \varphi^2 \tag{9}$$

where is as in formula 8.

The coefficient of determination (R^2) was used to determine what part of the data was explained by the model. The following classification of results was adopted: R^2 = 0.0-0.5 – insufficient goodness of fit; R^2 = 0.5-0.6 – weak fit; R^2 = 0.6-0.8 – satisfactory fit; R^2 = 0.8-0.9 – good fit; R^2 = 0.9-1.0 – very good fit.

All of the predictions carried errors. They were ranked based on the size of differences between actual prices and the prices predicted using the analysed models. When evaluating the efficiency of individual prediction models, standard errors were considered.

Standard errors of structural parameters in the trend equation ($S_{(a)}$ and $S_{(b)}$) were calculated from the formulae:

$$S_{(a)} = \frac{S(e_t)}{\sqrt{\sum_{i=1}^{n} t^2 - n\bar{t}^2}}$$

$$S_{(b)} = \sqrt{\frac{S^2(e_t)\sum_{i=1}^{n} t^2}{n\left(\sum_{i=1}^{n} t^2 - n\bar{t}^2\right)}} \tag{10, 11}$$

where $S(e_t)$ is as in formula 6, and *t* and *n* are as in formula 1.

Apart from the analysis of errors in the structural parameters of the equation, predictive errors were also estimated. To provide a reliable comparison of the obtained predictions with the actual PW values, the mean standard error of the investigated variables was calculated:

$$S_x = \frac{S}{\sqrt{N}} \tag{12}$$

where *S* is the standard deviation and *N* is the number of observations.

Additionally, the absolute error and the relative error of predicted PW in relation to actual PW were calculated:

$$\Delta x = x - x_0 \tag{13}$$

where Δx is the absolute error, *x* is the actual value of PW, and x_0 is the actual value of PW;

$$\delta = \frac{\Delta x}{x} \cdot 100\% = \frac{|x - x_0|}{x} \tag{14}$$

where δ is the relative error, and other symbols are as in formula 13.

In accordance with the assumptions adopted, predictions were made using three different time series for 3 different years (3 replications). The efficiency of individual forecasts provided by the analysed methods was evaluated based on averaged errors of individual predictions:

$$E_A = \frac{\delta_1 + \delta_2 + \delta_3}{3} \quad (15)$$

where E_A is the average predictive error of PW.

Results and discussion

In accordance with the adopted methodological assumptions, information was collected on PW from the period 2006-2017. First, PW prediction was performed using LAM. Following the adopted methodology, the formula of the linear function was determined and the applicability of the constructed models to further stages of the study was assessed. Based on the results obtained, all of the functions were classified as suitable to predict PW. The smallest relative and absolute errors were recorded for the prediction based on the linear function $\hat{y}_t = 5.277t + 161.70$. This function was constructed based on the 5-year time series. In the absolute system this error amounted to 1.59 PLN (€0.35) (Table 1). In the relative system the difference between predicted and actual PW was below 1%. The average predictive error (E_A) for prediction based on the 5-year trend was the smallest, at slightly over 1%. For the longer time series E_A was greater: for the 7-year time series it was 3.28%, and for the 9-year time series it was 5.09% (Table 1).

Next, prediction of PW was performed using BESM. Similarly as in the case of predictions obtained from the trend analysis, the smallest E_A was recorded for the 5-year time series. This error was approximately 1%. For longer time series E_A was greater, reaching 18.80% for the 7-year time series and 17.82% for the 9-year time series (Table 1).

The errors in predictions constructed using BESM were greater than those in predictions provided by LAM. The lowest E_A in BESM exceeded the greatest E_A for LAM.

Predictions concerning market changes, particularly in PW values, provide key information for management processes in the forestry and wood sector. For example, in Poland the timber conversion and processing sector employs approximately 330,000 people, which is 2.5% of employment in the entire national economy (CSO data). The aim of the present research was to compare two prediction methods for PW. It should be noted that at present no comprehensive solutions are available for price prediction dedicated to the forestry sector in Central Europe, including Poland. For this reason, it was decided to verify the selected prediction methods in terms of their applicability

Table 1. Summary of results for errors in the prediction of average wood raw material prices using the Linear Approximation Model and Brown's Exponential Smoothing Model in 2015-2017 with 5-, 7- and 9-year time series

	Linear Approximation Model (LAM)								
	5-year time series			7-year time series			9-year time series		
	2017	2016	2015	2017	2016	2015	2017	2016	2015
Absolute error	2.27 PLN	2.27 PLN	1.59 PLN	1.81 PLN	13.91 PLN	6.30 PLN	7.25 PLN	9.72 PLN	4.42 PLN
Relative error	1.15%	1.19%	0.83%	0.92%	7.28%	3.28%	3.68%	5.09%	2.31%

	Brown's Exponential Smoothing Model (BESM)								
	5-year time series			7-year time series			9-year time series		
	2017	2016	2015	2017	2016	2015	2017	2016	2015
Absolute error	10.64 PLN	4.34 PLN	24.99 PLN	2.09 PLN	15.59 PLN	36.06 PLN	2.36 PLN	12.83 PLN	34.18 PLN
Relative error	5.40%	2.27%	13.03%	1.06%	8.16%	18.80%	1.20%	6.72%	17.82%

in the PW forecasting process. In the opinion of the authors, the results constitute a basis for further studies on the construction of a homogeneous prediction model for market changes in forestry and the wood industry. This is particularly important in view of the economic uncertainty caused by the pandemic. It should be emphasised that the trend analysis presented in this paper covers the period of the world crisis in the years 2007-2008, which may provide an analogy to the expected decrease in economic growth in the coming years caused by COVID-19. It may also be observed here that in Poland, adjustment (reduction) of timber prices caused by the crisis of 2007-2008 was observed as late as 2009.

Based on the study it was concluded that prediction using LAM was more efficient than the price prediction provided by BESM. In view of the above, further research needs to be conducted using trend analysis. The best fit for price prediction was found for the linear function $\hat{y}_t = 5.277t + 161.70$. This function was constructed based on the 5-year time series. It is generally accepted that the longest possible time series should be used to identify a trend [Kędzior 2005]. The results also show that the predictions from the shortest time series carried the smallest error in relation to actual PW. Nevertheless, it should be remembered that the 5-year time series did not cover the economic crisis of 2007-2008, a fact which influenced the efficiency of predictions based on that time series. It is of interest that the predictions based on the 7-year time series,

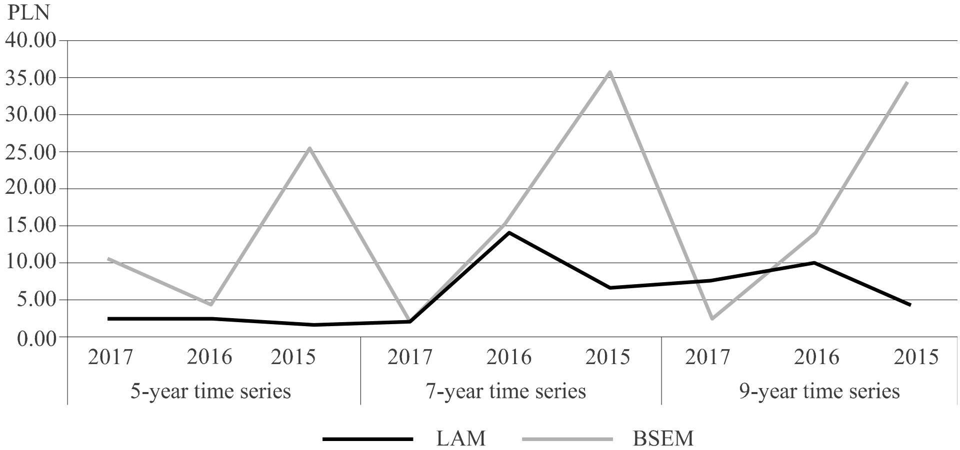

Fig. 1. Comparison of changes in BSEM and LAM absolute error

covering the years 2007-2014 (forecast for 2015) and 2008-2015 (forecast for 2016), were less accurate than those based on the 9-year time series. It should be noted that both linear functions $\hat{y}_t = 7.802t + 142.50$ and $\hat{y}_t = 7.491t + 138.14$ represent a trend covering the beginning and duration of the worldwide economic crisis. On this basis, it may be assumed that future forecasts for the situation on the timber market in relation to PW need to be based on time series covering the period preceding the current economic crisis. Additionally, it is suggested to investigate the potential application of other trend types in price predictions. For this reason, studies have already been initiated on the application of other trend types (logarithmic, exponential and percentage) to predict PW changes.

Conclusions

Based on the conducted evaluation of the potential and efficiency of application of the two methods used to investigate past PW changes in *ex ante* analysis, it was found that:

1. Predictions of changes in timber prices obtained using the method of approximation to the trendline was more efficient than price prediction using Brown's Exponential Smoothing Model. In the case of the former method the average predictive error for 5-year time series was below 1%, for the 7-year time series it was 3.83%, and for the 9-year time series it was 3.69%. Using the second method, the errors for the respective time series were 6.90%, 9.34% and 8.58%.
2. Predictions based on the 5-year time series proved to be the most efficient. This may have been caused by the fact that these predictions were constructed using data which did not cover the crisis of 2007-2008.

3. Future predictions covering the period of economic slowdown should be constructed based on the time series beginning before 2020. When comparing the predictions constructed based on the 7-year time series (beginning in the years 2007 and 2008) and those obtained using the 9-year time series (beginning before the crisis period), greater efficiency of prediction was found for the models constructed based on the 9-year time series.
4. The investigated methods of trend analysis may be applied in the forecasting of PW changes. In view of the global economic changes, which will lead to adjustment of prices for various goods and services, studies on the application of trends in price prediction need to be extended to include logarithmic, exponential and percentage trend analyses. At further stages of research, tests should also include models constructed based on the autoregressive integrated moving average (ARIMA) and seasonal autoregressive integrated moving average (SARIMA) models.

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