VIRTUAL ECONOMICS

2022 Volume 5 Number 2

ISSN 2657-4047 *(online)*

THE DYNAMICS OF TRADE RELATIONS BETWEEN UKRAINE AND ROMANIA: MODELING AND FORECASTING

Oleksandr Melnychenko, Valerii Matskul, and Tetiana Osadcha

Abstract. The article examines the monthly dynamics of exports, imports and balance of trade between Ukraine and Romania in the period from 2005 to 2021. Time series from 2015 to 2021 were used for modelling and forecasting (since the date the European Union–Ukraine Association Agreement took effect). Adequate models of the dynamics series of the Box-Jenkins methodology were built: additive models with seasonal component ARIMA (Autoregressive Integrated Moving Average)*ARIMAS (or SARIMA) and Holt-Winters exponential smoothing with a dampened trend. Forecasting of exports, imports and trade balance for the fourth quarter of 2021 and first quarter of 2022 were completed. The forecast results showed a small relative error compared to the actual data. Thus, when forecasting the trade balance between countries using the Holt-Winters model, the relative prediction errors were: for October 2021 – 1.3%; for November 2021 – 2.6%; for December 2021 – 0.4%.
Keywords: export, import, trade balance, ARIMA*ARIMAS, Holt-Winters models, forecasting
JEL Classification: B27; C22; C45

Authors:

Oleksandr Melnychenko
Gdansk University of Technology, Gdansk, Poland
E-mail: oleksandr.melnychenko@pg.edu.pl
https://orcid.org/0000-0002-7707-7888

Valerii Matskul
Odesa National Economic University, Odesa, Ukraine
E-mail: valerii.matskul@gmail.com
https://orcid.org/0000-0003-3897-5500

Tetiana Osadcha
Odesa Mechnikov National University, Odesa, Ukraine
E-mail: tatiana@osadcha.com
https://orcid.org/0000-0003-4258-0907

Citation: Melnychenko, O., Matskul, V., & Osadcha, T. (2022). The Dynamics of Trade Relations between Ukraine and Romania: Modelling and Forecasting. *Virtual Economics*, *5(2)*, 7-23. https://doi.org/10.34021/ve.2022.05.02(1)

Received: January 16, 2022. Revised: February 20, 2022. Accepted: March 9, 2022.
© Author(s) 2022. Licensed under the **Creative Commons License - Attribution 4.0 International (CC BY 4.0)**

www.virtual-economics.eu ISSN 2657-4047 (online)

1. Introduction

In recent years, trade relations between Ukraine and Romania began to develop intensively. After signing the EU–Ukraine Association Agreement, the trade turnover between Ukraine and Romania increased constantly and reached almost 2.3 billion US dollars in 2021 (see Figure 1).

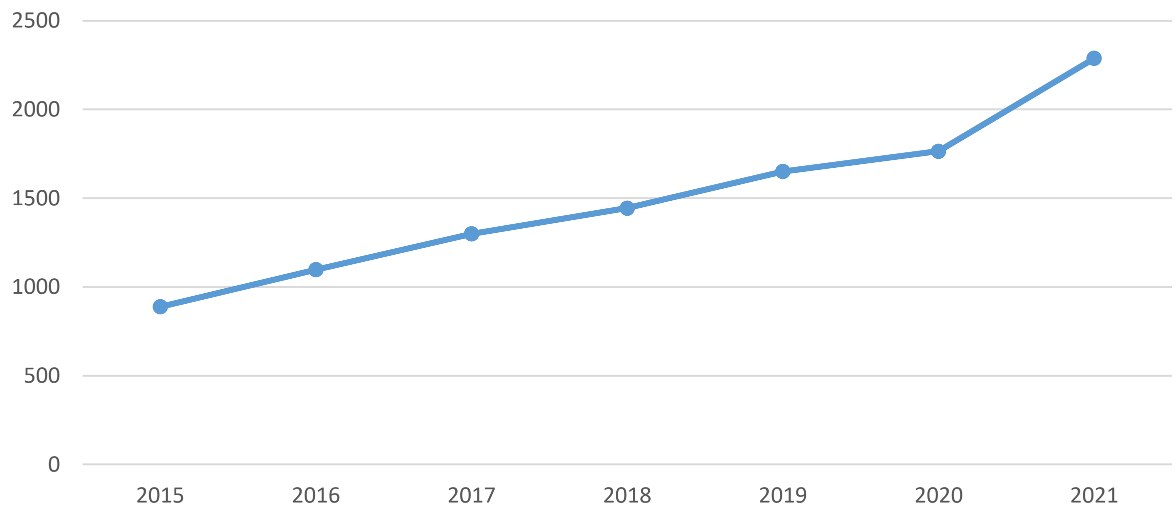


Figure 1. Dynamics of trade turnover (in million US dollars) between Ukraine and Romania for the period from 2015 to 2021
Source: SSSU, 2022

The main export items from Ukraine to Romania comprise: products of agriculture, food and metallurgical industries, fertilizers, wood and various finished products from it, while imports from Romania to Ukraine are dominated by the means of land transport (except for railways), aircraft, various products of the chemical (especially pharmaceutical) industry. The relevance of this study is justified by the fact that Romania has become one of the largest trading partners of Ukraine: according to the results of 2021, Romania ranked among the top ten of more than 100 trading partners of Ukraine.

2. Literature Review

Thanks to the classic work by Box (1976), time series models began to be intensively applied in various fields of science and technology. Their discrete version is widely used in the practice of economic research. For example, papers by Dzitsaki (2016) and Dzitsaki (2018) used Box-Jenkins-type models to simulate and forecast unemployment in Greece and the United States. In the studies (Ahmed, 2017; Dvorakova, 2017; Dritsaki, 2021; Eissa, 2020; Ghazo, 2021), the dynamics of the GDP in various countries was studied and predicted. The time series methodology (with diverse variations) was used to simulate and forecast inflation dynamics by the following scholas: Alderite (2020), Ahmed (2021), Dadyan (2020), Shinkarenko (2021). The ARIMA model was used by Kayikci (2020) to forecast ice evolution in the polar seas. These models were further developed (in combination with other types of time series models) in the works by Khashei (2012), Mohamed (2011), Streimikiene (2020), and Wang (2014). Numerous examples of the practical application of Box-Jenkins (and other) models for simulating and forecasting various economic processes can be found in the papers by Kozak (2017), Melnychenko (2020, 2021a, 2021b), Osadcha et al. (2021a, 2021b). It bears noting that when forecasting using an insufficiently large number of input data, Box-Jenkins models turn out to be more effective than Neural Networks that have been popular in recent years (Matskul, 2020). The latter work (considering the growing interest in international trade) complements the above sources and fills in the gaps in the study of the dynamics of trade relations between Ukraine and Romania. A number of recent scientific research were devoted to the development of the economic systems of the countries of Eastern Europe (Drożdż and Mróz-Malik, 2017; Drożdż et al. 2020a, 2020b; Dźwigoł 2021a, 2021b; Kharazishvili et al. 2021; Miśkiewicz 2019).

In addition, it is extremely necessary to mention scientific works with alternative methods of calculation of interdependence and optimal interaction, where models of economic development are presented, which, in one way or another, can contribute to the bifurcation effect in trade relations between countries. This factor should also be taken into account among others in forecasting the development of trade relations between countries. The above-mentioned publications are related to: artificial intelligence components and fuzzy regulators in entrepreneurship development (Bogachov et al. 2020); improving the development technology (Borodin et al. 2021); determinants and evolution methods in the context of digitalization and sustainability (Drożdż et al. 2021; Dzwigol 2020; Dźwigol et al. 2019, 2020; Hezam et al. 2023; Hussainet al. 2021; Ingber 2017; Kharazishvili et al. 2020, 2021b; Kianpour et al. 2021; Kotowicz et al. 2022; Kuzior et al. 2021a, 2021b; Kwilinski et al. 2019a, 2019b, 2019c; 2020a, 2020b, 2020c, 2020d, 2021, 2022a, 2022b, 2022c; Lyulyov et al. 2021a, 2021b; Miśkiewicz 2018, 2020, 2021; Miskiewicz et al. 2021, 2022; Moskalenko et al. 2022a, 2022b; Polcyn et al. 2022; Prokopenko and Miśkiewicz 2020; Saługa 2020, 2021; Szczepańska-Woszczyna Gatnar 2022; Tih et al. 2016; Tkachenko et al. 2019a, 2019b; Trzeciak et al. 2022; Vaníčková and Szczepańska-Woszczyna 2020; Yang et al. 2021).

Thus, the purpose of this article is to form a model for predicting the dynamics of trade relations between Ukraine and Romania on the basis of import-export data. The paper consists of 5 parts: introduction, literature review, materials and methods, results and discussion, and conclusions.

3. Material and Methods

The data for analysis are available on the website of the State Statistics Service of Ukraine (SSSU, 2022). The time for which the data will be available is the monthly export, import and trade balance (as the difference between export and import between the Ukraine and the Romania) starting from January 2005 and ending in December 2021, covering about 204 input data. The unit is a million of US dollars. Preliminary data processing was carried out in MS Excel spreadsheets. DELL STATISTICA software, version 12, was used when modelling and computing.

3.1 Box-Jenkins models

We use the following Box-Jenkins additive models of time series:

$$y_t = f(t) + S_t + e_t, \quad (1)$$

where $y_t$is a level of time series at time $t = 1, 2, \ldots$; $f(t)$ - trend is traced the long-term and evolution is deterministic in time; $S_t$stands for seasonal fluctuations; $e_t$denotes random fluctuations. This design allows exploring the dynamic series by eliminating its components.
ARIMA*ARIMAS model. It bears noting that a necessary condition for this model's application is the stationarity of the dynamic series, which is achieved by taking differences of a certain order (depending on the trend). In addition, the random component must be the so-called "white noise", i.e., satisfy the condition $e_t \epsilon N\ (0;\ \sigma)$. In our case, the trend is linear, so the stationarity of the series was achieved by taking the differences of the first order on lag 1. And the distribution of the residuals was visually compared with the normal distribution. After identification, the ARIMA*ARIMAS model for time series will look like:

$$y_t = p_{t-k} y_{t-k} + f(t) - q_{t-k} e_{t-k} + S_t, \quad (2)$$

where p_{t-k} is the auto-regression coefficients of the k-th order; q_{t-k} is a coefficient of the moving average model; e_{t-k} is an irregular component (random deviations or so-called white noise). The Smoothed Moving Average of first order $S_t = c + Q_{t-1} S_{t-1}$ was applied to find seasonal coefficients. Parameters of the model should be estimated at 95% confidence level (or 5% risk) with the condition of minimizing the MSE (Mean Square Error):

$$MSE = \sum_{i=1}^{n} \frac{(y_i - \tilde{y}_i)^2}{n}, \quad (3)$$

3.2 Holt-Winters model

The specificity of Holt-Winters model is that exponential smoothing (with its own parameter) is applied to each component of the Box-Jenkins model. So, for the main process, the alpha parameter is used, i.e., exponential smoothing is carried out according to the formula:

$$y_t = \alpha y_t + (1 - \alpha) y_{t+1}, \qquad t = 1{,}2 \quad (4)$$

The specific feature of this smoothing is that the last levels of the time series are more significant. So, for example, the value of the smoothing parameter alpha = 0.3 means that 30% of the last levels of a series of dynamics determine 70% of the forecast. The delta parameter is used to smoothen the seasonal component, and the trend is damped by the phi parameter. It bears noting that the successful application of exponential smoothing does not require the stationarity condition of the time series.

4. Results and Discussions

Figure 2, therefore, shows the dynamics of export, import and trade balance.

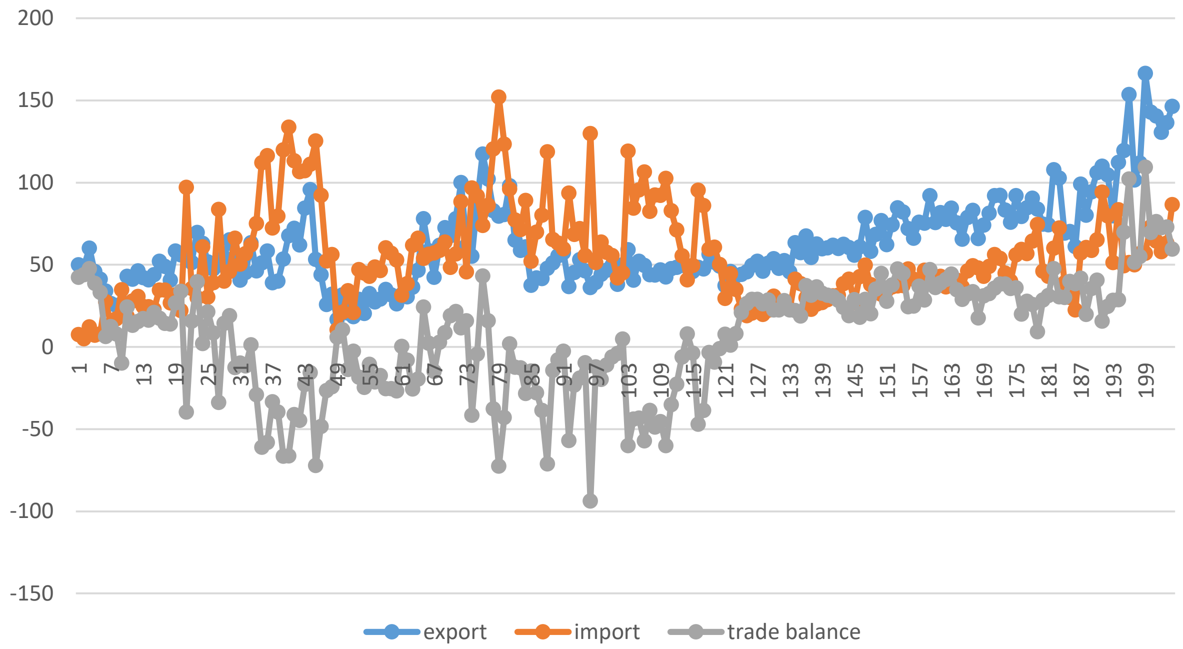


Figure 2. The dynamics of the export, import and trade balance between January 2005 to December 2021
Sources: developed by the authors.

The descriptive statictics of the data are given in Table 1.

Table 1. Descriptive characteristics of the data

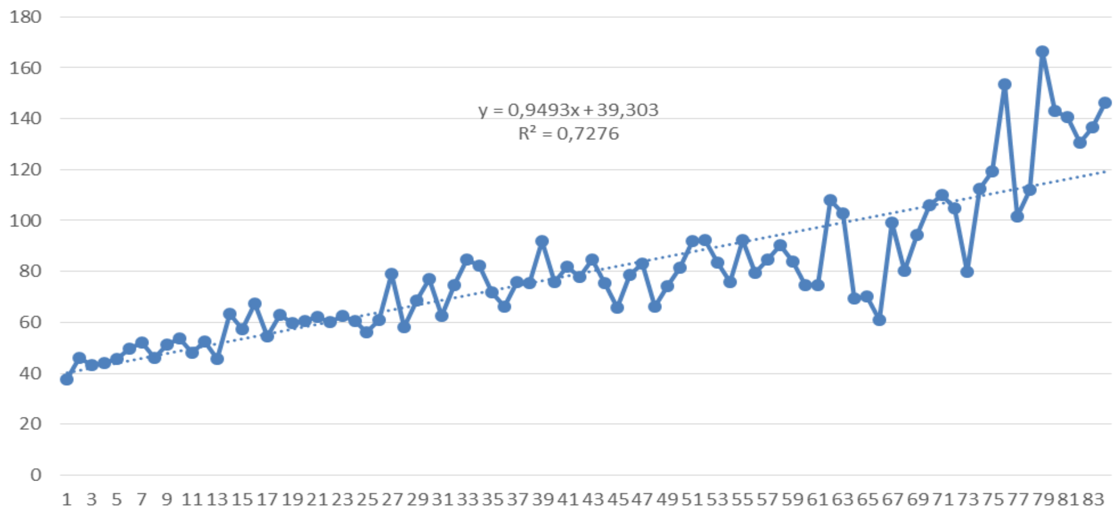
Variable	Average	Minimum	Maximum	Standard deviation
Export	58.49688	16.7	117.4	20.34272
Import	55.08229	5.1	152.1	29.0717
Trade Balance	3.414583	-93.7	47.8	31.44937

Source: estimated by the authors.

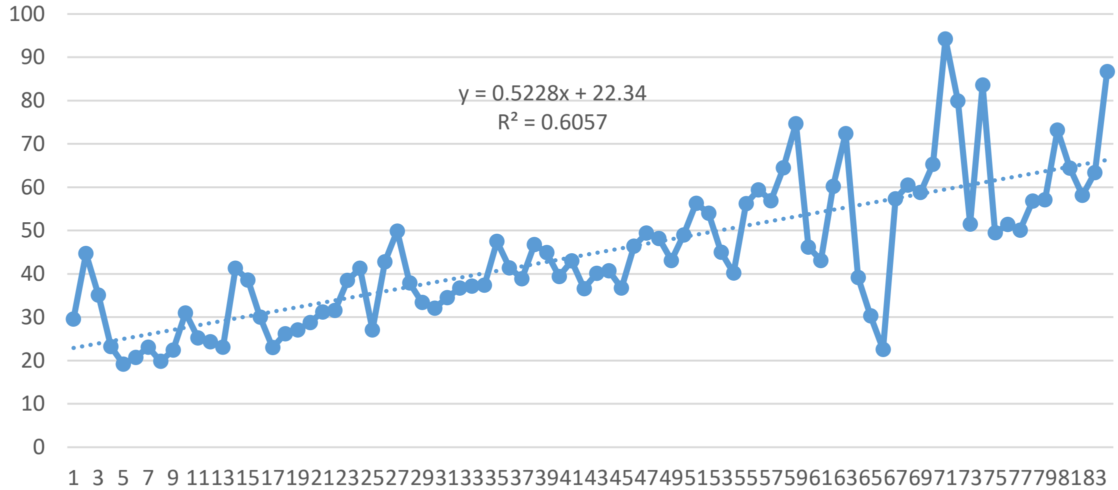
A visual analysis, as well as descriptive characteristics of time series, lead to a conclusion that for the period of 2005-2014, the dynamics of trade relations between the countries was noticeably unstable. Therefore, the period from 2015 to the present was selected for modelling and forecasting. A steady increase in the volume of export-import operations between two countries after signing the EU-Ukraine Free Trade Zone Agreement (even despite the COVID-19 pandemic), as well as a stable positive trade balance between Ukraine and Romania were of utmost importance.

Modelling and forecasting of export-import dynamics using one of the Box-Jenkins models (1) – the additive model ARIMA*ARIMAS – requires the model identification. First, the trends (the standard Least Squares Method is used to find the trend component) are built.

 ISSN 2657-4047 *(online)*



(a)

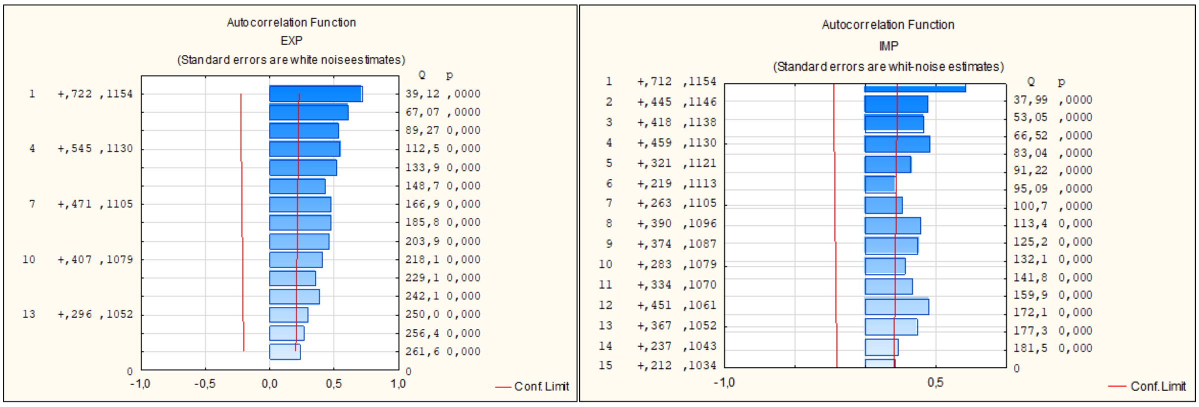


(b)

Figure 3. The dynamics of export (a) and import (b) from January 2015 (1) to December 2021
Sources: developed by the authors

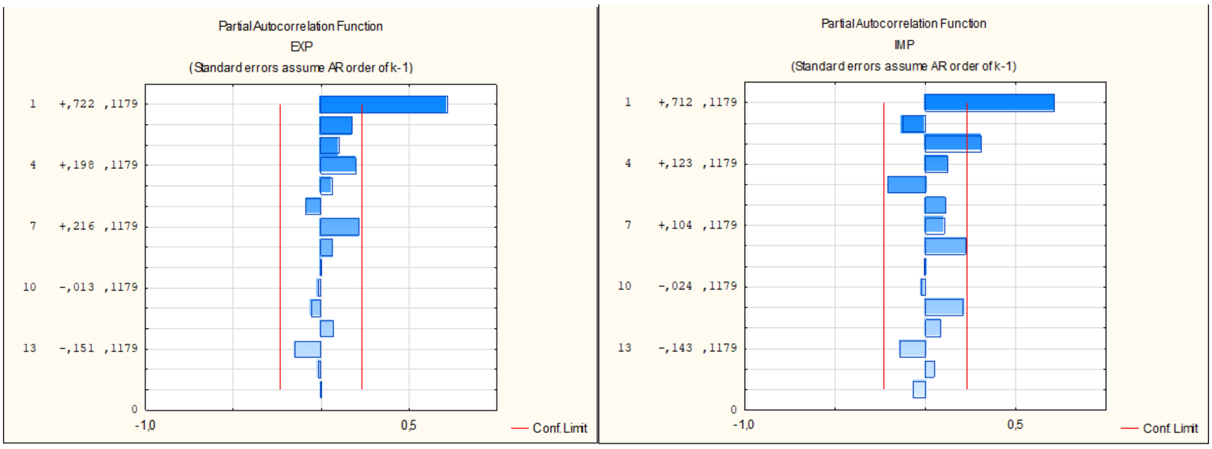
Analysis of correlograms in Figure 4 (graphs of autocorrelation coefficients) reveals the presence of the first-order autocorrelation at lag 1, as well as the presence of annual seasonality at lag 12.

Graphs in Figure 5 show that there are no higher-order autocorrelations. So, the model identification process is complete. To find estimates of the parameters of the ARIMA*ARIMAS model and forecasts, the "Time series and forecasting" module of the STATISTICS program is used. Elimination of the trend is carried out by transforming the time series by taking the first-order differences at lag 1. When smoothing both the main process and seasonal components, a simple two-point smoothing at lag 1 is used.



(a) (b)

Figure 4. Autocorrelation functions dynamics of export (a) and import (b)
Sources: developed by the authors



(a) (b)

Figure 5. Partial autocorrelation functions dynamics of export (a) and import (b)
Sources: developed by the authors

Finally, the ARIMA*ARIMAS models for the EXP (export) and IMP (import) variables have the following form:

$$y_t = p_{t-k}y_{t-k} + f(t) - q_{t-1}e_{t-1} + S_t, \quad (5)$$

where $y_t = \overline{1.81}$ is the levels of time series; $f(t) = 0.6965t + 46.077$ for variable EXP and $f(t) = 0.5388t + 21.963$ for variable IMP are a trend components; p_{t-1} is the auto-regression coefficients of the first order; q_{t-1} is a coefficient the moving average model; e_{t-1} is an irregular component (random deviations or so-called white noise). The Smoothed Moving Average of first order $S_t = c + Q_{t-1}S_{t-1}$ is applied to find seasonal coefficients.

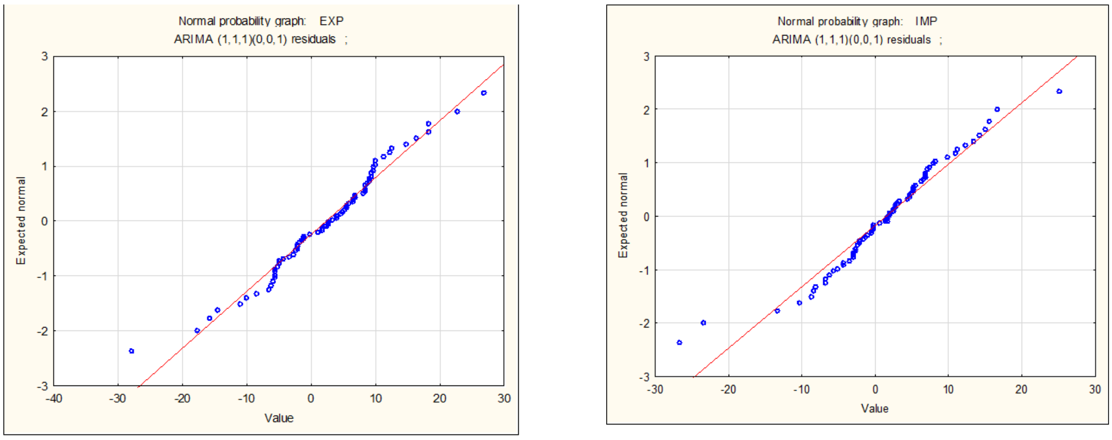
Parameters of the model should be estimated at 95% confidence level (or 5% risk) with the condition of minimizing the MSE (formula (3)). As a result, the following parameter estimates are obtained (Table 2).

Table 2. Parameter estimates of the model ARIMA*ARIMAS

Variable	EXP		IMP	
Parameter	Estimate	Standard deviation	Estimate	Standard deviation
p_{t-1}	0.214581	0.165761	0.567133	0.133668
q_{t-1}	0.780591	0.103687	0.912063	0.056426
Q_{t-1}	-0.381932	0.144834	-0.641404	0.125851

Source: estimated by the authors.

The adequacy of the ARIMA*ARIMAS models is confirmed by the closeness to the normal law of the distributions of residuals (differences between the actual and modelled levels of the time series), which are presented in Figure 6.



(a) (b)

Figure 6. Normality graphs of the models' residuals distribution: (a) export, (b) import
Sources: developed by the authors

The constructed models are applied to predict the volumes of exports and imports for the first quarter of 2021 (t = 82, 83, 84). Forecasting results, as well as relative forecasting errors, which are determined by the formulas (6) are shown in Table 3.

$$\delta_t = \frac{|y_t^{predict} - y_t^{actual}|}{|y_t^{actual}|}; t = 82, 83, 84, \quad (6)$$

Table 3. Forecasts for ARIMA*ARIMAS model and actual data

Export (EXP)			Import (IMP)		
Forecasts	Actual	Residuals	Forecasts	Actual	Residuals
80.49	79.9	0.007	53.64	51.5	0.039
116.62	112.4	0.036	90.31	83.6	0.074
123.28	119.5	0.031	53.27	49.5	0.070

Source: estimated by the authors.

 ISSN 2657-4047 (online)

From Table 3, it can be concluded that the relative prediction errors for the EXP variable do not exceed 3.6%, and for the IMP variable they account for 7.4%. Doing research, modelling and forecasting the trade balance (variable TB = EXP-IMP), similarly to the above, the ARIMA*ARIMAS model is applied first. Figure 7 shows the dynamics of the trade balance for 2015-2021:

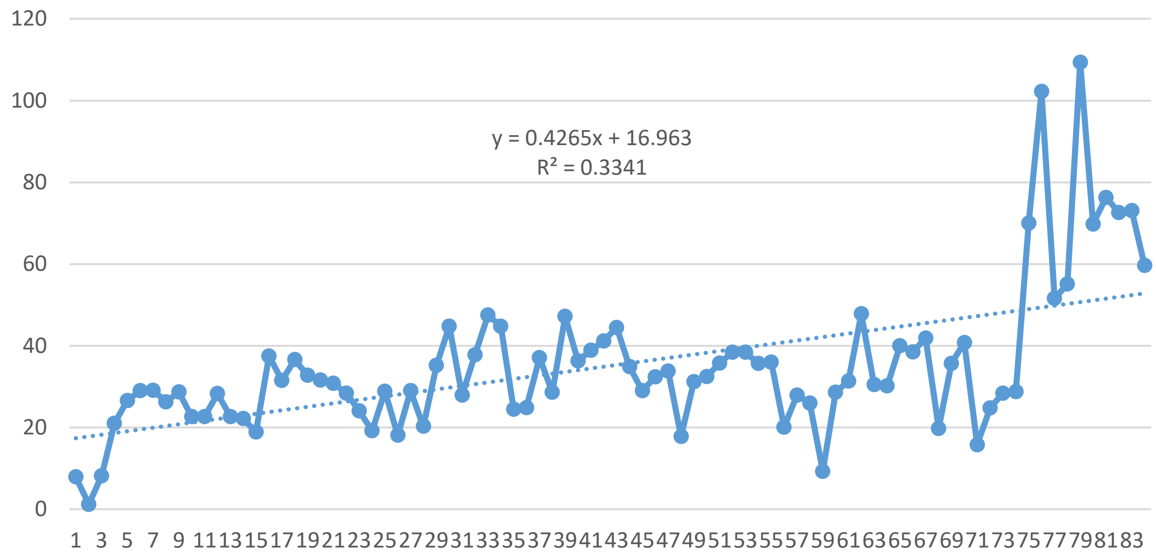


Figure 7. Graphs of the trade balance between Ukraine and Romania from January 2015 to December 2021 (with a trend)
Sources: developed by the authors

After identifying the model and applying the "Time series and forecasting" module of the STATISTICS program, the ARIMA*ARIMAS model is obtained (formula (5)) for the TB (trade balance) variable. The trend looks like $f(t) = 0.1177t + 24.113$; autocorrelation and smoothing parameters are shown in Table 4.

Table 4. Parameter estimates of the model ARIMA*ARIMAS

Variable	TB	
Parameter	**Estimate**	**Standard deviation**
p_{t-1}	0.179219	0.226005
q_{t-1}	0.754857	0.169613
Q_{t-1}	-0.305027	0.117950

Source: estimated by the authors.

To simulate again, the "Time Series and Prediction" module of the STATISTICS program is used again. Before building the Holt-Winters model, in order to find the optimal values of the smoothing parameters, the so-called "Search on the grid" is conducted. As a result, the following values were found: the smoothing parameter of the main process alpha = 0.3; smoothing seasonal component parameter delta = 0.1; trend damping parameter phi = 0.1. Table 5 shows the results of modelling and forecasting.

 ISSN 2657-4047 *(online)*

Table 5. Results of the modelling and forecasting (fragment) using the Holt-Winters model of exponential smoothing

Observation	TB	Smoothing TB	Residual	Season component
1	7.9	16.29	-8.39	-3.67
2	1.2	12.32	-11.12	-5.07
3	8.2	16.90	-8.70	3.22
4	21.0	16.85	4.14	0.61
5	26.6	15.17	11.43	4.58
6	29.0	21.04	7.96	7.26
7	29.1	22.57	6.53	5.01
8	26.3	16.64	9.66	-2.12
9	28.7	24.53	4.16	2.34
10	22.7	24.84	-2.13	0.73
11	22.7	12.84	9.85	-11.21
12	28.3	18.58	9.72	-9.32
81		70.58		
82		70.58		
83		71.45		
84		76.49		
85		84.66		
86		86.40		
87		97.77		

Source: estimated by the authors.

The adequacy of the obtained the Holt-Winters model of exponential smoothing by analysing the histogram of residuals and Normal curve is convincing (Figure 8).

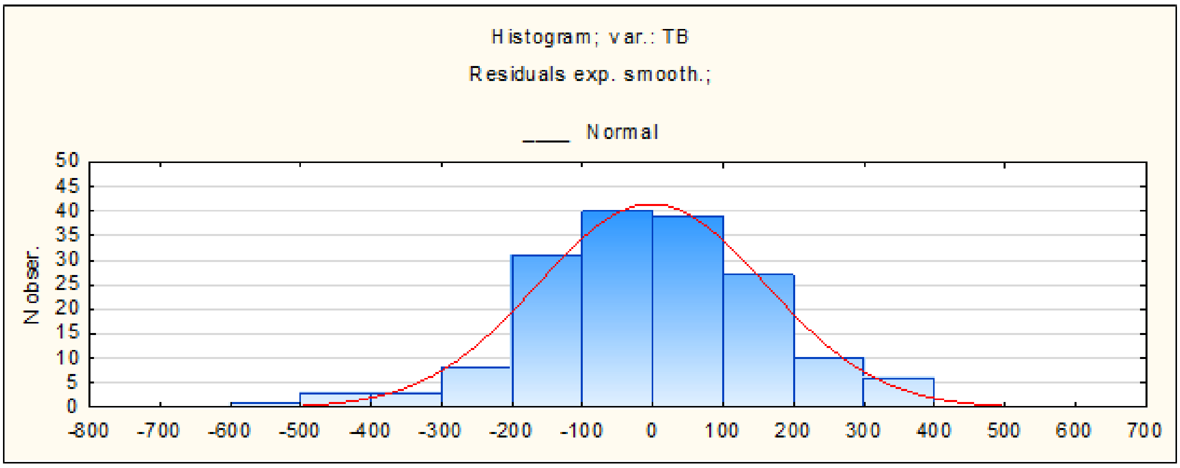


Figure 8. Graphs histogram of the residuals and Normal curve
Sources: developed by the authors

The following Figure 9, which shows the original and simulated time series, clearly demonstrates the quality of the constructed model.

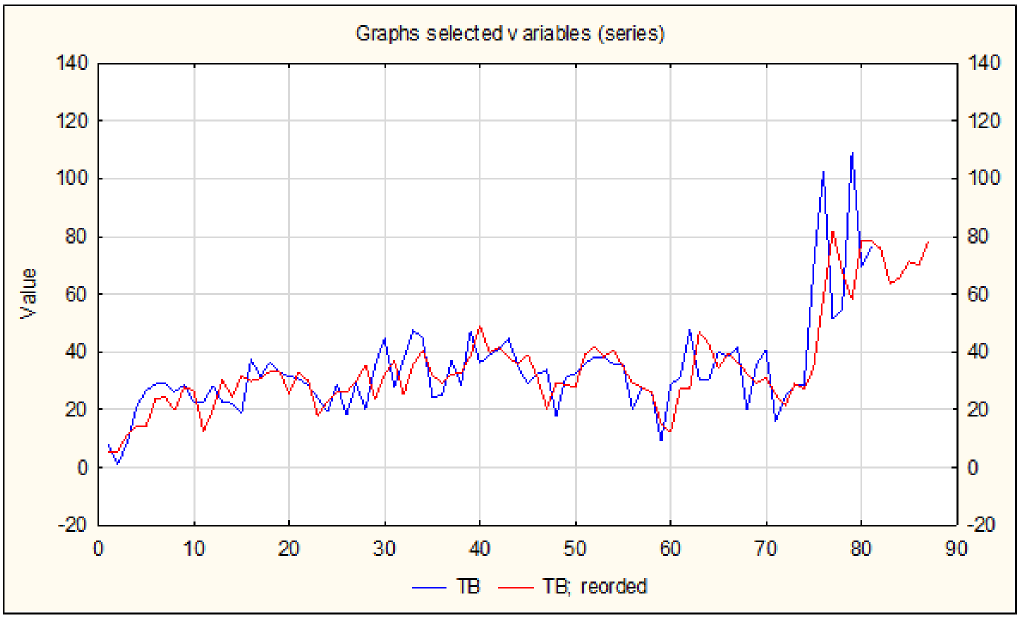


Figure 9. Visualization of source data and results obtained using the Holt-Winters model of exponential smoothing
Sources: developed by the authors

The constructed ARIMA*ARIMAS and Holt-Winters models are applied to predict the trade balance between Ukraine and Romania for the fourth quarter of 2021 (t = 82, 83, 84). The forecasting results, as well as the relative forecasting errors (which are determined by formulas (6)) are shown in Table 6.

Table 6. Forecasts for ARIMA*ARIMAS and Holt-Winters models and actual data

Forecasts (ARIMA* ARIMAS)	Actual	Residuals	Forecasts (Holt-Winters)	Actual	Residuals
29.35162	28.4	0.032421	28.79413	28.4	0.013688
31.93121	28.8	0.098061	28.05349	28.8	0.02661
69.91722	70	0.001184	70.28544	70	0.004061

Source: estimated by the authors.

Analysing the results presented in Table 6, it bears concluding that the relative forecast errors for the TB variable according to the ARIMA*ARIMAS model do not exceed 9.8%, and according to the Holt-Winters exponential smoothing model – 2.6%.

5. Conclusions

The conducted studies allowed for modelling and forecasting the dynamics of trade relations between Ukraine and Romania to build adequate models of Box-Jenkins time series: ARIMA*ARIMAS and Holt-Winters exponential smoothing. The results showed small relative forecast errors compared to actual data. In the paper, modelling and forecasting used the latest available data. So, according to preliminary data for January 2022, the models showed good forecasting results. After the Russian invasion of Ukraine, statistical data are not available. However, Romania remains Ukraine's largest trading partner.

The results of this study can be used in further research on models for predicting the dynamics of the trade relations development, in particular in the context of digitalization and sustainability.

References

Ahmed, R. R., Vveinhardt, J., Ahmad, N., & Štreimikienė, D. (2017). Karachi Inter-Bank Offered Rate (KIBOR) Forecasting: Box-Jenkins (ARIMA) Testing Approach. *E & M: Ekonomie a Management*, XX(2), 188–198. http://dx.doi.org/10.15240/tul/001/2017-2-014

Ahmed, R. R., Štreimikienė, D., Ghauri, S. P., & Aqil, M. (2021). Forecasting Inflation by Using the Sub-Groups of Both CPI and WPI: Evidence from Auto Regression (AR) and ARIMA Models. *Romanian Journal of Economic Forecasting*, XXIV(2), 144-161.

Alderite, A. A., & Capili, A. F. (2020). Comparison of ARIMA and Singular Spectrum analysis in forecasting the Philippine Inflation Rate. *Advances and Applications in Statistics*, 65 (1), 19-31. https://doi.org/10.17654/as065010019

Bogachov, S., Kwilinski, A., Miethlich, B., Bartosova, V., & Gurnak, A. (2020). Artificial Intelligence Components and Fuzzy Regulators in Entrepreneurship Development. *Entrepreneurship and Sustainability Issues*, 8(2), 487-499. https://doi.org/10.9770/jesi.2020.8.2(29)

Borodin, A., Tvaronavičienė, M., Vygodchikova, I., Kulikov, A., Skuratova, M., & Shchegolevatykh, N. (2021). Improving the Development Technology of an Oil and Gas Company Using the Minimax Optimality Criterion. *Energies*, 14(11), 3177. https://doi.org/10.3390/en14113177

Box, G. E. P., & Jenkins, G. M. (1976). Time Series Analysis: Forecasting and Control. San Francisco: Holden-Day.

Dadyan, E. G. (2020). Application of Neural Network Technologies for Inflation Forecasting. *International Journal of Mathematical Models and Methods in Applied Sciences*, 14, 34-37. https://doi.org/10.46300/9101.2020.14.9

Dritsaki, M., & Dritsaki, C. (2021). Comparison of the Holt-Winters Exponential Smoothing Method with ARIMA Models: Forecasting of GDP per Capita in Five Balkan Countries Members of European Union (EU) Post COVID. *Modern Economy*, 12(12), 1972-1998.

Drożdż, W., & Mróz-Malik, O. (2017). Morska energetyka wiatrowa jako istotny potencjał rozwoju polskiej gospodarki morskiej. *Problemy Transportu i Logistyki*, 37(1), 151-159

Drożdż, W., Szczerba, P., & Kruszyński, D. (2020a). Issues related to the development of electromobility from the point of view of Polish utilities. *Polityka Energetyczna – Energy Policy Journal*, 23(1), 49-64. https://doi.org/10.33223/epj/119074

Drozdz, W., Marszalek-Kawa, J., Miskiewicz, R., & Szczepanska-Waszczyna, K. (2020b). *Digital Economy in the Contemporary World*. Torun: Wydawnictwo Adam Marszalek.

Drożdż, W., Kinelski, G., Czarnecka, M., Wójcik-Jurkiewicz, M., Maroušková, A., & Zych, G. (2021). Determinants of Decarbonization – How to Realize Sustainable and Low Carbon Cities? *Energies*, 14, 2640. https://doi.org/10.3390/en14092640

Dzitsaki, C. (2016). Forecast of SARIMA models: An application to unemployment rates of Greece. *American Journal of Applied Mathematics and Statistics*, 4, 5, 136-148.

Dzitsakis, N., & Klareglon, P. (2018). Forecasting Unemployment Rates in USA Using Box-Jenkins Methodology. *International Journal of Economics and Financial Issues*, 8, 1, 9-20.

Dzwigol, H. (2020). Methodological and Empirical Platform of Triangulation in Strategic Management. *Academy of Strategic Management Journal*, 19*(4)*, 1-8.

Dźwigoł, H. (2021a). The Uncertainty Factor in the Market Economic System: The Microeconomic Aspect of Sustainable Development. *Virtual Economics*, 4(1), 98-117. https://doi.org/10.34021/ve.2021.04.01(5)

Dzwigol, H. (2021b). Meta-Analysis in Management and Quality Sciences. *Marketing and Management of Innovations*, 1, 324-335. http://doi.org/10.21272/mmi.2021.1-25

Dźwigol, H., Dźwigoł-Barosz, M., Zhyvko, Z., Miśkiewicz, R., & Pushak, H. (2019). Evaluation of the energy security as a component of national security of the country. *Journal of Security and Sustainability Issues*, 8(3), 307-317.

Dzwigol, H., Dzwigol-Barosz, M., Miskiewicz, R., & Kwilinski, A. (2020). Manager Competency Assessment Model in the Conditions of Industry 4.0. *Entrepreneurship and Sustainability Issues*, 7(*4*), 2630-2644. https://doi.org/10.9770/jesi.2020.7.4(5)

Dvorakova, L. (2017). CZ GDP Prediction via neural networks and Box-Jenkins Method. *SHS Web of Conferences*, 39, 01005.

Eissa, N. (2020). Forecasting the GDP per Capita for Egypt and Saudi Arabia Using ARIMA Models. *Research in World Economy*, 11(1), 247-258. https://doi.org/10.5430/rwe.v11n1p247

Ghazo, A. (2021). Applying the ARIMA Model to the Process of Forecasting GDP and CPI in the Jordanian Economy. *International Journal of Financial Research*, 12(3), 70-77. https://doi.org/10.5430/ijfr.v12n3p70

Hezam, I.M., Mishra, A.R., Rani, P., Saha, A., Smarandache, F., & Pamucar, D. (2023). An integrated decision support framework using single-valued neutrosophic-MASWIP-COPRAS for sustainability assessment of bioenergy production technologies. *Expert Systems with Applications*, 211, 118674. https://doi.org/10.1016/j.eswa.2022.118674

Holt, C. C. (2004). Forecasting seasonals and trends by exponentially weighted moving average. *International journal of forecasting*, 20(1), 5-10.

Hussain, H.I., Haseeb, M., Kamarudin, F., Dacko-Pikiewicz, Z., & Szczepańska-Woszczyna, K. (2021). The role of globalization, economic growth and natural resources on the ecological footprint in Thailand: Evidence from nonlinear causal estimations. *Processes*, *9(7)*, 1103. https://doi.org/10.3390/pr9071103

Ingber, L. (2017). Quantum path-integral qPATHINT algorithm. *Open Cybernetics and Systemics Journal*, 11, 119-133.

Kayikci, S. (2020). Autoregressive Integrated Moving Average Model for Polar Seas Ice Prediction. *International Journal of Mathematical Models and Methods in Applied Sciences*, 14, 110–113

Kharazishvili, Y., Kwilinski, A., Grishnova, O., & Dzwigol, H. (2020). Social safety of society for developing countries to meet sustainable development standards: Indicators, level, strategic benchmarks (with calculations based on the case study of Ukraine). *Sustainability*, 12(21), 8953. https://doi.org/10.3390/su12218953

Kharazishvili, Y., Kwilinski, A., Dzwigol, H., & Liashenko, V. (2021a). Strategic European Integration Scenarios of Ukrainian and Polish Research, Education and Innovation Spaces. *Virtual Economics*, 4(2), 7-40. https://doi.org/10.34021/ve.2021.04.02(1)

Kharazishvili, Y., Kwilinski, A., Sukhodolia, O., Dzwigol, H., Bobro, D., & Kotowicz, J. (2021b). The systemic approach for estimating and strategizing energy security: The case of Ukraine. *Energies*, 14(8), 2126. https://doi.org/10.3390/en14082126

Khashei, M., Bijari, M., & Ardali, G. A. R. (2012). Hybridisation of autoregressive moving average (ARIMA) with probabilistic neural networks (PNNs). *Computers & Industrial Engineering*, 63, 37-45.

Kianpour, M., Kowalski, S.J., & Øverby, H. (2021). Systematically Understanding Cybersecurity Economics: A Survey. *Sustainability*, 13(24), 13677. https://doi.org/10.3390/su132413677

Kotowicz, J., Węcel, D., Kwilinski, A., & Brzęczek, M. (2022). Efficiency of the power-to-gas-to-liquid-to-power system based on green methanol. *Applied Energy*, 314, 118933. https://doi.org/10.1016/j.apenergy.2022.118933

Kozak, Y., Matskul, V., & Shengelia, T. (2017). *Mathematical methods and models for master of economics. Practical applications*. Tbilisi, Universal.

Kuzior, A., Kwilinski, A., & Hroznyi, I. (2021a). The Factorial-Reflexive Approach to Diagnosing the Executors' and Contractors' Attitude to Achieving the Objectives by Energy Supplying Companies. *Energies*, *14*(9), 2572. https://doi.org/10.3390/en14092572

Kuzior, A., Lyulyov, O., Pimonenko, T., Kwilinski, A., & Krawczyk, D. (2021b). Post-Industrial Tourism as a Driver of Sustainable Development. *Sustainability*, 13(15), 8145. https://doi.org/10.3390/su13158145

Kwilinski, A., Ruzhytskyi, I., Patlachuk, V., Patlachuk, O., & Kaminska, B. (2019a). Environmental Taxes as a Condition of Business Responsibility in the Conditions of Sustainable Development. *Journal of Legal, Ethical and Regulatory Issues*, 22(Special Issue 2), 1-6.

Kwilinski, A., Tkachenko, V., & Kuzior, A. (2019b). Transparent Cognitive Technologies to Ensure Sustainable Society Development. *Journal of Security and Sustainability Issues*, 9(2), 561-570.

Kwilinski, A., Volynets, R., Berdnik, I., Holovko, M., & Berzin, P. (2019c). E Commerce: Concept and legal regulation in modern economic conditions. *Journal of Legal, Ethical and Regulatory Issues,* 22(2), 1-6.

Kwilinski, A., Dzwigol, H., & Dementyev, V. (2020a). Model of entrepreneurship financial activity of the transnational company based on intellectual technology. *International Journal of Entrepreneurship*, 24, 1-5.

Kwilinski, A., Dielini, M., Mazuryk, O., Filippov, V., & Kitseliuk, V. (2020b). System Constructs for the Investment Security of a Country. *Journal of Security and Sustainability Issues*, 10(1), 345-358.

Kwilinski, A., Zaloznova, Y., Trushkina, N., & Rynkevych, N. (2020c). Organizational and Methodological Support for Ukrainian Coal Enterprises Marketing Activity Improvement. *E3S Web of Conferences*, 168, 00031. https://doi.org/10.1051/e3sconf/202016800031

Kwilinski, A., Slatvitskaya, I., Dugar, T., Khodakivska, L., Derevyanko, B. (2020d). Main Effects of Mergers and Acquisitions in International Enterprise Activities. *International Journal of Entrepreneurship*, 24, 1–8.

Kwilinski, A., Litvin, V., Kamchatova, E., Polusmiak, J., & Mironova, D. (2021). Information Support of the Entrepreneurship Model Complex with the Application of Cloud Technologies. *International Journal of Entrepreneurship*, 25(1), 1-8.

Kwilinski, A., Lyulyov, O., Pimonenko, T., Dzwigol, H., Abazov, R., & Pudryk, D. (2022a). International Migration Drivers: Economic, Environmental, Social, and Political Effects. *Sustainability*, 14(11), 6413. https://doi.org/10.3390/su14116413

Kwilinski, A., Dalevska, N., & Dementyev, V.V. (2022b). Metatheoretical Issues of the Evolution of the International Political Economy. *Journal of Risk and Financial Management*, 15(3), 124. https://doi.org/10.3390/jrfm15030124

Kwilinski, A., Lyulyov, O., Dzwigol, H., Vakulenko, I., & Pimonenko, T. (2022c). Integrative Smart Grids' Assessment System. *Energies*, 15(2), 545. https://doi.org/10.3390/en15020545

Lyulyov, O., Pimonenko, T., Kwilinski, A., & Us, Y. (2021a). The Heterogeneous Effect of Democracy, Economic and Political Globalisation on Renewable Energy. *E3S Web of Conferences* 2021, 250, 03006. https://doi.org/10.1051/e3sconf/202125003006

Lyulyov, O., Vakulenko, I., Pimonenko, T., Kwilinski, A., Dzwigol, H., & Dzwigol-Barosz, M. (2021b). Comprehensive Assessment of Smart Grids: Is There a Universal Approach? *Energies*, 14(12), 3497. https://doi.org/10.3390/en14123497

Matskul, V., Okara, D., & Podvalna N. (2020). The Ukraine and EU trade balance: prediction via various models of time series. *SHS Web of Conferences*, 73, 01020.

Melnychenko, O. (2020). Is Artificial Intelligence Ready to Assess an Enterprise's Financial Security? *Journal of Risk and Financial Management*, 13, 191. https://doi.org/10.3390/jrfm13090191

Melnychenko, O. (2021a). Energy Losses Due to Imperfect Payment Infrastructure and Payment Instruments. *Energies*, 14, 8213. https://doi.org/10.3390/en14248213

Melnychenko, O. (2021b). The Energy of Finance in Refining of Medical Surge Capacity. *Energies*, 14, 210. https://doi.org/10.3390/en14010210

Miśkiewicz, R. (2018). The importance of knowledge transfer on the energy market. *Polityka Energetyczna*, *21(2)*, 49-62. https://doi.org/10.24425/122774

Miśkiewicz, R. (2019). Challenges Facing Management Practice in the Light of Industry 4.0: The Example of Poland. *Virtual Economics*, 2(2), 37-47. https://doi.org/10.34021/ve.2019.02.02(2)

Miskiewicz, R. (2020). Efficiency of electricity production technology from post-process gas heat: Ecological, economic and social benefits. *Energies*, 13(22), 6106. https://doi.org/10.3390/en13226106

Miśkiewicz, R. (2021). The Impact of Innovation and Information Technology on Greenhouse Gas Emissions: A Case of the Visegrád Countries. *Journal of Risk and Financial Management*, 14, 59. https://doi.org/10.3390/jrfm14020059

Miśkiewicz, R., Rzepka, A., Borowiecki, R., & Olesińki, Z. (2021). Energy Efficiency in the Industry 4.0 Era: Attributes of Teal Organisations. *Energies*, 14(20), 6776. https://doi.org/10.3390/en14206776

Miśkiewicz, R., Matan, K., & Karnowski, J. (2022). The Role of Crypto Trading in the Economy, Renewable Energy Consumption and Ecological Degradation. *Energies*, 15(10), 3805. https://doi.org/10.3390/en15103805

Mohamed, N., Ahmad, M. H., & Ismail, Z. (2011). Improving short term load forecasting using double seasonal ARIMA model. *Applied Sciences*, 15, 223-231.

Moskalenko, B., Lyulyov, O., Pimonenko, T., Kwilinski, A., & Dzwigol, H. (2022a). Investment Attractiveness of the Country: Social, Ecological, Economic Dimension. *International Journal of Environment and Pollution*, 69(1-2), 80-98. https://doi.org/10.1504/IJEP.2021.125192

Moskalenko, B., Lyulyov, O., & Pimonenko, T. (2022b). The Investment Attractiveness of Countries: Coupling Between Core Dimensions. *Forum Scientiae Oeconomia*, 10(2), 153-172. https://doi.org/10.23762/FSO_VOL10_NO2_8

Osadcha, T., Melnychenko, O. (2021a). Payment transactions' energy efficiency. *European Cooperation*, 2(50), 18-39. https://doi.org/10.32070/ec.v2i50.114

Osadcha, T., Melnychenko, O., & Spodin, S. (2021b). Money circulation in conditions of energy fever. *European Cooperation*, 3(51), 7-33. https://doi.org/10.32070/ec.v3i51.117

Polcyn, J., Us, Y., Lyulyov, O., Pimonenko, T., & Kwilinski, A. (2022). Factors Influencing the Renewable Energy Consumption in Selected European Countries. *Energies*, 15, 108. https://doi.org/10.3390/en15010108

Prokopenko, O., & Miśkiewicz, R. (2020). Perception of "green shipping" in the contemporary conditions. *Entrepreneurship and Sustainability Issues*, 8(2), 269-284. https://doi.org/10.9770/jesi.2020.8.2(16)

Saługa, P.W., Szczepańska-Woszczyna, K., Miśkiewicz, R., & Chład, M. (2020). Cost of equity of coal-fired power generation projects in Poland: Its importance for the management of decision-making process. *Energies*, 13(18), 4833. https://doi.org/10.3390/en13184833

Saługa, P.W., Zamasz, K., Dacko-Pikiewicz, Z., Szczepańska-Woszczyna, K., & Malec, M. (2021). Risk-adjusted discount rate and its components for onshore wind farms at the feasibility stage. *Energies*, 14(20), 6840. https://doi.org/10.3390/en14206840

Shinkarenko, V., Hostryk, A., Shynkarenko, L., & Dolinskyi L. (2021). A forecasting the consumer price index using time series model. *M3E2 2021, SHS Web of Conferences*, 107, 10002.

Streimikiene, D., Ahmed, R. R., Ghauri, S. P., Aqil, M., & Streimikis, J. (2020). Forecasting and the causal relationship of sectorial energy consumptions and GDP of Pakistan by using AR, ARIMA, and Toda-Yamamoto Wald models. *Romanian Journal of Economic Forecasting*, XXIII(2), 131-148.

Szczepańska-Woszczyna, K., & Gatnar, S. (2022). Key Competences of Research and Development Project Managers in High Technology Sector. *Forum Scientiae Oeconomia*, 10(3), 107-130. https://doi.org/10.23762/FSO_VOL10_NO3_6

SSSU. (2022). The State Statistics Service of Ukraine. Retrieved from http://www.ukrstat.gov.ua (accessed on 10 December 2021)

Tih, S., Wong, K.-K., Lynn, G.S., & Reilly, R.R. (2016). Prototyping, Customer Involvement, and Speed of Information Dissemination in New Product Success. *Journal of Business and Industrial Marketing*, 31(4), 437-448. https://doi.org/10.1108/JBIM-09-2014-0182

Tkachenko, V., Kwilinski, A., Klymchuk, M., & Tkachenko, I. (2019a). The Economic-Mathematical Development of Buildings Construction Model Optimization on the Basis of Digital Economy. *Management Systems in Production Engineering*, 27(2), 119-123. https://doi.org/10.1515/mspe-2019-0020

Tkachenko, V., Kwilinski, A., Klymchuk, M., & Tkachenko, I. (2019b). The Economic-Mathematical Development of Buildings Construction Model Optimization on the Basis of Digital Economy. *Management Systems in Production Engineering*, 27(2), 119-123. https://doi.org/10.1515/mspe-2019-0020

Trzeciak, M., Kopec, T.P., & Kwilinski, A. (2022). Constructs of Project Programme Management Supporting Open Innovation at the Strategic Level of the Organisation. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(1), 58. https://doi.org/10.3390/joitmc8010058

Vaníčková, R., & Szczepańska-Woszczyna, K. (2020). Innovation of business and marketing plan of growth strategy and competitive advantage in exhibition industry. *Polish Journal of Management Studies*, 21(2), 425-445. https://doi.org/10.17512/pjms.2020.21.2.30

Wang, Y., Wang, J., Zhao, G., & Dong, Y. (2014). Application of residual modification approach in seasonal ARIMA for electricity demand forecasting a case study of China. *Energy Policy*, 48, 284-294.

Winters, P. R. (1960). Forecasting sale by exponentially weighted moving averages. *Management Science*, 6(3), 324-342.

Yang, C., Kwilinski, A., Chygryn, O., Lyulyov, O., & Pimonenko, T. (2021). The green competitiveness of enterprises: Justifying the quality criteria of digital marketing communication channels. *Sustainability*, 13(24), 13679. https://doi.org/10.3390/su132413679