

“State debt assessment and forecasting: time series analysis”

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STATE DEBT ASSESSMENT AND FORECASTING: TIME SERIES ANALYSIS

Abstract

One of the pressing problems in the modern development of the world financial system is an excessive increase in state debt, which has many negative consequences for the financial system of any country. At the same time, special attention should be paid to developing an effective state debt management system based on its forecast values. The paper is aimed at determining the level of persistence and forecasting future values of state debt in the short term using time series analysis, i.e., an ARIMA model. The study covers the time series of Ukraine's state debt data for the period from December 2004 to November 2020. A visual analysis of the dynamics of state debt led to the conclusion about the unstable debt situation in Ukraine and a significant increase in debt over the past six years. Using the Hurst exponent, the paper provides the calculated value of the level of persistence in time series data. Based on the obtained indicator, a conclusion was made on the confirmation of expediency to use autoregressive models for predicting future dynamics of Ukraine's state debt. Using the EViews software, the procedure for forecasting Ukraine's state debt by utilizing the ARIMA model was illustrated, i.e., the series was tested for stationarity, the time series of monthly state debt data were converted to stationary, the model parameters were determined and, as a result, the most optimal specification of the ARIMA model was selected.

Keywords

debt, debt security, time series analysis, persistence, ARIMA model, Ukraine

JEL Classification

H60, H63

INTRODUCTION

Over the last years, the global financial system has undergone significant changes. Nowadays, it is impossible to find a state that would do without borrowing. The use of loans by the state is due to the lack of its own financial resources necessary to cover the state budget deficit, finance projects, maintain the stability of the national currency, etc. Used efficiently, the resources involved can become a positive factor in economic growth. However, an excessive and uncontrolled increase in debt can negatively affect the country's economic independence and become a burden on the national economy.

A quite significant amount of state debt, raising funds on unfavorable terms, their ineffective use, an unfavorable currency structure of public and state-guaranteed debt, and unsatisfactory values of debt security indicators point at an unstable debt situation in Ukraine. Determination of forecast values of state debt is an effective tool for making effective management decisions at the state level and developing effective measures to improve the economic and debt situation in Ukraine.

Modern econometric tools provide many opportunities and methods for forecasting economic indicators. Many of them are used to predict and analyze the dynamic behavior of both economic and individual sectors, as well as interrelated groups of indicators in many areas of economic and financial activity. However, quite often, when making

operational decisions at the macro- and microlevels, it is necessary to rely on the forecast values of indicators without delving into a detailed analysis of the factors that affect them.

A key question in the assessment and forecasting of state debt is the specificity of trends in its volume: the dynamics of state debt is random or has a memory. Persistence – the ability of a state to last longer than the process that created it – is the concept responsible for this characteristic of state debt. A significant level of persistence not only indicates autocorrelation in the dynamics of state debt, but also determines the choice of appropriate forecasting tools.

The size of Ukraine's state debt depends on many factors that directly or indirectly affect its formation and change. Considering all these factors when forecasting state debt indicators is a rather difficult process that may require significant expenditure of resources that do not correspond to the final result. Therefore, to verify autocorrelation, it is more expedient to use forecasting methods based on time series analysis (ARIMA modeling), but with a preliminary calculation of the persistence level.

1. LITERATURE REVIEW

The avalanche-like growth of global state debt causes increasing concern among economists around the world.

Tiftik et al. (2020), examining the long-term debt dynamics around the world, highlight that in 2019, global debt reached a record high of USD 255 trillion. As of early 2020, global debt exceeded 322% of GDP, 40% more than in 2007.

According to Galiński (2015), never before has state debt reached such high levels, in real terms and as a share of GDP, which most countries in the world faced after the 2008–2009 crisis.

Stawska (2015), in a study of state debt in the EU and Poland, emphasizes that high state debt, especially in developing countries, worsens conditions for investment and capital formation, which in turn contributes to slowdown in economic growth.

Given the existing zones of vulnerability to the impact of crisis factors caused by debt processes, the issues of assessing, optimizing the management and forecasting of state debt attract growing attention of scientists (Correia & Martins, 2019; Snieška, & Burksaitiene, 2018).

Reinhart and Rogoff (2010) conducted one of the most extensive studies of state debt analysis. They presented important results of analyses covering 44 developed and developing countries. In their opinion, the high level of state debt in relation to GDP (over

90%) is due to lower GDP growth rates. Nikoloski et al. (2017) (using the example of the Republic of Macedonia) and Martinez (2015) (using the example of the USA) consider the possibility of managing state debt by analyzing its dynamics and forecasting future values.

In recent years, the most painful problem of the Ukrainian financial system is the critical condition of state debt, which was formed haphazardly and under the influence of the needs for operational financing of current budget expenditures, which is evidenced in its structure and dynamics.

Bogdan (2013) and Salnikova (2017) evaluate and look for possible ways to improve the efficiency of state debt management. They argue that although Ukraine is not considered a world leader in the size of state debt, its growth has provoked growing debt pressure on the state budget.

D'yakonova et al. (2018) considered the interrelations between Ukraine's debt security management and the efficiency of economic security management of enterprises in the global environment.

Ukraine's state debt significantly affects public finance, the investment climate, money turnover, the development of international cooperation, and forecasting its future values plays a key role in managing state debt and ensuring debt security.

Scientists usually forecast the size of Ukraine's state debt based on the ratio of country's socio-economic and political indicators. For this purpose, one-way

and/or multivariate regression models are used, from which future values are extrapolated.

Jashchenko (2014) determines the predicted values of external and internal debt based on the revenues and expenditures of Ukraine's state budget, using a system of four equations, determining in turn the correlation between variables.

Kondrat (2011) forecasts the ratio of state debt to GDP using a conventional one-way regression model for 2011–2015. It should be noted that the probability of an error in the calculations of such a model is extremely high.

The choice of an adequate method (and/or model) plays an important role in forecasting state debt, which will allow predicting future values of the indicator with the least error. In modern statistical theory, these include methods of time series analysis that can be used to explain the behavior of a series and make forecasts for future periods.

Meanwhile, studies of the persistence of a time data series deserve special attention. Persistence indicates the non-random nature of the data set; at the same time, a significant level of persistence narrows the possibilities of using autoregressive models. Long memory analysis is widely used in the study of financial markets (Greene & Fielitz, 1977; Booth et al., 1982; Helms et al., 1984). Plastun et al. (2019) made a significant contribution to data persistence studies and to the improvement of the methodology for calculating the Hurst exponent using R/S analysis. It should be noted that the calculation of persistence for exclusively public debt has not been carried out, especially since information on persistence is extremely important for understanding the nature of the processes of any financial system.

Historically, one of the most successful methodologies for forecasting time series data was the construction of autoregressive models (models in which the dependent variable is determined by itself, but is shifted by a certain number of observations (lags) to the past). For the first time, the autoregressive model was proposed almost simultaneously by Slutsky (1927) and Yule (1927). The ARIMA (autoregressive integrated moving average) model is a time series forecasting method that was first developed and applied in the mid-70s of

the twentieth century by two American scientists Box and Jenkins (Box et al., 1994). In addition, Navapan and Boonyakunakorn (2017) examine forecasting state debt levels using time series analysis (Kliestik et al., 2020; Tung, 2020).

It's worth mentioning that ARIMA models are rarely used to forecast the size of Ukraine's state debt. Tsaruk (2007) developed a method for calculating the cyclical growth rate of direct state debt and, accordingly, made a forecast for the medium term using the optimal specification of the ARIMA model. The developed ARIMA model is practically the only one for the state debt predicting in Ukraine.

2. AIMS

The paper aims to analyze the dynamics of state debt, determine the level of its persistence and forecast future values of state debt in the short term using time series analysis.

3. DATA AND METHODS

The paper utilizes the time series of monthly data on the amount of Ukraine's state debt from December 2004 to November 2020.

The following basic research methods were used: generalization and systematization – to consider the scientific literature and substantiate the main theoretical positions; R/S analysis – to determine the Hurst exponent, and time series analysis (ARIMA model) – to analyze the dynamics and trends of state debt and forecast its values. The EViews software package is used to build an ARIMA time series model. ARIMA modeling is the procedure for determining the parameters p , d and q , where p is the order of the AR component, d is the order of the integrated series, and q is the order of the MA component.

The process of analyzing data and building an ARIMA model can be presented in several stages:

1. Analysis of the graph of the time series to identify trends and changes in the variability of the series; cycle, seasonality, zero values.

2. Determination of the Hurst exponent (formulating the conclusion about the presence of autocorrelation in a time data series). Analysis of the existing methodological approaches to calculating the Hurst exponent showed that the R/S analysis is the most acceptable. The Hurst exponent (H) is in the range $[0, 1]$. The exponent value ($H > 0.5$) indicates the presence of a long memory in a time data series, i.e., persistence.
3. Determination of the integration parameter d . In the case of non-stationary time series, the order of integration should be defined and justified, that is, the form in which it behaves as a stationary series (for example, the first or second differences, taking logarithms, seasonality adjustment, etc.).
4. Building a correlogram. Analysis of ACF/PACF graphs.
5. Model assessment. This stage uses regression techniques to obtain estimates of the parameters included in the model. Analysis of the improvement/deterioration of values of the Akaike and Schwarz information criteria (AIC and SIC).
6. Testing. Checking the basic prerequisites for regression analysis, checking the model for adequacy.
7. Using the model for forecasting.

4. EMPIRICAL RESULTS

The first stage is a visual analysis of the dynamics of Ukraine's state debt. For this, a simple line graph was chosen based on raw data with an additional histogram of the distribution along the axis. Figure 1 shows the results.

Figure 1 shows that Ukraine's total state debt continues to grow during the study period. Among the reasons for this growth, one can single out an irrational debt formation policy, high borrowing costs, an unstable situation with debt refinancing in previous years, currency debt risks, etc. Over the past decade, the total state debt has increased almost fivefold and amounted to UAH 2,398.20 billion (equivalent to USD 84.24 billion).

Based on the data obtained, it can be argued that since 2014 there has been a sharp aggravation of Ukraine's debt sustainability. The period from January 2014 to early 2015 can be called a phase of extensive growth with a peak in February 2015.

Meanwhile, it should be noted that the growth phase of 2004–2020 is not homogeneous, since at the very beginning and in 2020 these were completely different processes in terms of their quantitative assessment. That is, an analysis of only absolute values does not allow one to see qualitative differences in state debt. Thus, the first level differential of this data set was found to obtain more detailed characteristics of the data series under consideration. The results are presented in Figure 2 (monthly data analysis) and Figure 3 (annual data analysis).

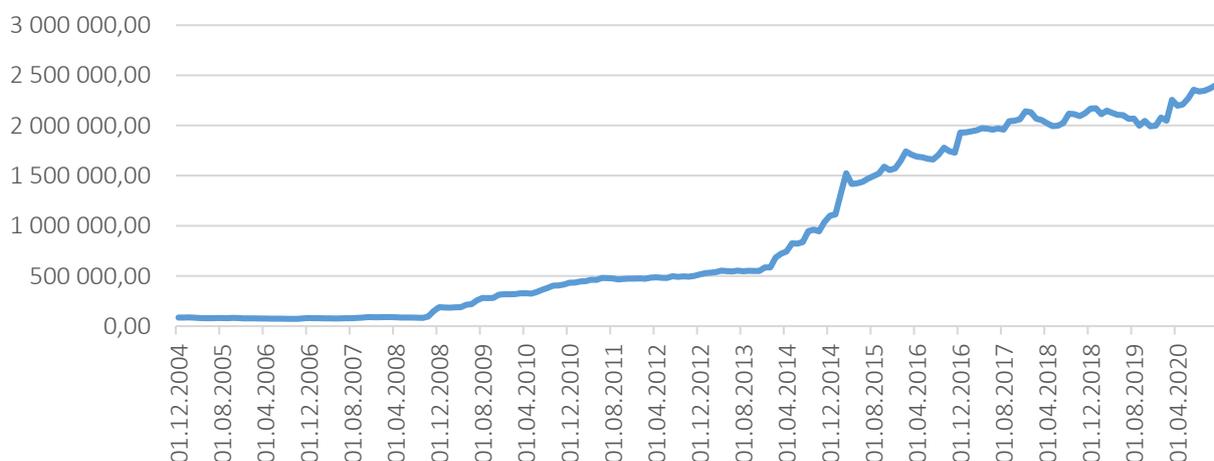


Figure 1. Time series graph of the State Debt of Ukraine 2004–2020, UAH mln

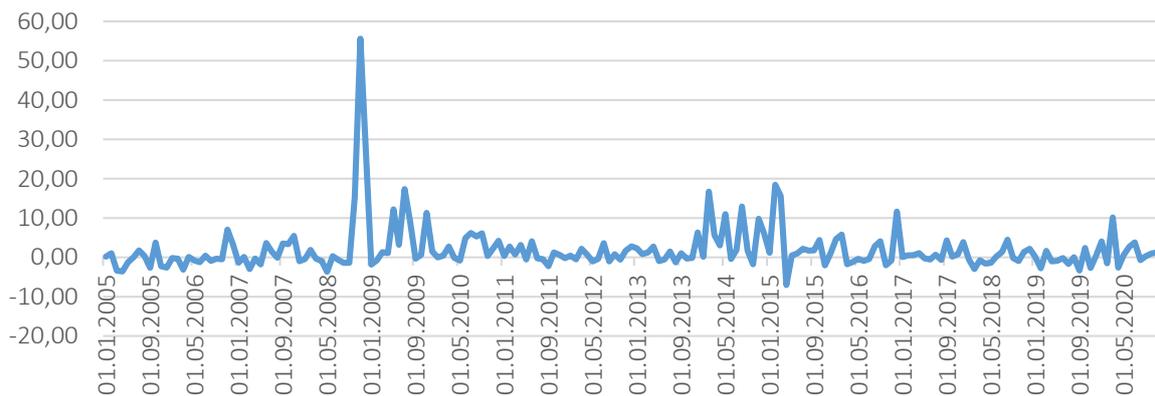


Figure 2. Monthly growth rates of Ukraine's state debt for 2004–2020, %

Figure 2 shows that in 2006–2009 the indicator increased with a peak in November 2008, and in 2010–2014 there was a slight decrease in state debt.

Under such conditions, the volume of domestic state debt in dollar terms amounted to USD 31.0 billion.

The observed series was transformed to bring it to a stationary process and adequately predict the data:

1. As primary data, the state debt denominated in foreign currency was taken. Since external debt traditionally prevails in the structure of the total state direct and guaranteed debt (61.04% of the total volume as of November 30, 2020), the growth of state debt in hryvnia is not always accompanied by additional borrowing. Sometimes, peaks have arisen due to higher exchange rates. It is important to note that as of January 1, 2015 the indicators were submitted by the Ministry of Finance of Ukraine, considering the national currency rate at the level of UAH 7.993 to the US dollar.

Figure 3 shows that in February 2015, total state debt showed a record growth due to a sharp devaluation. As a reminder, the lowest official hryvnia exchange rate was recorded on February 26, 2015 – UAH 3,001.01 per 100 US dollars. Meanwhile, on the cash market, the US dollar exchange rate reached, on average, UAH 31 per dollar (purchase) and UAH 37 per dollar (sale). The reason for the sharp hryvnia devaluation was the NBU's refusal to use the indicative exchange rate on the foreign exchange market and the termination of daily indicative foreign exchange auctions, which helped satisfy pent-up demand, to ensure a single exchange rate at the market level, according to official statements from the Central Bank. Under these conditions, the NBU was forced to return to administrative measures to regulate the mar-

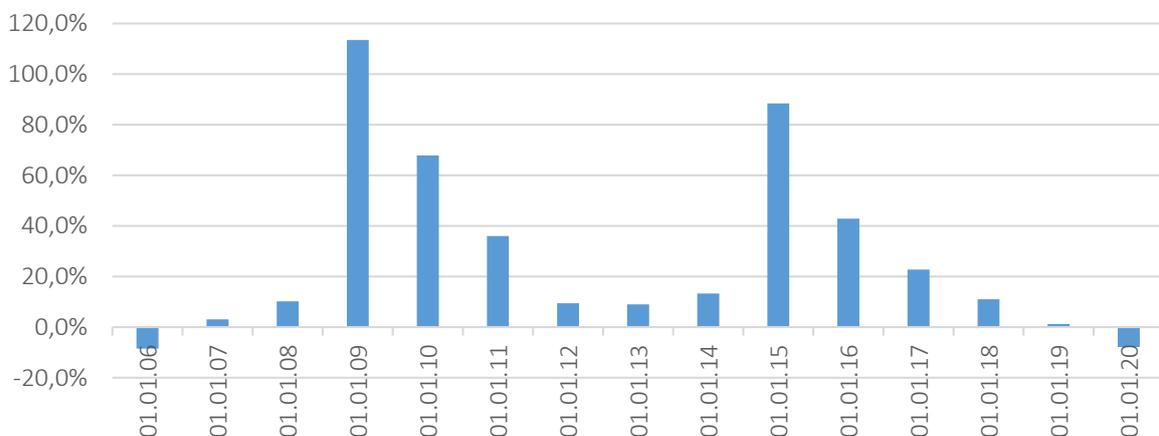


Figure 3. Annual growth rates of Ukraine's State Debt for 2004–2020, %

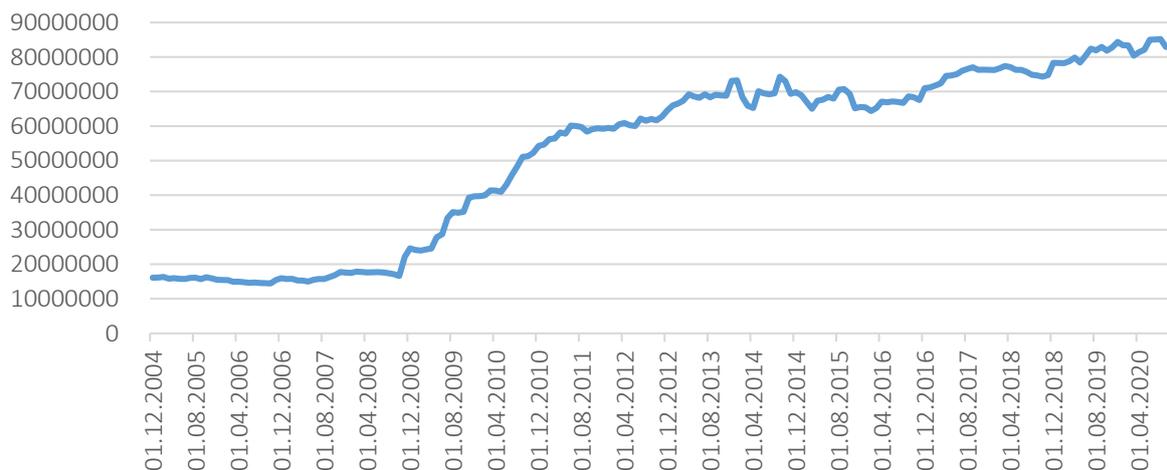


Figure 4. Time series graph of the State Debt of Ukraine 2004–2020, USD ths.

ket situation, which subsequently led to some strengthening of the hryvnia exchange rate.

2. Since this series has two anomalous values (in November 2008 and February 2015), which is not typical for the series as a whole, it was decided to replace them with the average value (between the previous and next) to prevent result distortions. The transformed time data series is shown in Figure 4.

Figure 4, where indicators in dollars are used to plot the dynamics of the total amount of state and state-guaranteed debt, shows that since the end of 2014 there has been some reduction in the total amount of state debt denominated in foreign currency.

For the presented data series, the Hurst exponent is 0.74, which points to a long memory in a time data series, that is, persistence. The significant level of persistence confirms autocorrelation in the dynamics of state debt and the possibility of using autoregressive models for forecasting.

Consider the ACF and PACF graphs of Ukraine’s state debt series (see Figure 5) to determine the general view of the specification of the future ARIMA model.

The correlogram of the state debt time series shows that the autocorrelation function decreases extremely slowly, and the partial autocorrelation function decreases sharply after the first lag,

which means that the series is not stationary. If the series is fixed, it is necessary to convert it to stationary by differentiation. Figure 6 shows a time series correlogram in first differences.

At the next stage, the time series is tested for stationarity. The Dickey-Fuller test is the most common time series test for stationarity. Table 1 shows the results of testing the series for stationarity in first differences.

Table 1. Results of testing time series for stationarity in first differences

Augmented Dickey-Fuller test statistic		t-Statistic	Prob.*
		-12.47074	0.0000
Test critical values:	1% level	-3.464827	
	5% level	-2.876595	
	10% level	-2.574774	

The results of the Dickey-Fuller test in first differences indicate the stationarity of the transformed series. The calculated value of the McKinnon τ -statistics (-12.47) is less (lies on the left) than the critical values at the significance levels of 1%, 5% and 10%. Therefore, the null hypothesis of the presence of a single root (nonstationarity) in the set of first differences is discarded with a minimum error probability of 0% (since the p -value is zero).

Thus, the model will be built for time series in the first differences with the order of integration 1.

To construct the forecast values of the transformed time series of Ukraine’s state debt, parameter es-

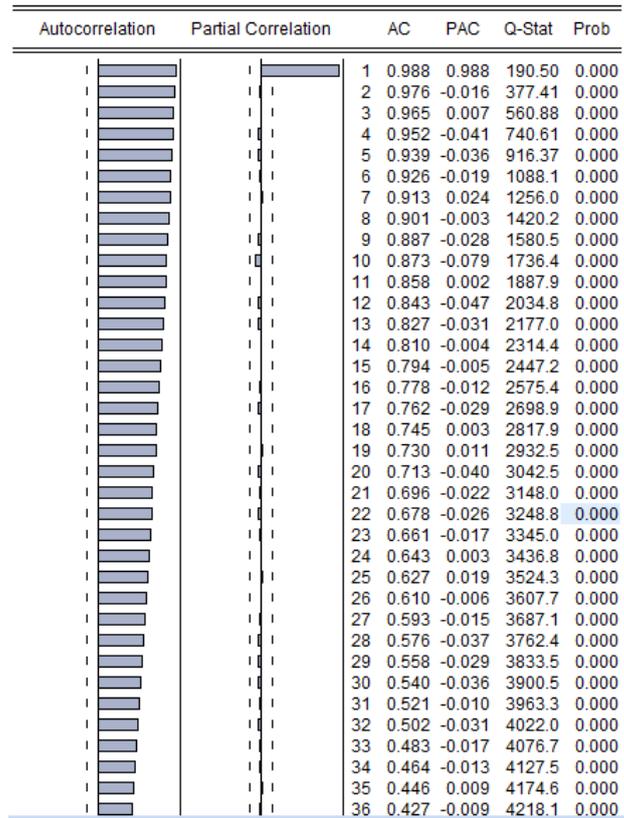


Figure 5. The State Debt of Ukraine 2004–2020 correlogram, USD ths.

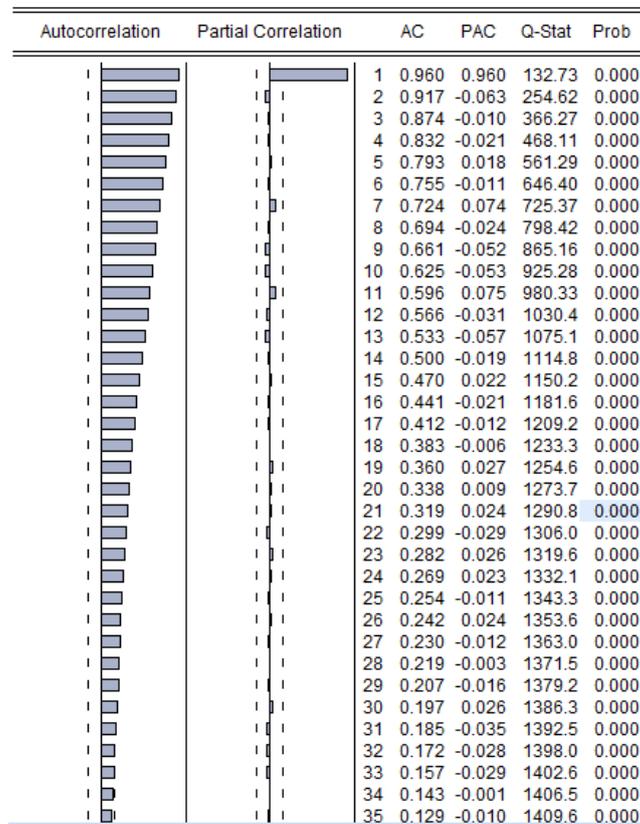


Figure 6. Correlogram of the State Debt of Ukraine 2004–2020 in first differences

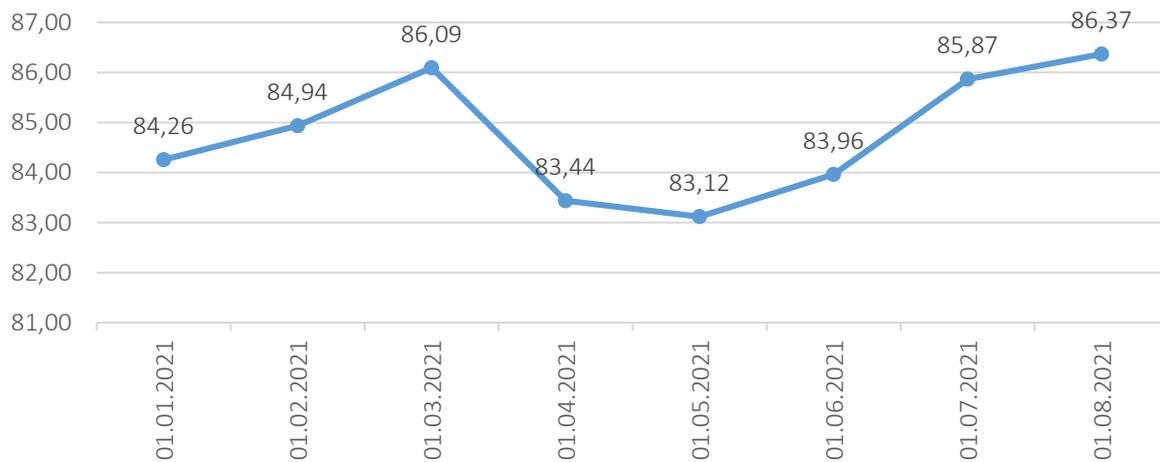


Figure 7. Forecasted amount of Ukraine's state debt, USD bln

timates were determined for 192 specifications of the ARIMA model with the number of parameters p , q and d from 1 to 12. Accordingly, the models with the lowest SIC and AIC values were selected for further analysis (Greene, 2012).

A consistent evaluation of the AR components showed that the minimum values of the AIC (4.48344) and SIC (4.56461) criteria were achieved for the ARIMA general specification (1;1;4).

Thus, this ARIMA model (1;1;4) most accurately describes the trend in the state debt dynamics and, accordingly, provides the greatest accuracy for further forecasting, and equation (1) reflects the model specification in the EViews format:

$$(d(debt)c d(debt(-1)) resid_tmp(debt(-4))).(1)$$

The model proposed in the work allows one to obtain the forecast values of Ukraine's state debt (Figure 7 shows the forecasting results in the next eight months). As can be seen from the figure, the projected growth of state debt has been increasing since January 2021 in the forecast horizon.

To assess the predictive quality of the model, the MAPE (mean absolute percentage error) criterion is used. For this example, MAPE = 11.8%, which indicates a fairly high predictive quality of the model. The ARIMA model for forecasting the values of the state debt indicator has confirmed its positive forecast properties. Therefore, it is recommended to use this technique in practice.

CONCLUSION AND FURTHER RESEARCH

The aim of the paper was to analyze the dynamics of state debt, determine the level of its persistence and forecast future values of state debt in the short term using time series analysis.

Integration processes across the globe have led to the fact that the problem of state debt, both external and internal, has grown into a global one. Given the existing zones of vulnerability to the impact of crisis factors caused by debt processes, the issues of optimizing the management and forecasting of state debt attract growing attention of scientists.

However, it is important to remember that loans mean that these resources must be returned at some point, and therefore a country needs to forecast its own capabilities. Particular attention should be paid to the substantial increase in Ukraine's external debt. Significant devaluation of the national currency in 2011–2018 led to an increase in the part of the debt denominated in foreign currency and the corresponding payments on it.

Summing up the results of ARIMA modeling of Ukraine's state debt in USD, it should be noted that the time data series is characterized by persistence, which indicates the feasibility of using autoregressive models in forecasting. During a certain period, the data on state debt represented a non-stationary time series, which can be reduced to a stationary one by performing a set of transformations (in particular, replacing anomalous values with the mean value of the series) and taking the first-order difference from the generated time series. To forecast the size of Ukraine's state debt, parameter estimates of various specifications of the ARIMA model were determined. The most optimal specification of the ARIMA model (1,1,4) was selected. In general, this model can be used in practice, but it requires revision and further calculations.

Thus, the constructed graph of the forecast values of Ukraine's state debt allows asserting that its increasing tendency will be traced in the future. A slight and short-term decrease in state debt should take place in April 2021. It should be noted that for this period a significant payment is planned to repay state debt.

Given the current situation and forecast values, in order to better understand the degree of debt burden, further research is needed to calculate a country's debt security indicators.

AUTHOR CONTRIBUTIONS

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Visualization: Hanna Filatova .

Writing – original draft: Hanna Filatova.

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