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APPLICATION OF SEM AND QARDL MODELS IN THE PRACTICE OF ANALYSIS OF THE INFLUENCE OF EXCHANGE RATE VOLATILITY ON MACROECONOMIC INDICATORS

ABSTRACT

This study is devoted to the analysis and forecasting of the impact of the volatility of the real effective exchange rate (REER) both directly and indirectly through various channels on macroeconomic indicators in Ukraine, in particular on economic growth and public debt. The work uses the simultaneous simulative equations model (SEM) and the quantile autoregressive distributed lag model (QARDL), which made it possible to use their capabilities and form a linear and non-linear approach to assessing the impact of volatility on selected indicators in the short- and long-term.

The main results demonstrate the ambiguous impact of REER volatility on economic parameters: exchange rate volatility slows down economic growth, but at the same time can reduce debt risk, mostly in the short term. The results of the quantile analysis show that individual economic indicators change the degree of their influence depending on the level of volatility and the state of the financial sector.

Also, an important factor through which volatility affects economic development or changes itself is the level, dynamics and structure of trade. The proposed approach and the results obtained on its basis can serve as a methodological basis for justification and decision-making regarding the implementation of a stabilizing macroeconomic policy by state institutions.

Keywords: macroeconomic analysis, econometric modelling, volatility, exchange rate, debt risk, structural model, quantile regression

JEL Classification: E52, C31, E47, E65

INTRODUCTION

The modern economy of Ukraine, as a country with an open economy, faces significant challenges associated with macroeconomic shocks and crisis situations. The instability of the hryvnia exchange rate, which is exacerbated by external and internal factors, is one of the most influential factors that determine the dynamics of economic growth, debt sustainability and currency risks of the state. In conditions of a significant and chronic budget deficit, which is financed mainly by external loans, significant volatility of the hryvnia can cause serious financial risks and further complicate the management of the public debt.

Therefore, it is important to investigate how currency fluctuations affect key macroeconomic indicators, in particular, economic development and debt security. There is a need for the development of modern methods of analysis that make it possible to take into account the asymmetric and non-linear nature of the impact of the exchange rate on various aspects of the economy, both in the short and long term and allow for accurate forecasting.

This study applies structural econometric and quantile distribution-lag models to estimate the multivariate relationships between the exchange rate and economic performance under conditions of economic instability. Using the quantile approach allows us to assess how different levels of exchange rate fluctuations (within individual quantiles) affect a selected group of indicators, highlighting short- and long-term consequences

for the economy, which is important for understanding how different factors can manifest themselves in different time horizons.

This methodical approach is innovative, as it provides consideration of structural changes in the impact of exchange rate volatility depending on specific economic conditions. The developed approach is relevant because it allows to adapt of models depending on the expected effect of exchange rate fluctuations on key indicators of the economy, in particular on economic growth and debt risk.

Thus, the purpose of this work is to develop analytically applied econometric tools that will allow us not only to understand the nature of the impact of currency volatility on macroeconomic processes better but also to increase the accuracy of forecasting the dynamics of economic development. The results of this study can serve as a basis for the development of an effective stabilization macroeconomic policy in Ukraine, aimed at reducing the impact of currency risks and increasing resistance to various types of shocks.

LITERATURE REVIEW

In modern scientific literature, special attention is focused on identifying and clarifying the nature of the relationships between macroeconomic indicators, which are formed under the influence of fluctuations in the exchange rate and its regimes (controlled exchange rate, floating or fixed) and thus affect the rates economic growth in countries with small open economies.

The study of the impact of the volatility of the indexes of the real effective exchange rate (REER) and the nominal effective exchange rate (NEER) of the hryvnia on macroeconomic indicators is a priority at this stage of the development of the economy in general and the monetary system in particular because the dynamics and nature of the volatility of the exchange rate are one of the prerequisites for ensuring macroeconomic and macro-financial stability.

The effects of exchange rate regimes on economic development can be manifested through direct and indirect channels. The analysis of numerous literary sources showed that one of the most adequate and effective tools for analyzing the mutual influence of exchange rate volatility on macroeconomic indicators is econometric modelling. At the same time, researchers often deal with the construction and exploration of nonlinear models.

In particular, Sarantis, N. (1999) reports the results of testing and analyzing non-linearities in real effective exchange rates of 10 major industrialized countries (G-10) based on STAR (Smooth Transition Autoregressive) models, which assume the existence of two different exchange rate regimes with potentially different dynamic properties, the transition between which is smooth. The results of the analysis reject linearity for eight exchange rates.

Miteza, I., Tanku, A. & Vika, I. (2023), using the example of Albania, are interested in whether in their country the exchange rate and its regimes act as shock absorbers for external shocks or, on the contrary, increase the negative effect on the economy and macroeconomic stability. The study includes the use of three different structural vector autoregression methods and an extended five-variable model and demonstrates that the real exchange rate has played a role in absorbing shocks, protecting the economy of this Balkan country primarily from real demand shocks. The analysis shows that monetary and supply-side shocks have a moderate contribution to real exchange rate volatility. This evidence in favour of an "absorbing" view of exchange rates supports Albania's policy choice of a flexible exchange rate system.

Gökmenoğlu, K.K., Eren, B.M., & Hesami, S. (2021) demonstrate the application of a quantile approach to estimate the asymmetric nature of exchange rate effects in selected EM countries on financial market returns for the period January 1994 to March 2019. Empirical results suggest that exchange rate flexibility plays a crucial role in determining market returns, but exchange rate fluctuations themselves have a minimal effect on these returns in most quantiles.

Ali, R., Mangla, I.U., Rehman, R.U., Xue, W., Naseem, M.A., & Ahmad, M.I. (2020) consider the impact of exchange rate volatility and gold prices on Pakistan stock market indexes using quantile regression and MGARCH models. The sample of quarterly data from 2001 to 2018 was divided into two parts due to the presence of the financial crisis. The results demonstrate that fluctuations in gold prices and exchange rates negatively affect the functioning of the country's financial market.

Nguyen, T.T., Nasir, M., Vo, X.V. (2022) investigate the interaction of foreign direct and foreign portfolio investment and REER volatility in 156 countries in the period from 2002 to 2017. From the results of the application of approaches based on MNC, fixed-effect model, random effects model and difference GMM, it can be concluded that the positive influence has a greater effect on the dynamics of the exchange rate both in developed and in countries with developing markets. The quality of the institutional component of state management (especially in EM countries) and GDP growth has a positive

effect on the exchange rate and a negative effect on its volatility. From a political point of view, it is worth noting that the degree of openness of the economy is of primary importance for the attraction of global capital flows.

Zhavoronok, A., Shchur, R., Zhezherun, Y., Sadchykova, I., Viadrova, N., Tychkovska, L. (2022) explore the role of the Ukrainian credit market in ensuring the stability of the banking system and macroeconomic stability. The application of econometric methods and models made it possible to assess the nature of the impact of credit services on the stability of the country's banking and financial system.

The analysis of macroeconomic indicators conducted by Pilko, A., and Chepyha, B. (2022) proved that the use of the classical vector autoregressive model (VAR) gives slightly better results than the use of the structural econometric model (SEM) in the context of the development of tools for the analysis and modelling of factors, which determine the regularities and trends in the formation of the national debt of Ukraine. At the same time, the results of the construction and analysis of the structural econometric model showed the adequacy of five of the six existing structural equations (with the exception of the inflation equation), which also indicates the perspective of using simulative models in the practice of analyzing and forecasting indicators of public debt in their relationship with monetary policy parameters and other macroeconomic indicators.

The approach to the analysis of the influence of managed monetary indicators on the amount of domestic public debt, proposed by Pilko A., Shchur R., Chepiha B., Sakun O., Matskiv V. (2024) proved that the use of the ARDL model gives slightly better results than the VECM in terms of adequacy of description and forecasting of the researched process. At the same time, both models proved their ability to describe the change in the amount of domestic public debt, and have high values of coefficients of determination and low values of the indicator of the average absolute percentage error.

The results achieved by Oppong-Baah, T., Yu., Twi-Brempong, C., Amoah, E.O., Prempeh, N.A., Addai, M. (2022) show that the degree of trade openness and the real exchange rate have a positive effect on economic growth according to random effect models in Nigeria and Ghana for 1998-2017. In contrast, inflation and investment have little effect on economic growth.

According to the research results of Chen, Z. (2022), the volatility of the real exchange rate in developing countries is negatively correlated with the level of openness of the economy but directly depends on the level of financial openness. The study also indicates that in countries with an imperfect financial system and insufficient amounts of foreign exchange reserves, a floating exchange rate regime is highly vulnerable to financial risks associated with international capital movements. This leads to the volatility of the national currency.

Hashmi, S. M., Chang, B. H., & Shahbaz, M. (2020) report the results of their research indicating that short-run exchange rate volatility has a symmetrical effect on cross-border trade between India and its major trading partners. However, in the long run, the effect is asymmetric. At the same time, non-linear distributed lag and multi-threshold non-linear distributed lag models are used, the latter of which divides the volatility value into quantiles and examines the impact of its extreme values on trade. For the study, samples were taken from January 1991 to December 2007 and from January 2010 to December 2019.

The article by Abdulqadir, I.A. (2020) is devoted to the analysis of the non-linearity of the impact of exchange rate pass-through on the currency invoice of exporters in 44 sub-Saharan African countries in the period from 2008 to 2017. The empirical results of the application of the asymmetric threshold regression model indicate a certain threshold value of real exchange rate depreciation under the influence of real income, openness and trade conditions, above which the effect on currency invoicing is significant. The results of the application of the quantile regression model prove the incomplete transfer of the exporter's currency invoice. In addition, dynamic panel two-step difference GMM estimators found statistically significant short-run and long-run effects of ERPT on the exporter's invoice currency.

Liu Nan & Sato Kiyotaka (2024) examined the impact of exchange rate pass-through on the behaviour of Japanese exporters across industries from January 2000 to December 2022. The application of a multi-threshold non-linear autoregressive distributive-lag model made it possible to include exchange rate forecasting errors in order to be able to clearly distinguish not only periods of conditionally "strong" or "weak" yen but also phases of its sudden increase and depreciation. The transmission of the exchange rate turned out to be asymmetric, and the change in price behaviour in some export sectors was strategic.

Bosupeng, M., Naranpanawa, A., Su, J. (2024) investigated whether the impact of an asymmetric exchange rate on the trade balance is asymmetric under conditions of exchange rate volatility. Based on a sample of developing and developed countries for the period from February 1960 to December 2020, using the GARCH (1,1)-M and SVAR models, results were obtained that indicate that for developed countries, exchange rate volatility reduces a positive shock for the trade balance

in both the long and short run. In the same time period, on the other hand, in developing countries, exchange rate fluctuations contribute to the positive impact of a devaluation shock.

Research by Ayana, O.U. (2024) examines the impact of REER volatility on Ethiopia's export earnings across different trading partners and major exports over a period of quarterly data from 2007 to 2021. The comparison of linear and non-linear autoregressive distributed-lag models made it possible to study the symmetric and asymmetric influence of currency volatility on the resulting indicator. The first model shows that the revaluation of the real effective exchange rate is statistically significant and reduces export earnings. The second indicates an asymmetric effect: positive volatility reduces total export earnings, while negative volatility is insignificant.

Trade indicators and industrial production have been significantly affected by the REER index and its fluctuations in the short and long term since the onset of the 2008 global financial crisis. The actual exchange rate regime is also included in the estimate. Thus, Đukić, D., Özer, M., Đukić, M. (2023) reconciled the findings by comparing linear and non-linear ARDL models and the Granger causality test in selected European countries (Hungary, Poland, Romania, Serbia; period 1st quarter 2000 - 4th quarter 2022).

AIMS AND OBJECTIVES

The purpose of the research is to study the possibilities of developing and applying structural econometric and quantile regression models in the practice of analyzing and forecasting the impact of exchange rate fluctuations on macroeconomic indicators and parameters of public debt. To achieve the goal, the following tasks were formulated and solved:

- existing approaches to setting and solving the problem of analyzing the spectrum of relationships between macroeconomic indicators using the capabilities of applied econometric tools were analyzed;
- a possible approach to conducting macroeconomic analysis using structural econometric models was proposed;
- an analysis of the influence of independent variables on various quantiles of the results in the short- and long-term was carried out using the quantile distributed lag model.

METHODS

Scientifically based results were obtained thanks to the application of methods of collecting and analyzing statistical information, the Granger test to identify the direction of causality between the studied macroeconomic indicators, and methods of building and evaluating the parameters of a structural econometric model. The methods of construction and analysis of the quantile distributed lag model were also used to determine the impact of the volatility of REER and other variables on the selected quantiles of the resulting indicators.

RESULTS

To investigate the nature of the influence of key factors on the GDP gap, REER volatility and debt risk, the first stage of the study considered the possibilities of analyzing the spectrum of relationships between macroeconomic indicators using simulation models. At the second stage of the research, the information obtained on the basis of the relevant equations of the simulative model is substituted into the quantile autoregressive distributed lag model (QARDL) without taking inertia into account. The quantile autoregressive distributed lag model (QARDL) is able to describe the effect of long-term and short-term relationships of regressors on different quantiles of the resulting indicator, while only the fifty per cent quantile (median) is estimated under the usual traditional approaches. To cover extreme values, the following quantiles were chosen: 10%, 30%, 50%, 70%, 90%. In order to study the nature of the impact of exchange rate volatility on indicators of economic development, an information base was formed based on data (Official website of the National Bank of Ukraine), (Economic Policy Uncertainty Index) and (Official site of the Independent Association of Banks of Ukraine (n.d.)).

Calculations were made using R statistical calculation software (RStudio). Based on the results of applying the methods of logical and correlation analysis, as well as the Granger causality test, Chepyha, B., Pilko, A. (2024) define the following endogenous and exogenous variables:

Endogenous variables:

- \hat{y}_t – GDP gap, calculated according to the Hodrick-Prescott filter;
- $reer_v_t$ – volatility of the real effective exchange rate (REER);

- dr_t – debt risk;
- π_t – inflation to the corresponding quarter of the previous year, %;
- s_fdi_t – the real value of the balance of direct foreign investments, UAH billion;
- fsd_t – financial sector development indicator, (monetary aggregate M3/GDP*4)*100%;
- $openess_t$ – openness of the economy, (volume of trade / GDP) *100%;

Exogenous variables:

- \hat{r}_t – real interest rate gap;
- cne_t – Commodity net export price index;
- π_t^{mtp} – inflation of MTP countries, %;
- r_ovdp_t – average annual rate of return on OVDP, %;
- i_t^{mtp} – the discount rate of MTP countries, %;
- $(E(\pi_{t+1}) - \pi_t^*)$ – the difference between inflation expectations of business and the inflation target, %;
- $debt_t$ – the difference between the ratio of public debt to GDP and the optimal level for a country with an emerging economy (60%), %;
- s_interv_t – the real value of the balance of currency interventions of the NBU, UAH billion;
- fsi_t – financial stress index;
- b_aid_t – the real amount of income to the budget from abroad, UAH billion;
- cr_gdp_t – the ratio of granted loans in the economy to GDP, %;
- Δuan_t – deviation of the hryvnia`s cash rate from the official one, UAH;
- $dolar_t$ – dollarization of the economy, (deposits in foreign currency / total deposits)*100%;
- gru_t – geopolitical risk index for Ukraine;
- npl_t – share of non-performing loans, %;
- $reserves_t$ – the ratio of gold and foreign exchange reserves to gross external debt minus 20 (again the critical level of debt security indicators), %.

The volatility of REER was calculated using the following formula:

$$REER_Volatility = \log\left(\frac{REER_t}{REER_{t-1}}\right) * 100$$

Based on the results of the conducted research, an approach was developed that involves estimating volatility and its substitution directly in the model of generalized autoregressive conditional heteroskedasticity (GARCH (2,1)), which is described in detail in Chepyha, B., Pilko, A. (2024).

Debt risk is calculated as the sum of yields from Ukrainian euro and dollar bonds multiplied by weighting factors, which were determined based on the amount of funds involved in the budget.

The basis of the analysis is a sample of data from the first quarter of 2016 to the third quarter of 2023, based on which a simultaneous structural equation model (SEM) was developed. The model was evaluated using 2OLS after checking the order and rank conditions. The model developed and described in detail by Chepyha, B., Pilko, A. (2024) has the following form:

$$\hat{y}_t = 5.81 + 0.59 * y_{t-1} - 0.76 * reer_{v_{t-1}} + 0.23 * \pi_{t-1} - 0.47 * fsd_t + 0.11 * cne_t + 3.5 * fsi_t - 2.68 * gru_t, R^2 = 0.69; (1)$$

$$reer_{v_t} = 0.13 + 0.2 * reer_{v_{t-1}} - 0.006 * y_{t-1} - 0.002 * \pi_{t-1} - 0.001 * fsd_{t-1} - 0.002 * \hat{r}_t - 0.0008 * (E(\pi_{t-1}) - \pi_{t-1}^*) - 0.001 * debt_t + 0.25 * fsi_t, R^2 = 0.71; (2)$$

$$dr_t = -1.68 + 0.33 * dr_{t-1} - 5.12 * reer_{v_t} + 0.14 * fsd_{t-1} - 0.09 * openess_{t-1} - 0.04 * \hat{r}_t + 0.44 * r_ovdp_t - 0.05 * b_aid_t - 0.08 * reserves_{t-1}, R^2 = 0.73; (3)$$

$$\pi_t = 6.83 + 0.67 * \pi_{t-1} - 0.15 * y_{t-1} + 0.65 * \pi_t^{mtp} - 1.34 * i_{t-1}^{mtp} - 0.53 * (E(\pi_{t+1}) - \pi_t^*), R^2 = 0.83; (4)$$

$$s_fdi_t = 41.12 - 0.03 * s_fdi_{t-1} - 51.23 * reer_v_{t-1} + 1.85 * \pi_{t-1} + 0.15 * fsd_{t-1} + 0.73 * s_interv_{t-1} - 0.49 * b_aid_t - 13.22 * gru_t - 0.8 * npl_t, R^2 = 0.587; \quad (5)$$

$$fsd_t = 77.86 + 0.33 * fsd_{t-1} - 0.06 * s_fdi_{t-1} - 0.28 * openness_{t-1} + 0.3 * cr_{gap}_t + 0.06 * \Delta uan_t - 1.65 * dolar_t + 0.08 * npl_t, R^2 = 0.751, \quad (6)$$

$$openess_t = 13.4 + 0.56 * openess_{t-1} + 50.71 * reer_v_t - 0.78 * fsd_t + 1.04 * dolar_{t-1} + 1.05 * gru_t. R^2 = 0.704, \quad (7)$$

Each equation of the model was tested using the Ljung Box test for the absence of serial autocorrelation of the residuals. At the 5% level of significance, the equation of the balance of foreign direct investment and the development of the financial sector is not devoid of serial autocorrelation of the residuals. However, at the 1% level, autocorrelation is absent.

Based on the results of the construction and research of such models as ETS, NNAR, TBATS and STL, the forecast values of the relevant exogenous variables were calculated, the average value of which was subsequently substituted into the simulative model to obtain a forecast of endogenous indicators (Table 1).

Table 1. Forecast calculation results.

Date	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Last 4 quarters, real data							
2022 Q4	-11.33	0.237	3.81	26.6	5.02	36.93	60.73
2023 Q1	-6.73	0.045	4.11	21.3	19.28	49.74	73.64
2023 Q2	-1.84	0.046	4.41	12.8	21.52	43.54	55.69
2023 Q3	2.55	0.047	4.13	7.1	9.63	37.62	46.31
Forecast for the next 4 quarters							
2023 Q4	-6.79	0.009	3.16	9.56	41.20	29.47	23.69
2024 Q1	-8.12	0.054	3.17	8.74	27.77	37.4	35.68
2024 Q2	-7.46	0.068	1.83	8.75	35.26	32.02	36.78
2024 Q3	-11.3	0.049	1.63	8.72	48.85	34.12	42.18

The forecast of macroeconomic indicators indicates that the volatility of REER may increase along with the increase in the GDP gap. Debt risk will decrease, while inflation will be within 8-10%. As for the balance of direct foreign investment, it is predicted to increase sharply. The latter two indicators will be somewhat lower than historical averages (Chepyha, B., Pilko, A. (2024).

In the next stage, the non-linear and asymmetric influence of independent variables on the GDP gap, REER volatility and debt risk was investigated. For this, the relevant equations of the simulative model were selected and substituted into the quantile autoregressive distributed lag model (QARDL) without taking inertia into account. It demonstrates the effect of long-term and short-term relationships of regressors on different quantiles of the resulting indicator when only the fifty per cent quantile (median) is evaluated under conventional approaches. To cover extreme values, we will choose the following quantiles: 10%, 30%, 50%, 70%, 90%.

Before building the models, we normalize the data according to the simple Min_Max method (Mazziotta, M., Pareto, A. (2022) so that their range varies from 0 to 1 (the minimum and maximum present value, respectively). This operation facilitates the perception of relationships between variables and can improve the quality of models built on such data.

The distribution density of the selected dependent variables is shown in Figures 1-3.

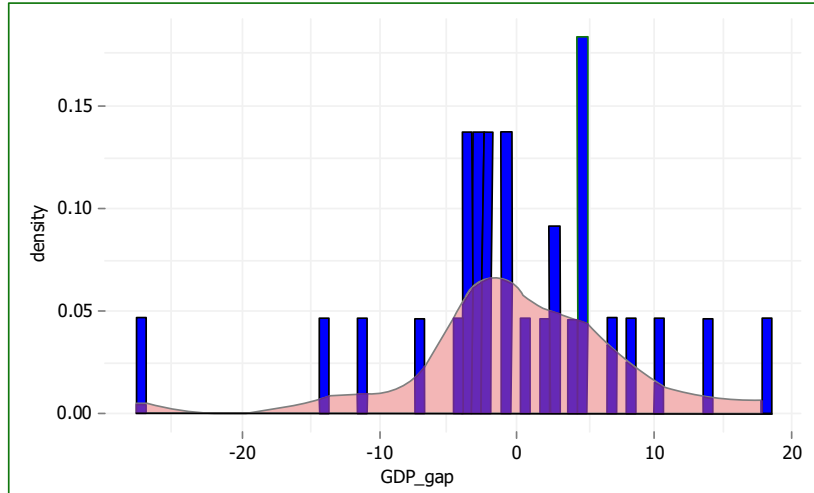


Figure 1. Density of the distribution of the GDP gap.

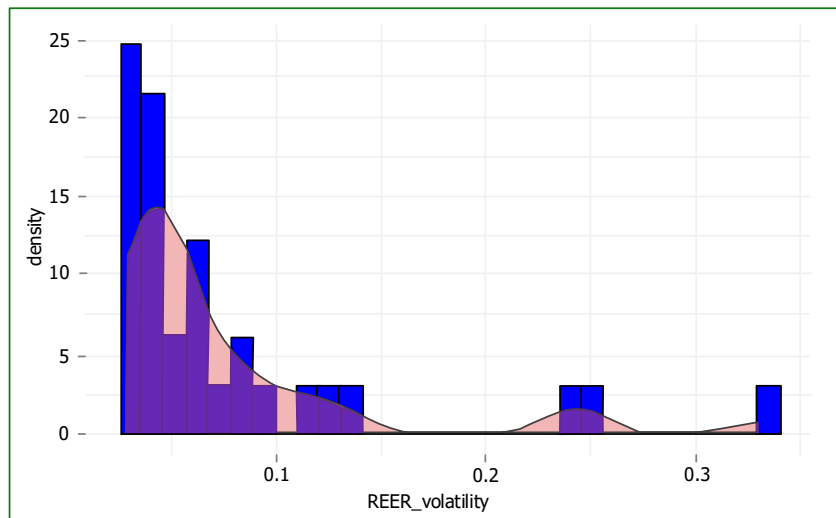


Figure 2. Density distribution of REER volatility.

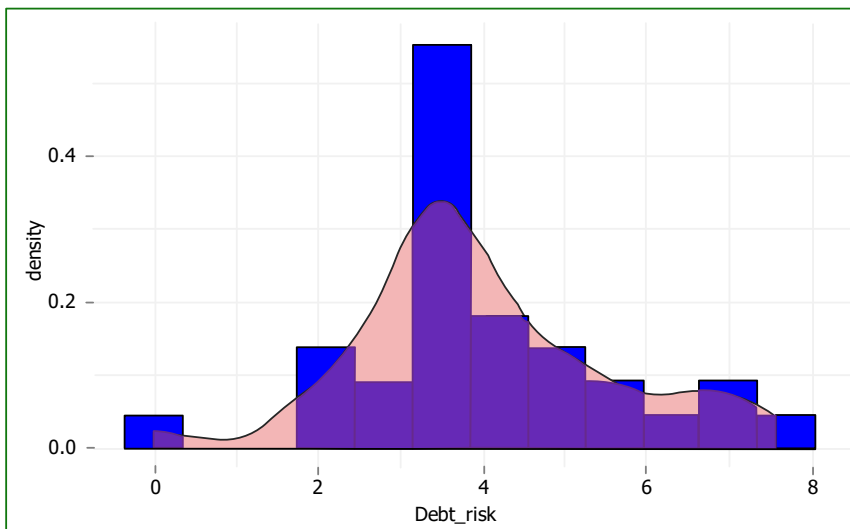


Figure 3. Density of debt risk distribution.

The presented figures make it possible to note that there is a significant skew in the distribution of REER volatility in the first quantiles, which indicates asymmetry. Instead, the distribution densities of the GDP gap and debt risk are closer to normal.

Tables 2-4 show the developed quantile autoregressive distributed lag models for the GDP gap, REER volatility and debt risk.

Table 2. QARDL model for the GDP gap.

Variable	Q=0.1	Q=0.3	Q=0.5	Q=0.7	Q=0.9
const	0.45	0.47	0.77	1.35	1.5
long-run coefficients					
$reer_v_{t-1}$	0.41	0.42	-0.19	-0.06	-0.21
π_{t-1}	0.18	0.13	-0.24	-0.66	-0.8
fsd_t	-0.35	-0.35	-0.15	-0.19	-0.16
cne_t	0.22	0.22	0.06	-0.66	-0.76
fsi_t	0.22	0.24	-0.57	-0.02	0.07
gru_t	-0.6	-0.6	0.53	0.08	-0.01
short-run coefficients					
$\Delta reer_v_{t-1}$	-0.16	-0.19	0.05	-0.24	-0.23
$\Delta \pi_{t-1}$	-0.15	-0.06	0.06	0.22	0.45
Δfsd_t	0.32	0.31	0.11	-0.07	-0.1
Δcne_t	-0.1	-0.13	0.04	0.12	0.57
Δfsi_t	0.41	0.33	-0.03	-0.02	-0.1
Δgru_t	0.25	0.31	-0.21	-0.33	-0.34
<i>pseudo</i> – R^2	0.72	0.43	0.406	0.39	0.598

Table 3. QARDL model for REER volatility.

Variable	Q=0.1	Q=0.3	Q=0.5	Q=0.7	Q=0.9
const	0.23	1.19	-0.18	-0.04	-0.1
long-run coefficients					
\hat{y}_{t-1}	-0.18	-1.23	-0.1	0.16	0.34
π_{t-1}	0.1	0.04	-0.23	-0.24	-0.26
fsd_{t-1}	-0.06	0.04	0.47	0.22	0.24
\hat{r}_t	-0.11	-0.22	0.4	0.08	0.01
$(E(\pi_{t-1}) - \pi_{t-1}^*)$	0.23	-0.07	-0.26	0.04	0.15
$debt_t$	-0.1	-0.43	0.33	0.27	0.39
fsi_t	-0.2	-0.19	-0.11	-0.2	-0.55
short-run coefficients					
$\Delta \hat{y}_{t-1}$	-0.28	0.06	-0.41	-0.93	-1.25
$\Delta \pi_{t-1}$	-0.35	-0.4	0.35	0.35	0.07
Δfsd_{t-1}	0.002	-0.06	-0.24	-0.1	-0.1
$\Delta \hat{r}_t$	-0.008	0.55	0.38	0.72	0.97
$\Delta(E(\pi_{t-1}) - \pi_{t-1}^*)$	0.57	0.15	1	0.34	0.59
$\Delta debt_t$	0.03	0.92	0.84	1.07	1.26
Δfsi_t	0.25	0.5	0.44	0.16	0.36
<i>pseudo</i> – R^2	0.23	0.31	0.4	0.62	0.84

Table 4. QARDL model for debt risk.

Variable	Q=0.1	Q=0.3	Q=0.5	Q=0.7	Q=0.9
const	0.08	0.83	0.1	0.77	0.75
long-run coefficients					
<i>reer_v_t</i>	0.12	0.1	-0.004	-0.31	-0.2
<i>fsd_{t-1}</i>	1.34	0.9	0.9	0.47	0.73
<i>openess_{t-1}</i>	-1.72	-1.46	-0.78	-0.64	-0.88
\hat{r}_t	0.3	-0.37	-0.22	-0.58	-0.67
<i>r_ovdp_t</i>	1.86	1.66	1.74	1.38	1.66
<i>b_aid_t</i>	-2.63	-2.18	-1.86	-1.06	-1.66
<i>reserves_{t-1}</i>	-0.04	-0.5	0.19	-0.23	-0.13
short-run coefficients					
$\Delta reer_{v_t}$	-0.02	-0.27	0.05	-0.14	0.1
Δfsd_{t-1}	-0.48	-0.2	-0.72	-0.07	0.04
$\Delta openess_{t-1}$	1.24	0.38	0.87	0.17	0.07
$\Delta \hat{r}_t$	-0.44	0.35	-0.34	0.15	0.25
Δr_{ovdp_t}	-0.44	-0.85	-1.23	-0.92	-2.09
Δb_{aid_t}	1.35	1.04	1.58	0.75	0.51
$\Delta reserves_{t-1}$	-0.41	0.19	-0.3	0.04	0.14
<i>pseudo - R²</i>	0.66	0.51	0.55	0.62	0.77

In cases where the quantile approach is used to evaluate the analysis of relationships between variables, the usual coefficient of determination cannot be applied, so the pseudo coefficient of determination is calculated according to the methodology given in Koenker, R., Machado, José A.F. (1999). This indicator of model quality can be calculated for each isolated quantile. The limits of its value coincide with the usual R^2 .

The results of applying the QARDL model to the GDP gap indicate that the long-term impact of REER volatility on economic growth is mostly stronger than the short-term. In terms of quantiles, it can be both positive and negative and not always proportional, which can be evidence of the effect of volatility on extreme values of this endogenous variable.

Inflation, net export commodity price index, financial stress index, and geopolitical tension index have a stronger influence on the resulting indicator in the long term than in the short term. The opposite can be said about the development of the financial sector, although in the long term, the effect is mostly negative.

The extreme values of the GDP gap are affected differently by the volatility of REER, inflation, and the price index of net export goods in both periods. In the short term, also from the development of the financial sector and indices of geopolitical tension and financial stress.

Analyzing the indicators that have the strongest impact on the GDP gap, one should note the index of geopolitical risk and inflation for both periods, the index of financial stress in the short term, and the index of prices for net export goods in the long term. The previously mentioned variables have the strongest effect on extreme values. The smallest effect is recorded from the price index of net export goods in the short term and the financial stress index in the long term. The quality indicator of the model for different quantiles is generally satisfactory.

Now we can proceed to the analysis of the QARDL model for the volatility of REER.

The analysis of the model variables indicates that the impact of the GDP gap is stronger in the short term and generally reduces the volatility of REER. At the same time, inflation increases exchange rate fluctuations in the long term and slightly reduces them in the short term. The impact of the development of the financial sector increases volatility in the long term but reduces it in the short term. The growth of the real discount rate gap, the deviation of inflation expectations from the inflation target, and the increase in the debt-to-GDP ratio generally increase the value of the resulting indicator. As for the financial stress index, it can be noted that instability in the financial sector increases the volatility of the hryvnia in the short term, but the opposite is true in the long term. Extreme values of volatility are affected differently by the gap between

GDP and the public debt ratio in the long term and by inflation, the development of the financial sector, and the gap in the real interest rate in both periods.

Analyzing the indicators that have the strongest impact on the volatility of REER, both in the short and long term, the debt-to-GDP ratio and the deviation of business inflation expectations from the inflation target stand out. In the short term, the gap in the real discount rate and inflation also has a significant effect, and in the long term, the development of the financial sector.

As for the variables that have the weakest influence on REER fluctuations, we will emphasize the development of the financial sector in the short term and the financial stress index in the long term. The quality indicator of the model is also satisfactory.

We will also analyze the QARDL model for debt risk. The results show that the volatility of REER has the greatest impact on debt risk in the short term, mostly by reducing it. Also, in the short-term perspective, compared to the long-term, the ratio of the amount of gold and foreign exchange reserves to the external debt has a greater effect. There is a noticeable difference in the impact of the development of the financial sector on debt risk: it increases in the long term, and vice versa in the short term. The same applies to the yield rate on government bonds. On the other hand, financial assistance to the budget from abroad reduces the risk in the long term. It should be noted that the extreme values of debt risk are affected differently by the volatility of REER, the real interest rate gap in both periods and the yield rate of OVDP and the ratio of gold and foreign reserves in the short term.

Analyzing the indicators that have the strongest impact on debt risk, both short-term and long-term, the openness of the economy, the rate of return on government bonds, budget assistance from abroad, and the development of the financial sector also stand out in the long term.

Among the indicators that have the weakest influence on the change in debt risk, both in the short-term and in the long-term is the volatility of REER. The quality of the model is generally quite excellent. Thus, the application of a non-linear approach to the analysis of the relationships between the selected outcome variables made it possible to cover the nature of the interactions more widely, and the applied QARDL model demonstrates good adequacy indicators at the extreme quantiles, which can be useful for studying the explanation of the effect of changing the critical values of some indicators.

DISCUSSION

The conducted analysis proved that the volatility of the exchange rate is a significant factor that must be taken into account in the process of planning activities for macroeconomic stabilization. This is explained by the fact that the volatility of the exchange rate significantly affects a number of macroeconomic indicators, in particular, the GDP gap and debt risk. The approach proposed in the paper based on the use of the quantile autoregressive distributed lag model (QARDL) made it possible to take into account the impact of exchange rate fluctuations on macroeconomic indicators, in particular on their extreme values, which is usually not provided using structural econometric models. This makes it possible to assess the asymmetric nature of the impact of currency volatility more accurately, which can differ significantly at different stages of the economic cycle.

Authors of previous studies describe similar results. Ameziane Karim, Bouchra Benyacoub (2022) analyze the application of the CS-ARDL Panel model to estimate the direct and indirect effects of currency volatility on economic growth indicators in developing countries. The results indicate a confirmation of the negative impact of volatility. Perazzi, J. R., Romero, H. (2022) indicate that exchange rate manipulation to stimulate trade and government spending can lead to macroeconomic instability. The results obtained by Bosupeng, M., Naranpanawa, A., & Su, J. (2024) indicate that for developing countries, a devaluation shock under exchange rate volatility has a positive effect on the economy, while in developed countries the effect is negative. Mathias Manguzvane & Mduduzi Biyase (2023) report the results of a non-linearity analysis of the relationship between currency volatility and sovereign default risk using quantile regression and regime-switching models and argue that for volatile economies, volatility increases the probability of default.

This study has a number of limitations that should be taken into account when interpreting the obtained results. First, the QARDL model does not take into account the inertial effect, which can affect the accuracy of long-term forecasts and limit the model's ability to estimate the constant reaction of macroeconomic indicators to currency shocks. Second, the results are based on data up to the third quarter of 2023, so any changes in macroeconomic policy or further escalation of external factors may change the observed patterns.

It should also be noted that the selection of selected variables could limit the complexity of the model. For example, the factors of global economic instability, such as changes in world prices for energy resources, which probably affect the REER of Ukraine, are not taken into account.

CONCLUSIONS

As a part of the research, the possibilities of developing and applying structural econometric and quantile regression models in the practice of analyzing and forecasting the impact of exchange rate fluctuations on macroeconomic indicators and public debt parameters were analyzed.

The analysis of the results of existing studies in setting up and solving the problem of analyzing the spectrum of relationships between macroeconomic indicators using the capabilities of applied econometric tools made it possible to propose a possible approach to conducting macroeconomic analysis based on structural econometric models.

The results of the study show that the volatility of the exchange rate is an important factor that significantly affects the macroeconomic indicators in Ukraine, in particular, the GDP gap and debt risk. The use of the quantile autoregressive distributed lag model (QARDL) made it possible to consider not only the overall impact but also to assess how exchange rate fluctuations affect different levels (quantiles) of macroeconomic indicators, in particular, extreme values that are not usually covered by traditional models. This makes it possible to assess the asymmetric nature of the impact of currency volatility more accurately, which can differ significantly at different stages of the economic cycle.

The practical value of the obtained results lies in the fact that the results of the study, in particular, approaches to determining the impact of REER volatility on economic growth and national debt and the effect of other indicators on fluctuations of the national currency can serve as a basis for justification and decision-making regarding the implementation of a stabilizing macroeconomic policy by state institutions. The prospect of conducting further research in this direction is to expand the range of indicators that are taken into account in the models, as well as the use of alternative tools with a comparative analysis of the obtained results.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ЗАСТОСУВАННЯ SEM ТА QARDL-МОДЕЛЕЙ У ПРАКТИЦІ АНАЛІЗУ ВПЛИВУ ВОЛАТИЛЬНОСТІ ОБМІННОГО КУРСУ НА МАКРОЕКОНОМІЧНІ ПОКАЗНИКИ

Це дослідження присвячене аналізу й прогнозуванню впливу волатильності реального ефективного обмінного курсу (РЕОК) й безпосередньо, й опосередковано через різні канали на макроекономічні показники України, зокрема на економічне зростання й державний борг. У роботі застосовані модель одночасних симультативних рівнянь (SEM) та квантильна авторегресивна дистрибутивно-лагова модель (QARDL), що дозволило використати їхні можливості

й сформувані лінійний і нелінійний підходи щодо оцінки впливу волатильності на обрані індикатори в коротко- та довгостроковому періодах. Основні результати демонструють неоднозначний вплив волатильності РЕОК на економічні параметри: курсова нестабільність сповільнює економічне зростання, але водночас здатна знизити борговий ризик, здебільшого короткостроково. Результати проведення квантильного аналізу показують, що окремі економічні індикатори змінюють ступінь свого впливу залежно від рівня волатильності й стану фінансового сектора. Також важливими чинниками, через які волатильність впливає на економічний розвиток або ж сама змінюється, є рівень, динаміка й структура торгівлі. Запропонований підхід та отримані на його основі результати можуть слугувати методичною основою для обґрунтування та ухвалення рішень щодо проведення стабілізуючої макроекономічної політики державними інституціями.

Ключові слова: макроекономічний аналіз, економетричне моделювання, волатильність, обмінний курс, борговий ризик, структурна модель, квантильна регресія

JEL Класифікація: E52, C31, E47, E65