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THE IMPACT OF REER VOLATILITY ON ECONOMIC ACTIVITY IN UKRAINE

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Abstract This study examines the nonlinear impact of the volatility of the real effective exchange rate (REER) on economic activity in Ukraine. In it, we use a threshold vector autoregression (TVAR) model for the period from June 2009 to December 2021. Our results indicate that there is a threshold for REER fluctuations of 1.8%. Below this threshold, volatility stimulates economic activity, but above 1.8% the effect is negative. This nonlinear effect is more noticeable for industries involved in foreign trade and with elastic demand for their own goods. Therefore, the National Bank of Ukraine should strive to keep REER volatility below 1.8% so that exchange rate fluctuations do not harm the economy.

JEL Codes C30, E23, E52, F31, F43

Keywords VAR-TVAR, REER volatility, economic activity

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1. INTRODUCTION

Ukraine previously faced many crises before 2022 that significantly reduced economic activity in the country.[1] Then, due to the full-scale russian invasion, Ukraine's GDP in real terms decreased by 28.8% in 2022.[2] The shocks of the war contributed to a decrease in economic activity and significant fluctuations in the dynamics of the national currency exchange rate. Exchange rate volatility can affect economic activity in the country through inflation (Syarifuddin et al., 2014) and the creation of an uncertain environment (Morina et al., 2020).

Some studies suggest that moderate exchange rate volatility can boost economic activity (Verheuvel, 2016; Audi, 2024), particularly in developed economies. The governments of developed countries are able to prevent high exchange rate fluctuations, allowing economic agents in these countries to protect themselves from risks and use moderate volatility as a stimulus for development.

In contrast, less developed economies are less likely to manage high exchange rate fluctuations more effectively. As a result, they often experience the negative consequences of excessive volatility (Ameziane and Benyacoub, 2022; Bosupeng et al., 2024).

Developed nations are more prone to experiencing moderate, homogeneous volatility, which could imply a linear effect of exchange rate movements on their economic performance. In contrast, a nonlinear relationship is more likely in less developed countries.

Between 2009 and 2021, Ukraine's exchange rate experienced notable shifts in volatility. The crisis years of 2014-2015 were marked by substantial currency

[1] https://apostrophe.ua/ua/article/economy/2021-07-11/trudnyiy-rebenok-istoriya-ukrainyi---eto-istoriya-krizisov/40570
[2] https://biz.censor.net/news/3464639/derjstat_pokraschyv_otsinku_padinnya_vvp_ukrayiny_za_2022_rik

fluctuations coupled with economic downturn. In contrast, other periods saw greater stability. Notably, the adoption of an inflation targeting (IT) regime by the central bank after 2016 signifies a development in Ukraine's institutional framework for economic management. This evolution could enhance the authorities' ability to manage exchange rate fluctuations and potentially leverage them to support economic growth.

Consequently, we have grounds to hypothesize a nonlinear relationship between exchange rate volatility and economic activity in Ukraine, potentially with a specific volatility threshold triggering this nonlinearity. This suggests the possibility that moderate volatility could be beneficial for economic activity, while high volatility might be detrimental. Therefore, a retrospective analysis of exchange rate volatility's impact on the Ukrainian economy in earlier periods is valuable. Given the current high volatility due to the war, this research can provide insights into the potential economic effects of exchange rate fluctuations post-2022, ultimately aiding the central bank in formulating more effective exchange rate policies.

Researchers mostly use the REER index instead of the nominal exchange rate to study the impact of exchange rate volatility on economic activity (Morina et al., 2020). Therefore, in this study, we follow their practice and choose REER, as this indicator reflects real purchasing power and trade competitiveness.

While previous studies have explored the relationship between exchange rate volatility and aggregate economic indicators like GDP growth or GDP per capita (Morina et al., 2020; Ramoni-Perazzi and Romero, 2022), our research recognizes the importance of examining potential sectoral differences in this impact. Moreover, unlike studies that typically analyze the linear or nonlinear effects of the REER separately (Đukić et al., 2023) or focus solely on identifying volatility thresholds (Kamel, 2021), our study simultaneously investigates both the nature of the impact and the existence of a specific threshold.

Thus, the purpose of this study is to research the impact of the REER volatility on economic activity in Ukraine. In particular, we aim to examine whether the impact is nonlinear and if there exists a certain threshold value.

In this paper, we employ monthly data from June 2009 to December 2021 to investigate whether there is a nonlinear impact of the REER volatility on a set of indicators of economic activity. Available data for the research period begins in 2009 and ends with the end of the recording of monthly data on the volume of agricultural production at the beginning of a full-scale russian invasion.

This research begins with a vector autoregression (VAR) model to initially assess the linear impact of REER volatility on economic activity. Recognizing the potential for nonlinearity, we then employ tests such as the Terasvirta test and the Likelihood Ratio (LR) test to detect its presence. Subsequently, we utilize a TVAR model to provide a more in-depth analysis of how exchange rate fluctuations affect economic activity.

Furthermore, this paper extends the analysis by examining the impact of these fluctuations on various sectors of the economy. Finally, we investigate whether REER volatility leads to increased inflation and whether the central bank intervenes to mitigate significant exchange rate movements.

Our findings reveal a nonlinear relationship between REER volatility and economic activity, with an identified threshold of approximately 1.8%. Specifically, REER volatility exceeding this 1.8% threshold negatively impacts economic activity, while volatility below this level appears to have a stimulative effect. This suggests the central bank should actively work to prevent exchange rate fluctuations from surpassing this identified threshold to avoid detrimental effects on the economy.

The robustness of our results is confirmed across alternative indicators of economic activity. Replacing industrial output with domestic trade, construction output, and agricultural output does not alter our core finding of a nonlinear impact of REER volatility. Moreover, the nonlinearity appears most evident in sectors with strong ties to international trade and elastic demand for their products and services, such as industrial output and domestic trade. This suggests that these sectors are particularly sensitive to the nuances of exchange rate volatility.

Our analysis indicates that inflationary pressures intensify when exchange rate fluctuations exceed the 1.8% threshold. Furthermore, we observe that monetary policy, through interest rate hikes, is employed to manage volatility once it surpasses this level. The 1.8% threshold thus represents a clear signal for the National

Bank of Ukraine to intervene proactively and curb further REER fluctuations to mitigate inflationary risks and maintain economic stability.

This study is the first research in Ukraine to specifically investigate both the impact and the form of the relationship between REER volatility and economic activity. In doing so, it contributes to the broader literature on several fronts: the nonlinear impact of exchange rate fluctuations with identified threshold levels (Fourie et al., 2016; Amor et al., 2023; Kamel, 2021); the amplified effect of exchange rate volatility on internationally traded sectors with elastic demand (Verheuvel, 2016; Kamel, 2021; Đukić et al., 2023); the inflationary consequences of excessive volatility (Syarifuddin et al., 2014; Fabris and Lazić, 2022); and the policy imperative for central banks to manage exchange rate volatility (Kuncoro, 2020).

The rest of this paper is structured as follows: Section 2 reviews the existing body of research on the relationship between REER volatility and economic growth. Section 3 describes the data sources and the methodology applied in our analysis. Section 4 presents the core results of our study, including the outcomes of robustness tests. The concluding section, Section 5, summarizes our key findings and discusses their practical relevance for central bank policy.

2. LITERATURE REVIEW

Exchange rate volatility can have a positive or negative impact on economic growth, depending on the government's ability to prevent large fluctuations, the economy's capacity to function well even with exchange rate instability, and the potential for economic agents to benefit from volatility (Verheuvel, 2016; Audi, 2024). These factors rely on effective monetary policy, strong financial markets, and a robust institutional structure. Consequently, developed countries typically avoid high exchange rate volatility. Their well-developed financial markets also allow businesses to diversify risks (Ramoni-Perazzi and Romero, 2022; Tiwary et al., 2022), and they can leverage moderate volatility for adaptation and growth. Therefore, the impact of volatility in more developed economies on economic growth is often positive.

In contrast, less developed countries cannot easily cope with high exchange rate fluctuations, and they create an unfavorable environment for economic growth. Several other factors worsen the negative impact of fluctuations: first is the tendency to use fixed or managed exchange rate regimes, which limits the economy's ability to absorb external shocks (Đukić et al., 2023); second, trade risks are higher due to the economy's high openness and reliance on global market prices (Ofori et al., 2018).

According to Kamel (2021) and Fourie et al. (2016), the nonlinearity in exchange rate dynamics affecting economic growth can be attributed to factors such as the diverse behaviors of foreign exchange market investors, the presence of transaction costs in international trade, and the exposure of domestic exporters to currency risk. Notably, more developed countries often possess mechanisms to dampen excessive exchange rate volatility, which can lead to a more linear and potentially positive effect of volatility on their economies. Conversely, less developed economies, characterized by a wider range of exchange rate fluctuations, may be more prone to experiencing a nonlinear impact of volatility on their economic growth.

The potential for a nonlinear effect of exchange rate fluctuations on economic growth can be attributed to the existence of a specific threshold (Jaramillo Rodríguez et al., 2019). Firms often adjust their product prices when exchange rate movements surpass this threshold. Furthermore, exchange rate fluctuations influence firms' input choices between foreign and domestic sources. While perfect access to both might negate price changes, the reality of imperfect access means firms tend to switch input resources to mitigate further price increases once volatility exceeds a certain threshold.

When REER volatility surpasses this critical threshold, it can lead to financial instability and heightened inflationary pressures through the mechanism of exchange rate pass-through (ERPT), as highlighted by Syarifuddin et al. (2014) and Fabris and Lazić (2022). In response to these risks, central banks frequently adopt restrictive policies aimed at curbing exchange rate volatility. This underscores the potential for central banks to actively employ interest rate policy (Kuncoro, 2020) as a tool to influence and manage exchange rate fluctuations.

REER volatility influences economic growth through the following channels: investment, inflation, external debt, economic openness, and financial sector development

(Ameziane and Benyacoub, 2022). Furthermore, exchange rate fluctuations themselves can be influenced by the terms of trade (Yensu et al., 2022; Amor et al., 2023). Consequently, the terms of trade can indirectly affect economic growth by shaping exchange rate dynamics (Janus and Riera-Crichton, 2015; Kamel, 2021).

REER volatility also affects the functioning of particular sectors of the economy (Verheuvel, 2016). The volatility effect depends on whether a certain industry is more focused on the domestic or external consumer and belongs to the trading sector. Exchange rate fluctuations can lead exporters to shift their supply of goods from external to domestic markets, resulting in a decline in external trade (Kamel, 2021). Exchange rate dynamics can also affect the redistribution of resources between sectors, which can stimulate the development of trading or non-trading industries. Moreover, exchange rate fluctuations affect price competition between producers (Đukić et al., 2023). Demand for goods tends to be more stable if goods and services are more high-tech and less sensitive to price competition.

The literature reveals a nuanced relationship where exchange rate volatility can exert both positive and negative influences on economic growth, indicating a potential for nonlinearity with various underlying causes. Furthermore, the impact of exchange rate fluctuations is not uniform across economic sectors. Notably, substantial exchange rate movements can generate inflationary pressures, often necessitating a response from the central bank to manage this volatility.

3. DATA AND METHODOLOGY

3.1. Data

Table 2 of Appendix A shows information about the data we use in this study, the symbols of the indicators, and their definitions.

The NBU database is the main source for this study. In particular, we selected data on economic activity indicators, the REER index, inflation and rates on new corporate loans from June 2009 to December 2021. However, we need additional sources of information, since the exchange rate can strengthen or weaken the impact of the external environment on the domestic economy. These additional sources of data are the IMF database (data on terms of trade for Ukraine) and the MarketWatch database (data on three-month London Interbank Offered Rate (LIBOR)) from for the same time period. The research period begins in 2009 with the start of recorded data for monthly output of economic activity indicators, and ends with agricultural output as of the beginning of a full-scale russian invasion.

War shocks make it harder to assess the impact of exchange rate volatility on economic activity because the economy's structure has changed significantly. The outbreak of russia's full-scale invasion forced Ukraine to adopt anti-crisis measures, including the introduction of a fixed national currency exchange rate to curb panic in society and to maintain overall macroeconomic stability. The aggressor also destroys many enterprises in various sectors of the economy, so the change in operating conditions is not related to purely economic factors.

We select the volume of industrial output as the main indicator of economic activity due to the sector's inherent characteristics. As a tradeable sector, industry is significantly exposed to the dynamics of exchange rate fluctuations (Đukić et al., 2023). This sensitivity makes it a relevant proxy for capturing the impact of these fluctuations on the broader economy. Figure 1 shows the dynamics of Ukraine's monthly nominal industrial output. The output of the industrial sector of the economy accounts for a significant share of exports, and their value often depends on world prices.[3] We observe some seasonality, with a slight increase in production at the end of the year – possibly due to higher seasonal demand and budget spending. Ukraine had a fixed exchange rate until 2014. This resulted in weak economic activity, near-zero inflation, and growing imbalances, so industrial output remained relatively stable. Industrial output gradually increased[4] after the adoption of a flexible exchange rate and IT regime in 2015, and the shift in trade towards EU countries. In 2019-2020, Ukraine's industrial sector contracted due to lower global steel prices and the COVID-19 crisis[5], but it later recovered[6].

[3] https://fru.ua/images/doc/analitics/2021/promyslovist_1_2021.pdf
[4] https://tyzhden.ua/torhivlia-z-ies-pereoriientatsiia-vdalasia/
[5] https://epravda.com.ua/news/2020/01/22/656135/
[6] https://www.unicef.org/ukraine/media/9231/file/UNICEF%20Ukraine%20Concensus%20COVID%20Youth%202020%20ukr.pdf

In addition to industrial output, we incorporate domestic trade, construction output, and agricultural output to provide a more nuanced and complete picture of economic activity in Ukraine. These indicators offer supplementary insights into different facets of the economy. As shown in Figure 2, construction and domestic trade share similar seasonal patterns with industrial production. In contrast, agricultural output peaks mid-year due to its inherent seasonality. Consistent with our observations for industrial output, these sectors also experienced stagnant activity during the fixed exchange rate period leading up to 2014, followed by a period of growth after 2015. Interestingly, the nominal value of domestic trade proved resilient to the COVID-19 crisis, and agricultural output saw a significant surge in 2021 due to exceptional harvests.

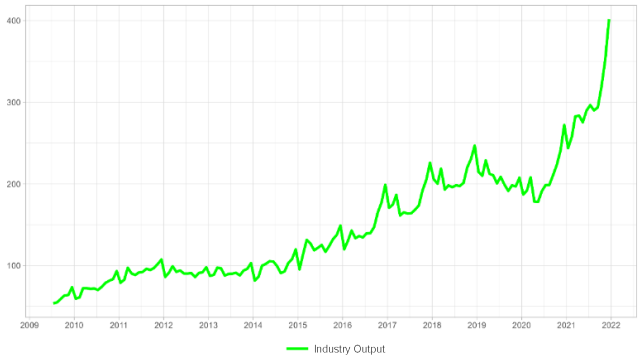

Figure 1. Dynamics of the Output of Products Sold by Ukrainian Industry, bln UAN

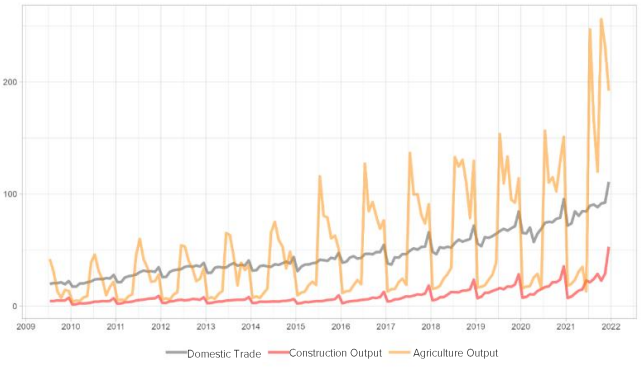

Figure 2. Dynamics of Production Output for Domestic Trade, Agricultural Sector and Construction, bln UAN

For subsequent analysis, we subjected our variables to a series of transformations. To isolate real economic changes from inflationary effects, we deflated all nominal variables using June 2009 as the base period. To better discern underlying trends and patterns by removing predictable seasonal fluctuations, we applied the x13arima-seats seasonal adjustment method to our indicators. In the case of agricultural production, we also removed outliers to enhance the representativeness of our subsequent results. Lastly, to meet the requirements of our autoregressive models, we transformed the production output data for each sector into percentage changes from the previous period.

We performed stationarity tests on our variables in both levels and first differences (results presented in Table 1). For variables that exhibited non-stationarity in their level form, we applied a first-difference transformation to achieve stationarity. This procedure was necessary for construction output, agricultural output, terms of trade, credit rate, and LIBOR. However, for ease of interpretation in the subsequent analysis, we maintained the exchange rate volatility variable in its level form.

Table 1. Stationary Tests

Variable	I(0)		I(1)	
	ADF test	KPSS test	ADF test	KPSS test
ind_output	-4.305***	0.209	-8.299***	0.029
domestic_trade	-3.361***	0.249	-7.978***	0.020
constr_output	-3.218*	0.706**	-9.116***	0.110
agr_output	-3.112	2.673***	-6.786***	0.050
reer_volatility	-3.115	0.244	-6.340***	0.026
inflation	-3.891**	0.171	-8.149***	0.020
credit_rate	-5.009***	0.091	-7.657***	0.027
tot	-2.984	0.133	-7.932***	0.019
libor	-3.476**	0.229	-7.776***	0.019

* p<0.10, ** p<0.05, *** p<0.01. Null hypotheses: (i) ADF (H0: non stationary), (ii) KPSS: (H0: stationary).

Descriptive statistics for the economic activity indicators across the entire research period are presented in columns 2-4 of Table 3 in Appendix A. The average values for industrial output, domestic trade, and construction output indicate a trend of gradual increase throughout the observation period. Interestingly, the agricultural sector shows a decline in average activity, potentially resulting from the handling of outliers in the data.

We further analyzed the data by dividing the research period into distinct sub-periods (presented in Table 3, Appendix A, columns 5-13) to explore potential changes in the behavior of Ukraine's economic activity indicators. This segmentation allows us to consider the

impact of the 2014-2015 crisis, the preceding era, and the subsequent period marked by structural economic changes and a reorientation of foreign trade towards European partners. The initial russian invasion (2014-2015) had a detrimental effect on growth in most sectors, with construction being an exception. Notably, the industrial sector experienced both its peak and trough growth rates during this crisis, likely influenced by a depressed basis of comparison. Conversely, the highest growth rates for domestic trade, construction, and agriculture were recorded in the final sub-period of our analysis. We attribute the peak in domestic trade to increased purchasing power and the growth of online commerce (Gorobchenko, 2023), the peak in construction to increased housing construction in 2021[7], and the peak in agriculture to record harvests in 2021[8].

The next key variable in this study is the exchange rate and its volatility. We use the REER index as a proxy for the exchange rate. The REER reflects real purchasing power and trade competitiveness (Morina et al., 2020).

In this research, we define the REER as the month-over-month percentage change in the inverted REER index. To measure exchange rate volatility, we calculate the standard deviation of the REER index over a rolling three-month window (Figure 3), consistent with methodologies used by Verheuvel (2016) and Morina et al. (2020). Higher values of this volatility measure indicate more pronounced exchange rate movements, encompassing both significant depreciations and appreciations.

Table 4 of Appendix A shows descriptive statistics for REER volatility across the entire research period and its sub-periods. We observed the highest volatility in 2014-2015. This was caused by the significant devaluation of the hryvnia after the fixed exchange rate was abandoned, rising inflation, and the initial russian invasion. The average fluctuations and the range of the exchange rate increased after the introduction of the IT regime, which involves a flexible exchange rate. Flexible exchange rate regime may lead to slightly higher exchange rate volatility, due to the freer capital movements and a smaller presence of the central bank in the foreign exchange market (Syarifuddin et al., 2014).

We define a REER volatility shock as a shock that creates uncertainty affecting the economic environment, especially businesses' ability to predict their activities. This uncertainty is particularly important for industries that rely heavily on imports and exports. It can affect investment, inflation expectations, and the consumer price index (CPI), as imports make up a large share of Ukraine's trade. Therefore, both internal and external shocks contribute to changes in the REER and its volatility (Morina et al., 2020).

We consider inflation as a significant channel through which the exchange rate affects economic activity, operating through the exchange rate pass-through effect. Moreover, inflation can help explain the potential nonlinear impact of volatility on economic growth, with firms potentially reacting to volatility by adjusting prices at certain inflation levels (Jaramillo Rodríguez et al., 2019). Inflation also has a direct impact on the REER and the real economy (Morina et al., 2020). For our analysis, inflation is calculated as the monthly percentage change in the CPI.

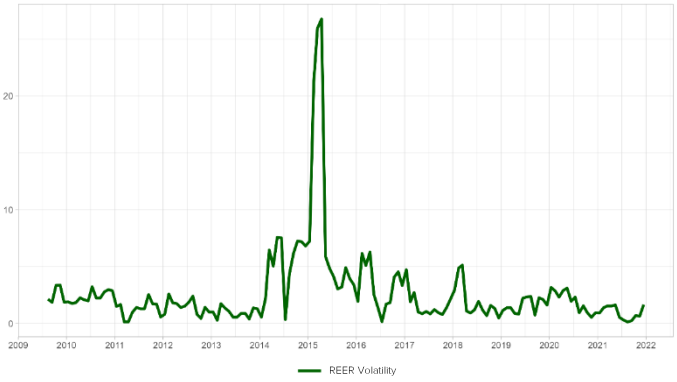

Figure 3. REER Volatility, %

We use the annual weighted average interest rate on rates on new corporate loans as a proxy for monetary policy to test if the response of central bank is restrictive. We chose the rate on new corporate loans because it reflects the impact of monetary policy on the real sector of the economy, and therefore on economic activity. Interest rates influence investment, which also in turn affects economic activity (Morina et al., 2020).

Figure 4 depicts the dynamics of inflation and new business loan rates during our research period. The sharp increase in inflation observed in 2014-2015 is primarily linked to the devaluation of the hryvnia

[7] https://gmk.center/ua/posts/zmina-lidera-na-budivelnomu-rinku-v-2021-roci-zminivsya-drajver-zrostannya/
[8] https://latifundist.com/spetsproekt/956-rekordnij-2021--bilshe-100-mln-t-vrozhayu-mozhemo-zvikati-do-sotki-chi-tse-vinya

exchange rate.[9] The new business loan rate generally follows a stationary process, with a temporary dip from late 2012 to 2013 that may be explained by high liquidity in the banking sector.[10] The volatility of this rate decreased after 2016, which aligns with typical patterns for monetary policy rates under the IT regime (Ogrokhina and Rodriguez, 2024).

In this study, we look at some external factors that influence economic activity through REER volatility. These include terms of trade, as noted in Amor et al., 2023, and the relationship between the exchange rate and economic growth (Kamel, 2021). The second external indicator is LIBOR, which served as a benchmark for many financial instruments in the world and thus affects exchange rate volatility through uncovered interest rate parity (Cui et al., 2016).

In summary, this section has described the characteristics of the variables used in our study. We observed that the 2014-2015 crisis period had high exchange rate fluctuations and rising inflation, along with a decrease in economic activity. In contrast, other periods saw increased economic activity, with lower REER volatility and inflation. These links between variables could be related. We use this information to further model the nonlinear effect of exchange rate volatility on economic activity.

3.2. Empirical Model

In our analysis of the impact of REER volatility on economic activity, we use two types of models. We start with a VAR model to estimate the linear impact of exchange rate fluctuations on economic activity. We proceed further using a TVAR model to delve deeper into the analysis of the impact of exchange rate volatility on economic activity, and to test the hypothesis that there is a nonlinear relationship between exchange rate volatility on economic activity, with a certain threshold level.

We choose the lag length based on the Akaike information criterion (AIC), Hannan–Quinn information criterion (HQC), Schwarz criterion (SC) and Final Prediction Error (FPE) criterion. Table 5 of Appendix A presents the size of the lags according to each criterion.

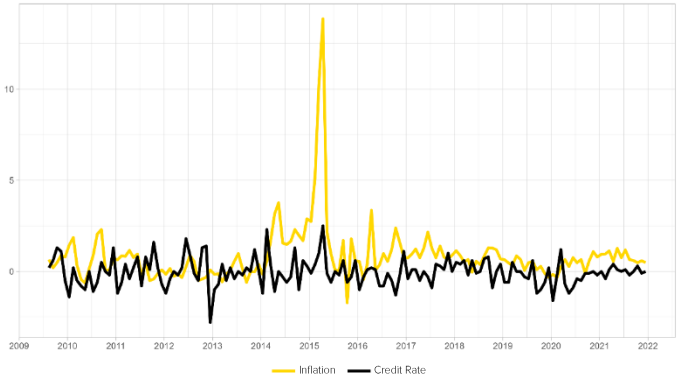

Figure 4. The Dynamics of Inflation and Interest Rates on New Corporate Loans, %

The specification of the VAR model is as follows:

$$y = f(ind\_output, inflation, reer\_volatility, credit\_rate, exog = (tot, libor)), \quad n.lags = 1, \tag{1}$$

where y is the vector of variables that includes such endogenous indicators as: the volume of output of the industry production: (ind_output), inflation $(inflation)$, REER volatility $(reer\_volatility)$, interest rates on new corporate loans $(credit\_rate)$; and exogenous indicators: terms of trade (tot), and the LIBOR rate $(libor)$. Endogenous variables reflect macroeconomic conditions within the Ukraine economy and are identified by an econometric model, while exogenous describe the impact of the external environment on exchange rate fluctuations.

As highlighted in the literature review (Section 2), the relationship between exchange rate volatility and economic activity is likely nonlinear and characterized by a specific threshold. Determining the value of this threshold is crucial, as the impact of exchange rate volatility on the economy can shift from positive to negative depending on whether this threshold is crossed. Consequently, identifying this critical level could provide valuable insights into the optimal range for managing exchange rate fluctuations.

These assumptions indicate that a conventional linear VAR model that captures only linear relationships between indicators may be insufficient. Therefore, we use a set of tests to detect the presence of nonlinearity between exchange rate volatility and economic activity.

[9] https://epravda.com.ua/columns/2016/01/14/576523/
[10] https://zakon.rada.gov.ua/laws/show/v0209500-13#Text

The test results identify whether it is appropriate to use a TVAR. Threshold models are useful for modeling economic growth and the factors that affect it (Hansen, 2011).

First, we employ the Terasvirta Neural Network test to assess the presence of nonlinearity between our set of indicators and economic activity. Subsequently, we conduct the LR test, which is central to this study, to specifically detect nonlinearity between REER volatility and a set of indicators including economic activity. The results of the LR test can inform the appropriateness of using a TVAR model. A more detailed explanation of these nonlinearity tests can be found in Appendix B.

Employing the TVAR model enables us to analyze how exchange rate fluctuations affect our system of variables under different volatility regimes, specifically when exchange rate volatility is either above or below a defined threshold (in the case of a single threshold). In this framework, exchange rate volatility acts as the threshold indicator that determines which regime the system is in.

While our initial VAR model includes both endogenous and exogenous indicators to capture broader relationships, the subsequent TVAR analysis focuses solely on endogenous variables. This approach aligns with the inherent strength of TVAR models in investigating the dynamic interrelationships among endogenous variables, particularly in uncovering nonlinear effects. This allows for a detailed examination of how exchange rate volatility nonlinearly affects economic activity, contingent on a specific threshold.

One of our hypotheses posits a threshold effect of REER volatility on a set of indicators, including economic activity. We employ a TVAR model that utilizes simulations to select this REER volatility threshold. The chosen threshold is the value that minimizes both the sum of squared residuals (SSR) and the AIC. We also have the option for manual threshold setting.

The structure of the TVAR model for two regimes of REER volatility – that is, for one threshold value – is as follows:

$$Y_t = c_j + \sum_{i=1}^{p} A_{j,i} Y_{t-1} + \sum_{j}^{1/2} e_{t,j}, = 1, \qquad (2)$$

where:

regime $j = 1$ if $wt - d < r$

regime $j = 2$ if $wt - d > r$, where

$w\_(t,j)$ is the threshold variable (included in Y_t),

r – the threshold value of the threshold variable,

d – the time lag of the threshold variable that is important for the regime change,

p – degree of autoregression,

Y_t – matrix/vector of endogenous variables,

c_j – a vector of constants for the corresponding regime j,

$A_{j,i}$ – matrix/vector of coefficients of regime j and time lag i,

$e_{t,j}$ – matrix/vector of residuals for the corresponding regime j,

$\sum_{\text{j}}$ – matrix of variances and covariances for the corresponding regime j.

VAR and TVAR models enable us to use orthogonalized impulse response functions (OIRFs) to analyze the impact of a sudden increase (shock) in REER volatility on economic activity. The ordering of variables is crucial in specifying these models. We assume that a shock to exchange rate volatility first affects the monetary policy response, and subsequently influences other variables in the system, such as economic activity and inflation. The shock horizon is set to 18 months. Within this timeframe, the system is expected to revert to its initial equilibrium state (zero).

The significance of the effect of exchange rate volatility on economic activity may vary based on the involvement of economic sectors in foreign trade with elastic demand for their own goods (Verheuvel, 2016; Kamel, 2021; Đukić et al., 2023). Therefore, to test this hypothesis, we replace the main indicator of economic activity with the output of domestic trade ($domestic\_trade$), construction ($constr\_output$), and agricultural output (agr_output). Consequently, the specification of model (1) is slightly modified but maintains the same lag order.

In the methodology review, we outlined the sequence of econometric tools employed and their significance in our research. We emphasized OIRFs as a primary tool for analyzing the impact of REER fluctuations on economic activity.

4. EMPIRICAL FINDINGS

4.1. Results: REER Volatility and Economic Activity

In this section, we present the results of modeling the impact of REER volatility on economic activity, using industrial output as the main indicator. We begin with the VAR model and its OIRFs. Table 6 in Appendix A displays the results of the Terasvirta and LR tests for nonlinearity within the set of indicators. Subsequently, we describe the findings from the TVAR model, considering both a threshold value selected by the model and a manually set threshold (based on the median volatility). Finally, we analyze the impact of exchange rate fluctuations on different economic sectors by using alternative indicators of economic activity.

Figure 5 illustrates that a 1% increase in REER volatility leads to a decrease in economic activity (measured by industrial output), as indicated by the negative response dynamics of this indicator (dark green line in the initial periods). These results are statistically significant, as the confidence intervals (light green area) do not cross zero. This outcome aligns with our expectations, given that industry constitutes a significant portion of Ukrainian exports, and the demand for many industrial product groups is price elastic (Zadoia, 2023). Consequently, exchange rate fluctuations can generate uncertainty and affect price competitiveness, negatively impacting this sector. This finding supports the hypothesis of an adverse effect of exchange rate fluctuations on sectors actively engaged in international trade (Verheuvel, 2016; Kamel, 2021).

The Terasvirta test result for the industrial sector (Table 6, Appendix A, column 2) indicates a nonlinear relationship between industrial output and other variables, as the p-value is below 5%. The LR test (Table 7, Appendix A, column 2) shows that we reject the null hypothesis of linearity at the 5% significance level for both two and three regimes. Furthermore, the "2vs3" test confirms nonlinearity in two regimes, not three, suggesting the presence of one threshold level, thus justifying the use of the TVAR model.

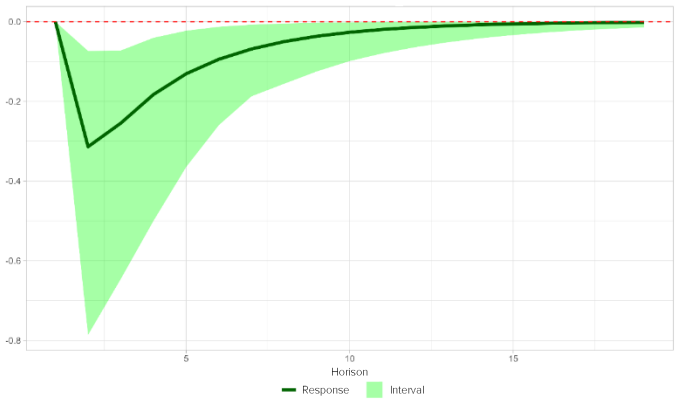

Figure 5. The Impact of a Volatility Shock on Industrial Output, %

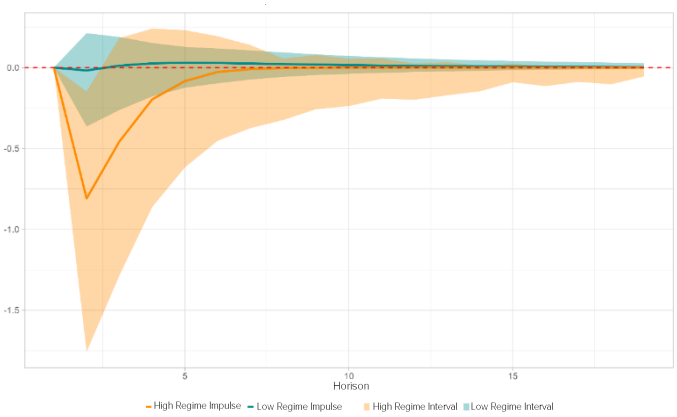

Figure 6. The Impact of a Volatility Shock on Industrial Output under Different Regimes, %

We apply a TVAR(1) model, which indicates that the threshold level of REER fluctuations on a set of indicators, including economic activity, is 5.06% (Figure 11, Appendix C, in red). Consequently, 89.2% of the periods fall into the relatively lower volatility regime, while 10.8% are in the higher volatility regime. Figure 6 presents the OIRFs from the TVAR model for industrial output. Our results show that a REER volatility shock above 5% reduces economic activity (in orange), as the response of this indicator is negative and statistically significant. Conversely, exchange rate fluctuations below 5% (in green) do not significantly affect industrial output, evidenced by the lack of substantial fluctuations and confidence intervals that cross zero. This confirms the findings of Fourie et al. (2016), Kamel (2021), and Iqbal et al. (2023) regarding the presence of a threshold

effect of exchange rate fluctuations on economic activity.

The differing responses of macroeconomic indicators to REER volatility shocks can be understood by considering what each regime in the model captures. The higher volatility regime mainly reflects extreme values, largely from the 2014-2015 crisis. As we see in Figure 11 (Appendix C, above the red line), most periods with REER volatility above 5% occurred during this crisis. This created a big difference in the number of observations between the two regimes. Because of this, we can say that the results for the lower volatility regime show how macroeconomic indicators typically respond under normal, non-crisis conditions.

An interesting avenue for future research would be to examine a larger number of conditionally high volatility episodes that occur more frequently. To achieve a more balanced representation, we adjust the TVAR model to divide volatility around its median value or a point close to it, resulting in approximately 50% of the observation periods falling into each regime.

We divided REER volatility almost exactly at its median. The resulting threshold level of REER volatility in this adjusted TVAR(1) model is 1.76% (Figure 11, Appendix C, in yellow). Consequently, 51.4% of the observations fall into the relatively lower volatility regime, and 48.6% are in the higher volatility regime.

Figure 7 displays the OIRFs from this adjusted model. The results show that a REER volatility shock above 1.76% reduces economic activity (orange line). Conversely, exchange rate fluctuations below 1.76% increase industrial output by a larger magnitude than the decrease observed in the high volatility regime (green line). These opposing effects are more pronounced and statistically significant than those observed at the 5% threshold, evidenced by the distinct impulse dynamics and confidence intervals that do not cross zero. This again confirms the hypothesis of nonlinearity. Furthermore, it supports the hypothesis that moderate exchange rate volatility can stimulate economic activity (Verheuvel, 2016; Audi, 2024). Therefore, we consider the main threshold to be approximately 1.8% of REER volatility.

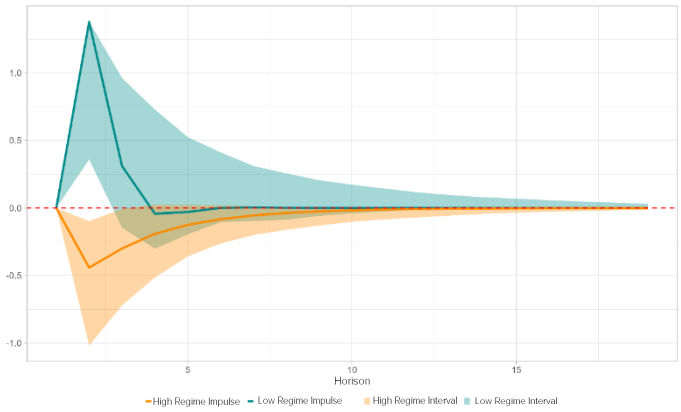

Figure 7. The Impact of a Volatility Shock on Industrial Output under Different Regimes (volatility is divided by the median), %

Next, we examine how this median-based division of REER volatility (around a 1.8% threshold) affects other economic activity indicators, specifically domestic trade output, construction output, and agricultural output. We also investigate whether the impact of REER volatility on economic activity varies depending on the extent of a sector's involvement in foreign trade and the price elasticity of demand for its goods.

Continuing our analysis, we now use domestic trade output as the primary indicator of economic activity instead of industrial output. The results of the Terasvirta test (Table 6, Appendix A, column 3) indicate a nonlinear relationship between the volume of domestic trade and the other variables. Similarly, the LR test reveals that at the 5% significance level, we find evidence of nonlinearity in two regimes, suggesting one threshold level (Table 7, Appendix A, column 3).

The threshold level of volatility is now 1.83%. Figure 8 shows the OIRFs from this TVAR model. The results indicate that REER volatility above 1.83% negatively affects domestic trade output. On the other hand, lower volatility tends to increase it. However, the statistical significance of these results is questionable due to the wide confidence intervals. We anticipated these findings because domestic trade output, while not directly export-oriented, has a high import component for non-food goods, which constitute a large share of retail trade turnover (Ishchuk and Sozanskyi, 2019) and for which demand is elastic. These results align with those for industrial output: dividing REER fluctuations by the median suggests that lower volatility can support economic activity, while higher volatility can harm it.

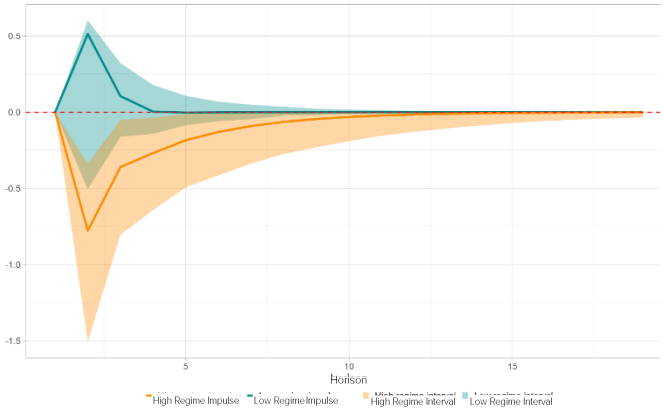

Figure 8. The Impact of a Volatility Shock on Domestic Trade under Different Regimes (volatility is divided by the median), %

Next, we examine the influence of exchange rate volatility on the output of the construction sector. The results of the Terasvirta test for the construction sector indicators show that there is no nonlinear relationship between the volume of construction and other variables (Table 6, Appendix A, column 4). However, the LR test demonstrates that at the 5% significance level, the test confirms the existence of nonlinearity in two regimes (Table 7, Appendix A, column 4).

The threshold level of volatility is 1.76%. Figure 9 demonstrates that volatility above 1.76% is more likely to negatively affect construction output. However, the wide confidence intervals do not indicate statistical significance. We anticipated these results, as the share of imported construction materials in the Ukrainian market is relatively small, accounting for only 14% in 2021.[11] Instead, we again observe that in lower volatility regimes, REER fluctuations tend to support economic activity. Therefore, the impact of REER fluctuations on the construction sector is not strong.

Next, we examine the influence of REER volatility on the output of the agricultural sector. The results of the Terasvirta test (Table 6, Appendix A, column 5) indicate that there is no nonlinear relationship between agricultural output and the other variables, but the LR test confirms the presence of nonlinearity in two regimes (Table 7, Appendix A, column 5).

The threshold level of volatility is 1.83%. Figure 10 demonstrates that exchange rate fluctuations tend to stimulate economic activity in the lower volatility regime and harm it in the higher volatility regime. However, we consider these results questionable due to the overlapping confidence intervals that cross zero. We anticipated these findings: while agricultural output constitutes a significant portion of Ukrainian exports, the demand for these goods has low price elasticity (Zadoia, 2023). This low elasticity likely explains why exchange rate fluctuations do not have a significant impact on this sector.

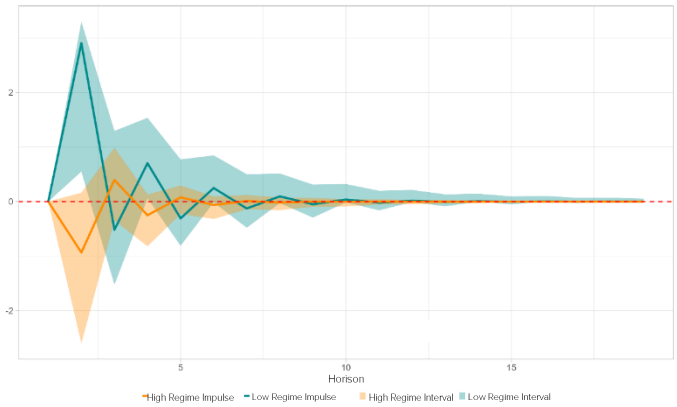

Figure 9. The Impact of a Volatility Shock on Construction under Different Regimes (volatility is divided by the median), %

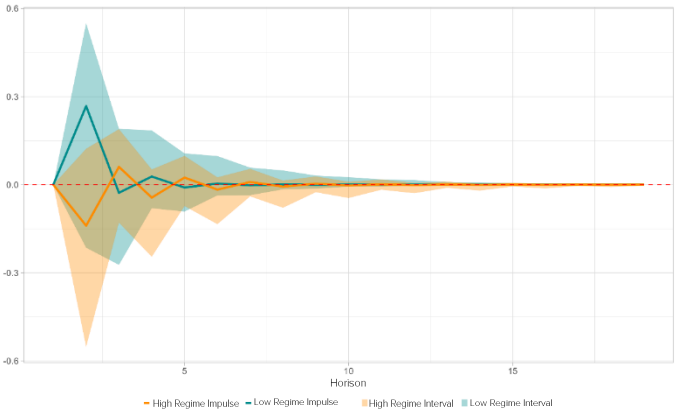

Figure 10. Impact of a Volatility Shock on the Agricultural Sector under Different Regimes (volatility is divided by the median), %

In conclusion, it's important to highlight that exchange rate volatility has a nonlinear effect on economic activity, with an identified threshold of approximately 1.8%. Above this level, REER fluctuations negatively impact economic activity, while below it, they tend to have a positive effect. Therefore, managing REER volatility to remain below this 1.8% threshold is advisable to avoid harming the economy. This nonlinearity is more pronounced for sectors heavily involved in international trade with elastic demand for

[11] https://propertytimes.com.ua/novosti/chastka_importnih_budivelnih_materialiv_naukrayinskomu_rinku_zrosla_do23_ekspert

their products, specifically industrial output and domestic trade. Conversely, the nonlinearity is less evident in the construction and agricultural sectors, although the 1.8% threshold remains relevant. Our findings corroborate the varying significance of exchange rate fluctuations across different economic sectors (Verheuvel, 2016; Kamel, 2021; Đukić et al., 2023). Notably, we also confirm a stronger nonlinearity in those sectors where the Terasvirta test indicated its presence.

4.2. Results: Inflation and Monetary Policy Implications

We have established a volatility threshold of approximately 1.8%, above which REER volatility negatively impacts economic activity. We now turn our attention to how this threshold affects inflation and the central bank's response. The results from our TVAR model indicate that inflation accelerates when REER volatility exceeds this 1.8% threshold (Figure 14, Appendix C). Below this threshold, inflation does not show a statistically significant response to exchange rate shocks. This finding holds consistently across all our indicators of economic activity (Figures 14-17, Appendix C). Thus, we confirm the impact of ERPT (Syarifuddin et al., 2014; Fabris and Lazić, 2022) and the tendency for producers to adjust their output prices above a certain volatility level (Jaramillo Rodríguez et al., 2019), both contributing to accelerating inflation.

Secondly, the TVAR model results demonstrate that an increase in REER volatility above 1.8% not only escalates inflation but also triggers an increase in rates on new corporate loans (Figures 14-17, Appendix C). Below this threshold, the interest rate decreases. This outcome confirms Kuncoro's (2020) findings regarding a restrictive monetary policy response. This conclusion remains consistent across all economic activity indicators. Therefore, crossing this 1.8% threshold serves as a clear signal for the central bank to implement measures in response to the adverse consequences of exchange rate fluctuations.

To summarize briefly, our findings indicate that when the volatility threshold of 1.8% is exceeded, inflation tends to accelerate. This inflationary pressure prompts the central bank to raise the key policy rate, which in turn tightens lending conditions and increases the rate on new corporate loans. These results remain consistent across our main indicators of economic activity, namely domestic trade, construction, and agricultural output.

5. CONCLUSIONS

This study examines the impact of a shock to REER volatility on economic activity in Ukraine. Utilizing VAR and TVAR models with data spanning 2009 to 2021, we aim not only to confirm the effect of volatility on economic activity but also to investigate the presence of a nonlinear impact characterized by a specific threshold and its underlying reasons. Furthermore, we analyze whether inflation accelerates and how monetary policy responds to exchange rate fluctuations.

First, our TVAR model reveals that the impact of REER volatility on economic activity is indeed nonlinear, with an estimated threshold of approximately 1.8%. Above this level, REER fluctuations exert a negative influence, while below it, they appear to stimulate economic activity. Notably, this threshold remains consistent not only for industrial output but also for other indicators of economic activity. We contribute to the existing literature on the nonlinear relationship by identifying this specific threshold level (Kamel, 2021).

We confirm that the nonlinear impact of exchange rate volatility on economic activity is more pronounced for sectors of the economy more engaged in foreign trade with elastic demand for their goods and services, specifically the industrial and domestic trade sectors. This finding supports the hypothesis that the effect of exchange rate fluctuations differs across economic sectors (Verheuvel, 2016; Kamel, 2021; Đukić et al., 2023). While the LR test revealed nonlinearity for all indicators of economic activity, the Terasvirta test detected it only in sectors in which nonlinearity is more pronounced (industrial and domestic trade). Although the Terasvirta test alone was insufficient to support a nonlinear model, it proved to be a valuable tool in identifying potential nonlinearities.

Secondly, inflation actively accelerates when the volatility threshold exceeds approximately 1.8%. We attribute this to ERPT (Syarifuddin et al., 2014; Fabris and Lazić, 2022) and the necessity for firms to adjust their own prices after a certain level of volatility is reached (Jaramillo Rodríguez et al., 2019). Therefore, we can partially explain the nonlinearity in the impact of exchange rate fluctuations on economic growth through the channel of inflation.

Thirdly, the rate on new corporate loans increases only after the volatility threshold of approximately 1.8% is reached. Below this level, it decreases. Consequently, this study provides the NBU with a potential indicator for determining when intervention to smooth out excessive REER volatility becomes necessary. To prevent negative economic consequences from exchange rate fluctuations and to potentially stimulate economic activity, the central bank should aim to keep REER volatility below 1.8%. This research corroborates the findings of previous studies on the restrictive reaction of monetary policy (Kuncoro, 2020).

Future research could build upon these findings in several ways. Firstly, researchers could further explore the nonlinear impact of exchange rate fluctuations on economic activity by employing alternative nonlinear models or models with time-varying coefficients. This approach could provide a deeper understanding of the impact, potentially accounting for structural changes in the economy such as shifts in the exchange rate regime and the implementation of inflation targeting. Secondly, the set of indicators representing economic activity could be expanded, particularly to include those relevant during wartime (Constantinescu et al., 2024), to analyze the effect of REER volatility in such contexts. Thirdly, the range of central bank tools for responding to excessive exchange rate volatility could be broadened to include foreign exchange interventions (Jara and Piña, 2023) and capital flow controls, recognizing that adjustments to monetary policy rates alone may be insufficient to curb extreme volatility or may need to serve multiple objectives simultaneously.

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APPENDICES

APPENDIX A. TABLES

Table 2. Data used in the Study

Name	Definition	Source
	Endogenous indicators	
ind_output	Seasonally adjusted real value of change in industrial output sold compared to the previous month, %	NBU, own calculations
agr_output	Seasonally adjusted real value of change in agricultural output compared to the previous month, %	NBU, own calculations
constr_output	Seasonally adjusted real value of change in construction output compared to the previous month, %	NBU, own calculations
domestic_trade	Seasonally adjusted real value of change in retail trade turnover of enterprises (domestic trade) compared to the previous month, %	NBU, own calculations
inflation	The difference in the Consumer Price Index compared to the previous month, %	NBU, own calculations
reer_volatility	The standard deviation of the change in the REER compared to the previous month (%) over the last three months (REER volatility), %	NBU, own calculations
credit_rate	The difference in the rate on new corporate loans compared to the previous month, %	NBU, own calculations
	Exogenous indicators	
tot	Seasonally adjusted change in the net export price index for Ukrainian goods (terms of trade) compared to the previous month, %	IMF, own calculations
libor	The difference between the three-month London Interbank Offered Rate (LIBOR) and the previous month, %	MarketWatch data stream, own calculations

Table. 3. Descriptive Statistics: Economic Activity Indicator

Variable	2009.m8-2021.m12			2009.m8-2013.m12			2014.m1-2015.m12			2016.m1-2021.m12			Source
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
ind_output	0.69	-7.37	10.34	0.93	-7.34	5.73	-0.43	-7.37	10.34	0.89	-5.70	8.31	NBU
domestic_trade	0.77	-16.69	9.11	1.39	-3.43	4.64	-1.29	-16.69	6.66	1.00	-14.87	9.11	NBU
constr_output	0.14	-48.07	46.87	-0.31	-16.68	21.35	0.54	-33.52	34.58	0.34	-48.07	46.87	NBU
agr_output	-0.11	-14.18	13.59	-0.05	-7.11	4.90	-0.29	-3.25	2.82	-0.08	-14.18	13.59	NBU

Table 4. Descriptive Statistics: REER Volatility

Variable	2009.m8-2021.m12			2009.m8-2013.m12			2014.m1-2015.m12			2016.m1-2021.m12			Source
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
reer_volatility	2.67	0.15	26.76	1.61	0.15	3.38	7.34	0.36	26.76	1.90	0.15	6.28	NBU

Table 5. Selecting the Lag Length According to the Criteria

Variables / Criterion	*ind_output*	*domestic_trade*	*constr_output*	*agr_output*
(1)	(2)	(3)	(4)	(5)
AIC	1	3	5	3
HQ	1	1	1	1
SC	1	1	1	1
FPE	1	3	5	3

Table 6. Terasvirta Neural Network Test for Detecting Nonlinearity

Variables / Terasvirta test	*ind_output*	*domestic_trade*	*constr_output*	*agr_output*
(1)	(2)	(3)	(4)	(5)
p-value	0.002	0.000	0.952	0.996
X-squared	37.721	48.004	7.900	5.025

Table 7. A Multivariate Extension of the Linearity Test from Hansen (1999) and Lo and Zivot (2001)

Variables / LR test	*ind_output*	*domestic_trade*	*constr_output*	*agr_output*
(1)	(2)	(3)	(4)	(5)
p-value 1vs2	0.008	0.000	0.002	0.002
LR.statistic 1vs2	73.232	99.556	67.614	70.943
p-value 1vs3	0.034	0.000	0.000	0.066
LR.statistic 1vs3	108.513	139.326	111.602	93.328
p-value 2vs3	0.420	0.288	0.244	0.902
LR.statistic 2vs3	35.282	39.771	43.988	22.385

APPENDIX B. NONLINEARITY TESTS

We employ a set of tests to identify nonlinearity both between our broader set of indicators and economic activity, and specifically between REER volatility and economic growth. The two selected tests and their key features are described in more detail below.

The Terasvirta Neural Network test (Teräsvirta et al., 1993) is used to detect nonlinearity between a specific set of indicators and a resulting variable. This test has been shown to outperform the Ramsey RESET test and the White test in identifying nonlinear relationships (Prabowo et al., 2020). Our focus is on the alternative hypothesis, which posits the presence of nonlinearity.

Lo and Zivot (2001) developed a multivariate extension of the linearity test (LR test) originally proposed by Hansen (1999). This test is designed to detect the presence of nonlinear interactions among multiple variables. The null hypothesis of the LR test is that a linear relationship exists between the variables, which can be adequately described by a standard VAR model. The alternative hypothesis suggests that the sample can be better divided into two or even three distinct regimes (or modes) within a TVAR model, based on the values of a threshold variable.

The LR test compares the covariance matrices of a linear VAR model and a nonlinear TVAR model to determine if the difference is statistically significant. If the p-values for the "1vs2" test (testing one regime against two, implying the presence or absence of one threshold) and the "1vs3" test (testing one regime against three, implying the presence or absence of two thresholds) are similar, we then perform the "2vs3" test to distinguish between a model with two regimes and one with three.

The LR test can be described as follows:

$$LR_{01} = T\left(ln\left(det\left(\hat{\sum}_0\right)\right) - ln\left(det\left(\hat{\sum}_1\right)\right)\right), \quad (3)$$

where:

T – number of observations in the sample;

$det\left(\hat{\sum}_0\right)$ – determinant of the covariance matrix for the linear model (null hypothesis);

$det\left(\hat{\sum}_1\right)$ – determinant of the covariance matrix for the threshold model (alternative hypothesis).

APPENDIX C. FIGURES

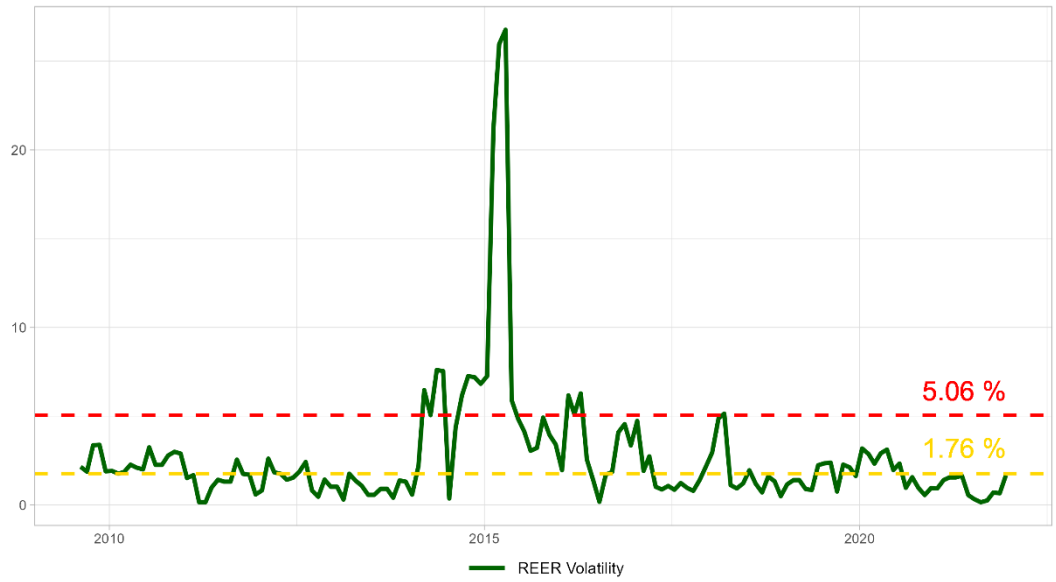
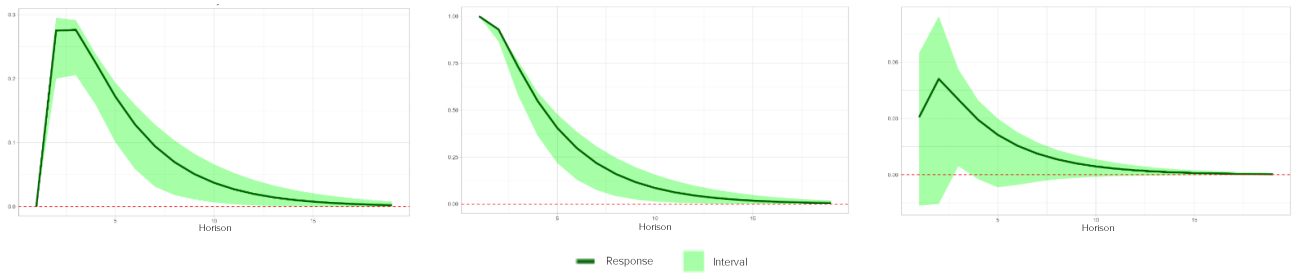


Figure 11. REER Volatility and Threshold Level, %

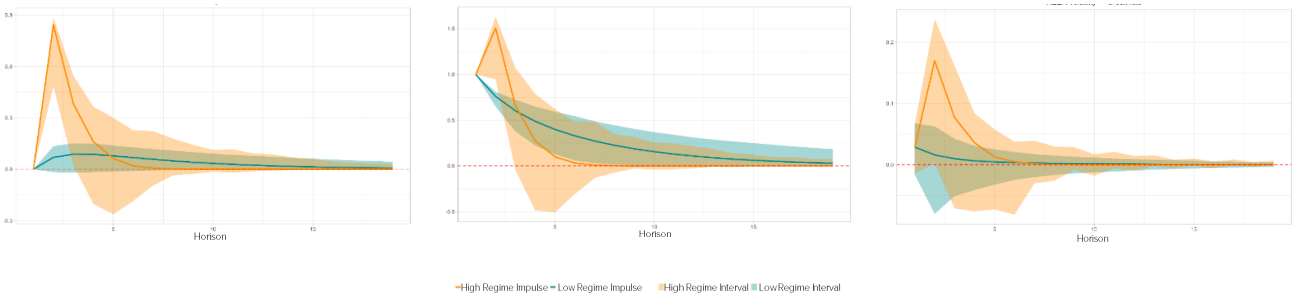


a) Reer Volatility ➔ Inflation

b) Reer Volatility ➔ Reer Volatility

c) Reer Volatility ➔ Credit Rate

Figure 12. Impulse response functions of the VAR model for Industrial Output, %

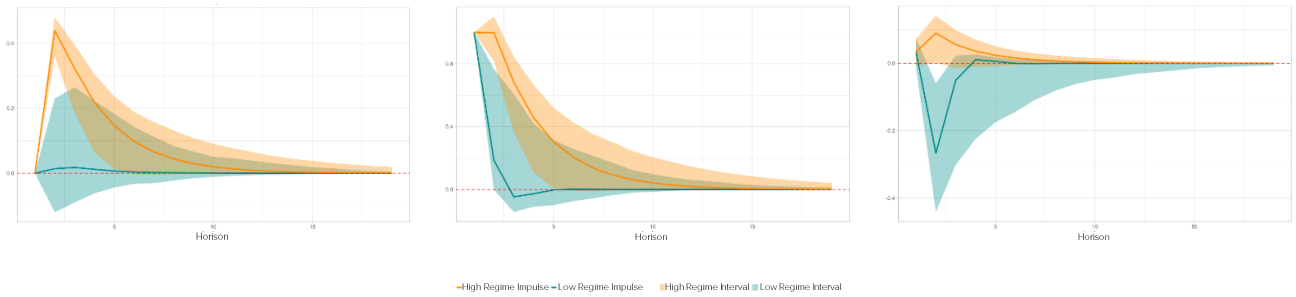


a) Reer Volatility ➔ Inflation

b) Reer Volatility ➔ Reer Volatility

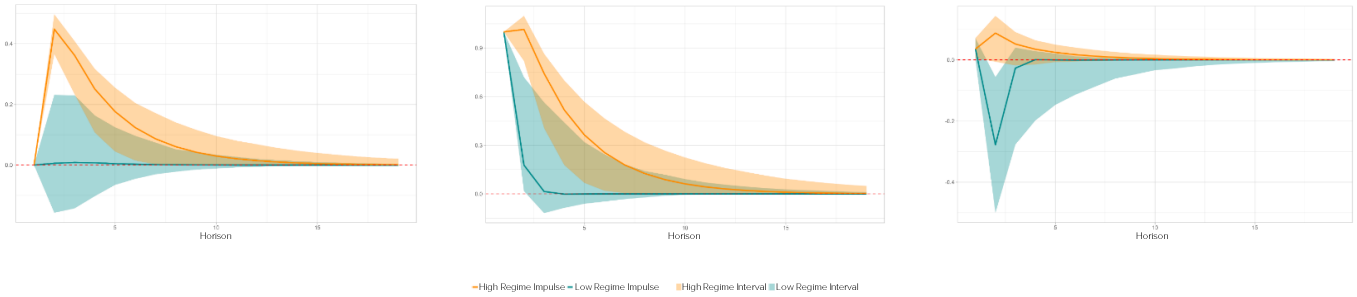
c) Reer Volatility ➔ Credit Rate

Figure 13. Impulse Response Functions of the TVAR Model for Industrial Output, %



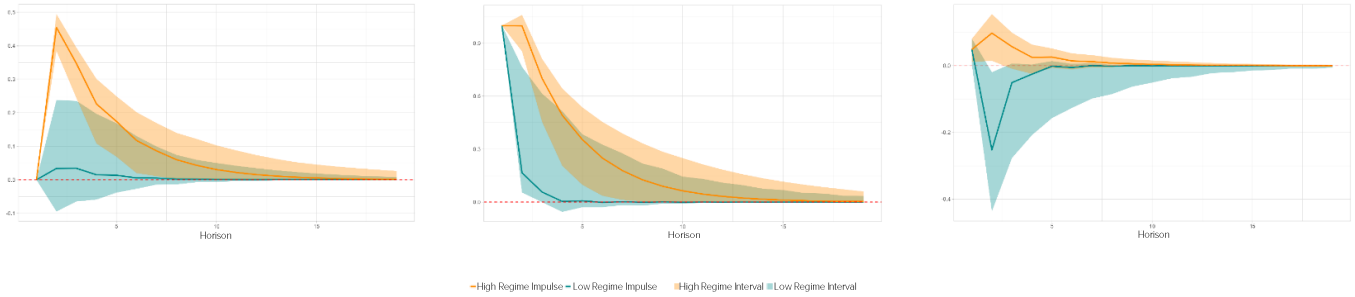
a) Reer Volatility ➔ Inflation b) Reer Volatility ➔ Reer Volatility c) Reer Volatility ➔ Credit Rate

Figure 14. Impulse Response Functions of the TVAR Model for Industrial Output when Volatility is divided by the Median, %



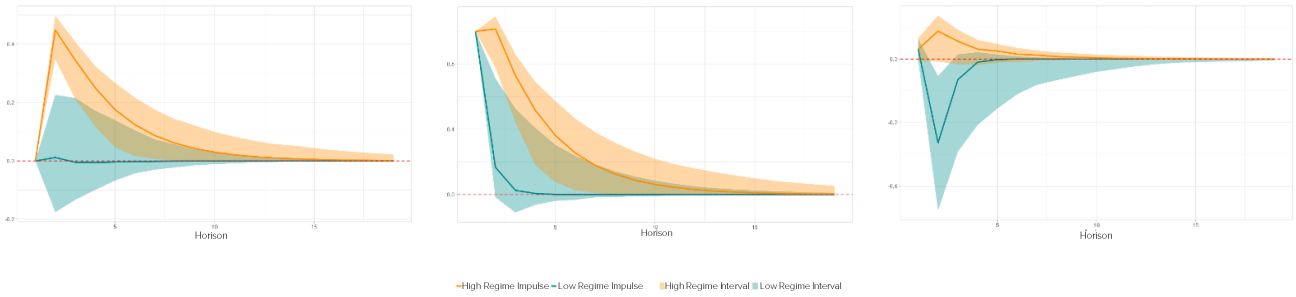
a) Reer Volatility ➔ Inflation b) Reer Volatility ➔ Reer Volatility c) Reer Volatility ➔ Credit Rate

Figure 15. Impulse Response Functions of the TVAR Model for Domestic Trade when Volatility is divided by the Median, %



a) Reer Volatility ➔ Inflation b) Reer Volatility ➔ Reer Volatility c) Reer Volatility ➔ Credit Rate

Figure 16. Impulse Response Functions of the TVAR Model for Construction Output when Volatility is divided by the Median, %



a) Reer Volatility ➔ Inflation b) Reer Volatility ➔ Reer Volatility c) Reer Volatility ➔ Credit Rate

Figure 17. Impulse Response Functions of the TVAR Model for Agriculture Output when Volatility is divided by the Median, %