

Time-varying parameters error correction model for real ruble exchange rate and oil prices: What has changed due to capital control and sanctions?

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Abstract

This paper aims to analyze changes in the long-term and short-term oil price elasticities of the real ruble exchange rate, as well as the speed of convergence of the exchange rate to a long-term equilibrium. The analysis is conducted using an error correction model with time-varying parameters. The results indicate that the short-term oil price elasticity of the exchange rate has consistently increased after the 2008–2009 crisis, reaching its peak in 2015. This peak coincided with the implementation of an inflation targeting regime by the Bank of Russia, as well as economic crises caused by sanctions and a decline in oil prices. During this period, the short-term elasticity exceeded the long-term elasticity, leading to a significant “overshooting” effect in response to oil shocks. Subsequently, the short-term elasticity gradually decreased as the economic situation stabilized, and by 2022–2023, it became insignificant. This was influenced by such factors as the inaction of financial markets and the implementation of capital controls. On the other hand, the long-term oil price elasticity remained relatively stable throughout most of the observation period, although it decreased during crisis periods.

Keywords: real ruble exchange rate, oil prices, error correction model, time-varying parameters model, capital control, sanctions, Russian economy.

JEL classification: E52, F31.

1. Introduction

The real effective exchange rate (REER) assesses a national currency’s value against a weighted average of major trading partners’ currencies, serving as

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a primary indicator of a country's international competitiveness. It is essential to model the REER for formulating effective monetary policies and analyzing their consequences.

The terms of trade are a major determinant of the real ruble exchange rate. Given that oil, oil products, and natural gas constitute vital components of Russian exports, oil prices are often used as a proxy for the terms of trade.

This study examines the relationship between the ruble real effective exchange rate and oil prices, utilizing an error correction model with time-varying parameters. The analysis covers data spanning from 1994 to 2023 encompassing shifts in Russia's monetary policy regimes, such as the ruble devaluation during the 2008–2009 crisis and the transition to a floating exchange rate regime with inflation targeting in 2014. This approach allows an estimation of the error correction model while accommodating changes in the studied relationship.

2. Literature review

A substantial body of literature underscores the influence of oil prices on the real ruble exchange rate. Utilizing an error correction model is a prominent approach in studying this dependence. Cointegration, in particular, provides an effective foundation for modeling long-term relationships. Many studies aim to capture temporal shifts in this relationship, accounting for structural breaks, crises, and economic reforms.

Various research groups modeled the relationship between the exchange rate and oil prices (Beckmann and Czudaj, 2013; Ferraro et al., 2015; Nusair and Kisswani, 2015). Nusair and Kisswani (2015) tested a long-term relationship of the exchange rate with structural shifts across Asian countries, observing its presence in nearly all cases. Analyzing the relationship between the dollar exchange rate and oil prices, Beckmann and Czudaj (2013) incorporated nonlinear adjustment dynamics through a vector error correction model with Markov regime switching. Ferraro et al. (2015) explored the correlation between oil prices and the nominal exchange rate using the example of Canada to predict the exchange rate. The study highlighted the enhanced detection of cointegration in low-frequency data.

Sosunov and Shumilov (2005) estimated an error correction model, factoring in terms of trade, productivity in the non-tradable goods sector, and capital flows as fundamental variables for REER analysis. The estimated long-term oil price (terms of trade) elasticity of the real effective exchange rate stood at 0.64 (data up to 2003), with an adjustment rate of -0.3 , indicating relatively swift convergence to equilibrium. Other studies endeavor to incorporate regime changes when modeling the relationship between the real effective ruble exchange rate and oil prices (Polbin, 2017; Skrobotov and Fokin, 2018; Polbin et al., 2019). For instance, Polbin (2017) proposed an error correction model considering the change in the Bank of Russia's monetary policy regime in November 2014. The model estimates highlighted post-policy-switch a substantial alteration in the speed of real exchange rate adjustment to long-term equilibrium. Skrobotov and Fokin (2018) used a threshold error correction model to forecast changes in convergence using asymmetric reactions to positive and negative shocks in external economic conditions, indicating faster convergence during oil price decreases. Polbin et al. (2019) employed an error correction model

with Markov regime switching, revealing two regimes of ruble exchange rate dynamics: fast and slow adjustments to long-term equilibrium. The authors did not reject the hypothesis of an invariant long-term relationship between the real ruble exchange rate and oil prices.

This paper attempts to estimate a time-varying parameter error correction model (TVP-ECM) for the real ruble exchange rate, capturing fluctuations in all parameters over time through a random walk process. This class of models is widely used in macroeconomic research. Pioneering works (Cogley and Sargent, 2005; Primiceri, 2005) introduced changes in vector autoregression model parameters according to a random walk process, incorporating shifts in innovation covariance and stochastic volatility. This approach has been applied in exchange rate analysis (Byrne et al., 2016; Dybowski et al., 2018; Liu et al., 2020), economic growth (Antolin-Diaz et al., 2017; Inglesi-Lotz et al., 2014), and the influence of oil prices on the economy (Baumeister and Peersman, 2013; Gong and Lin, 2018; Lyu et al., 2021). For example, Dybowski et al. (2018) employed a TVP-SVAR model with stochastic volatility to characterize the Bank of Canada's monetary policy and the role of the exchange rate in interest rate determination. Time-varying parameter models are also useful for estimating trend inflation (Chan et al., 2018; Clark and Doh, 2014; Stock, Watson, 2016). Chan et al. (2018) used a TVP-ECM model to analyze trend inflation's relationship with long-run forecast of inflation exhibited variations across different time periods. Cogley (2005) employed a TVP-ECM model to describe the relationship between household consumption and aggregate income, estimating trend growth.

In recent years, the relationship between the real exchange rate and oil prices has been studied in the context of the COVID-19 pandemic and the uncertainty associated with oil prices. Kumeka et al. (2022) showed that in the post-pandemic period, oil shocks could weaken real exchange rates. However, the authors believe that the situation will return to normal along with the easing of trade restrictions. Śmiech et al. (2021) demonstrated that the increase in uncertainty of oil prices led to a decline in production in oil-exporting countries, namely Russia, Mexico, Canada, and Norway. In Russia, the drop in production was the most pronounced, and furthermore, the uncertainty shock led to a long-term weakening of the real exchange rate. Wang et al. (2022) used the copula functions to enhance the quality of forecasts for oil-exporting economies.

Future research could focus on identifying causes of oil shocks (Kilian, 2009). The reasons behind specific oil price shocks, whether supply-driven, related to global activity, or speculative in nature, should be considered. Currently, ongoing debates about identification techniques lead to differing results (Baumeister and Hamilton, 2019). Recent work underscores the importance of these factors for real exchange rate modeling (Kilian, Zhou, 2022), noting that exogenous oil market shocks account for a significant portion of U.S. real exchange rate variation. This includes 8% attributed to oil supply shocks, and 31% to flow and storage demand shocks, implying the substantial impact of global economic activity shocks on the real exchange rate. The authors also present evidence of a reverse effect, where exogenous shocks in the U.S. dollar's real exchange rate influence oil prices. While in this paper we do not differentiate between these shocks due to ongoing discussions on identification techniques, the TVP version of the model may capture some effects related to changing shock dynamics.

3. Model specification

To examine the cointegration relationship between the ruble's real effective exchange rate and oil prices, a time-varying parameters error correction model (TVP-ECM) is employed. This model enables the evaluation of changes in both long-term and short-term relationships between the two variables and utilizes data from the maximum available time period. Additionally, this approach is capable of capturing non-linear relationships within the data. The estimation of this model was conducted using the Bayesian approach. The analysis is based on monthly data spanning from January 1994 to June 2022. The equation to be estimated is given below:

$$\Delta y_t = \theta_t(y_{t-1} - \alpha_{t-1} - \beta_{t-1}x_{t-1}) + \phi_t\Delta y_{t-1} + \psi_t\Delta x_t + \varepsilon_t, \quad (1)$$

where y_t —natural logarithm of the ruble's real effective exchange rate; x_t —natural logarithm of the real price of Brent crude oil; ε_t —random error that follows a normal distribution, $N(0, \sigma_\varepsilon^2)$.

We opted for this simple and concise specification as the experiments conducted indicated that the other lags did not have a significant impact.

To confine the adjustment parameter within the range of $(-1; 0)$, we employ the following transformation:

$$\theta_t = f(\kappa_t) = -\frac{e^{\kappa_t}}{1 + e^{\kappa_t}}, \quad (2)$$

where κ_t and other parameters represent the random walk process:

$$\kappa_t = \kappa_{t-1} + v_t, \quad (3)$$

$$\alpha_t = \alpha_{t-1} + \eta_t, \quad (4)$$

$$\beta_t = \beta_{t-1} + \gamma_t, \quad (5)$$

$$\phi_t = \phi_{t-1} + \zeta_t, \quad (6)$$

$$\psi_t = \psi_{t-1} + \xi_t. \quad (7)$$

Following Primiceri (2005), a preliminary OLS regression is estimated on the small initial subsample to calibrate a priori distributions for the starting values of the parameters. The period from January 1994 to December 1999 was chosen as this subsample. The starting values of the parameters are normally distributed with the following parameters:

$$\alpha_0 \sim N(\widehat{\alpha^{OLS}}, 4\sigma_{\alpha^{OLS}}^2), \quad (8)$$

$$\beta_0 \sim N(\widehat{\beta^{OLS}}, 4\sigma_{\beta^{OLS}}^2), \quad (9)$$

$$\phi_0 \sim N(\widehat{\phi^{OLS}}, 4\sigma_{\phi^{OLS}}^2), \quad (10)$$

$$\psi_0 \sim N(\widehat{\psi^{OLS}}, 4\sigma_{\psi^{OLS}}^2), \quad (11)$$

The mean and variance of prior distribution for κ_0 were calculated using the delta method:

$$\kappa_0 \sim N\left(f^{(-1)}\left(\widehat{\theta^{OLS}}\right), 4\sigma_{\widehat{\theta^{OLS}}}^2\left[f^{(-1)'}\left(\widehat{\theta^{OLS}}\right)\right]^2\right), \tag{12}$$

where $f(\cdot)$ corresponds to the function from equation (2).

For the standard deviation of the error ε_t , the log-normal prior distribution is used:

$$\ln\sigma_\varepsilon \sim N\left(\ln\widehat{\sigma^{OLS}}, 1\right). \tag{13}$$

Precision of error distributions in equations (2)–(7), $\tau = 1/\sigma^2$, are treated as hyper-parameters. The following values are used: $\tau^{(\alpha)} = \tau^{(\beta)} = 2000$, $\tau^{(\kappa)} = 500$, $\tau^{(\phi)} = \tau^{(\psi)} = 250$.

After calibrating the prior distributions, the TVP-ECM model was estimated on the subsample from January 2000 to June 2023 using WinBUGS, where the posterior distribution of parameters is estimated using MCMC methods.

3. Test for unit roots and cointegration

In this section the results of the DF-GLS test for unit roots and the Engle–Granger test (Engle and Granger, 1987) for cointegration are presented. These tests were performed on the sample data from January 2000 to June 2023, which was used for estimating the model. Initially, we conducted the standard ADF test for unit root with lag selection based on modified Akaike’s information criteria (AIC). Then, using the selected set of lags based on Modified AIC, we proceeded with the DF-GLS test for our series (Ng and Perron, 2001; Perron and Qu, 2007). Based on the results of the tests, it can be concluded that the real exchange rate and oil prices are non-stationary and are I(1) series (see Table 1).

Test for cointegration was conducted using the two-step Engle–Granger procedure. In the first step, a cointegration relation is estimated using OLS on the sample data from 2000 to 2023. In the second step, the residuals of the estimated relation were tested for a unit root using MacKinnon critical values (MacKinnon, 2010). The null hypothesis of no cointegration between the real exchange rate and oil prices is rejected at all significance levels (see Table 2). This suggests that it is unlikely that there are missing long-run fundamental variables in the model that could affect the stationarity of the long-term relationship. Based on these test results, the ECM model is considered as the main specification of the model. However, an ARX model is also estimated in section 5 for robustness check.

Table 1
The DF-GLS test results for unit roots.

Variable	Observed Value	Number of Lags
y_t	−0.52	3
Δy_t	−12.09***	0
x_t	−1.23	2
Δx_t	−9.01***	0

Note: *** $p < 0,01$, ** $p < 0,05$, * $p < 0,1$; 1% critical value = −2.57, 5% critical value = −1.94, 10% critical value = −1.62.

Source: Authors’ calculations.

Table 2

The ADF test with MacKinnon critical values results for residuals of the estimated with OLS cointegration relation.

Variable	Observed value	Critical values
$y_t - \widehat{\alpha^{OLS}} - \widehat{\beta^{OLS}}x_t$	−5.68***	1% critical value = −3.94 5% critical value = −3.36 10% critical value = −3.06

Note: *** $p < 0,01$, ** $p < 0,05$, * $p < 0,1$.

Source: Authors' calculations.

4. Results

The results of the model estimation indicate that the parameter of adjustment to the long-term equilibrium, θ_t , is significant for the entire period. The estimate ranges from −0.15 to −0.11 (Fig. 1), suggesting a high rate of adjustment of the ruble exchange rate to the long-term equilibrium in certain periods. Specifically, there was a high rate of adjustment from 2003 to 2006, followed by a decline up to Global Financial Crisis. During this period, the Bank of Russia maintained a managed exchange rate regime for the ruble. From 2011 to 2014, the adjustment parameter increased, presumably due to a more flexible exchange rate regime managed by the Bank of Russia. During 2015 to 2017, when inflation targeting was implemented by the Bank of Russia, the speed of adjustment was high. However, it began to decrease with the introduction of a new budget rule in Russia. Under this rule, the Central Bank bought foreign currency following the request of the Ministry of Finance when oil prices were high. This suggests that the adjustment of the real exchange rate to the long-term equilibrium is partly driven by consumer inflation.

The coefficient of the current difference of the logarithm of oil prices (short-term elasticity)¹ is depicted in Fig. 2. The real exchange rate will adjust more quickly to the equilibrium if the short-term elasticity is higher, as its initial change will be greater. From the figure, it can be observed that this parameter was not significant until the end of the 2008–2009 crisis in Russia. Additionally, this parameter became insignificant towards the end of the estimation period, around the beginning of 2022. The point estimate of the parameter increased throughout the entire period, indicating an increase in the speed of adjustment of the real exchange rate to new long-run equilibrium after oil price shocks. This suggests that the real exchange rate of the ruble became more flexible for almost the entire period. However, at present, the situation has changed and returned to that of the late 2000s.

This could be attributed to the fact that in 2022, there were significant restrictions on operations in the financial market, which affected the dynamics of the exchange rate. The oil market has a characteristic feature of price rigidity in contracts, meaning that substantial supplies of Russian oil, gas, and oil products are determined by fixed contract prices. In a period of flexible exchange rate formation, an increase in prices on the global oil market leads to expectations of future changes in contract prices. This, in turn, results in an inflow of petrodol-

¹ This parameter is referred to as the short-term elasticity because it represents the percentage change in the real exchange rate immediately following a change in oil prices. It is essentially the starting point or initial impulse response of the real exchange rate to oil price shocks.

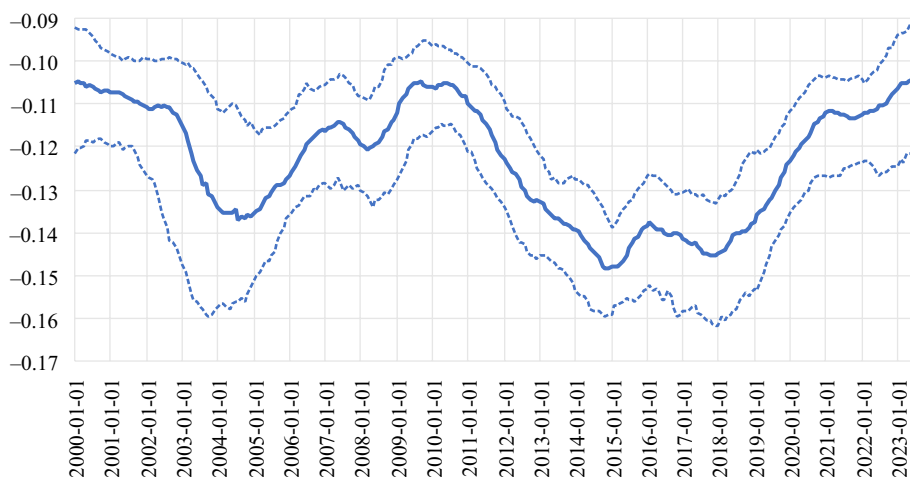


Fig. 1. Correction parameter (θ_t) estimate and 68% confidence interval.

Source: Authors' calculations.

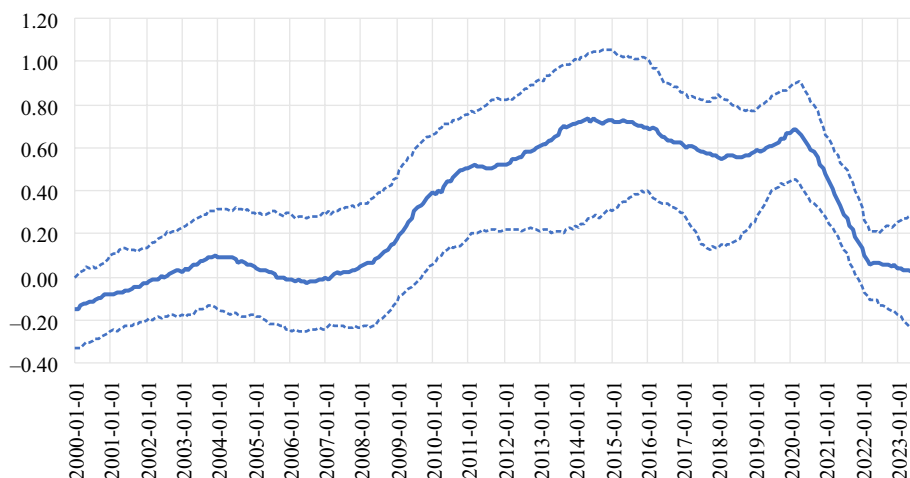


Fig. 2. Short-term oil prices elasticity of the real ruble exchange rate parameter (ψ_t) estimate and 68% confidence interval.

Source: Authors' calculations.

lars into the country and strengthens the exchange rate. This process involves an information channel, where economic agents anticipate a future strengthening of the ruble and engage in operations that strengthen it at present.

However, due to the restrictions in the financial market, this channel does not operate effectively. The dependence of the ruble exchange rate on the current increase in oil prices diminishes, and adjustments towards long-term equilibrium occur slowly. In 2023, there was some relaxation of financial restrictions. Nevertheless, sanctions were imposed, including price ceilings for oil purchases and limitations on insurance for oil transportation by sea. As a result, actual sales prices of oil became largely undisclosed, and world oil prices became a noisy indicator of actual oil sales. Moreover, aggregate statistics on actual export earnings from oil sales were published with a significant delay. Consequently,

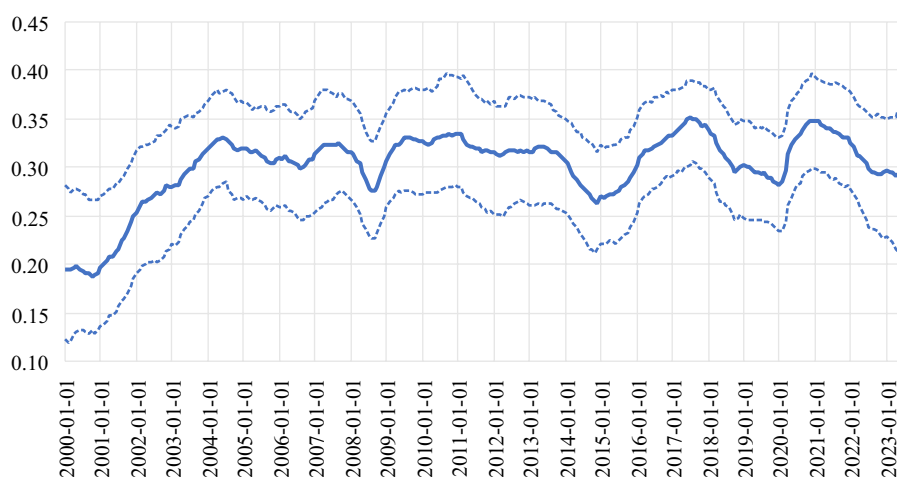


Fig. 3. Long-term oil prices elasticity of the real ruble exchange rate parameter (β_l) estimate and 68% confidence interval.

Source: Authors' calculations.

the dynamics of the ruble exchange rate became largely influenced by shocks in economic agents' expectations.

Our findings indicate that long-term elasticity² of the real exchange rate remains relatively stable throughout the analyzed period (Fig. 3). This aligns with theoretical expectations, which suggest that long-term parameters should change gradually and insignificantly. There is a noticeable period of growth in this parameter in the early 2000s, followed by fluctuations around 0.3 for the rest of the period. During economic recessions in Russia, such as in 2008–2009, 2015, 2020, and 2022, the long-term elasticity experiences a slight decline but remains consistently above 0.25. The median estimate of 0.3 is in line with other studies that employ similar estimation periods and models, further validating our findings—0.33 (Polbin, 2017) and 0.26 (Polbin et al., 2019). The decline in long-term elasticity observed during the 2022–2023 period may be attributed to the implementation of price ceiling sanctions and a decrease in oil production.

The overshooting effect refers to a situation where the real exchange rate responds more in the short run to a shock, such as changes in oil prices, than it does in the long run. In this case, the value of the long-run change in the real exchange rate is significantly lower than the initial change observed after the shock. From 2010 to 2021, there was a prolonged period where this overshooting effect was observed in the response of the Russian ruble's real exchange rate to oil shocks. This means that when there was a shock in oil prices, the ruble's real exchange rate would initially experience a larger change compared to the long-term equilibrium level. However, over time, the real exchange rate would gradually adjust and move closer to its long-run value.

Fig. 4 show the three-dimensional visualization of the time varying impulse response functions to a positive 10% permanent oil prices shock. In the context of this study, a “permanent shock” refers to a sustained and enduring increase

² We refer to this parameter as long-term elasticity because it measures the percentage change in the real exchange rate for a 1 percent change in oil prices after the exchange rate converges to a long-term cointegration ratio.

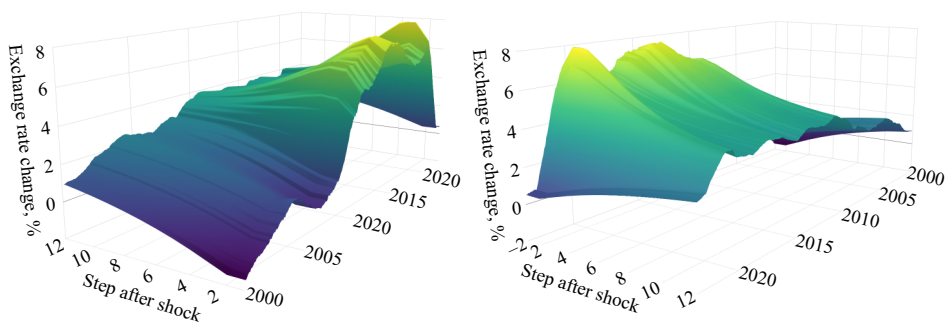


Fig. 4. The real ruble exchange rate time-varying impulse response function to a 10% permanent oil prices shock.

Source: Compiled by the authors.

of 10% in oil prices, which remains constant over time. Each impulse response curve is constructed by using median parameter estimates and is independently calculated for each time point within the specified period.

This figure illustrates our previous findings regarding the adaptation trajectory of the real exchange rate to equilibrium in response to oil price shocks. The response trajectory evolves over time. In the initial period under consideration (2000–2009), the dynamics of the responses were conventional, characterized by a slow adjustment towards equilibrium within the framework of a managed nominal exchange rate regime. Following the 2008–2009 crisis and the implementation of a more flexible exchange rate, the trajectory underwent changes. The short-term response of the real exchange rate became more pronounced than the long-term response (the overshooting effect), which was particularly evident in 2014–2015, caused by the transition of the Bank of Russia to the inflation targeting regime and the abandonment of interventions in the nominal exchange rate, despite sporadic interventions in certain periods. The introduction of a fiscal rule in 2017 began to steer the response trajectory back towards the patterns observed in the 2000s. However, the subsequent pandemic led to a return to the 2014–2015 dynamics. Of particular interest is the current period of 2022–2023, during which the response of the real exchange rate has once again exhibited a smooth adjustment in response to shocks. At present, the impulse response trajectory is reverting to the dynamics observed during the managed nominal exchange rate regime, which carries the risk of higher inflation compared to a more flexible exchange rate regime.

5. Robustness analysis

Additionally, we explore the use of the ARX model as an alternative to the ECM model to test the robustness of our results. The ARX model does not assume cointegration between the variables being analyzed. It is possible that we may have overlooked other important long-term determinants of the ruble's real exchange rate, such as the productivity differential between the tradable and non-tradable sectors compared to trading partners. The omission of this variable from our econometric model is due to the difficulty of its measurement.

The absence of these important long-term exchange rate determinants may introduce problems in evaluating the ECM model due to the incorrect specification

of the cointegration relationship. However, this is not a problem for evaluating the vector autoregressive (VAR) model in first differences for a subset of non-cointegrated variables. According to Lütkepohl (2005), if a set of variables is described by a VARMA model, then any linear transformation of that set will also be a VARMA process. We can exclude a subset of variables from the original VARMA model and focus on a smaller set, such as the logarithmic differences in real oil prices and the ruble exchange rate.

Furthermore, if the initial process is described by a vector error correction model (VECM), it can be easily represented as a VAR model by introducing a new variable representing the deviation from the cointegration relationship. In practice, when the moving average (MA) component of the VARMA model is invertible, it can be approximated by a finite-order VAR model.

We estimate the ARX model with the same number of lags as in the ECM model (other lags were insignificant):

$$\Delta y_t = \phi_t \Delta y_{t-1} + \psi_t \Delta x_t + \varepsilon_t, \quad (14)$$

where ε_t —normal distributed random variable, $N(0, \sigma_\varepsilon^2)$. The parameters ϕ_t and ψ_t are random walks (see equations 6–7), and their values defined as in ECM model (see equations 10–11). For the standard deviation of the error ε_t , the log-normal prior distribution is used (see equation 13).

Here we are taking the OLS estimates from ARX model estimated on the 1994–1999 sample.

Figs. 5–6 illustrate the trajectories of the common parameters in both the ECM and ARX models. These parameters include the short-term elasticity of the real exchange rate in relation to oil prices and the parameter at the first lag of the real exchange rate.

Based on these figures, it can be observed that the point estimates of the parameters exhibit similar dynamics. While there are some differences in the short-term elasticity between the ARX and ECM models, the overall trends remain

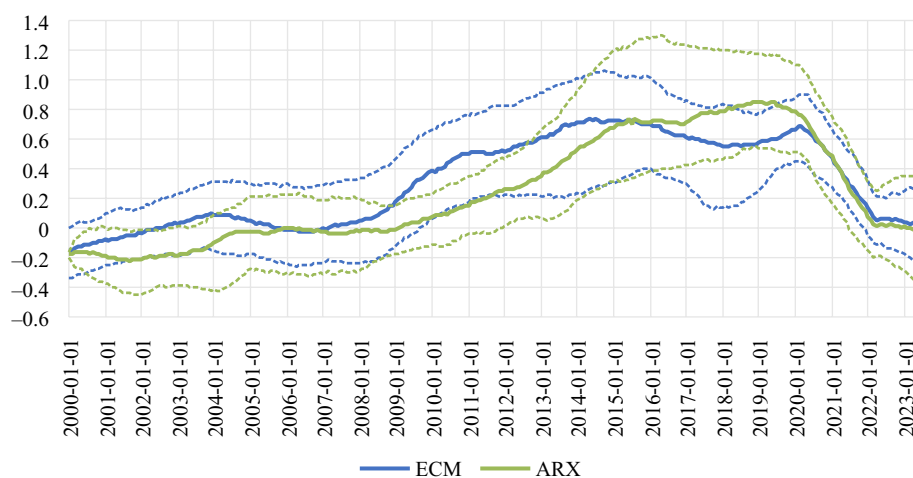


Fig. 5. Short-term oil prices elasticity of the real ruble exchange rate parameter (ψ_t) estimate in the ECM and the ARX models and 68% confidence interval..

Source: Authors' calculations.

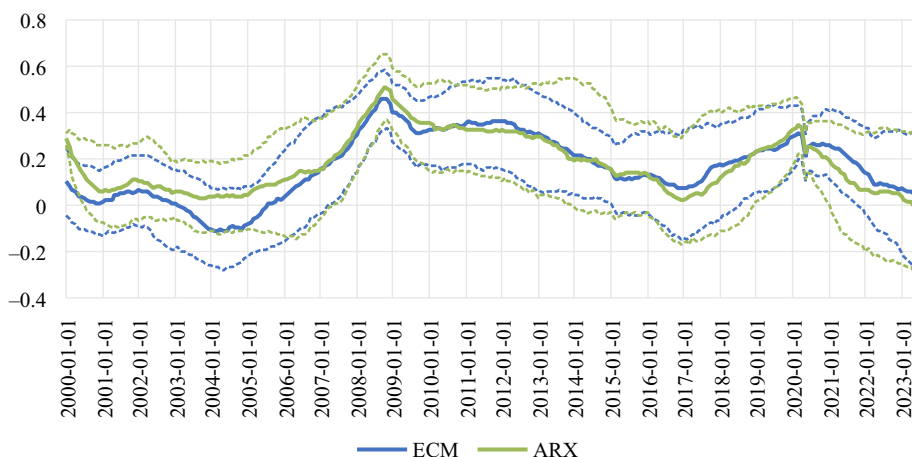


Fig. 6. Real ruble exchange rate first lag parameter (ϕ) estimate in the ECM and the ARX models and 68% confidence interval.

Source: Authors' calculations.

consistent. In both models, the short-term elasticity experiences growth throughout most of the period until the 2022 crisis.

6. Policy implications

Based on the results, despite a sharp decline in the short-term elasticity of the exchange rate concerning oil prices, the long-term elasticity remains high. Analyzing only the short-term correlations between the exchange rate and oil prices may create the illusion that the dependence of the exchange rate on oil prices has weakened, when in fact it has only weakened in the short term. This consideration is crucial when formulating economic policy measures, as the ruble exchange rate impacts inflation through the exchange rate pass-through effect on prices (Ponomarev et al., 2014) and affects the purchasing power of the population.

Currently, significant risks exist regarding potential future decreases in oil revenues due to sanctions and reduced global business activity. Additional risks arise from the international community's intention to curb hydrocarbon consumption as part of the fight against global warming. Consequently, substantial risks are present for a weakening of the ruble exchange rate, which could lead to negative socio-economic consequences. Therefore, economic authorities must develop a comprehensive set of measures to support the population and citizens in the event that such negative scenarios materialize.

In both the media and academic circles, an alternative perspective has often been presented, suggesting that the overall relationship between the exchange rate and oil prices has diminished. Such a viewpoint could lead to distortions in the perceptions of economic agents and decision-makers.

7. Conclusion

The analysis of the real ruble exchange rate in this study was conducted using an error correction model with time-varying parameters. This approach allowed

for an assessment of the relationship between the real effective exchange rate and oil prices over a wide time interval, including periods of crises and changes in monetary policy regimes. The estimates obtained in this study are consistent with previous research findings and also reveal a change in the relationship based on new data for 2023.

As demonstrated in this paper, the process of adjusting the real ruble exchange rate has undergone significant changes during the observation period. Initially, the adjustment process was slow due to low short-run elasticity. The speed of adjustment, as indicated by the correction parameter, increased slightly compared to short-run elasticity. This suggests that the adjustment of the real exchange rate to oil shocks was driven more by inflation than by sizable changes in the nominal exchange rate, even during periods of high oil price growth.

Following the recession in 2009, the situation changed, and the real exchange rate became more flexible. This flexibility continued for five years after the Bank of Russia switched to an inflation targeting regime instead of managing the nominal exchange rate. The fast adjustment of the real exchange rate to a new equilibrium caused by oil shocks, and even the occurrence of “overshooting” effects, where the real exchange rate changes more in the short-term than in the long-term, were observed during this period.

Currently, the mechanism has returned to its pre-2009 version, which can be attributed to the impact of sanctions and capital controls, resulting in less flexibility of the real exchange rate. However, the long-term elasticity remains stable. Therefore, analyzing only the short-term correlation between the exchange rate and oil prices may create an illusory impression that the overall relationship between the exchange rate and prices has diminished.

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