WORKING PAPER

ECONOMETRIC ANALYSIS OF DETERMINANTS OF THE NATIONAL BANK OF SERBIA’S FX RESERVES: IMPLICATIONS FOR THE PRESERVATION OF FINANCIAL STABILITY AND RESILIENCE TO EXTREME MACROECONOMIC SHOCKS

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Econometric analysis of determinants of the National Bank of Serbia's FX reserves: implications for the preservation of financial stability and resilience to extreme macroeconomic shocks

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Abstract: The aim of this paper is to analyse the determinants and dynamics of the conditional volatility of the National Bank of Serbia's gross FX reserves, with a focus on institutional resilience to systemic risks. The applied methodological framework comprises linear and nonlinear autoregressive distributed lag models, which enable the simultaneous assessment of the long-run and short-run effects of key macroeconomic determinants, the M3 monetary aggregate, foreign direct investment, and the degree of dinarisation of receivables. The risk profile was analysed using a GARCH(1,1) specification assuming a Student's *t*-distribution, while institutional resilience was assessed using a conditional macroeconomic stress test based on extreme value theory and Monte Carlo simulations with 15,000 iterations. The bounds test confirms a stable cointegrating relationship. The M3 monetary aggregate channel exerts a dominant positive effect on the accumulation of FX reserves. The analysis of dinarisation dynamics confirms the effectiveness of the adopted Dinarisation Strategy, as an increase in the share of dinar receivables reduces exposure to FX risk and optimises the need for holding precautionary FX reserves. The analysis of conditional volatility indicates an absence of volatility clustering, confirming the effectiveness of liquidity sterilisation by the central bank. At the same time, the statistically significant use of the Student's *t*-distribution confirms the presence of "heavy tails" in the distribution of residuals, indicating the system's exposure to rare but severe extreme shocks. Simulations of extreme events show that, at a 99% confidence level, the maximum cumulative outflow would amount to EUR 5.27 bn, while the system would retain more than an adequate level of available liquidity. These findings unequivocally confirm the high resilience of the domestic monetary policy and the preservation of long-term exchange rate stability..

Key words: FX reserves, financial stability, ARDL/NARDL models, Student-t GARCH, macroeconomic stress testing.
[JEL Code]: C22, E58, F21, F31

Non-technical summary

This paper provides a systematic assessment of the determinants and adequacy of the National Bank of Serbia's (NBS) gross FX reserves, which, over the period under review, have proven to be a key pillar and safeguard of the country's macroeconomic stability. The analysis confirms that the sustained growth in FX reserves is directly associated with developments in the M3 monetary aggregate, the expansion of which the central bank has offset through timely and proactive interventions in the FX market. This strategic approach enabled the successful containment of speculative pressures and the preservation of dinar exchange rate stability, thereby transforming monetary expansion into enhanced defensive capacities across the financial system.

In addition to monetary factors, the dynamics of FX reserves are significantly shaped by foreign direct investment flows, whose cycles – ranging from import requirements in the initial stages to profit repatriation in the mature phase – necessitate the maintenance of higher levels of FX liquidity. On the other hand, empirical findings provide strong support for the rationale behind the Dinarisation Strategy. A higher share of dinar receivables fundamentally limits risks to the corporate and household sectors and reduces the need to accumulate excessive precautionary assets, thereby directly minimising the opportunity costs associated with holding such assets.

Finally, a quantitative assessment of the system's resilience, based on FX reserves of EUR 29.0 bn at end-2025 and record-high gold reserves of 52.5 tonnes, demonstrates the capacity of FX reserves to absorb extreme external shocks. The conducted stress testing, which simulates hypothetical crisis scenarios, shows that even in the event of extreme, synchronised and simultaneous shocks, the maximum cumulative outflow would amount to EUR 5.2 bn. The fact that, even after such a severe shock, the NBS would retain more than EUR 23.8 bn in available liquidity provides empirical confirmation that the level of FX reserves and exchange rate stability are sustainable over the long term and from an economic perspective..

Contents

1 Introduction

An analysis of the determinants and dynamics of FX reserves represents one of the fundamental issues of macroeconomic stability in a small, open economy, particularly under conditions of high import dependence and a high degree of euroisation. The current macroeconomic environment in the Republic of Serbia is characterised by a dynamic setting marked by global geopolitical tensions, fragmentation of supply chains, and restrictive monetary policy adjustments by major central banks. Under such circumstances, increased investor risk aversion and volatility in commodity prices are testing the flexibility of the domestic economic system (Calvo, 1998). **In the conditions of heightened global uncertainty, FX reserves are not merely a conventional indicator of external liquidity, but rather a primary macroeconomic shield against external shocks, a safeguard of financial stability, and a key instrument for maintaining confidence in the national currency.** Guided by the principles of liquidity and safety, the NBS uses FX reserves as one of the key mechanisms for maintaining the relative stability of the dinar exchange rate, meeting external obligations, and cushioning systemic balance-of-payments imbalances in the event of potential crises. **At end-2025, the NBS's gross FX reserves stood at a very high level of EUR 29.0 bn (or EUR 24.6 bn net), supported by record-high gold reserves of 52.5 tonnes (equivalent to EUR 6.2 bn, accounting for 21.4% of total gross assets).**

A comprehensive assessment of FX reserves adequacy based on traditional and composite indicators confirms that the NBS's gross FX reserves fully support the macroeconomic environment and the stability of the domestic financial system, as the value of each individual indicator exceeds all established international reference minimums and optimal adequacy thresholds. The specifically designed internal indicator, the "right measure for Serbia," further confirms the system's high resilience to shocks that directly reflect the domestic structure of debt and potential outflows of FX and dinar deposits of the corporate and household sectors. At the same time, the **Jeanne–Rancière stress-testing model** (Jeanne & Rancière, 2006) **empirically demonstrates that the country's external position is highly resilient to the simultaneous impact of multiple factors and a sudden stop in capital inflows, ensuring the preservation of financial stability, even under the assumptions of the most conservative stress scenarios and the risk of extreme, low-probability events**, **in the sense of the black swan concept** (Taleb, 2007; National Bank of Serbia, 2025).

However, although these traditional models provide quantitative confirmation of reserve adequacy, by their nature they offer a predominantly static picture, as they rely on pre-calibrated parameters and do not capture dynamic, nonlinear adjustments in real time, which fully justifies the application of more advanced dynamic econometric models. The aim of the research is to precisely quantify, based on empirical monthly data for the period from January 2008 to December 2025, the nature of the long- and short-run relationships between gross FX reserves and their main macroeconomic determinants. The empirical focus is placed on the dynamic impact of three key transmission channels: the M3 monetary aggregate; foreign direct investment (FDI), expressed as a share of gross domestic product (GDP); and the degree of dinarisation of household and corporate receivables – **the evaluation of which also provides**

direct empirical confirmation of the long-term success of the NBS's Dinarisation Strategy (National Bank of Serbia, 2025), **given that an increase in the share of dinar deposits and receivables systematically mitigates the exposure of the corporate and household sectors to FX risk.**

To address the issue of non-stationarity in the series (Dickey & Fuller, 1979; Zivot & Andrews, 1992) and avoid the phenomenon of spurious regression, while at the same time preserving long-run information on equilibrium levels, the paper employs a modern econometric approach based on the linear (Pesaran et al., 2001) and nonlinear autoregressive distributed lag (NARDL) models (Shin et al., 2014). In addition to examining the long-run cointegrating relationship, which was further validated by applying equation-based cointegration tests (Banerjee, Dolado & Mestre, 1998), the conditional volatility and risk profile of FX reserves was analysed using a Student-t GARCH (1,1) specification (Danielsson, 2011). Furthermore, with a view to macroeconomic stress testing of resilience to systemic risks arising from extreme events, the paper conducts a conditional macroeconomic stress test based on the extreme value distribution (EVT-GEV), using 15,000 stochastic Monte Carlo simulations (McNeil and Frey, 2000; Coles, 2001) over a twelve-month projection horizon. In this way, the study provides a comprehensive empirical analysis of the effectiveness of monetary policy and the NBS's Dinarisation Strategy.

The structure of the paper is organised as follows. Following an introductory discussion of the importance of FX reserves, the second section provides a detailed overview of the methodological framework for econometric modelling, including testing the properties of the time series and the specification of the baseline ARDL model. The third section is devoted to cointegration analysis and the bounds test, with a focus on estimating long-run multipliers and short-run dynamics through an error correction model. The fourth section examines the structural stability of the parameters. The fifth section analyses the nonlinear (asymmetric) effects of the dinarisation strategy and monetary shocks using the NARDL model. The sixth section models the conditional volatility of FX assets using a GARCH(1,1) specification, incorporating the assumption of a Student's *t*-distribution, together with diagnostic testing of the normality of residuals (Jarque & Bera, 1987). The seventh section presents the results of the macroeconomic stress testing based on the GEV distribution and stochastic Monte Carlo simulations of extreme risks. The paper concludes with synthesised conclusions and a review of the literature used.

2 Methodological econometric modelling framework and baseline ARDL model specification

2.1 Testing the properties of time series

Prior to specifying the dynamic ARDL model, it is methodologically imperative to formally determine the order of stationarity of each individual series in order to rule out the presence of $I(2)$ processes. To accurately determine the order of integration of the variables, the Augmented Dickey–Fuller (ADF) unit root test was applied (Dickey & Fuller, 1979). For the level variables exhibiting a pronounced time trend (gross FX reserves and the M3 monetary aggregate), the test was conducted with a constant and deterministic trend included, while for the other level series (FDI as a share of GDP and the dinarisation of receivables), as well as for all variables in first differences, a specification with a constant included was used. The optimal number of lags was determined automatically based on the Bayesian Information Criterion (BIC).

The empirical results of the ADF test, presented in Table 1, reveal distinct stochastic properties across the analysed macroeconomic series. **FDI is the only variable that achieves full stationarity already in its original levels**, as evidenced by its very low *p*-value. This finding indicates that the FDI series follows an $I(0)$ integration process, reflecting the relatively rapid reversion of the series to its long-run mean after temporary shocks.

In contrast, gross FX reserves, the M3 monetary aggregate, and the degree of dinarisation of receivables exhibit pronounced non-stationarity in levels, implying a strong persistence component and a long-run trend in their movements. However, following the application of the first-difference operator, all three variables become stationary, confirming that they are processes integrated of order one, i.e. $I(1)$ series.

Table 1 **Results of the Augmented Dickey-Fuller unit root test**

Variable	Series form	Model specification	ADF statistics	*p*-value
Gross FX reserves	Level	Constant+deterministic trend	-1.7237	0.7375
	First difference	Constant	-11.6504	0.0000***
M3 monetary aggregate	Level	Constant+deterministic trend	-1.5535	0.8079
	First difference	Constant	-15.6178	0.0000***
FDI	Level	Constant	-6.0808	0.0000***
Dinarisation of receivables	Level	Constant	-0.9038	0.7857
	First difference	Constant	-6.5889	0.0000***

Note: *** indicates rejection of the null hypothesis of a unit root and the presence of stationarity at the 1% significance level.
Source: Authors' calculation based on NBS data.

These consistent diagnostic results confirm that the key variables are integrated of order zero or one, thereby definitively ruling out the presence of second-order integrated processes in the system and confirming the full methodological appropriateness of employing the ARDL/NARDL methodology and the bounds testing approach.

2.2 Specification of the baseline ARDL model and empirical results of the primary regression

Following confirmation of the appropriate order of integration of the time series through the diagnostic tests presented above, the general linear ARDL model is specified in levels. This baseline dynamic model is specified as follows:

$$\ln(FXR_t) = c + \sum_{i=1}^{p} \phi_i \ln(FXR_{t-i}) + \sum_{j=0}^{q_1} \beta_{1,j} \ln(M3_{t-j}) + \sum_{k=0}^{q_2} \beta_{2,k} FDI_{t-k} + \sum_{m=0}^{q_3} \beta_{3,m} DIN_{t-m} + \varepsilon_t$$

where the defined symbols denote:

- $\ln(FXR_t)$ – the natural logarithm of the monthly level of the NBS's gross FX reserves at time *t* (dependent variable);
- c – model constant;
- $\ln(M3_t)$ – the natural logarithm of the monthly level of the M3 monetary aggregate;
- FDI_t – share of monthly net FDI inflow in monthly GDP;
- DIN_t – share of dinar-denominated household and corporate receivables in total household and corporate receivables on a monthly level;
- i, j, k, m – optimal lags for the dependent and independent variables, respectively;
- ϕ_i, $\beta_{1,j}$, $\beta_{2,k}$, $\beta_{3,m}$ – short-run dynamic coefficients capturing the effects of the lags;
- ε_t – white noise.

Since official GDP data are published on a quarterly basis, whereas the econometric model requires all analysed variables to be available at a monthly frequency, quarterly GDP was disaggregated to a monthly frequency using the standard Chow–Lin method (Chow & Lin, 1971). The monthly industrial production index was used as the high-frequency indicator (auxiliary series) in the interpolation procedure, as it represents the most reliable monthly indicator of economic activity in the Republic of Serbia. This approach ensures full accounting consistency, whereby the sum of the three disaggregated monthly values equals the official quarterly GDP, while preserving the actual monthly dynamics of the business cycle. Finally, the variable was defined as the ratio of monthly net FDI inflows to the monthly GDP obtained in this manner, thereby normalising inflows relative to the size of the economy and eliminating the scale effect.

A key step in the construction of this model is the precise determination of the optimal number of lags for each variable individually. To this end, a systematic search algorithm was conducted across the space of possible lag combinations (grid search), guided by rigorous minimisation of the Bayesian Information Criterion (BIC) (Wooldridge, 2021). This criterion was selected because it imposes a stronger penalty on models with a large number of parameters than other information criteria, thereby ensuring parsimony and mitigating the risk of overfitting the model to the sample.

The aforementioned *BIC* criterion identified ARDL(1, 1, 1, 0) as the optimal specification. This result indicates that the current level of gross FX reserves contains a pronounced inertia component (dependence on the previous month), while also responding promptly to one-month lags in the money supply and FDI, as well as to current changes in the degree of dinarisation of receivables. The model specification is presented as follows:

$$\ln(FXR_t) = \beta_0 + \beta_1 \ln(FXR_{t-1}) + \beta_2 FDI_{t-1} + \beta_3 \ln(M3_t) + \beta_4 \ln(M3_{t-1}) + \beta_5 DIN_t + \varepsilon_t$$

The empirical results of estimating the baseline ARDL(1, 1, 1, 0) regression using the ordinary least squares (OLS) method are systematically presented in Table 2. The high adjusted coefficient of determination, which is common for dynamic ARDL models in levels with a lagged dependent variable, confirms that the selected system of variables explains **as much as 99.3% of the variability in the NBS's gross FX reserves**, while the overall statistical significance of the regression is confirmed by the F-statistic at the 1% significance level.

The high coefficient on the first lag of FX reserves indicates a pronounced autoregressive component and strong inertia in the dynamics of FX assets. This is fully consistent with the macroeconomic nature of FX reserves as a systemic safeguard, the level of which is characterised by a high degree of accumulation and gradual adjustment over time.

The current level of the M3 monetary aggregate exhibits a positive and statistically significant coefficient, while its first lag has a negative sign. The combined effect of these coefficients reflects the dynamic response of FX reserves to net changes in the money supply, confirming that monetary expansion in the short run is directly associated with an increase in the NBS's FX reserves due to foreign exchange purchases in the interbank market aimed at maintaining the relative stability of the dinar exchange rate.

Table 2 **Results of the ARDL(1, 1, 1, 0) model**

Independent variable	Coefficient	*p*-value
Constant	-0.1387	0.0424**
$\ln(FXR_{t-1})$	0.9703	0.0000***
$\ln(M3_t)$	0.6545	0.0000***
$\ln(M3_{t-1})$	-0.6040	0.0000***
FDI_{t-1}	-0.0017	0.0017***
DIN_t	-0.0028	0.0205**
Statistical and diagnostic model indicators		
Determination coefficient	0.9934	
Adjusted determination coefficient	0.9932	
F-statistics (*p*-value)	6,252.439 (0.000***)	
Durbin-Watson statistics	1.7711	

Note: ** and *** denote statistical significance at the 5% and 1% levels, respectively.
Source: Authors' calculation based on NBS data.

The exclusion of the contemporaneous FDI term and the retention of only its first lag has a clear economic and operational rationale. FDI inflows do not translate immediately into the central bank's FX reserves, as some time is required for the funds to pass through the interbank market and the payment system. In addition, the initial capital inflow in the same month is often accompanied by imports of equipment or raw materials required for the investment, temporarily offsetting the initial positive effect on FX reserves. Consequently, the actual net impact of FDI on the accumulation of FX reserves is recorded only with a one-month lag, as also empirically confirmed by the information criteria used in model selection.

The statistically significant negative coefficient on the degree of dinarisation of receivables reflects the effects of implementing the Dinarisation Strategy, whose key objective is to reduce the impact of euroisation on domestic economic flows. By reducing reliance on foreign currency funding, the economy becomes less dependent on FX interventions, thereby reducing the need for the central bank to maintain high levels of FX reserves. In this way, pressure on the FX balance is effectively eased, confirming the positive effect of dinar flows on macroeconomic stability.

Standard diagnostic tests indicate that the model residuals exhibit neither serial correlation nor conditional heteroskedasticity. The Box–Ljung test confirms the absence of autocorrelation and partial autocorrelation, indicating the robustness and efficiency of the estimated model. Accordingly, the estimated parameters are statistically valid for the subsequent stages of the analysis, including the cointegration analysis and the bounds testing procedure.

3 Cointegration analysis and bounds testing

3.1 Bounds testing

Once the high quality of the baseline regression has been confirmed, the next methodological step is to examine whether a long-run cointegration relationship exists among the economic variables under consideration. To formally verify cointegration, the bounds test is conducted within the framework of an Unrestricted Error Correction Model (UECM). This model represents a dynamic reparameterisation of the baseline ARDL equation *(Pesaran et al.,* 2001) and is specified as follows:

$$\begin{aligned}\Delta\ln(FXR_t) = c &+ \rho\ln(FXR_{t-1}) + \lambda_1\ln(M3_{t-1}) + \lambda_2 FDI_{t-1} + \lambda_3 DIN_{t-1}\\ &+ \sum_{i=1}^{p-1}\gamma_i\,\Delta\ln(FXR_{t-i})\\ &+ \sum_{j=0}^{q_1}\alpha_j\,\Delta\ln(M3_{t-j}) + \sum_{k=0}^{q_2}\psi_k\Delta FDI_{t-k} + \sum_{m=0}^{q_3}\phi_m\Delta DIN_{t-m} + \varepsilon_t\end{aligned}$$

where the delta operator denotes the first difference of the variables, capturing their short-run dynamics. Within this framework, testing for long-run cointegration amounts to examining the joint statistical significance of the coefficients on the lagged level variables. Accordingly, the null hypothesis is formulated to rule out the existence of a long-run cointegration relationship among the variables under consideration, while the alternative hypothesis assumes that at least one of the coefficients is different from zero, indicating the existence of a long-run cointegration relationship:

$$H_0 : \rho = \lambda_1 = \lambda_2 = \lambda_3 = 0$$

H_1 : at least one of the coefficients is different from zero.

Table 3 **Results of the Pesaran bounds test**

	Value		
Calculated *F*-statistic	4.6572		
p-value of linear restriction	0.0013***		
Number of independent variables (*k*)	3		
Model specification	Case III (unrestricted constant, no trend)		
Critical values (Pesaran, Shin & Smith, 2001 – Case III, k=3)			
Level of significance (α)	**Lower bound *I*(0)**	**Upper bound *I*(1)**	**Test result**
0.10	2.72	3.77	Cointegration exists
0.05	3.23	4.35	Cointegration exists
0.01	4.29	5.61	Test is inconclusive

Note: *** denotes statistical significance at the 1% level.
Source: Authors' calculation based on NBS data and critical values (*Pesaran et al*., 2001).

The test is conducted by calculating a joint *F*-statistic, the empirical value of which is compared with the non-standard critical values (Pesaran et al., 2001). These tabulated values are defined by the lower bound *I*(0), which assumes that all variables are stationary in levels, and the upper bound *I*(1), which assumes that all variables are stationary in first differences. If the calculated *F*-statistic exceeds the upper critical bound *I*(1), the null hypothesis is rejected in favour of the existence of cointegration. If the calculated *F*-statistic falls below the lower critical bound *I*(0), the null hypothesis is not rejected, and the conclusion is that there is no cointegration relationship. In contrast, an *F*-statistic value falling between the two critical bounds renders the test inconclusive. The empirical results of the bounds test conducted in this study are summarised in Table 3.

Model results show that the calculated *F*-statistic (4.6572) exceeds the critical value of the *I*(1) upper bound at the standard 5% significance level, as well as at the 10% significance level. Accordingly, the null hypothesis is rejected with a high degree of statistical confidence, providing **evidence of a strong, stable and economically justified long-term relationship among FX reserves, the M3 monetary aggregate, the share of FDI in GDP, and the degree of dinarisation of receivables**. The very low *p*-value of the linear restriction provides additional mathematical confirmation of the stability and high statistical significance of the specified long-run restrictions.

3.2 Long-run dynamics and multipliers

Once cointegration has been confirmed, the next step is to reparametrise the model into an error correction form in order to analyse short-run dynamics:

$$ln(FXR_t) = \beta_0 + \beta_1 ln(M3_t) + \beta_2 FDI_t + \beta_3 DIN_t + \varepsilon_t$$

where coefficients $\beta_1, \beta_2, \beta_3$ represent the long-run elasticities or semi-elasticities of the variables. The estimated long-run coefficients, which quantify the effects of the independent variables on gross FX reserves, are presented in Table 4.

In analysing the estimated long-run equilibrium coefficients, the M3 monetary aggregate emerges as a key determinant of gross FX reserves. With a positive coefficient of 1.7027, which is statistically highly significant at the highest 1% level, **this monetary aggregate implies that a 1% increase in the money supply is associated, in the long term, with an approximately 1.70% increase in gross FX reserves**. This finding is consistent with the economic rationale underlying the regime of a relatively stable dinar/euro exchange rate. In the presence of appreciation pressures on the domestic currency arising from capital inflows, the central bank engages in net FX purchases in the interbank FX market. Through these interventions, the NBS simultaneously accumulates FX assets and generates dinar liquidity. Consequently, an increase in the M3 monetary aggregate is accompanied by a corresponding increase in the level of FX reserves, thereby contributing to the mitigation of pressures on the dinar exchange rate.

Table 4 **Overview of long-run cointegration coefficients**

	Coefficient	***p*-value**
Long-run impact of M3 monetary aggregate (in %)	1.7027	0.1294
Long-run impact of FDI (in pp)	-0.0589	0.0010***
Long-run impact of the degree of dinarisation of receivables (in pp)	-0.0938	0.0670*

Note: * and *** denote statistical significance at the 10% and 1% levels, respectively.
Source: Authors' calculation based on NBS data.

Directly structurally linked to the dynamics of domestic monetary aggregates is the process of dinarisation, which is quantified in the model by the degree of dinarisation of household and corporate receivables. The estimated negative long-run coefficient amounts to -0.09 and is statistically significant at the 10% level, providing empirical support for the rationale underpinning the objectives set out in the Dinarisation Strategy consistently pursued by the NBS. Since the dinarisation variable is expressed in levels as a percentage share, this coefficient represents the semi-elasticity of the model, implying that **each 1 pp increase in the degree of dinarisation of the financial system leads to a structural reduction in the underlying need for FX reserves by approximately 0.09%**. From a macroprudential policy perspective, a sustained increase in the share of dinar loans in total receivables reduces the banking sector's systemic exposure to foreign currency-indexed credit risk, i.e. the risk of a deterioration in the solvency of unhedged borrowers due to exchange rate fluctuations. As this systemic risk is mitigated, the central bank's need to accumulate high precautionary foreign exchange buffers (Jeanne & Rancière, 2006), maintained through the reserve requirement imposed on commercial banks, is also reduced. In this way, a higher degree of long-run dinarisation facilitates the NBS's balance sheet assets optimisation and reduces the opportunity costs associated with holding excessive FX reserves.

In contrast to the monetary channels, the long-run effect of FDI is associated with specific and moderate structural pressures, with a cointegrating coefficient estimated at -0.06; however, the coefficient is not statistically significant at conventional significance levels. Since, in the absence of statistical significance, the estimated coefficient cannot be reliably distinguished from zero, these results do not provide a basis for drawing robust conclusions about the long-run effect of FDI on the level of FX reserves. In econometric practice, interpreting the economic significance of the sign and magnitude of a statistically insignificant parameter lacks empirical support. Therefore, within the given specification, this factor cannot be regarded as a statistically relevant long-run determinant of FX reserves.

3.3 Short-run dynamics and the error correction model

To examine short-run adjustments and the operational responses of the monetary system at the monthly frequency, the model is transformed into its final restricted error correction form by introducing a lagged error correction term (ECT_{t-1}).

$$\Delta ln(FXR_t) = \alpha_0 + \sum_{i=1}^{p} \gamma_i \, \Delta ln(FXR_{t-i}) + \sum_{j=0}^{q_1} \delta_j \, \Delta ln\big(M3_{t-j}\big) + \sum_{k=0}^{q_2} \phi_k \, \Delta FDI_{t-k}$$
$$+ \sum_{m=0}^{q_3} \psi_m \, \Delta DIN_{t-m} + \theta ECT_{t-1} + \varepsilon_t$$

where delta denotes the first-difference operator, while ECT_{t-1} denotes the error correction term, defined as follows (Pesaran, Shin & Smith, 2001):

$$ECT_{t-1} = ln(FXR_{t-1}) - (\beta_0 + \beta_1 ln(M3_{t-1}) + \beta_2 FDI_{t-1} + \beta_3 DIN_{t-1})$$

This term quantifies the deviation of the dependent variable from the long-run equilibrium path established in the previous period. The short-run dynamic model is estimated using the ordinary least squares (OLS) method, and the obtained results of the short-run dynamics are presented in Table 5.

Table 5 **Overview of short-run cointegration coefficients**

	Coefficient	***p*-value**
Error correction term	-0.033	0.0000***
Monthly change in M3 monetary aggregate	0.681	0.0000***
Monthly change in FDI	-0.001	0.312
Monthly change in degree of dinarisation of receivables	-0.014	0.002***

Note: *** denotes statistical significance at the 1% level.
Source: Authors' calculation based on NBS data.

Turning to the analysis of current short-run dynamics within the error correction model, the key empirical indicator of the financial system's dynamic stability is found in the error correction term. The estimated coefficient on $ECT_{t-1}$is -0.0331, has the theoretically consistent, strictly negative sign, and is highly statistically significant at the 1% level. This finding provides unequivocal empirical evidence of the existence of a functional selfcorrecting mechanism in the financial system of the Republic of Serbia (Banerjee et al., 1998). **In a monthly interval, 3.31% of the deviation of gross FX reserves from their long-run equilibrium path** (caused by sudden external shocks, geopolitical tensions or speculative pressures) **is systematically neutralised over the long term**. Such a moderate speed of adjustment indicates that the system has the capacity to gradually absorb shocks, which is often associated in the economic literature with the concept of precautionary FX reserve holdings aimed at safeguarding against long-term macroeconomic disturbances (Jeanne & Rancière, 2006). Although the statistical properties of the error correction term alone do not allow definitive conclusions to be drawn regarding FX market interventions, this convergence parameter indicates the absence of abrupt, procyclical depletion of FX reserves and primarily reflects a stable and controlled process of returning to the long-run equilibrium.

In the context of current monthly changes, the short-run impact of the M3 monetary aggregate amounts to 0.6811 and is highly statistically significant. At the monthly level, this coefficient directly reflects the primary channel through which domestic liquidity is created under a managed floating exchange rate regime. When there is a net inflow of foreign currency into the interbank FX market (through exports, remittances or foreign capital inflows), pressures for short-term appreciation of the domestic currency arise. To preserve exchange rate stability and price competitiveness, the NBS enters the FX market as a net buyer of foreign currency. Through these operational interventions, the central bank acquires foreign exchange assets and directly increases gross FX reserves, while simultaneously injecting primary dinar liquidity into the banking system, thereby leading to a parallel increase in the M3 monetary aggregate. Accordingly, **for every 1% increase in the M3 monetary aggregate, gross FX reserves increase by an average of 0.68% in the same month**, providing empirical evidence that short-run money supply creation is fully backed by the accumulation of FX assets.

In contrast to monetary developments, the short-run dynamics of the degree of dinarisation of receivables have a statistically significant negative impact on monthly changes in gross FX reserves, with an estimated coefficient of -0.0142. Since the dinarisation variable is expressed as a percentage, this coefficient represents a semi-elasticity of the model, meaning that **a 1 pp increase in the degree of dinarisation of receivables in the current month results in an average short-run decrease in gross FX reserves of 1.42%**. The above finding precisely quantifies the operational effects of tactical balance-sheet restructuring by commercial banks and their short-run interactions with the central bank. In the context of stronger demand for dinar-denominated loans, commercial banks adjust their liquidity positions by releasing the FX reserve requirement held with the NBS, which is maintained against FX funding sources, thereby freeing up lending capacity in domestic currency. From the perspective of systemic stability, this short-run decline in gross FX reserves does not represent a destabilising factor, but rather an expected second-round effect within the operational framework that supports the achievement of a higher strategic objective – stable dinarisation of the domestic financial system.

Finally, short-run changes in FDI with an estimated coefficient of -0.001, are not statistically significant at any of the conventional significance levels. This finding conveys an important macroeconomic message: current monthly fluctuations and short-run informational noise in the initial stages of FDI inflows do not warrant operational interventions in the FX market. The process of deploying foreign capital is characterised by a pronounced time lag and phased implementation, as the FX funds initially remain deposited in companies' FX accounts with commercial banks and only gradually affect official FX reserves through subsequent import transactions, purchases of capital equipment, and international payment flows. The absence of short-run statistical significance confirms that FDI operates through a delayed transmission channel and provides the NBS with considerable room to plan its operational actions strategically and over the longer term, without the need for *ad hoc* responses to monthly fluctuations.

4 Testing the structural stability of parameters

One of the most common methodological challenges in econometric modelling of macroeconomic time series over a long period is the potential presence of structural breaks (Zivot & Andrews, 1992). Given that the sample covers a period of more than 17 years, the historical horizon is marked by pronounced global and domestic economic shocks. This period was characterised by the global financial crisis, significant domestic fiscal reforms and consolidation, the COVID-19 pandemic, as well as energy shocks accompanied by inflationary pressures (Krugman, Obstfeld & Melitz, 2012). If the estimated coefficients of the dynamic ARDL model were found to be unstable and to vary significantly over time, all conclusions and recommendations derived from the model would lose their scientific credibility and practical relevance for economic policymaking.

To address this concern and assess the robustness of the results, two complementary tests of structural stability based on recursive regression residuals were conducted: the CUSUM (Cumulative Sum) test and the CUSUM Squares (Cumulative Sum of Squares) test (Brown, Durbin & Evans, 1975). The CUSUM test primarily focuses on detecting gradual, systematic changes in the parameters, particularly in the model constant, whereas the CUSUM Squares test is particularly sensitive to sudden, sharp structural breaks affecting the conditional variance of the error term.

Mathematically, the CUSUM statistic is constructed as the cumulative sum of recursive residuals standardised by the estimated standard deviation of the model:

$$W_t = \frac{1}{\hat{\sigma}_w} \sum_{r=k+1}^{t} \omega_r \ , \qquad t = k+1, \ldots, T$$

where ω_r represents the recursive residual at time r (based on the model estimated up to time $r-1$), while $\hat{\sigma}_w$ is the estimated standard deviation of the residuals over the entire sample, calculated as:

$$\hat{\sigma} = \sqrt{\frac{\sum_{t=1}^{T} (\omega_t - \overline{\omega})^2}{T-k-1}}$$

The stability of the model parameters is statistically and visually confirmed if the empirical cumulative sum line W_t remains within the strictly defined critical bounds throughout the entire observation period, at a 5% level of statistical significance. The critical bounds evolve linearly over time in accordance with the methodology of Brown, Durbin and Evans (1975) and are symmetrically defined as:

$$\pm\left[a \cdot \sqrt{T-k} + \frac{2 \cdot a \cdot (t-k)}{\sqrt{T-k}}\right]$$

where parameter a = 0.948 represents the critical value corresponding to the significance level of 5%.

In the case of the CUSUM Squares test, the S_t test statistic is based on the cumulative squares of the recursive residuals and is mathematically defined as:

$$S_t = \frac{\sum_{j=k+1}^{t} \omega_j^2}{\sum_{j=k+1}^{T} \omega_j^2}, \qquad t = k+1, \ldots, T$$

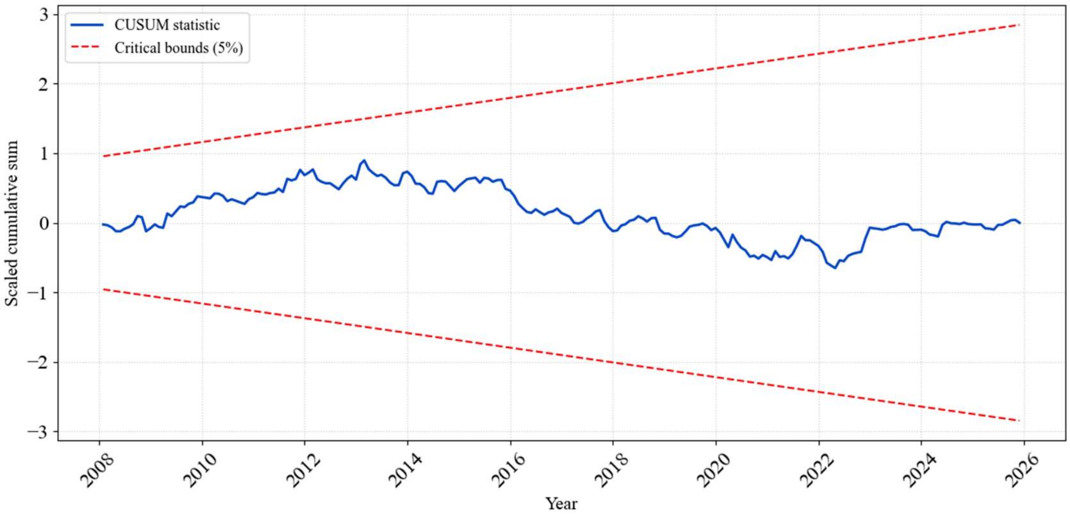
The critical bounds for the S_t statistic are defined as a parallel corridor around the expected mean: $E(S_t) = \frac{t-k}{T-k}$ in form $E(S_t) \pm c_{0,05}$, where critical value $c_{0,05}$ for significance level of 5% equals: $c_{0,05} = \frac{1,358}{\sqrt{T-k}}$.

The empirical results of the CUSUM test unequivocally confirm the high methodological stability of the estimated model. The test generated a high empirical p-value of 0.4025, whereby the null hypothesis H_0 regarding the structural stability of the parameters cannot be rejected at any standard significance level.

The maximum amplitude of the dynamic deviation was recorded in March 2013. At this point, the scaled maximum CUSUM value stands at 0.8405, which is significantly below the then-permissible critical boundary of ±1.4948. This result indicates that the recorded deviation does not constitute a structural break in the model's parameters. The recorded maximum amplitude is econometrically entirely valid and reflects a short transitional period of consolidation in the domestic FX market, following the implementation of the new monetary policy framework and the stabilisation of the exchange rate in the second half of 2012. It was precisely during that period that the foundations of the new, proactive FX intervention regime were laid, which enabled the absorption of external shocks and calmed the volatility of the domestic financial market. Chart 1 clearly shows that the cumulative sum line does not leave the symmetric confidence interval at any single point of the observed sample.

On the other hand, the results of the CUSUM Squares test (Chart 2) provide a more detailed insight into the dynamics of the conditional variance of the residuals. The calculated maximum deviation of the cumulative sum of squared residuals from the theoretical trajectory amounts to 0.1066, which slightly exceeds the critical threshold of ±0.0939 at the 5% significance level. This spike was recorded in January 2023, when the empirical S_t statistic line briefly moved above the upper critical bound.

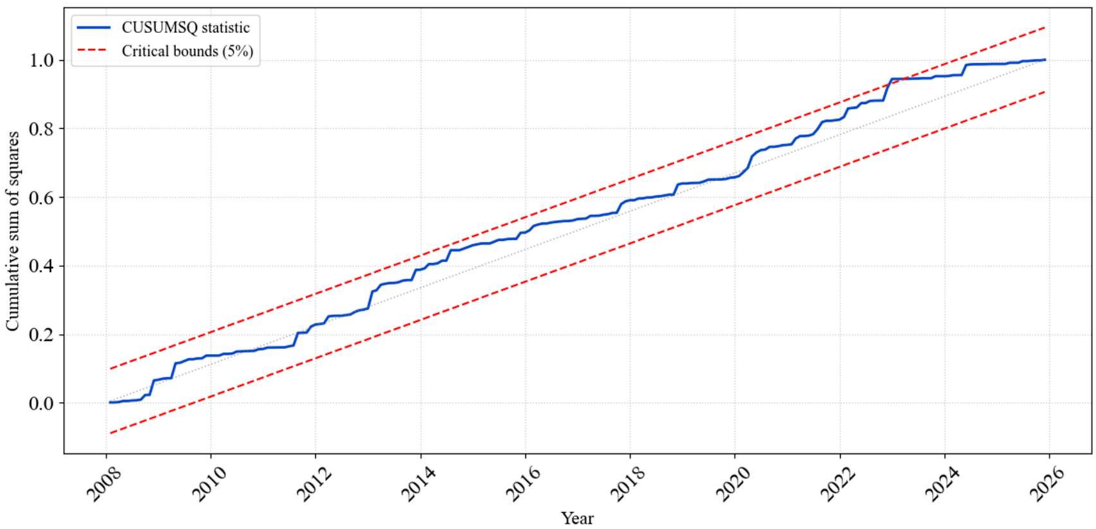
Chart 1 **Cumulative sum of recursive residuals**



Source: Authors' calculation based on NBS data.

The aforementioned temporary increase in residual variability is econometrically entirely justified and directly reflects the cumulative effect of strong exogenous shocks from early 2023. During that period, the peak of the spill-over from the global energy crisis, record imported inflation in Europe, and intensive FX market intervention by the NBS to preserve the relative stability of the domestic currency were recorded. It is important to emphasize that after the brief peak, the CUSUM Squares statistic fully returned within the permissible confidence interval already during 2024, confirming that no permanent destabilisation of systemic risks occurred.

Chart 2 **Cumulative sum of squared recursive residuals**



Source: Authors' calculation based on NBS data.

A synthesis of the results of both tests leads to the key methodological conclusion. Since the CUSUM test confirms that all model coefficients are structurally stable over time, and the CUSUM Squares test shows rapid dissipation and a return of the variance to the control corridor after a short-lived external shock, the estimated ARDL model possesses high analytical robustness. The results provide strong empirical evidence that the NBS's monetary policy and the Strategy of Dinarisation of the Financial System have been consistent, and that the long-term relationships between gross FX reserves, the monetary aggregate M3, FDI and the degree of dinarisation of receivables are highly resilient to geopolitical and macroeconomic shocks.

5 Nonlinear ARDL (NARDL) model and asymmetric effects of the dinarisation strategy

Traditional linear econometric models rest on the rigid and often unrealistic assumption that economic variables respond symmetrically. This would imply that shocks of the same magnitude, but opposite sign (positive and negative) would produce effects of identical strength. However, in the real world of financial markets, the behaviour of economic agents is strongly influenced by psychological factors, risk aversion and institutional asymmetries. To overcome these linear limitations and more realistically model the dynamics of the Serbian financial system, the research introduces the **nonlinear ARDL (NARDL) model**, developed by Shin, Yu & Greenwood-Nimmo (2014). The primary focus of this model is directed at examining the potential presence of an asymmetric response of gross FX reserves to positive and negative changes in the degree of dinarisation of receivables, as well as in the monetary aggregate M3.

To this end, the total degree of dinarisation of receivables (DIN_t) and the broad money supply ($M3_t$) have been decomposed into two separate cumulative partial sums that track positive and negative shocks in isolation. For the dinarisation variable, the decomposition is formally written as:

$$DIN_t = DIN_0 + DIN_t^+ + DIN_t^-$$

where DIN_0 denotes the initial value of the series at the beginning of the observed period, which is absorbed within the constant term of the model in the econometric estimation, while DIN_t^+ and DIN_t^- are the cumulative sums of positive (increase in dinarisation and strengthening of confidence in the domestic currency) and negative changes (decline in dinarisation, i.e. return to euroisation due to heightened risk perception):

$$DIN_t^+ = \sum_{i=1}^{t} \Delta DIN_i^+ = \sum_{i=1}^{t} \max(\Delta DIN_i\,, 0)$$

$$DIN_t^- = \sum_{i=1}^{t} \Delta DIN_i^- = \sum_{i=1}^{t} \min(\Delta DIN_i\,, 0)$$

In the same manner, the total broad money supply ($M3_t$) is decomposed within the nonlinear specification by the following equation:

$$\ln(M3_t) = \ln(M3_0) + \ln(M3_t^+) + \ln(M3_t^-)$$

where $\ln(M3_0)$ denotes the initial logarithmic value of the series at the beginning of the observed period, which is absorbed into the constant term of the model in the econometric estimation, while $\ln(M3_t^+)$ and $\ln(M3_t^-)$ are the cumulative sums of positive (monetary expansion and growth of liquidity in the system) and negative changes (monetary contraction and withdrawal of dinar liquidity):

$$\ln(M3_t^+) = \sum_{i=1}^{t} \Delta \ln M3_i^+ = \sum_{i=1}^{t} \max(\Delta \ln(M3_i)\,, 0)$$

$$\ln(M3_t^-) = \sum_{i=1}^{t} \Delta \ln M3_i^- = \sum_{i=1}^{t} \min(\Delta \ln(M3_i), 0)$$

By incorporating these decomposed series, the final regression specification of the asymmetric NARDL model takes the following structural form:

$$\Delta \ln(FXR_t) = c + \gamma \ln(FXR_{t-1}) + \beta_{FDI} FDI_{t-1} + \alpha^+ \ln(M3_{t-1}^+) + \alpha^- \ln(M3_{t-1}^-) + \beta^+ DIN_{t-1}^+ + \beta^- DIN_{t-1}^- + \sum_{i=1}^{P} \phi_i \Delta \ln(FXR_{t-i}) + \varepsilon_t$$

Table 6 **Empirical results of the estimate of the asymmetric *NARDL* model**

	Coefficient	*p*-value
Constant	0.523	0.027**
Gross FX reserves, lagged by one period	0.941	0.000***
FDI as a share of GDP, lagged by one period	-0.001	0.024**
Cumulative positive shock of the monetary aggregate M3, lagged by one period	0.106	0.017**
Cumulative negative shock of the monetary aggregate M3, lagged by one period	0.098	0.458
Cumulative positive shock of dinarisation of receivables, lagged by one period	-0.004	0.047**
Cumulative negative shock of dinarisation of receivables, lagged by one period	-0.002	0.462

Note: ** and *** denote a statistical significance at the levels of 5% and 1%, respectively.
Source: Authors' calculation based on NBS data.

The model was optimised according to the BIC criterion and estimated using the ordinary least squares method. Its empirical parameters and accompanying significance statistics are presented in detail in Table 6.

In order to calculate the actual long-run elasticities of positive and negative shocks on gross FX reserves, a normalisation of the estimated coefficients on the lagged level variables was performed with the pair of lagged dependent variables. The speed of adjustment of the model towards equilibrium is first defined ($\theta = \gamma_1 - 1$ = –0,0591). The formula for calculating the long-run asymmetric multipliers is as follows:

$$\delta^{+} = -\frac{\beta^{+}}{\theta}, \quad \delta^{-} = -\frac{\beta^{-}}{\theta}$$

By applying this mathematical matrix to the estimated values from Table 6, the following long-run effects are obtained:

- **Long-run effect of M3 growth ($\boldsymbol{\delta_{M3}^{+}}$):** 0.1063/0.0591= 1.799
- **Long-run effect of M3 decline ($\boldsymbol{\delta_{M3}^{-}}$):** 0.0978/0.0591= 1.655
- **Long-run effect of dinarisation growth ($\boldsymbol{\delta_{DIN}^{+}}$):** -0.0036/0.0591= -0.061
- **Long-run effect of dinarisation decline ($\boldsymbol{\delta_{DIN}^{-}}$):** -0.0020/0.0591= -0.034

In order to determine whether the observed differences between the positive and negative multipliers are statistically significant (i.e. whether formal long-run asymmetry exists), a **Wald test of linear restrictions** was conducted. Two separate null hypotheses of complete equality of the long-run effects were tested:

1. **For the monetary aggregate M3 ($\boldsymbol{H_0: \alpha^{+} = \alpha^{-}}$):**
    - Empirical value of the Wald *F*-statistic: **0.0042**
    - Corresponding significance level (*p*-value > *F*-statistic): **0.9486**
    - Given the high *p*-value, the null hypothesis of coefficient equality is not rejected. The long-run impact of the monetary aggregate M3 on gross FX reserves, viewed through the formal Wald test, is symmetric.
2. **For the degree of dinarisation of receivables ($\boldsymbol{H_0: \beta^{+} = \beta^{-}}$):**
    - Empirical value of the Wald *F*-statistic: **0.2648**
    - Corresponding significance level (*p*-value > *F*-statistic): **0.6074**
    - The null hypothesis of coefficient equality cannot be rejected at standard significance levels. Viewed through the strict statistical test, the effects of changes in the degree of dinarisation behave symmetrically in the long run.

However, although the Wald test, in a purely mathematical sense of coefficient equality, does not reject the null hypothesis of multiplier symmetry, economic logic and the matrix of statistical significance of the estimated parameters from Table 6 reveal a substantive asymmetry in the significance of the transmission:

- **Monetary aggregate M3 channel:** An increase in the money supply generates a long-run multiplier of **1.799**, which is statistically significant at the 5% level (p = 0.017). This result confirms that systemic expansion of liquidity and economic activity naturally leads to a cumulative easing and strengthening of the central bank's foreign assets through net FX purchases. By contrast, a decline in the monetary aggregate M3 has a long-run coefficient of **1.659**, but it is not statistically significant (p = 0.456). **This disparity in statistical significance clearly indicates that, through successful monetary policy, the NBS's gross FX reserves have been largely insulated from negative shocks to domestic monetary liquidity**.

- **Dinarisation of receivables to the household and corporate sector channel:** An increase in the degree of dinarisation produces a statistically significant long-run effect of -0.061 ($p = 0.047$), confirming a structural release of FX assets. A systemic increase in the share of dinar loans reduces FX exposure and the structural risk of banks, thereby reducing the need for a precautionary maintenance of a high level of mandatory FX reserves. By contrast, a decrease in the degree of dinarisation, with a coefficient of -0.034, is not statistically significant (p = 0.462), demonstrating that **episodes of a temporary decline in dinarisation do not cause permanent or significant consequences for the level of the NBS's FX reserves**.

6 Modelling conditional volatility

A comprehensive assessment of the stability and resilience of the domestic financial system requires, in addition to level analysis, precise modelling of the risk profile, i.e. the dynamics of conditional volatility of FX reserves (Danielsson, 2011). Prior to the specification of nonlinear conditional volatility models, a diagnostic check of the residuals of the baseline regression was performed. Testing for normality of the error distribution was conducted using the Jarque–Bera (JB) test (Jarque & Bera, 1987), which simultaneously uses information on skewness and kurtosis of the distribution to examine the null hypothesis that the residuals are normally distributed. The results are as follows:

- **Jarque–Bera statistic (JB):** 24.4445 (with an accompanying *p*-value of 0.000)
- **Skewness coefficient:** 0.4813 (positive skewness)
- **Kurtosis coefficient:** 4.3425

The extremely low p-value of the Jarque–Bera test (0.000) implies that the null hypothesis of normally distributed residuals is explicitly rejected at all levels of statistical significance. The obtained skewness coefficient of 0.4813 indicates a right-skewed distribution, while the kurtosis coefficient of 4.3425 (>3) clearly signals a leptokurtic distribution, i.e. a pronounced presence of a fat-tailed distribution, meaning an increased probability of extreme deviations relative to the standard Gaussian distribution (Coles, 2001; McNeil & Frey, 2000).

Nevertheless, from the standpoint of statistical inference, it is important to emphasize that given the relatively large sample (N = 216), the central limit theorem guarantees the unbiasedness and asymptotic validity of ordinary least squares estimation. Therefore, the absence of strict normality does not impair statistical inference, nor does it undermine the reliability of the estimated long-run and short-run ARDL coefficients. The residuals still display strong accumulation around zero and are well dispersed along the tails of the distribution (Verbeek, 2017). However, although the lack of normal distribution does not invalidate the level estimates in the ARDL model, the presence of leptokurtosis and time-varying dispersion within the tails raises the diagnostic suspicion that the residuals may potentially exhibit characteristics of conditional heteroskedasticity with volatility clustering.

As an appropriate methodological framework for modelling the conditional variance, the paper proceeds to advanced **nonlinear modelling of conditional volatility through the specification of a GARCH(1,1) model with the assumption of a Student's *t*-distribution**

(Danielsson, 2011). This approach simultaneously optimises the mean equation and the conditional variance equation, using the standardised Student's *t*-distribution of the error terms precisely in order to mathematically absorb and precisely quantify the characteristic fat tails of macroeconomic series.

Mean Equation:

$$\ln(FXR_t) = \mu_t + \varepsilon_t$$

where the stochastic disturbance ε_t follows a standardised Student's *t*-distribution with ν degrees of freedom: $\varepsilon_t = \sigma_t \cdot z_t,\ z_t \sim t_\nu(0,1,\nu)$

Conditional Variance Equation: $\sigma_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2$

where the parameter ω defines the constant component of variance, the ARCH parameter (α_1) measures the reaction of volatility to current short-run shocks, while the GARCH parameter (β_1) quantifies the degree of persistence of conditional volatility from previous periods. The parameters were estimated using the maximum likelihood estimation (MLE) method, and the results are systematised in Table 7.

Table 7 **Parameter estimates of the Student-t GARCH(1,1) model**

	Coefficient	***p*-value**
Constant	0.000	0.440
ARCH effect	0.0603	0.491
GARCH effect	0.4264	0.570
Student's shape parameter	3.8627	0.000***

*Note: *** denotes statistical significance at the 1% level.
Source: Authors' calculation based on NBS data.

The estimated ARCH parameter (α_1 = 0.0603) and GARCH parameter (β_1 = 0.4264) are not statistically significant at any conventional significance level. This empirical outcome indicates that the potential diagnostic suspicion of volatility clustering has not been confirmed in the final model, i.e. that there is no significant temporal risk accumulation or autoregressive spillover of volatility over time in the residuals. From a macroeconomic perspective, this confirms that the NBS's proactive interventions successfully neutralise the transmission of short-run volatility shocks over time.

Unlike the variance coefficients, the Student's shape parameter (ν = 3.8627) exhibits exceptionally high statistical significance. Such a low value of the degrees of freedom parameter ($\nu < 5$) formally verifies that the residuals are burdened with pronounced fat tails, thereby fully justifying the Student's *t*-distribution specification. This finding provides a crucial methodological insight that the deviation from the normal distribution identified by the Jarque–Bera test is not a consequence of time-varying conditional volatility, but rather the presence of rare but strong economic shocks in the tails of the distribution, which the specified model has fully captured through the Student's *t*-distribution.

Although the sum of the point estimates of the ARCH and GARCH coefficients amounts to 0.4867, which mathematically satisfies the condition of covariance stationarity ($\alpha_1 + \beta_1 < 1$), the absence of statistical significance of the individual parameters prevents the conditional variance from possessing a strong mean-reverting property. More precisely, the conditional variance of FX reserves behaves as a stable, essentially constant unconditional variance with pronounced Student's tails, without autoregressive accumulation of volatility shocks over time. From a macroeconomic perspective and from the standpoint of monetary policy makers, the obtained results provide strong confirmation of the structural stability of the domestic financial system.

The absence of statistically significant ARCH and GARCH effects demonstrates that the movement of the NBS's gross FX reserves is not subject to persistent volatility nor to systemic risk accumulation. Through timely and measured interventions in the interbank FX market, the central bank effectively sterilises external disturbances, allowing all initial shocks to be rapidly absorbed, thereby preserving long-term exchange rate stability and overall macro-financial stability.

7 Macroeconomic stress testing and quantification of extreme event risk

7.1 Construction of stress scenarios and the Monte Carlo simulation methodological framework

Although the previously specified and estimated linear and nonlinear ARDL models provide empirically consistent insight into long-run cointegration relationships and the short-run dynamics of FX reserve determinants, their projection capacity is structurally limited under conditions of extreme macroeconomic disruptions. Classical linear models are based on the assumption of symmetry of shocks and normal distribution of error terms, which *a priori* renders them inadequate for modelling nonlinear systemic crisis periods. In the real economic environment, the distribution of extreme FX reserve outflows exhibits pronounced asymmetry and leptokurtosis. Given that the previous empirical analysis of the residuals of the primary ARDL specification confirmed the strong presence of fat tails and a high Jarque–Bera statistic value, the institutional standard in systemic risk analysis requires the abandonment of the normality assumption and the implementation of the conceptual framework of Extreme Value Theory (EVT) (Coles, 2001).

In this context, this paper develops a conditional forecasting system that methodologically integrates three complementary econometric segments within the so-called Conditional EVT approach (McNeil and Frey, 2000):

1. An **ARDL(1,1,1,0) conditional mean model**, which filters deterministic trends, temporal interdependence and long-run structural influences of macroeconomic variables on the level of gross FX reserves;

2. A **GARCH(1,1) conditional volatility model with a Student's *t*-distribution**, which dynamically filters time-varying volatility and provides standardisation of residuals;

3. A **Generalised Extreme Value (GEV) distribution of the Fréchet type**, which is applied to the standardised residuals in order to perform an asymptotic approximation of the behaviour of the left tail of the distribution, i.e. the quantification of the most severe systemic risks.

The forecasting horizon is set to a dynamic period of 12 months, up to and including December 2026. As a reference starting point, the model uses the end of the analysed sample, i.e. December 2025, with the initial level of gross FX reserves defined at EUR 29,008.30 mn.

In order to generate a complete empirical density distribution of future FX reserve levels and eliminate the statistical error characteristic of small samples at the extreme tails, the algorithm was run through 15,000 independent stochastic Monte Carlo simulations. The introduction of such a high number of iterations represents a key methodological turning point in the paper for two reasons:

- **First**, it enables asymptotic convergence of the GEV distribution parameters in the most critical domains (above the 95^{th} and 99^{th} percentiles), thereby reducing the standard error of the estimated FX Reserve-at-Risk (FX RaR) indicators to a statistically negligible level;
- **Second**, it ensures the complete insensitivity of the results to random fluctuations in the stochastic process, providing a methodologically sound and reliable basis for decision-making in the domain of preserving macro-financial stability.

The systemic shock is constructed as a coherent scenario of the simultaneous manifestation of three independent, but economically connected, transmission channels which jointly exert a systemic shock on the central bank's liquidity:

- **Monetary channel (domestic liquidity expansion)**: Within this channel, a continuous and relatively aggressive growth of the monetary aggregate M3 is modelled at a fixed rate of 1.2% per month (which cumulatively represents an annual monetary expansion of over 15.3%). In accordance with the portfolio balance theory and the monetary approach to the exchange rate (Krugman, Obstfeld & Melitz, 2012), the continuous generation of excess dinar liquidity exceeds real money demand defined by economic activity. Amid heightened macroeconomic uncertainty, economic agents seek to optimise the structure of their financial assets. In order to protect the purchasing power of capital from potential inflationary pressures, they initiate a process of currency substitution, channelling excess dinar funds into the purchase of foreign currency. This portfolio reallocation exerts direct pressure on the interbank FX market through a sharp increase in FX demand. To prevent the depreciation of the domestic currency and preserve the relative stability of the exchange rate as an anchor for inflation expectations, the NBS acts reactively as a net FX seller. Through FX interventions, the central bank absorbs excess dinar liquidity, but this directly causes an outflow of gross FX reserves.
- **External channel (balance of payments shock)**: Within this channel, an extreme negative shock is modelled through the phenomenon of a "sudden stop" of capital inflows (Calvo, 1998). This scenario assumes a sudden and complete halt in net FDI inflows, with their value set to zero throughout the entire 12-month projection horizon, with the possibility of slightly negative net values due to capital repatriation. From an economic perspective, FDI represent a key inflow for covering the current account deficit, whereby, in addition to equity components, they partly include debt instruments, such as intercompany loans. Their sudden absence prevents the

conventional financing of the foreign trade deficit. Since FX demand for settling goods and services import and servicing foreign liabilities remains high, while the inflow of foreign capital from FDI is drying up, a sharp financing gap and a significant narrowing of FX liquidity supply occur in the interbank FX market. The resulting shortage of FX funds directly spills over to the central bank, which is forced to compensate for the missing foreign capital through the continuous sale of FX from its reserves in order to maintain the regular settlement of the country's international obligations and prevent uncontrolled disruptions in the FX market.

- **Systemic stability channel (currency substitution in the banking sector)**: Within this channel, the impact of an intensive systemic disruption is quantified through a continuous decline in the degree of dinarisation of total receivables at a rate of 0.50 pp per month (which cumulatively represents a reduction of 6.0 pp on an annual basis). This trend reflects a sharp increase in the perception of systemic risk and the erosion of market participants' confidence in the domestic currency, triggering a process of re-euroisation of the banking sector's balance sheets. During the massive shift of dinar deposits into FX deposits, commercial banks face serious mismatches in the currency structure of their sources of funds and receivables. In order to maintain the regulatory minimums for net open FX positions and meet increased demands for FX liquidity, commercial banks withdraw FX funds from their clearing and ring-fenced accounts with the central bank, or convert excess dinar reserves into FX assets. This structural turn of the entire banking sector towards foreign currency creates additional pressure on the NBS's primary liquidity, causing a direct and rapid outflow of funds from FX reserves.

The mathematical implementation of the stochastic simulation is carried out recursively over time for a 12-month ahead horizon. At each individual step, within each of the 15,000 iterations, a stochastic increment is generated from the previously estimated GEV distribution. This asymmetric shock is then scaled by the current value of conditional volatility derived from the GARCH equation, and implemented into the ARDL structure. The resulting dynamic model does not simulate a passive decline in FX assets, but actively quantifies the real volume of net outflows through which the NBS, via FX interventions in the interbank FX market, sterilises excess dinar liquidity and successfully preserves the relative stability of the exchange rate under the most severe conditions of extreme event risk. The core dynamic equation modelling the movement of gross FX reserves over the projection period is as follows:

$$FXR_{t+h}^{(i)} = c + \sum_{j=1}^{p} \phi_j \, FXR_{t+h-j}^{(i)} + \sum_{m=0}^{q} \beta_m \, X_{t+h-m}^{(i)} + \left(\sigma_{t+h|t} \cdot \eta_{t+h}^{(i)}\right)$$

where the conditional volatility within the innovation is updated through the accompanying GARCH(1,1) structure:

$$\sigma_{t+h|t}^2 = \omega + \alpha\varepsilon_{t+h-1}^2 + \beta\sigma_{t+h-1|t}^2$$

and the stochastic shock is generated from the extreme value distribution:

$$\eta_{t+h}^{(i)} \sim \mathrm{GEV}(\mu, \psi, \xi)$$

- $FXR_{t+h}^{(i)}$ – simulated value of gross FX reserves for each individual month of the projection horizon h ($h = 1,2,\dots,12$), within each individual Monte Carlo iteration i ($i = 1,2,\dots,15{,}000$),
- c – constant term estimated from the long-run ARDL specification,
- ϕ_j – autoregressive forecasting coefficients for the lags of gross FX reserves ($j = 1,\dots,p$),
- β_m – coefficients of long-run and short-run multipliers for the accompanying macroeconomic determinants,
- $X_{t+h-m}^{(i)}$ – vector of simulated values of selected macroeconomic determinants (monetary aggregate M3, FDI and the degree of dinarisation of receivables) over the projection horizon,
- $\sigma_{t+h|t}$ – dynamic conditional standard volatility derived from the GARCH(1,1) specification, incorporating the Student's t-distribution, which quantifies current market uncertainty at time $t + h$ based on information available at time t,
- ω, α, β – GARCH parameters: the constant variance term (ω), the ARCH parameter for short-run shocks (α) and GARCH parameter for volatility persistence (β),
- ε_{t+h-1} – the residual or shock from the previous projection period,
- $\eta_{t+h}^{(i)}$ – stochastic increment (random variable) generated from the empirically estimated GEV distribution,
- μ, ψ, ξ – GEV distribution parameters: the location parameter (μ), the scale parameter (ψ) and the shape parameter (ξ), which directly measures the fat tails and the probability of the occurrence of extreme shocks.

7.2 Empirical results of stochastic simulations and valorisation of FX reserve resilience

Following the execution of 15,000 stochastic simulations over a twelve-month horizon under the constructed extreme systemic stress scenario, the final empirical density distribution of future FX reserve levels was generated. The comprehensive numerical results of the FX Reserve-at-Risk (FX RaR) indicators for various statistical confidence levels are systematised in Table 8.

The FX RaR indicator represents the key methodological framework for the quantitative assessment of the systemic vulnerability of the FX balance under conditions of extreme macroeconomic disruptions. Based on the principles of the Value-at-Risk concept, this indicator enables the estimation of the maximum expected decline in the level of FX reserves at a given level of statistical confidence (Danielsson, 2011).

Table 8 **Quantification of extreme event risk and projected outflow of FX reserves in the conditional Monte Carlo model (December 2026)**

Indicator of simulated systemic stress	Indicator value (in EUR mn)	Quantified maximum decline in FX reserves
Starting level (December 2025)	29,008.3	Starting point of the econometric model
Expected value after 12 months	28,218.21	790.09
Critical value at 90% confidence level	25,436.64	3,571.66
Critical value at 95% confidence level	24,846.47	4,161.83
Critical value at 99% confidence level	23,742.41	5,265.89

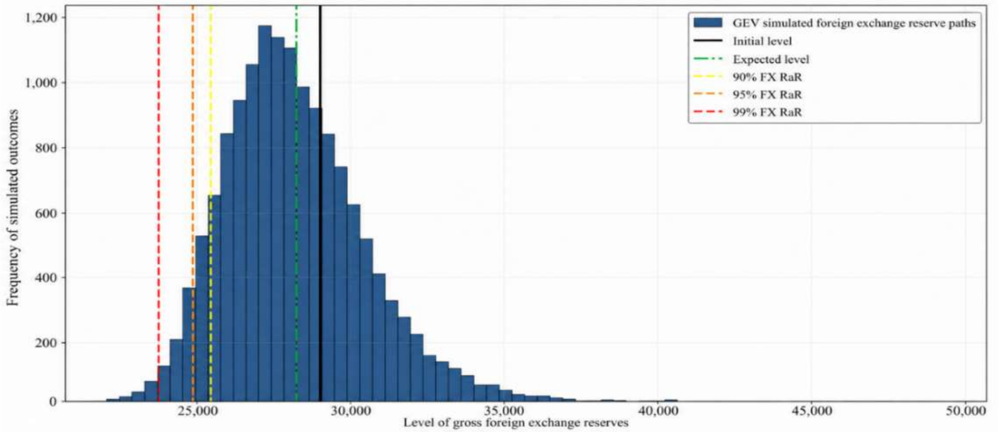
Source: Authors' calculation based on the conditional ARDL-GARCH-GEV Monte Carlo model with 15,000 iterations.

The expected value of gross FX reserves after one year of continuous exposure to combined systemic pressures amounts to EUR 28.22 bn. This result implies a moderate, gradually distributed and entirely controllable average outflow of only EUR 0.8 bn (i.e. a decline of just 2.72% relative to the initial level). Econometrically speaking, such stability at the central point of the distribution is a direct consequence of the exceptionally high value of the autoregressive parameter of the initial ARDL specification ($\phi_1 = 0.9717$). This coefficient quantifies the high temporal persistence and inertia of the NBS's FX reserves, confirming that the available defence mechanisms are sufficiently strong to absorb and neutralise the initial shock waves of a crisis. At the same time, the property of gradual decay of conditional volatility over time ensures that temporary volatility spikes are of a limited nature. This eliminates the possibility of uncontrolled outflows and guarantees the stability of the central bank's balance sheet.

If the analysis shifts from average values towards the left tail of the empirical distribution, the econometric model, by identifying quantiles at the 90% and 95% confidence levels, delineates the frameworks of possible but extreme macroeconomic shocks. As Chart 2 illustrates, in these scenarios – encompassing episodes such as capital outflows, adverse movements in the terms of trade or FX speculation – the value of FX reserves declines to EUR 25.44 bn (at 90% confidence) and EUR 24.85 bn (at 95% confidence). In practice, this means that the maximum cumulative outflow of funds would range between EUR 3.57 bn and EUR 4.16 bn.

From the standpoint of external economic stability assessment, these results confirm that the NBS possesses substantial levels of FX reserves. Even in the event of materialisation of serious market pressures, the system retains strong defence capacities. The available FX mechanism enables the uninterrupted neutralisation of adverse outflows without undermining the fundamental equilibrium in the market, which testifies to the long-run resilience of the domestic financial framework to external shocks.

Chart 3 **Empirical distribution of the NBS's FX reserves**



Source: Authors' calculation based on NBS data.

The position at the far left tail of the empirical distribution (99% confidence level) represents a scenario of extremely low probability of materialisation, but with serious macroeconomic consequences (a black swan scenario) (Taleb, 2007). Thanks to the implementation of 15,000 stochastic iterations, the estimate of this quantile is fully stabilised, thereby eliminating the high-variance problem characteristic of standard non-parametric methods. At this critical point, a simultaneous interaction of shocks occurs: accelerated growth of the monetary aggregate M3 creates a significant excess of dinar liquidity that exerts pressure on the FX market, which coincides with a decline in market participants' confidence (reflected through a 0.50 pp monthly decline in the degree of dinarisation) and a sharp slowdown in FDI inflows.

Under these circumstances, the GEV distribution precisely estimates the asymmetry of the left tail of the distribution and projects a decline in FX reserves to a critical minimum of EUR 23.74 bn at the 99% confidence level. The numerical calculation shows that the central bank, in the event of highly unfavourable macroeconomic developments, would have to spend a maximum of EUR 5.17 bn of gross FX reserves for the complete neutralisation of depreciation pressures and the preservation of exchange rate stability. Although this amount represents a significant expenditure (around 17.8% of initial assets), the fact that even in this scenario the system retains over EUR 23.8 bn in liquidity represents a strong confirmation of overall stability. The model empirically confirms that the existing defence mechanisms are sufficiently robust to absorb even the most severe extreme shocks, thereby ensuring the long-term credibility of monetary policy and the stability of the domestic exchange rate.

8 Conclusion

The empirical analysis conducted in this paper unequivocally confirms the high resilience, structural stability and methodological robustness of the NBS's macroeconomic framework. By applying advanced linear and nonlinear econometric specifications (ARDL/NARDL) on a sample from January 2008 to December 2025, it has been demonstrated that gross FX reserves have evolved from a passive indicator of external liquidity into a key instrument of macroeconomic stability of the domestic financial system.

The results of the bounds test confirm the existence of a stable long-run cointegration relationship within the system, in which the monetary aggregate M3 plays a dominant role. With a long-run coefficient of 1.70, this aggregate represents the key pillar of stability, implying that the expansion of domestic liquidity has been consistently supported by adequate FX assets through **successful interventions in the interbank market, thereby timely neutralising speculative pressures on the dinar exchange rate**.

The estimation of long-run multipliers provides strong empirical evidence of the justification of the Dinarisation Strategy. The statistically significant negative coefficient on the degree of dinarisation of receivables (-0.09) indicates that an increase in the share of dinar loans substantially limits the systemic risk of exchange rate exposure, thereby reducing the need to hold excessive preventive FX assets. The findings of the NARDL model further confirm the resilience of the system: FX reserves are successfully insulated from negative monetary shocks, as the central bank, through effective interventions, rapidly absorbs short-run currency shocks, preventing their spill-over into long-run imbalances.

Risk profile management, tested through the GARCH(1,1) specification with the assumption of a Student's *t*-distribution, reveals the high operational efficiency of the domestic monetary system. The absence of statistically significant ARCH and GARCH parameters demonstrates that shocks do not cause long-run accumulation or persistence of volatility. In other words, external pressures are efficiently absorbed through the central bank's actions, thereby preventing the spread of instability and maintaining a high degree of predictability of the macroeconomic environment. Methodologically, the centrepiece of the paper is the conditional macroeconomic stress test with 15,000 stochastic Monte Carlo simulations, which provides the final institutional confirmation of the high resilience of the domestic monetary framework. The analysis of the extreme black swan scenario, which simultaneously activates a sharp increase in M3, a complete halt in FDI inflows and a steep decline in the degree of dinarisation, shows that at a 99% confidence level, the maximum cumulative outflow would amount to EUR 5,166.42 mn. The fact that even after such a shock, gross FX reserves retain over EUR 23.8 bn in available liquidity represents the key proof that the credibility of the domestic monetary anchor is long-term secured and sustainable.

With a view to further strengthening macro-financial stability and optimising the monetary policy framework, the presented results impose two key recommendations for economic policy makers, relating to: the continuation of the practice of timely and measured two-way interventions in the interbank FX market for the effective mitigation of short-run liquidity shocks; and the further strengthening and institutional support of the dinarisation process through the development of dinar instruments.

Finally, the conducted diagnostic tests of parameter stability confirm the absence of structural breaks and the stability of the estimated parameters throughout a seventeen-year sample marked by numerous global crises. These findings indicate that the **NBS's policy is grounded in a consistent institutional framework. The accumulated FX reserves and efficient transmission mechanisms transcend the traditional role of a mere shock absorber, representing a key pillar for the preservation of financial stability and long-term economic growth of the Republic of Serbia in conditions of pronounced global uncertainty**.

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