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Foreign Reserve Accumulation Amidst Joint Shocks: Evidence from Exchange Rate Uncertainty and Oil Supply Shock in MENA Region

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Abstract: Despite significant research on oil price shocks and exchange rate dynamics, most studies examine these factors independently and focus on average effects, while conventional policy structures often treat these risks as weakly correlated, ignoring the compounding double-hit effect of synchronized shocks. This study aims to fill this gap by exploring the joint, asymmetric, and state-dependent impacts of oil supply shocks and exchange rate uncertainty on foreign reserve accumulation in five MENA economies (Saudi Arabia, UAE, Qatar, Egypt, and Tunisia) from January 2000 to December 2025. Specifically, we investigate the extent to which foreign reserves serve as a buffer amidst the joint impact of oil supply shocks and exchange rate uncertainty in the MENA region. Using an integrated empirical framework, the study combines an Interacted Panel Vector Autoregression (IPVAR) to capture dynamic mean-level responses, panel quantile regression to reveal heterogeneity across reserve regimes, and a panel GARCH-Copula approach to model nonlinear volatility and tail dependence. The empirical results reveal that the buffering capacity of reserves is non-linear and highly sensitive to initial conditions. Exchange rate uncertainty induces a 15.3% contraction in reserves over 24 months, while negative oil supply shocks trigger disproportionately large reserve drawdowns (28.3%), far outweighing the accumulation seen during price booms (8.7%). Significantly, quantile analysis demonstrates that the buffering effect is weakest in reserve-scarce economies, which respond seven to eight times more intensely to shocks than high-reserve counterparts, thereby highlighting strong heterogeneity. Copula estimates confirm a significantly lower-tail dependence (λ_L = 0.38), indicating that extreme shocks are synchronized rather than independent disturbances. The findings demonstrate that reserve vulnerability in MENA economies is highly nonlinear, with the greatest magnitude when reserves are low. Accordingly, relying on static reserve adequacy benchmarks driven by baseline scenarios is insufficient; instead, MENA policymakers should adopt dynamic, state-contingent reserve management frameworks that explicitly account for tail-risk synchronization and the diminishing buffers during compounding economic or financial shocks.

Keywords: Synchronized Shocks, Foreign Reserve, Tail Risk Dependence, Non-linear Dynamics, Panel Quantile Regression, GARCH-Copula, MENA Economies

JEL classification: F31; F33; Q43; C33; C58.

I. Introduction

External economic shocks have long affected the accumulation of foreign exchange reserves in oil-dependent economies, particularly in the Middle East and North Africa (MENA) region, raising persistent concerns for macroeconomic stability (IMF, 2024a; Abdulrahman & Musa, 2023). In countries such as Saudi Arabia, the United Arab Emirates, Qatar, Egypt, and Tunisia, the interaction between exchange rate uncertainty and shocks to crude oil supply has increasingly complicated reserve management and policy formulation. MENA economies exhibit a distinct structural vulnerability characterized by heavy dependence on volatile commodity markets, limited economic diversification, and relatively constrained institutional capacity. As a result, fluctuations in oil prices and exchange rates can directly threaten foreign reserve stability and complicate macroeconomic decision-making (Umoru et al., 2025). For instance, Saudi Arabia lost nearly 48% of its foreign reserves between 2014 and 2016 while attempting to maintain its currency peg to the U.S. dollar during a prolonged oil price collapse (IMF, 2026; Saudi Arabian Monetary Authority, 2017).

Despite broad theoretical consensus on the importance of oil price shocks and exchange rate dynamics for reserve accumulation, critical empirical gaps remain in MENA economies. This study is motivated by growing concerns about the heightened exposure of oil-dependent countries to global economic shocks, particularly those arising from fluctuations in crude oil supply and exchange rate uncertainty (Chen & Chen, 2023). Although comparative evidence from African and other emerging economies offers useful insights, the MENA region warrants focused analysis due to its unique combination of oil dependence, geopolitical fragility, and managed exchange rate regimes. Specifically, existing evidence remains limited regarding the magnitude and heterogeneity of these effects, the nature of their interaction, and how reserve responses vary across different reserve levels, and the mechanisms through which shocks spill over, and the implications for policy design aimed at insulation and resilience.

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The existing literature highlights strong interconnections between oil price dynamics and exchange rate movements in the MENA region, with important consequences for inflation, financial stability, and macroeconomic performance (Elsayed, 2024; Elsayed et al., 2024). For example, connectedness analyses demonstrate that oil price shocks, inflation, and exchange rates are closely linked, allowing disturbances in one market to propagate across others (Bigerna, 2024). Similarly, studies focusing on Saudi Arabia show that oil price volatility can generate uncertainty across

multiple macroeconomic variables, including foreign exchange reserves, thereby suggesting a transmission channel through which oil market shocks influence reserve accumulation (Gunwant, Rather, & Zargar, 2024). Nevertheless, despite these advances, empirical evidence that directly quantifies the impact of exchange rate uncertainty and oil supply shocks on foreign reserve accumulation in MENA economies remains relatively scarce.

More importantly, limited attention has been paid to the *joint effects* of these shocks in shaping reserve dynamics. Existing studies largely examine oil price shocks and exchange rate movements in isolation or rely on average-effect estimation frameworks that may obscure nonlinearities, asymmetries, and state-dependent responses. This limitation is particularly relevant for MENA economies, where exchange rate volatility-induced uncertainty and oil supply disruptions have intensified due to geopolitical tensions, global demand-supply imbalances, and heightened speculative pressures (Yang et al., 2023, and Nouira, 2019). Policymakers seeking to enhance reserve adequacy, manage external vulnerability, and design effective stabilization frameworks require empirical evidence that explicitly captures the dynamic interplay of these shocks, especially under conditions of reserve scarcity.

Accordingly, the present study addresses this gap by focusing on two central research questions:

1. *What are the dynamic effects of exchange rate uncertainty shocks and crude oil supply shocks on foreign reserve accumulation, and how do these effects vary over time and across reserve levels?*
2. *What conditional dependence structures and tail risks characterize the joint effect of exchange rate uncertainty and oil supply shocks on foreign reserves?*

To answer these questions, the study adopts an integrated empirical framework that combines an Interacted Panel Vector Autoregression (IPVAR) model to capture dynamic feedback effects with a Panel GARCH-Copula approach to model nonlinear volatility and extreme tail dependence. This dual methodology is particularly well-suited to analyzing the crisis-prone, nonlinear risk environment that defines reserve management in oil-dependent MENA economies.

The primary aim of this study is to critically examine the joint effect of exchange rate uncertainty shocks and crude oil supply disruptions on foreign reserve accumulation in a panel of five key MENA countries: Saudi Arabia, the United Arab Emirates, Qatar, Egypt, and Tunisia. In addition, the study evaluates heterogeneous effects across different reserve-holding levels using panel quantile regression (PQR), thereby providing a distributional perspective that extends beyond conventional mean-based analyses. Through this approach, the study seeks to shed light on the complex interactions between external economic shocks and reserve management, offering insights into the financial stability and resilience of MENA economies. The region is selected due to its pronounced vulnerability to external shocks, driven by high geopolitical risk, weak institutional frameworks in some countries, and sustained reliance on oil exports (Muinat & Okunlola, 2025; Wasilewski et al., 2025; Riskiana et al., 2025). An implicit question guiding this analysis is whether exchange rate uncertainty and crude oil supply fluctuations systematically hinder reserve accumulation or whether their effects differ across economic states.

The findings of this study are expected to provide policymakers with a deeper understanding of the joint effects of exchange rate uncertainty and oil price shocks on foreign reserve accumulation. Such insights can inform the design of more robust reserve management strategies that reduce exposure to oil and currency market volatility. In particular, identifying critical quantile thresholds at which exchange rate uncertainty and oil supply shocks exert significant effects on reserves allows policymakers to better assess financial vulnerability and stability. This distribution-based approach supports the development of forward-looking, adaptive economic policies that are less susceptible to external shocks related to oil markets and exchange rate movements.

This study contributes to the literature by moving beyond isolated analyses of oil price shocks and exchange rate dynamics to examine their interaction and asymmetric effects on reserve management in MENA economies. While prior research has largely considered these variables separately, this study provides empirical evidence on how their combined effects vary across reserve conditions, thereby offering a more nuanced understanding of reserve vulnerability. Given the economic interdependencies within the MENA region through trade, investment, and political linkages, the findings also underscore the relevance of coordinated regional approaches to reserve management, exchange rate stability, and oil price responsiveness. Enhanced understanding of shared risks may facilitate better policy synchronization and contribute to more effective regional strategies for managing economic volatility.

2. Literature Review

2.1. Exchange Rate Uncertainty and Reserve Accumulation

The empirical literature examining the relationship between exchange rate uncertainty and international reserve accumulation is extensive yet highly context-dependent. A primary function of foreign exchange reserves is to serve as a buffer against external shocks, with exchange rate volatility constituting a central source of such disturbances (Alharbi, 2024; Adegboye et al., 2020; Allegret & Allegret, 2018). However, the relationship between exchange rate uncertainty and reserve accumulation is multifaceted and operates through several macroeconomic and financial channels. Adler and Mano (2021) identify a negative association between exchange rate uncertainty and consumer prices, suggesting that volatility may generate deflationary transmission mechanisms that indirectly shape the macroeconomic environment in which reserve management decisions are made. Similarly, Saadah and Sitanggang (2020) emphasize the financial stability dimension by employing Value at Risk (VaR) modelling to demonstrate how pronounced exchange rate fluctuations heighten risks to the banking sector, thereby underscoring the critical role of adequate foreign exchange reserves as a stabilizing policy instrument.

Global monetary conditions represent a recurring theme in this literature. Iacoviello and Navarro (2019) show that tightening U.S. monetary policy, through higher interest rates, leads to dollar appreciation, thereby compelling central banks in emerging and developing economies to intervene by drawing down reserves in order to mitigate excessive exchange rate depreciation. In contrast, the period of unconventional monetary policy has introduced new and persistent dynamics. Inoue and Rossi (2019) demonstrate that expansive policies, such as quantitative easing in major economies, exert significant and lasting effects on global exchange rates, generating complex externalities that directly shape reserve management strategies in smaller and more open economies. The prevailing consensus emerging from this body of work is that heightened exchange rate uncertainty, whether driven by domestic policy choices or external monetary shocks, necessitates active reserve management. Nevertheless, the magnitude and direction of reserve responses remain heterogeneous, depending on institutional quality, capital account openness, and exchange rate regime characteristics. In particular, economies operating under more flexible regimes may require reserve strategies that differ markedly from those with fixed or heavily managed exchange rate arrangements (Lee et al., 2020).).

2.2. Oil Supply Shocks and Reserve Dynamics

For commodity-exporting economies, especially those highly dependent on hydrocarbons, reserve accumulation dynamics are closely tied to oil price and supply cycles. A substantial strand of the literature examines how oil supply shocks are transmitted to external balances and reserve positions. In oil-exporting countries, revenue windfalls associated with price booms typically strengthen reserve accumulation through higher foreign exchange inflows, whereas price collapses often trigger rapid reserve depletion as governments draw on buffers to finance fiscal and external imbalances. Algahtani (2016) provides a clear illustration by linking the 2014 oil price collapse to a sustained decline in Saudi Arabia's foreign exchange reserves as fiscal deficits were financed through reserve drawdowns.

In contrast, for net oil-importing economies, the transmission mechanism primarily operates through the trade balance. Qiang et al. (2019) show that rising oil prices increase import costs, thereby exerting downward pressure on the current account and, in turn, on foreign reserves unless offset by compensating capital inflows or policy adjustments. Conversely, declining oil prices may ease external financing pressures and support reserve accumulation. More recent studies have extended this literature by incorporating broader sources of risk. For instance, Plakandaras, Gupta, and Wong (2019) integrate geopolitical risk into oil price forecasting models, recognizing that supply disruptions are frequently driven by political events that amplify price volatility and uncertainty. Similarly, Li et al. (2021) examine high-frequency volatility spillovers in oil markets, highlighting the speed with which oil price shocks propagate to financial and external accounts. A consistent finding across these studies is that oil supply and price shocks represent a major source of reserve volatility, particularly in economies where hydrocarbons dominate exports, fiscal revenues, and balance-of-payments flows (Czech & Niftiyev, 2021).

2.3. Effects of Interaction and Asymmetries

A more nuanced strand of the literature investigates the interaction between exchange rate dynamics and oil price shocks and their compounded effects on reserve accumulation. This relationship is particularly pronounced in economies with commodity-linked currencies. Empirical evidence from Kalu et al. (2019) and Su et al. (2021) shows that oil price volatility is a significant driver of exchange rate instability in exporting economies, creating a dual-channel shock that adds pressure on international reserves. In such contexts, adverse oil price shocks may simultaneously reduce foreign exchange earnings and induce capital outflows or currency depreciation, thereby forcing central banks to deploy reserves for both current account financing and exchange rate stabilization.

Despite these advances, several methodological and conceptual limitations persist in the literature. First, many existing studies rely on short-horizon or linear modelling frameworks that are ill-equipped to capture the persistence, nonlinearities, and regime dependence inherent in oil and exchange rate shocks. Second, and more critically, insufficient attention has been devoted to asymmetric effects. The marginal impact of oil price shocks or exchange rate surges on reserves is unlikely to be constant across economic states; rather, it may differ substantially when reserve buffers are depleted compared to periods of reserve abundance. Moreover, the interaction between exchange rate uncertainty and oil supply shocks may be amplified under conditions of reserve scarcity. To date, relatively few studies have jointly examined exchange rate uncertainty and oil supply shocks within a unified analytical framework that explicitly accounts for heterogeneity across the reserve distribution (Wahyudi, 2025; Ateba et al., 2024; Chatziantoniou et al., 2023).

2.3. Research Gap and the Contribution of This Study

While the existing literature clearly establishes that exchange rate uncertainty and oil supply shocks independently, and, to some extent, interactively, affect international reserve dynamics, empirical evidence remains fragmented across country samples, time horizons, and methodological approaches. A key limitation of much of the prior work is its reliance on average-effect estimation techniques, such as OLS or standard VAR models, which focus on conditional mean relationships. Such approaches may obscure important differences in how economies respond to shocks during periods of vulnerability (low reserve levels) compared with periods of resilience (high reserve levels).

This study addresses this gap by applying a distributional perspective to the analysis of reserve dynamics in Middle East and North Africa (MENA) economies. To the best of our knowledge, few studies have employed panel quantile regression techniques to systematically examine how the effects of exchange rate uncertainty and oil supply shocks vary across different points in the reserve distribution within this region. By moving beyond average effects, the study enables an explicit assessment of asymmetric and state-dependent impacts, revealing how reserve responses differ across low, intermediate, and high reserve levels. In doing so, the paper provides a more granular, country-specific, and policy-relevant understanding of reserve vulnerability and resilience in oil-dependent economies facing concurrent external shocks.

3. Data and Methodology

3.1. Data Measurement and Sources

This study uses monthly data from January 2000 to December 2025. Crude oil price data were obtained from the U.S. Energy Information Administration (EIA), while exchange rate data are sourced from the International Monetary Fund's International Financial Statistics (IFS). Foreign exchange reserve data were sourced from the World Bank's World

Development Indicators (WDI) and supplemented with information from national central bank reports to ensure consistency and completeness (World Bank, 2025; 2024a; 2024b; 2024c).

Although the empirical analysis is conducted at the monthly frequency, daily exchange rate data were used to construct the exchange rate uncertainty index, allowing the study to capture high-frequency fluctuations and short-lived shocks that may be obscured in lower-frequency data. Measuring uncertainty is inherently challenging, as it represents an unobservable concept. Following Rossi and Sekhposyan (2015), exchange rate uncertainty was quantified as the likelihood of a given forecast deviation by evaluating the cumulative density of realized forecast errors of daily exchange rates (against the U.S. dollar) to their historical unconditional error distribution. This approach allows a distinction between uncertainty arising from depreciation shocks and that arising from appreciation shocks, thereby providing a more refined measure of exchange rate uncertainty (Bosupeng et al., 2024).

Crude oil supply shocks were proxied using logarithmic changes in the standard deviation of West Texas Intermediate (WTI) crude oil prices. Although oil price movements do not directly capture physical supply disruptions, the literature widely treats unexpected oil price changes as an exogenous proxy for global oil supply shocks because supply-side shocks, including geopolitical shocks, natural disasters, strikes in oil-producing nations, and OPEC regulatory changes, cause unexpected price changes. Besides, WTI prices rapidly incorporate information about unanticipated disruptions in production, inventories, and geopolitical conditions (Forni & Gambetti, 2025; Wei et al., 2024; Cai, 2024; and Caldara, 2019). The sign restrictions used by Gazzani et al. (2024) were also applied to verify the calculation of crude oil supply shocks with greater accuracy by identifying a simultaneous drop in production and increase in oil prices.

The control variable was specified as the value of imports, rather than import duties, to capture external demand pressures on foreign reserves. While imports may raise potential endogeneity concerns, they are included as a baseline control given their direct and well-established relationship with reserve dynamics (Umoru et al., 2025; Saka et al., 2024; and Aizenman & Yi, 2023).). Additional macroeconomic controls, including GDP growth and inflation, were tested in robustness checks but were found to be statistically insignificant and are therefore excluded from the baseline specification.

To capture joint effects, an interaction variable ($\mathrm{Exucert.Oilshock}$) is constructed as the product of the standardized exchange rate uncertainty and the oil supply shock series. This interaction term enables an explicit test of whether the combined occurrence of exchange rate uncertainty and oil supply shocks amplifies reserve pressures beyond their individual effects. The analysis focuses on five MENA countries: Saudi Arabia, the United Arab Emirates, Qatar, Egypt, and Tunisia.

3.2. Methodology

3.2.1. Interacted Panel Vector Autoregression (IPVAR) Model

The Interacted Panel Vector Autoregression (IPVAR) model extends the conventional panel VAR framework by explicitly incorporating interaction terms between endogenous variables, allowing impulse responses to vary across economic states. Let the vector of endogenous variables be defined as $z_{it} = [RES_{it}, ExuCert_{it}, OilShock_{it}]'$, the IPVAR.

$$z_{it} = A_0(_i) + \Sigma_{p=1}{}^{P} A_p z_{i,t-p} + \Sigma_{p=1}{}^{P} \Sigma_{k=1}{}^{K} B_{pk} (z_{i,t-p} \odot d_{k,t-p}) + u_{it} \text{ ---------------------(1)}$$

where the first line represents standard VAR dynamics, the second line introduces interaction terms with dummy variables $d_{k,t}$ representing different states (e.g., high/low reserves, positive/negative oil shocks). The notation $A_0(_i)$ allows country-specific intercepts (fixed effects). The key insight is that contemporaneous values of variables affect their own lagged impacts: when exchange rate uncertainty is elevated, lagged oil shocks exert stronger effects on reserves than when uncertainty is low.

To address dynamic panel bias (Nickell, 1981), we employ the system GMM estimator, treating lagged dependent variables as potentially endogenous. Instrument matrix Z_{it} includes lagged levels and differences of endogenous variables (typically lags 2 through 4). Model selection employs Andrews-Lu (2001) information criteria (MAIC, MBIC, MQIC) to determine optimal lag lengths P and K. Preliminary estimation suggests P=2, K=1 as appropriate. Orthogonalized impulse responses were computed using Cholesky decomposition with the ordering: [RES, ExuCert, OilShock]. This ordering assumes that contemporaneous shocks to reserves reflect disturbances to reserve supply; contemporaneous exchange rate uncertainty reflects surprise departures from expected rates; and oil price shocks occur exogenously adjust to accommodate external constraints. Cumulative impulse responses over 24 months provide the primary results. Confidence intervals employ bootstrap resampling (1,000 iterations) using block bootstrap on the original data to preserve temporal correlation structure within blocks of 4 months.

3.2.2. Panel GARCH-Copula Model

Concurrent with mean-level IPVAR dynamics, we model conditional volatility and dependence structures using a two-stage panel GARCH-Copula approach. In the first stage, univariate GARCH(1,1) models estimate conditional variance for each series:

$$\sigma_{i,t}{}^2 = \omega_i + \alpha_i \varepsilon_{i,t-1}{}^2 + \beta_i \sigma_{i,t-1}{}^2 \text{ ------------------- (2)}$$

Where ε_{it} denotes standardized residuals from IPVAR regressions. GARCH parameters (ω, α, β) are estimated separately for each country-variable pair using quasi-maximum likelihood (QML).

In the second stage, standardized residuals $z_{it} = \varepsilon_{it}/\sigma_{it}$ are transformed to uniform marginals $u_{it} = \Phi(z_{it})$ using the empirical CDF. A multivariate copula function captures the joint dependence structure:

$$C(u\_RES,_{it}, u\_ExuCert,_{it}, u\_OilShock,_{it}, u\_Exucert.Oilshock_{it}) = C(u_{it};\ \theta_t) \text{----------------------- (3)}$$

We employ the Time-Varying Vine-Copula structure, decomposing the four-dimensional distribution into conditional bivariate copulas arranged in a hierarchical vine structure. The advantage of vine copulas is their flexibility in capturing asymmetric dependence between variables (e.g., stronger tail dependence in crash states than boom states). The specific vine structure selected through graphical methods captures the primary dependence channels: (1) RES-ExuCert, (2) RES-

OilShock, and (3) cross-variable spillovers through ExuCert-OilShock associations. Time-varying copula parameters are modeled using the Patton (2006) specification:

$$\theta_t = \Lambda(\bar{\theta} + \rho[\Phi^{-1}(u_{s,t-1}) - \mu_s][\Phi^{-1}(u\_g_{,t-1}) - \mu\_g])\text{------------------}(4)$$

where $\Lambda(\cdot)$ restricts parameters to valid ranges and ρ measures sensitivity to lagged extreme observations. This approach captures how market stress dynamically increases conditional correlations. Tail dependence indices quantify joint extreme movements. Lower tail dependence λ_L measures the probability of simultaneous extreme lows; upper tail dependence λ_UU measures simultaneous extremes. Mathematically, Lower tail dependence measures how two variables move together when they both have very low values at the same time. The coefficient of lower tail dependence, represented as, λ_L is frequently computed using copulas, which simulate the structure of dependence between variables.

$$\lambda_L = \lim_{u \to 0} P(\upsilon_1 \leq u, \upsilon_2 \leq u) / P(\upsilon_1 \leq u)\text{-------------------------}(5)$$

Where υ_1, υ_2 are the two random variables' marginal distributions (in this case, oil supply shock and exchange rate uncertainty shock), $\rho(\upsilon_1 \leq \upsilon_2 \leq \upsilon$ demonstrates how likely it is that both variables will fall below a certain level; $\rho(\upsilon_1 \leq \upsilon$ the marginal CDF of υ_1 which shows how likely it is that the first variable will drop below μ. This equation estimates the probability that both variables are in the lower tail, i.e., have very low values, rather than just one. A higher value of $\lambda_{\mathcal{L}}$ suggests that the two variables are more likely to exhibit extreme negative outcomes together, as evidenced by a greater reliance on the lower tail. Empirical copula estimates are used in practice to calculate the lower tail dependency, which is frequently employed in risk management and finance to represent extreme occurrences like financial crises or abrupt drops in asset prices. Non-zero tail dependence (particularly lower tail dependence) indicates that reserves and exchange rates/oil prices move together in crisis states, amplifying shock transmission.

3.2.3. Panel Quantile Regression

The QR technique was employed to understand the impact of exchange rate uncertainty and crude oil supply shock across different points in the distribution of foreign reserves, providing a more detailed picture of the relationships. The general quantile regression model is specified as given in equation (6).

$$Q_\tau(Y_{it}|W_{it-1}) = \alpha_i(\tau) + \emptyset_i(\tau)^T S_{it} + e_{it}(\tau)\text{ ----------------}(6)$$

where $Q_\tau(Y_{it}|W_{it-1})$ is the τth conditional quantile of Y_{it}, $\alpha_i(\tau)$ captures the individual-specific fixed effects at quantile τ, $\emptyset_i(\tau)$ Stands for the vector of coefficients for control variables, stands for the vector of control variablesS_{it}, $\mu_{it}(\tau)$ is the error term with zero median at the quantile τ. Based on the variables of the research, the QR model is specified as given in equation (7).

$$Q_\tau(Reslvt_{it}|W_{it-1}) = \alpha(\tau) + \varphi_1(\tau)Exucert_{i,t} + \varphi_2(\tau)Oilshock_{i,t} + \varphi_3(\tau)Exucert.Oilshock_{i,t} + \mu_i + W_t + \epsilon_{i,t}(\tau)\text{----}(7)$$

where $Q_\tau(Reslvt_{it}|W_{it-1})$ is the τth conditional quantile of $Reslvt_{i,t}$, $\alpha(\tau)$ is the intercept at quantile τ, $\varphi_j(\tau)$ are the quantile-specific coefficients, μ_i are the fixed effects for each country, W_t Captures time effects such as seasonal dummies of Fourier terms, T_t represents time trend, $\epsilon_{i,t}(\tau)$ and represents the error term at quantile τ. For specific quantiles τ, the model can be specified as:

For the 10th quantile (τ=0.10):

$$RES(0.1) = \alpha(0.1) + \varphi_1(0.1)Exucert_{i,t} + \varphi_2(0.1)Oilshock_{i,t} + \varphi_3(0.1)Exucert.Oilshock_{i,t} + \mu_i + W_t + \epsilon_{i,t}(0.1)\text{-----}(8)$$

For the 50th quantile (τ=0.50) (Median Regression): $RES(0.5) = \alpha(0.5) + \varphi_1(0.5)Exucert_{i,t} + (0.5)Oilshock_{i,t} + \varphi_3(0.5)Exucert.Oilshock_{i,t} + \mu_i + W_t + \epsilon_{i,t}(0.5)$------------------------(9)

For the 90th quantile (τ=0.90):

$$RES(0.9) = \alpha(0.9) + \varphi_1(0.9)Exucert_{i,t} + \varphi_2(0.9)Oilshock_{i,t} + \varphi_3(0.9)Exucert.Oilshock_{i,t} + \mu_i + W_t + \epsilon_{i,t}(0.9)\text{-----}(10)$$

where $\varphi_1(\tau)$ represents the change in the τ-th quantile of RES_t associated with a percentage change in uncertainty in the exchange rate, $\varphi_2(\tau)$ represents the change in the τ-th quantile of RES_t associated with a percentage change in crude oil supply shock, and $\varphi_3(\tau)$ represents the change in the τ-th quantile of $RESes_t$ associated with a percentage change in import duties. To capture heterogeneous effects across reserve distributions, we estimate quantile regressions at levels of τ as once again re-specified in equation (11).

$$Q\_\tau(\Delta \ln RES_{it} \mid X_{it}) = \alpha\tau_{(i)} + \delta\tau\ Exucert_{it} + \gamma\_\tau\ OilShock_{it} + \delta\tau\ Exucert.Oilshock_{it} + \psi\tau\ ExuOil_{it} + \xi_{it},\tau\text{-------------------}(11)$$

Quantile-specific estimations are conducted at the 10th, 50th, and 90th percentiles to capture low-, median-, and high-reserve regimes (Equations 8–10). Panel quantile parameters are estimated using iterative linear programming methods, with standard errors obtained via bootstrap procedures (500 replications). Coefficient estimates across quantiles reveal whether reserve-scarce economies respond more strongly to shocks than those with adequate buffers.

3.2.4. Countries and Sample Period

The sample includes five MENA countries selected to maximize variation in oil dependence, reserve behavior, and institutional characteristics: Saudi Arabia, United Arab Emirates, Qatar, Egypt, and Tunisia. Monthly observations from January 2000 to November 2025 yield 311 observations per country. The sample spans multiple global and regional shock episodes, including the 2008 global financial crisis, the 2014–2016 oil price collapse, the COVID-19 pandemic, and the

2022–2025 global monetary tightening cycles, thereby providing a robust setting for dynamic and nonlinear analysis (Chatziantoniou et al., 2023).

4. Results and Discussions

Table 1 reports the preliminary descriptive statistics for the variables used in the analysis. Several important features emerge from the data. Foreign exchange reserves exhibit substantial volatility, with a standard deviation of 3.47% and pronounced asymmetry toward depletion episodes, as indicated by a minimum value of −18.45% compared to a maximum of 21.33%. This asymmetry suggests that sharp reserve drawdowns occur more abruptly than accumulation phases. Exchange rate uncertainty displays marked right skewness (skewness = 2.18), implying that extreme volatility episodes are infrequent but severe when they occur. Oil supply price shocks exhibit a near-zero mean and fat tails (kurtosis = 3.52), consistent with financial return distributions influenced by geopolitical disruptions and supply-side surprises. These stylized facts justify the use of a GARCH–copula framework, which is well suited to capturing non-normality and tail dependence.

Pairwise correlations further motivate a conditional and nonlinear analysis. Exchange rate uncertainty is negatively correlated with reserve changes (−0.34) and statistically significant, while the correlation between oil supply shocks and reserves is weaker (−0.18). The relatively modest oil–reserve correlation likely reflects heterogeneity across countries, as oil exporters may accumulate reserves even during price declines when exchange rate pressures prompt defensive accumulation or policy intervention. These preliminary associations underscore the need for models that account for state dependence and cross-country variation.

Table 1: Preliminary Statistics for the Panel of MENA Countries (monthly Series: January 2000 – November, 2025)

Variable	Mean	Std Dev	Min	Max	Skewness	Kurtosis
ΔlnRES (%)	0.18	3.47	-18.45	21.33	0.12	4.81
ExuCert	1.04	1.23	0.11	8.45	2.18	7.33
OilShock (%)	0.08	7.82	-32.14	28.92	-0.34	3.52

Source: Authors' 2025 results

Panel unit root and co-integration test results are reported in the Appendix (A, B, C, D, E, F, G, J, K, L). The findings indicate that all variables become stationary after first differencing, implying the presence of unit roots at levels. Exchange rate uncertainty shows mixed evidence at levels, although the overall panel suggests stationarity. Co-integration results confirm the existence of a long-run relationship among foreign reserves, exchange rate uncertainty, oil supply shocks, and imports for the MENA countries. These properties ensure that the subsequent dynamic and distributional analyses are statistically valid and reliable.

Table 2 presents the impulse response results from the IPVAR model, illustrating the individual and combined effects of exchange rate uncertainty and oil supply shocks on reserve accumulation over a 24-month horizon. In the short run (months 1–6), a one-standard-deviation shock to exchange rate uncertainty leads to a decline in reserves ranging from −0.8 to −1.5 percentage points, with the negative effect intensifying over the initial months. This pattern suggests that heightened uncertainty rapidly undermines investor confidence and capital inflows, forcing central banks to rely on reserves to stabilize external conditions. In the medium term (months 7–12), the adverse impact moderates to approximately −0.6 percentage points, indicating partial adjustment as economic agents adapt to the new exchange rate environment. Although the effect remains negative, the reduced magnitude suggests that policy responses and market adjustments help absorb part of the initial shock. In the long run (months 13–24), the effect gradually dissipates, implying that exchange rate uncertainty does not exert a persistent influence on reserve dynamics once stabilization mechanisms and structural adjustments take hold.

The cumulative 24-month effect of a one-standard-deviation increase in exchange rate uncertainty amounts to a 15.3% reduction in reserves. This result highlights the economically meaningful and persistent nature of exchange rate volatility for reserve accumulation in MENA economies, even when short-run effects appear to fade. Negative oil supply price shocks generate substantially larger effects. In the short run, a decline in oil prices reduces reserves by approximately 2.1 to 2.8 percentage points within the first six months. Given the heavy dependence of MENA economies on hydrocarbon revenues, this result reflects immediate losses in foreign exchange earnings and increased fiscal pressures. The adverse effects persist over time, as oil revenues typically recover slowly following price collapses. Over the 24-month horizon, the cumulative impact of a negative oil shock reaches −28.3%, underscoring the pronounced vulnerability of oil-exporting economies to adverse oil market conditions.

By contrast, positive oil price shocks generate only modest reserve gains. In the short run, reserves increase by approximately 0.9 to 1.2 percentage points during the first six months as higher oil revenues translate into foreign exchange inflows. However, these gains diminish in the medium term as fiscal spending, exchange rate regimes, or policy adjustments offset part of the windfall. In the long run, the positive effect largely dissipates, yielding a cumulative 24-month impact of only +8.7%. The asymmetry between negative and positive oil shocks indicates that reserve depletion during downturns is considerably stronger than reserve accumulation during booms. When exchange rate uncertainty and oil supply shocks occur simultaneously, their combined impact is more severe than the sum of their individual effects. In the average case, the short-run reserve response reaches −3.8 percentage points, slightly exceeding the additive benchmark of −3.7 percentage points. This amplification indicates that interaction effects intensify reserve pressures. Over time, the combined shock follows the general trajectory of the individual shocks, continuing to exert stress on reserve positions.

The amplification becomes particularly pronounced under crisis conditions, defined as periods when reserves lie in the lower tail of the distribution (10th percentile). In this regime, the short-run impact of the combined shock reaches −5.2 percentage points and remains persistent over the medium and long term. The interaction effect contributes an additional −1.5 percentage points beyond the individual shocks, highlighting the heightened vulnerability of reserve-scarce economies. These findings suggest that countries with limited reserve buffers are disproportionately exposed to the joint occurrence of exchange rate uncertainty and adverse oil market conditions. Overall, the results demonstrate that exchange rate uncertainty exerts a significant negative effect on foreign reserves in MENA economies, both independently and in combination with oil supply shocks. Oil price declines generate particularly strong and persistent reserve losses, while positive oil shocks yield comparatively limited gains. The interaction between exchange rate uncertainty and oil supply shocks further amplifies reserve depletion, especially during periods of reserve scarcity. These findings underscore the critical importance of effective exchange rate management, diversification of revenue sources, and precautionary reserve policies in safeguarding macroeconomic stability in oil-dependent MENA economies.

Table 2: IPVAR Cumulative Impulse Responses (24-Month Horizon)

Shock Type	Short-Run Impact (Months 1-6)	Medium-Run (Months 7-12)	Long-Run (Months 13-24)	Cumulative 24-Month Effect
1. Exchange Rate Uncertainty (1 S.D.)	-0.8 to -1.5 pp (Intensifies)	-0.6 pp (Moderates)	Dissipates to zero	-15.30%
2. Oil Supply Shock				
a) Negative (1 S.D.)	-2.1 to -2.8 pp (Strong decline)	Cont. negative effect	Gradual adjustment	-28.30%
b) Positive (1 S.D.)	+0.9 to +1.2 pp (Modest gain)	Positive effect fades	Dissipates	8.70%
Interactive Combined Shock (1 S.D. to Both)				
a) Average-Case	-3.8 pp (vs. -3.7 pp additive)	Path follows components	Path follows components	Amplification: +0.1 pp
b) Crisis-Case (Reserves at 10th Q)	-5.2 pp (Peak impact)	Likely more persistent	Likely more persistent	Amplification: +1.5 pp

Source: Authors' 2025 results f*rom the Interacted Panel VAR (IPVAR) system GMM estimation.*
Notes: pp = percentage points. S.D. = Standard Deviation. Q = Quantile.

Table 3 presents the conditional volatility dynamics and tail dependence estimates derived from the Panel GARCH(1,1) and time-varying copula models. The GARCH(1,1) results indicate strong and persistent volatility clustering across all variables and countries, with persistence parameters ($\alpha + \beta$) ranging between 0.88 and 0.94. In particular, oil supply price shocks exhibit the highest persistence ($\alpha + \beta = 0.96$ for WTI), implying that volatility generated by oil market disturbances decays very slowly and remains elevated for extended periods. This finding reflects well-documented structural characteristics of the global oil market, including supply rigidity, geopolitical disruptions, and inventory adjustments, which tend to generate prolonged price fluctuations. For oil-dependent MENA economies, such persistent oil price volatility implies sustained spillovers into fiscal revenues, current account balances, and foreign reserve dynamics.

Exchange rate uncertainty shocks also display high volatility persistence ($\alpha + \beta = 0.91$), although slightly lower than that observed for oil prices. This indicates that once exchange rate uncertainty arises, whether due to policy interventions, speculative pressures, or external shocks, it tends to remain elevated, placing continuous pressure on reserve buffers. The persistence of reserve dynamics themselves is moderate to high ($\alpha + \beta$ ranging from 0.88 to 0.94), suggesting that periods of reserve accumulation or depletion tend to be prolonged and strongly influenced by both policy responses and external shocks. Collectively, these findings underscore the importance of incorporating time-varying volatility into reserve dynamics analysis, as ignoring volatility clustering would lead to an underestimation of risk during turbulent periods and an overestimation of stability during tranquil episodes.

The copula-based tail dependence results reveal pronounced asymmetry between lower- and upper-tail dependence across all variable pairs. Lower-tail dependence is substantially stronger, indicating that key variables become tightly interconnected during periods of financial stress. In particular, the lower-tail dependence between foreign reserves and exchange rate uncertainty (RES-ExuCert) is estimated at $\lambda_L = 0.38$, implying a 38% probability of simultaneous extreme reserve depletion and heightened exchange rate uncertainty during crisis episodes. This probability is considerably higher than would be expected under independence and suggests that adverse shocks in the MENA region tend to converge rather than offset one another. Such behavior challenges conventional diversification assumptions in reserve management, which often presume weaker correlations during extreme events.

Lower-tail dependence between reserves and oil supply shocks is also economically meaningful ($\lambda_L = 0.31$), indicating a significant joint downside risk. This result reflects the susceptibility of oil-exporting economies to dual-crisis scenarios in which oil price collapses simultaneously reduce foreign exchange inflows and necessitate reserve drawdowns to stabilize currencies and finance essential imports. The weakest lower-tail dependence is observed between exchange rate uncertainty and oil supply shocks (ExuCert-OilShock), with $\lambda_L = 0.24$, suggesting a comparatively looser, but still non-negligible, association during periods of stress. Together, these patterns indicate that reserves, exchange rate uncertainty, and oil supply shocks are interdependent in distinct ways, reinforcing the need to account for evolving dependence structures in crisis management and policy design.

Upper-tail dependence is consistently low across all variable pairs ($\lambda_U \approx 0.08$–0.15), indicating weak co-movement during favorable economic conditions such as oil price booms or currency appreciations. This asymmetry implies that reserve accumulation during positive shocks is not necessarily synchronized with favorable movements in exchange rates or oil prices. Consequently, relying on benign conditions for reserve accumulation may be insufficient, highlighting the importance of proactive and rule-based reserve accumulation strategies.

The time-varying copula results further demonstrate that tail dependence is highly regime-specific and intensifies during episodes of systemic stress. During the relatively stable pre-2007 period, lower-tail dependence remained modest (approximately 0.15–0.20), reflecting limited co-movement risk. In contrast, during the Global Financial Crisis of 2008-2009, lower-tail dependence surged to values between 0.45 and 0.52, signalling a sharp increase in synchronized stress across reserves, exchange rates, and oil markets. A similarly elevated dependence persisted during the 2014-2016 oil price collapse, with λ_L ranging from 0.35 to 0.42, highlighting the region-specific vulnerability of oil-dependent economies to commodity-driven crises. The peak dependence occurred during the COVID-19 pandemic in 2020, when λ_L reached approximately 0.55, reflecting an unprecedented convergence of shocks across oil markets, exchange rates, and capital flows.

These findings provide strong evidence that economic relationships evolve rapidly during global and regional shocks and that reserve adequacy assessments must account for changing dependence structures. While traditional reserve metrics may appear sufficient during tranquil periods, crisis episodes are characterized by sharply elevated risks of simultaneous adverse shocks. The post-pandemic period (2022–2025) exhibits moderately elevated lower-tail dependence in the range of 0.30–0.40, potentially reflecting improved policy frameworks or enhanced shock-absorbing capacity across MENA economies, though systemic vulnerability remains non-trivial.

Table 3: Conditional Volatility Dynamics and Tail Dependence

Analysis Dimension	Key Metric / Variable Pair	Estimated Value	Interpretations
Volatility Persistence **(α + β)**	Crude Oil Supply Shocks (WTI)	$\alpha + \beta = 0.96$	Extremely high persistence; shocks have long-lasting effects.
	Exchange Rate Uncertainty Shock	$\alpha + \beta = 0.91$	High persistence; volatility clusters significantly.
	Foreign Reserves	0.88 – 0.94 (range)	Moderate to High
Tail Dependence			
Lower Tail (Crisis States)	RES ↔ ExuCert	$\lambda_L = 0.38$	High probability (38%) of joint crashes.
	RES ↔ OilShock	$\lambda_L = 0.31$	Significant joint downside risk.
	ExuCert ↔ OilShock	$\lambda_L = 0.24$	Moderate linkage during stress.
Upper Tail (Boom States)	All Pairs	$\lambda_U = 0.08, 0.10, 0.15$: $\lambda_U \approx 0.08 – 0.15$	Weak co-movement during booms.
Time-Variation in λ_L	Calm Period (2000-2007)	0.15 – 0.20	Low baseline systemic risk.
	Global Financial Crisis (2008-2009)	Spike to 0.45 – 0.52	Extreme systemic risk materializes.
	Oil Collapse (2014-2016)	Rise to 0.35 – 0.42	High regional stress reactivates dependencies.
	COVID-19 Pandemic (2020)	Briefly > 0.55	Peak synchronized stress.
	Post Covid-19 (2022 – 2025)	0.30 - 0.40	Monetary policy tightening

Source: Authors' 2025 results

Table 4 reports the panel quantile regression results linking exchange rate uncertainty (ERU) and oil supply shocks to the reserve response trajectory of MENA countries across different points of the reserve distribution. By estimating effects at multiple quantiles, this approach allows the impact of shocks to vary with reserve levels, providing a more nuanced perspective than conventional mean-based regressions. At the lower end of the reserve distribution, exchange rate uncertainty exerts a pronounced negative effect on reserve dynamics. At the 10th quantile, the ERU coefficient is −0.245 and statistically significant at the 1% level (t-statistic = −2.99). This result indicates that when reserves are already low, an increase in exchange rate uncertainty leads to substantial reserve depletion. Quantitatively, a one-unit increase in exchange rate uncertainty is associated with a 0.245-unit decline in reserve accumulation, holding other factors constant.

A similar, though slightly attenuated, effect is observed at the 25th quantile, where the ERU coefficient is −0.187 (t-statistic = −2.75), also significant at the 1% level. The reduction in magnitude relative to the 10th quantile suggests that while reserve responses remain strongly negative, the sensitivity to exchange rate uncertainty diminishes as reserve buffers increase. Together, these findings indicate that countries with low initial reserve levels are particularly vulnerable to exchange rate uncertainty, likely due to limited buffers and reduced capacity to absorb external shocks without resorting to reserve drawdowns. At the median of the distribution (50th quantile), the ERU coefficient declines further to −0.124 and remains marginally significant at the 10% level (t-statistic = −1.75). This result suggests that exchange rate uncertainty continues to exert a negative influence on reserves, but the effect is notably weaker than in lower-reserve regimes. Countries at this level may benefit from greater reserve diversification, improved access to financial markets, or more effective policy tools that partially mitigate the impact of uncertainty.

In contrast, exchange rate uncertainty has no statistically significant effect at higher reserve levels. At the 75th quantile, the coefficient is −0.068 (t-statistic = −0.93), and at the 90th quantile it falls to −0.031 (t-statistic = −0.35), both of which are statistically insignificant. These results imply that countries with ample reserve buffers are largely insulated from exchange rate uncertainty shocks and do not need to adjust reserves aggressively in response to heightened volatility. Stronger institutional frameworks and more credible policy regimes may further contribute to this resilience. Overall, the quantile results clearly demonstrate that exchange rate uncertainty has a heterogeneous impact on reserve dynamics in MENA economies. The adverse effects are concentrated in low-reserve regimes and diminish progressively as reserve levels increase, underscoring the stabilizing role of adequate reserve buffers.

The effects of oil supply shocks on reserve responses exhibit a similar pattern of distributional heterogeneity. At the 10th quantile, the oil shock coefficient is −0.437 with a t-statistic of −3.52, indicating a strong and statistically significant negative impact at the 1% level. This finding implies that when reserves are scarce, oil supply shocks generate substantial reserve losses, reflecting heightened vulnerability to oil price fluctuations in low-buffer environments. At the 25th quantile, the negative effect remains significant but declines in magnitude, with a coefficient of −0.312 (t-statistic = −2.89). Although reserves at this level provide some additional cushioning, oil supply shocks continue to exert considerable pressure on reserve positions. At the median (50th quantile), the coefficient further decreases to −0.198 and remains statistically significant at the 5% level (t-statistic = −2.08), suggesting that oil shocks still matter for reserve dynamics but with reduced intensity.

In contrast, oil supply shocks have no statistically significant effect at higher reserve levels. At the 75th quantile, the coefficient drops to −0.089 (t-statistic = −0.87), and at the 90th quantile it falls to −0.034 (t-statistic = −0.30). These results indicate that countries with substantial reserve buffers are largely shielded from oil supply shocks, likely due to stronger fiscal positions, diversified revenue sources, or more effective macroeconomic stabilization mechanisms. Taken together, the quantile regression results confirm that oil supply shocks disproportionately affect countries with low reserve levels, while their impact weakens markedly as reserves increase. This pattern reinforces the importance of reserve adequacy as a key determinant of resilience to commodity-related external shocks.

Table 4: *Panel Quantile Regression Results for Shock Effects on Reserve Accumulation in the MENA Region*

Reserve Quantile (τ)	ExuCert Coeff.	t-stat	OilShock Coeff.	t-stat
10th (Low Reserves)	-0.245	-2.99**	-0.437	-3.52**
25th	-0.187	-2.75**	-0.312	-2.89**
50th (Median)	-0.124	-1.75*	-0.198	-2.08*
75th	-0.068	-0.93	-0.089	-0.87
90th (High Reserves)	-0.031	-0.35	-0.034	-0.30

**Notes: ** p<0.01, * p<0.05. Coefficients show the change in ΔlnRES for a one-unit increase in the shock variable.* Source: Authors' 2025 results from Panel Quantile Regression with bootstrapped standard errors*

5. Discussion

The IPVAR and panel GARCH–Copula approaches capture complementary dimensions of shock transmission in MENA economies. While the IPVAR framework identifies mean-level dynamic responses of foreign reserves to exchange rate uncertainty and oil supply shocks, the copula-based analysis reveals how extreme events co-occur and amplify adverse outcomes through time-varying dependence structures. Together, these methods show that reserve management in the region operates in a multidimensional risk environment shaped by nonlinear dynamics, threshold effects, and tail risks. Consequently, reliance on baseline or average scenarios alone is insufficient, as synchronized exchange rate and oil price shocks are both plausible and economically consequential (IMF, 2024b).

The IPVAR results indicate that exchange rate uncertainty reduces reserve accumulation by approximately 15.3% over a 24-month horizon, while crude oil supply shocks generate substantially larger effects, particularly for negative shocks, which lead to cumulative reserve losses of 28.3%. The asymmetry between negative and positive oil shocks suggests that precautionary reserve drawdowns dominate countercyclical accumulation behavior in oil-dependent economies. Panel quantile regression further reveals pronounced heterogeneity across reserve regimes: countries with low reserve buffers are seven to eight times more sensitive to exchange rate and oil shocks than those with high reserves. This highlights the central role of reserve adequacy in mitigating external vulnerability.

The panel GARCH–Copula results reinforce these findings by showing strong lower-tail dependence between reserves and exchange rate uncertainty ($\lambda_L = 0.38$) and between reserves and oil supply shocks ($\lambda_L = 0.31$). These estimates imply that crisis episodes are characterized by synchronized extreme movements rather than independent shocks. Moreover, tail dependence intensifies during periods of global stress, such as the Global Financial Crisis, the 2014–2016 oil price collapse, and the COVID-19 pandemic, often exceeding 0.45. This evidence challenges conventional policy assumptions that treat exchange rate and commodity risks as weakly correlated during crises (Arbatli-Ece & Gopinath, 2024; Opoku et al, 2023).

The results align with precautionary savings theory, which views reserves as buffers against external volatility, but they also extend existing models by demonstrating stronger-than-predicted responses in reserve-scarce economies. While standard theoretical elasticities typically range between −0.15 and −0.25, the quantile estimates for low-reserve countries reach −0.25 to −0.35, suggesting that political economy constraints, credibility concerns, and limited policy space intensify precautionary behavior beyond benchmark predictions. The asymmetric response to oil price movements, where reserve drawdowns following negative shocks exceed accumulation during positive shocks, is consistent with recent evidence for MENA exporters (Elshamy & Kassem, 2023), but the present study shows that this asymmetry is most pronounced when reserves are scarce.

Cross-country heterogeneity further refines these insights. Egypt and Tunisia exhibit strong adverse reserve responses across most quantiles, reflecting limited buffers and constrained shock-absorption capacity. In contrast, the United Arab Emirates demonstrates resilience consistent with diversified external assets and stronger institutional frameworks, while Qatar's reserve stability during positive oil shocks is most evident at higher reserve levels. The interaction between exchange rate uncertainty and oil supply shocks magnifies reserve pressures in reserve-scarce economies, supporting buffer-stock models of reserves while emphasizing the importance of initial reserve conditions and country-specific characteristics (Umoru et al., 2025; Rath et al., 2025; Kurul, 2025; Coulibaly et al., 2023).

This study contributes in three main ways. First, it demonstrates that exchange rate uncertainty and oil supply shocks affect reserves asymmetrically across the reserve distribution. Second, it integrates these shocks within a unified empirical framework that captures both mean-level dynamics and tail-risk dependence for MENA economies. Third, it highlights substantial cross-country heterogeneity, underscoring the limitations of uniform reserve management strategies across the region. At a policy level, the findings suggest that countries with persistent reserve scarcity require enhanced stabilization mechanisms and greater exchange rate flexibility, while oil exporters need stronger fiscal smoothing tools to manage revenue volatility.

6. Conclusions

This study examines how exchange rate uncertainty and crude oil supply shocks jointly affect foreign reserve accumulation in MENA economies using an integrated IPVAR, panel quantile regression, and panel GARCH–Copula framework. The findings show that reserve dynamics in the region are shaped by nonlinear interactions, distributional heterogeneity, and time-varying tail risks that are not captured by conventional average-effect models. The IPVAR results indicate that exchange rate uncertainty significantly reduces reserve accumulation over a two-year horizon, while crude oil supply shocks exert larger and more persistent effects, particularly in the case of negative shocks. The asymmetry between negative and positive oil shocks confirms that reserve drawdowns during downturns are substantially stronger than reserve accumulation during booms. Panel quantile regression further reveals pronounced heterogeneity across reserve regimes: countries with low reserve buffers experience markedly stronger adverse effects from both exchange rate uncertainty and oil shocks, whereas high-reserve countries are largely insulated.

The panel GARCH–Copula analysis provides complementary evidence that crisis periods are characterized by strong lower-tail dependence between reserves, exchange rate uncertainty, and oil supply shocks. This implies that external shocks in MENA economies tend to occur simultaneously rather than independently, amplifying reserve vulnerability during periods of global and regional stress. Taken together, these results demonstrate that reserve vulnerability is greatest when reserves are scarce and that tail-risk dependence plays a critical role in shaping reserve outcomes. This study contributes by integrating exchange rate uncertainty and oil supply shocks within a unified, distribution-sensitive framework for MENA economies. The findings highlight the limitations of static reserve adequacy benchmarks and underscore the importance of accounting for nonlinearities, asymmetries, and joint risks in reserve management. Future research may extend this framework to other oil-dependent regions to assess the generalizability of the distributional effects documented here.

7. Policy Implications

The results suggest that MENA economies require more dynamic and state-contingent reserve management frameworks. Countries with high exposure to oil and exchange rate shocks should maintain reserve buffers above conventional adequacy thresholds to account for joint tail risks. Reserve policy should be coordinated with fiscal rules that promote counter-cyclical savings during commodity booms and limit reserve erosion during downturns. Exchange rate regimes should allow sufficient flexibility to absorb shocks without excessive depletion of reserves, particularly during periods of synchronized stress. For pegged or heavily managed regimes, pre-announced contingency mechanisms, such as temporary band widening or managed flexibility, may help preserve reserves for essential external financing. At the regional level, enhanced financial cooperation, including swap arrangements or pooled stabilization mechanisms, could further strengthen resilience against shared external shocks.

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Appendix A: Panel Unit Root Test Results for MENA Countries

S/N	Variable	ADF-Fisher Chi-Square	ADF- Choi Z-Stat	ADF-Fisher Chi-Square Prob**	ADF- Choi Z-Stat Prob**	Order of Integration
1	Reslv	186.348	-289.4879	0.0000	0.0000	I(1)
2	Exucert	127.3487	-39.2278	0.0000	0.0028	I(0)
3	Oilshock	287.3872	-42.4821	0.0000	0.0000	I(1)
4	Imports	356.872	-286.487	0.0000	0.0000	I(1)

Source: Authors' 2025 results

Appendix B: Panel Co-integration Test Results for MENA Countries

Measures	Unweight Statistic	Weighted statistic
Panel v-Statistic	39.50531***	3.533960***
" rho-Statistic	-259.0427***	-272.7933***
" PP-Statistic	-69.35301***	-72.68481***
" ADF-Statistic	-50.63540***	-49.27137***

Source: Authors' 2025 results

Appendix C: Quantile Regression Results for UAE

Variables	10th	20th	30th	40th	50th	60th	70th	80th	90th
C	1.07***	1.09***	1.10***	1.12***	1.11***	1.09***	1.11***	1.12***	1.10***
Exucert	-3.19**	-2.64**	-2.02**	-1.10	-1.82*	-3.23**	-2.26**	-2.52**	-4.48**
Oilshock	-1.26	-3.92	-7.10	-1.23**	-8.28*	-1.81	-5.79	-4.23	2.20
ExuOilsh	0.001**	0.012**	0.029**	0.004**	0.002*	0.134**	0.012**	0.009	0.001***
Imports	1.61	1.35*	1.07***	1.43***	1.15***	6.26*	9.3**	8.55*	3.88*

Source: Authors' 2025 results

Appendix D: Symmetric Quantiles Test Results for UAE

Test Summary		Chi-Sq. Statistic	Probability value
Wald Test		20.300768	0.0000
Quantiles	Variable	Restr. Value	-
0.25, 0.75	C	-1.330808	0.0000
	Exucert	1069216.	0.0000
	Oilshock	6122304.	0.0000
	Import	-44075681	0.0000

Source: Authors' 2025 results

Appendix E: Quantile Regression Results for Qatar

Variables	10th	20th	30th	40th	50th	60th	70th	80th	90th
C	1.17***	1.09**	1.18***	1.19***	1.14***	1.20**	2.13***	1.52**	1.10***
Exucert	-3.34**	-0.323**	-2.15**	-0.28***	-1.94**	-3.20**	-2.76**	-1.06***	1.23***
Oilshock	1.94**	10.7***	2.23***	1.53***	9.22***	5.13***	7.89***	6.81**	3.71***
ExuOilsh c	-0.516***	-0.013**	-0.018***	-0.196**	-0.174*	-0.239***	-0.149**	-0.026**	-0.011***
Imports	-2.23***	-2.23***	-0.15***	-0.17***	-0.13***	-1.29***	-0.11***	-0.04**	-0.16***

Source: Authors' 2025 results

Appendix F: Symmetric Quantiles Test Results for Qatar

Test Summary		Chi-Sq. Statistic	Prob.
Wald Test		11.792950	0.0000
Quantiles	Variable	Restr. Value	-
0.25, 0.75	C	70761661	0.0000
	Exucert	1528959.2	0.0000
	Oilshock	-2317776.3	0.0000
	Import	-883065.8	0.0000

Source: Authors' 2025 results

Appendix G: Quantile Regression Results for Egypt

Variables	10th	20th	30th	40th	50th	60th	70th	80th	90th
C	1.31***	0.33***	1.02***	0.34***	1.07***	0.15***	0.19***	0.01***	0.18**
Excuert	-1.21	1.15	-1.95	-0.240	-1.91***	-1.29***	-0.11***	-0.54***	-1.43**
Oilshock	-1.63***	-1.02***	-1.07***	-1.59***	-1.62***	-2.93***	-1.13***	-1.52***	-1.22**
ExuOilsh	-1.289**	-0.167**	-0.132**	-0.114**	-1.123*	-0.134***	-0.165**	-0.012**	-0.139***
Imports	-1.02***	-2.63***	-0.10***	-3.20***	-1.40***	-1.58***	-1.76***	-1.29***	-1.67**

Source: Authors' 2025 results

Appendix H: Symmetric Quantiles Test Results for Egypt

Test Summary		Chi-Sq. Statistic	Probability Value
Wald Test		12.810661	0.0000
Quantiles	Variable	Restr. Value	-
0.25, 0.75	C	90083254	0.0000
	Exucert	-6882907.	0.0000
	Oilshock	665516.2	0.0000
	Import	3209918.	0.0000

Source: Authors' 2025 results

Appendix I: *Quantile regression results for Saudi Arabia*

Variables	10th	20th	30th	40th	50th	60th	70th	80th	90th
C	1.89***	1.01***	1.27***	1.03**	1.25***	1.14***	1.05***	1.13**	1.08***
Exucert	0.43	1.25	0.13	0.26***	1.14	0.38	0.17	0.28	1.07
Oilshock	-1.91***	-1.60**	-1.52**	-1.59***	-1.97**	-1.73**	-1.93**	-2.00**	-1.90***
ExuOilsh	0.024**	-0.109**	-0.049**	-0.135**	-0.273*	-0.119**	-0.872**	-0.109**	-0.0129**
Import	-2.53**	-2.19***	-1.20**	-1.08**	-1.27**	-0.46**	-2.37**	-1.96**	-2.17***

Source: Authors' 2025 results

Appendix J: *Symmetric Quantiles Test Results for Saudi Arabia*

Test Summary		Chi-Sq. Statistic	Probability Value
Wald Test		10.1572	0.0000
Quantiles	Variable	Restr. Value	-
0.25, 0.75	C	-1.80909	0.0000
	Exucert	510360.4	0.0000
	Oilshock	3085366.	0.0000
	import	29261333	0.0000

Source: Authors' 2025 results

Appendix K: *Quantile Regression Results for Tunisia*

Variables	10th	20th	30th	40th	50th	60th	70th	80th	90th
C	10.8***	10.8***	10.9***	11.0***	11.0***	11.0***	11.1***	11.1***	11.1**
Exucert	-1.35**	-0.69*	-1.85**	-0.968***	-1.73**	-1.68**	-0.44**	-0.392**	-0.02**
Oilshock	-1.66**	-1.02***	-1.33***	-1.63***	-1.19**	-1.12**	-1.15***	-1.01***	-1.94**
ExuOilsh	-0.49**	-0.013**	-0.193**	-0.143**	-1.022*	-0.10**	-0.192**	-0.011**	-0.017**
Imports	-1.93**	-1.89***	-1.37***	-1.94***	-0.12**	-0.90**	-0.29***	-0.37***	-0.42**

Source: Authors' 2025 results

Appendix L: *Symmetric Quantiles Test Results for Tunisia*

Test summary		Chi-Sq. Statistic	Probability Value
Wald Test		11.968200	0.000
Quantiles	Variable	Restr. Value	-
0.25, 0.75	C	-62170466	0.0000
	Exucert	730403.0	0.0000
	Oilshock	259146.3	0.0000
	Import	7687826.	0.0000

Source: Authors' 2025 results