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Volatility and the Monetary Approach: Evidence from the Mexican Exchange Market

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ABSTRACT

This study employs a novel approach by using the GARCH-MIDAS model to estimate the volatility of the nominal exchange rate, incorporating variables of the monetary approach as a long-run component. We analyze the daily closing prices of the peso-dollar nominal exchange rate from July 1991 to December 2022 and the quarterly macroeconomic fundamentals from September 1988 to December 2022. Our findings reveal a significant influence of the monetary approach variables on the long-term feature of the exchange rate volatility. We find that the bias of long-term volatility is contingent upon the distinctive functional relationship fundamental to the demand for real money balances. Our investigation concludes that the specification grounded in the monetary approach yields more robust volatility predictions when compared with alternative models.

Keywords: Exchange rate, Monetary approach, GARCH-MIDAS, Volatility
JEL Classifications: F31, G15, G17

1. INTRODUCTION

The economic and financial integration process that the Mexican economy experienced over the past 30 years, stemming from initiatives such as trade liberalization in 1986, the restructuring of an independent monetary policy through the autonomy of the Central Bank in 1994, and the implementation of the Balanced Budget Rule since 2006, reflects the increasingly significant role played by the peso-dollar nominal exchange rate in both external and internal adjustment processes within the Mexican economy in the last 30 years. This evolution has followed within a flexible exchange rate regime and unrestricted capital mobility since 1995[1].

The purpose of this paper is to investigate to what extent the monetary approach contributes to explaining the fluctuations observed in the peso-dollar nominal exchange rate in the Mexican exchange market, given that the fundamental macroeconomic aggregates involved in the financial market and the nominal exchange rate behave as non-stationary time series showing signs of cointegration and display high volatility and thick tails.

Obstfeld and Rogoff (2000) acknowledge that while a reasonable link exists between the nominal exchange rate and the fluctuation of prices inherent in any bilateral exchange rate, this connection is weak. According to MacDonald and Taylor (1994) and Engel (2014), the limited correlation noted between the nominal

1 The most noteworthy efforts in terms of market access occurred in 1986 with the signing of the Accession Protocol to the General Agreement on Tariffs and Trade (GATT 47) and in 1994 with the signing of the North American Free Trade Agreement (NAFTA). In 1994, the Central Bank Autonomy was established, and in December of the same year, the exchange rate regime transitioned from a band floating system to a flexible one. In 2006 the Balanced Budget Rule was formally approved in the Federal Budget and Fiscal Responsibility Law (LFPRH) and its by Law (RLFPRH).

exchange rate and fundamental macroeconomic variables indicates a particular weakness attributed to other independently distributed variables. Engel (2014) points to economic policy announcements as a potential source for mitigating this unexplained gap.

In this context, the severe deterioration of the world economic outlook during the pandemic in industrialized and emerging economies reflected a significant worsening in global economic activity indicators, signaling recession episodes and higher inflation pressures coming from the demand and supply sides in industrialized and emerging economies[2].

Some other external factors, including rises in the Federal Reserve's reference interest rate, the hawkish instrumentation of the monetary policy in the Central Bank of Mexico, renegotiations of the North American Free Trade Agreement (NAFTA) to the United States-Mexico-Canada Agreement (USMCA), along with internal factors like the sluggish economic growth observed during the outset of the 2018-2024 Mexican Government Administration, have pressured the nominal exchange rate peso-dollar reflecting higher volatility episodes in the Mexican exchange market[3].

According to Engel (2014), exchange rate volatility captures additional variation in asset prices when the market has more information about the future of economic fundamentals whose present values are stationary. In this context, exchange rate volatility describes the variation that "informational shocks" (disturbances) present on the macroeconomic fundamentals of the exchange rate series.

This article examines whether the monetary approach contributes to explaining the variations observed in the peso-dollar nominal exchange rate of the Mexican exchange market. In doing so, we follow Engle et al. (2013) and the GARCH-MIDAS[4] model based on a regression scheme that Ghysels et al. (2007) introduced. This methodology allows the inclusion of data from different frequencies into the same model, making it possible to combine exchange rate data observed in high frequencies (daily) with macroeconomic variables observed in lower frequencies (quarterly).

The remainder of this paper is organized as follows. In Section 2, we survey the specialized literature on this subject. Section 3 introduces the monetary approach and methodology for estimating macroeconomic fundamentals under volatility conditions. In Section 4, we present the GARCH and GARCH-MIDAS models and the assessment of the models' performance. Section 5 shows the data and empirical results. Finally, Section 6 presents the main conclusions and suggested lines for future research.

2. LITERATURE REVIEW

Since the publication of the Handbook of International Economics in 1995 (Grossman and Rogoff, 1995), a substantial number of empirical studies have identified various determinants of the evolution of the nominal exchange rate. It provided models whose predictive value is statistically significant and comparatively superior to that obtained from a stochastic random walk process in the short and long terms[5].

On the other hand, Engel (2014) provides a detailed account of theoretical and empirical contributions regarding the determinants of the exchange rate, aiming to bridge the gap between the 1995 review and the latest developments, particularly those of an empirical nature[6].

In this context, Engel (2014) highlights that while the monetary market-based approach to identifying the determinants of the nominal exchange rate remains appealing, its long-term predictive accuracy is controversial. Conversely, focusing on financial market efficiency and deviations in rational expectations have become significant in the short term[7].

Within the second stream, the econometric methodology relies on vector autoregression (VAR) or error correction models (VEC), employing time series data of the exchange rate alongside macroeconomic fundamentals of matching frequencies.

Fullerton et al. (2001) and Capistrán et al. (2019) examined the case of Mexico. The former introduced error correction models for the nominal exchange rate between the Mexican peso and the United States dollar based on the balance of payments and monetary theories. In contrast, the latter authors estimated a structural cointegrated vector autoregression (VAR) model, explicitly incorporating long-run theoretical relationships among macroeconomic variables, including purchasing power parity (PPP), uncovered interest parity (UIP), money demand (M2),

2 Review the Reports on The World Economic Outlook that the International Monetary Fund (IMF) published on this issue.

3 Based on the VIX (Volatility Index) associated with the S&P 500 stock index, two specific periods of financial stress are worth noting: i) between July 4 and December 12, 2011, a pronounced deterioration was observed in global economic activity indicators, accompanied by increased volatility in international financial markets. This volatility mirrored concerns regarding the fiscal sustainability of the United States and the peripheral countries within the eurozone and the declining global growth prospects, and ii) from February 27 to July 14, 2020, this period underscores the unprecedented economic challenges caused by the pandemic in industrialized and emerging market economies. It reflected a significant deterioration in global economic activity indicators, signaling recession episodes in several countries. This economic and financial downturn, accompanied by heightened risk aversion, raised in stock and debt markets worldwide.

4 The acronyms GARCH and MIDAS stand for Generalized Autoregressive Conditional Heteroskedasticity and Mixed Data Sampling, respectively.

5 For literature surveys before the publication of the Handbook of International Economics Vol. 3, consult MacDonald (1991), MacDonald and Taylor (1989, 1991, 1993), Dornbusch (1985), Boughton (1988), Kenen (1987), Mussa (1990), Meese (1990), and Krugman (1993). For literature reviews after the Handbook of International Economics Vol. 3 publication, refer to Engel (2014).

6 Review Froot and Rogoff (1995) and Frankel and Rose (1995) contributions.

7 Traditionally, numerous studies have relied on macroeconomic fundamentals, such as PPP for long-term convergence models, and uncovered interest rate parity for short-term determinants to model exchange rate behavior. An alternative approach emerges in modeling exchange rate behavior based on deviations from PPP and UIP, supported by empirical evidence. This alternative approach represents a second stream of models. For a prompt reference, consult Lewis (1993), Flood and Garber (1980), and Svensson (1992).

and the relationship between Mexico and the United States (US) output levels (GDP).

Among these studies are those by Jang and Ogaki (2004), who investigated the effects of shocks to Japanese monetary policy on exchange rates and other macroeconomic variables using structural VEC modeling methods with long-run restrictions.

Likewise, comparing different econometric techniques, Gallegos et al. (2022a) use the standardized framework where the uncovered interest rate (UIP) and the purchase power parities (PPP), flexible prices, and a typical demand for real monetary balances determine long-run prices. Using the monetary approach, they compare a VEC model with a univariate ARIMA-EGARCH and a multivariate ARIMAX-EGARCH models[8].

Unlike previous works that implicitly assumed constant exchange rate volatility, Lorenzo and Ruíz (2012; 2019) used TGARCH[9] models based on the observed volatility of the exchange rate series to describe the evolution of the peso-dollar and the dependence of exchange rate returns on oil returns under high volatility episodes.

Engle et al. (2013) pointed out that using the GARCH-MIDAS model during periods of heightened volatility on the daily evolution of the exchange rate contributes to the analysis of time series data with varying frequencies to determine the long-run volatility component[10].

Following Gallegos et al. (2022a), time series data from macroeconomic fundamentals that partially explain the exchange rate's statistical behavior are not only leptokurtic with thick tails but also publicly reported with different time frequencies[11].

Likewise, in studies exploring exchange rate volatility, researchers have conducted univariate time series analyses across various countries[12]. Abreu (2021) utilized the GARCH-MIDAS model to distinguish between the short-term and long-run components of exchange rate volatility in the Philippines and the United States. Their findings indicate that heightened volatility in macroeconomic variables corresponds to diminished volatility in long-term exchange rates. Similarly, You and Liu (2020) employed a GARCH-MIDAS approach. They observed significant enhancements in forecasting the daily fluctuations of exchange rates by incorporating the volatilities of monthly macroeconomic fundamentals as predictors into the volatility component of the model.

In this paper, we employ the GARCH-MIDAS methodology to investigate the long-term volatility component of peso-dollar exchange rate yields, focusing on monetary fundamentals.

3. THE MONETARY MODEL

The monetary approach to determining the nominal exchange rate under a flexible exchange rate regime assumes that the variables interacting in the monetary market determine the evolution of consumer prices in the long run, which in turn determines the nominal exchange rate. In this context, monetary policy exogenously explains the evolution of the growth rate of the nominal money supply if the demand for real money balances depends functionally on the nominal interest rate and the income level.

In the monetary market, the exogenous growth rate of the nominal supply determines the rate of change in prices, which is explained by the difference between the rate of change in the money supply and the growth rate of income levels when the explicit functional form of the demand for real money balances depends solely on income levels. These differences in the referred rates influence the evolution of the nominal exchange rate in the long term.

3.1. The Monetary Approach

At this point, seminal works on exchange rate determinants by Frenkel (1977), Mussa (1978), and Bilson (1978) used a simple demand for real money balances where the logarithm of the demand for real money balances conceived a contemporaneous-linear function of the real income and the nominal interest rate.

Accordingly, equilibrium conditions for the monetary market in the domestic and foreign countries are the result of having predetermined real balances for a specific demand of real monetary balances, as shown in the following equations:

$$m_t - p_t = \phi y_t - \lambda i_t \tag{1}$$

$$m_t^* - p_t^* = \phi y_t^* - \lambda i_t^* \tag{2}$$

Where m_t, y_t, and p_t represent the logarithm of the nominal money stock, gross domestic product (GDP), and the consumer index price (CPI), for the Mexican market at time t, and m_t^*, y_t^*, and p_t^* in the US market, respectively.

The paradigm of the monetary approach assumes that the long-term purchasing-power parity is fulfilled. This means that the exchange rate variation depends on the rate of variation of price indexes involved in the bilateral exchange rate, i.e., $s_t = p_t - p_t^*$. Where s_t represents the proportional change in the nominal exchange rate, and p_t and p_t^*, represent price variations. Therefore, from equations (1) and (2):

8 The acronym ARIMA stands for an Autoregressive Integrated and Moving Average model. EGARCH stands for an Exponential General Autoregressive Conditional Heteroskedasticity model, and ARIMAX stands for an Autoregressive Integrated and Moving Average model with Exogenous Variables (X).

9 TGARCH is a Threshold GARCH, allowing the conditional variance to respond accordingly to positive and negative shocks.

10 See Ghysels et al. (2007).

11 In Gallegos et al. (2022a), the Gross Domestic Product (GDP) is reported quarterly. Still, exchange rate series are reported daily, so time series data for the macroeconomic fundamentals and the nominal exchange rate had to be matched monthly. See Gallegos et al. (2022b) for another application of a TGARCH model on time series of oil prices.

12 For a recent review on the issue of volatility and exchange rates, see Flores-Sosa et al. (2022), and Hossain and Sultana (2022). Refer to Benavides and Capistrán (2012), Zhou et al. (2020), Bush and López (2021), Beckmann (2021), and Kurasawa (2016) for specific case studies.

$$s_t = \left(m_t - m_t^*\right) - \phi\left(y_t - y_t^*\right) + \lambda\left(i_t - i_t^*\right) \tag{3}$$

Statistical analysis of time series data reveals that non-stationary stochastic processes with unit roots (I(1)) generate the nominal exchange rate, interest rate, income level, and money supply. This suggests cointegration between the nominal exchange rate and the fundamental macroeconomic variables. Studies by Groen (2000), Mark and Sul (2001), and Rapach and Wohar (2002) confirm cointegration between the nominal exchange rate, nominal money supply, and income level, rejecting the null hypothesis of no unit roots or cointegration.

We obtain differences (Δ) in eq. (3) to statistically adjust and use a linear regression approach[13].

$$\Delta s_t = \Delta\left(m_t - m_t^*\right) - \phi\Delta\left(y_t - y_t^*\right) + \lambda\Delta\left(i_t - i_t^*\right) \tag{4}$$

Equation (4) shows that exchange rate returns are linearly dependent on the differences between the growth rates of real balances, income, and the interest rate between the Mexican and the US economies.

The values of ϕ and λ values are estimated through the following linear regression, where the parameters under the null hypothesis are expected to be[14]:

$$\Delta s_t = \beta_0 + \beta_1\Delta\left(m_t - m_t^*\right) + \beta_2\Delta\left(y_t - y_t^*\right) + \beta_3\Delta\left(i_t - i_t^*\right) + \varepsilon_t \tag{5}$$

i.e., where $\beta_0 = 0$; $\beta_1 > 0$; $\beta_2 < 0$ and $\beta_3 < 0$.

3.2. Exchange Rate Volatility

To compute the exchange rate volatility under the monetary approach, we use equation (6) to derive the conditional variance representing the squared volatility[15].

$$\sigma_{st}^2 = \sigma_{(m-m^*)t}^2 + \phi^2\sigma_{\left(y-y^*\right)t}^2 + \lambda^2\sigma_{\left(i-i^*\right)t}^2 + COV \tag{6}$$

Where the acronym COV stands for the covariances, that is, the crossed terms in the matrix of variances and covariances.

13 Time series that are not stationary -like those involved in equation (3)-, need some differentiation. Review Box and Jenkins (1976) and Guerrero (1991) for a detailed explanation.

14 Under the null hypothesis, we theoretically should expect that $\beta_0 = 0$, i.e., a line with no intercept; $\beta_1 > 0$, i.e., suggesting that a positive difference in the natural logarithm of nominal monetary balances would lead to depreciation in the nominal exchange rate; $\beta_2 > 0$, indicating that a positive difference in the natural logarithm of GDP between Mexico and the US would result in depreciation of the nominal exchange rate; and finally, $\beta_3 < 0$, implying that a positive difference in nominal interest rates would correspond to a depreciation of the nominal exchange rate.

15 The Exchange rate volatility, a crucial factor in our study, can significantly impact domestic economies in various ways. Firstly, higher exchange rate volatility affects exports, as more volatile exchange rates make export earnings uncertain. This causes a reduction in the consumers' welfare and increases uncertainty about future consumption and the income of individuals and companies. Secondly, it amplifies the risk perception of foreign investors and, therefore, affects capital inflows between industrialized and emerging economies. Thirdly, it also threatens financial investors since the exchange rate volatility increases the risk on investment portfolios. Hence, understanding the exchange rate volatility concerning macroeconomic fundamentals is a theoretical challenge and a practical necessity. See Deschamps et al. (2022).

In particular, to obtain the conditional variances of equation (6), ($\sigma_{(m-m^*)t}^2$, $\sigma_{\left(y-y^*\right)t}^2$, and $\sigma_{\left(i-i^*\right)t}^2$), we take the vector $x_t = \left[\left(m_t - m_t^*\right), \left(y_t - y_t^*\right), \left(i_t - i_t^*\right)\right]'$ and fit the vector autoregressive model (VAR):

$$x_t = \sum_{i=1}^{q} B_i x_{t-i} + u_t \tag{7}$$

he squared error term, u_t^2, fitted from equation (7), is then used to approximate the volatilities ($\sigma_{(m-m^*)t}^2$, $\sigma_{\left(y-y^*\right)t}^2$, and $\sigma_{\left(i-i^*\right)t}^2$) and, using the result from Eichler and Littke (2018), we consider the long-run volatility component of the daily exchange rate returns as a linear combination of the monetary approach and substitute the estimated coefficients from regression of equation (5) into equation (6).

4. METHODOLOGY

Volatility stands as one of the most prevalent risk measures within the realm of finance. Defined as the conditional standard deviation, it is typically expressed annually. This metric captures the stochastic process that delineates the dispersion of continuous returns, often represented in logarithmic form. Its estimation and prediction find numerous applications, including portfolio selection to minimize risk, risk value assessment, portfolio hedging, and asset valuation, notably in financial options. However, volatility remains unobservable, so its estimation and prediction depend on specific models. Moreover, volatility lacks a definitive "true" value, with its determination invariably contingent upon the model employed[16].

Incorporating volatility into models enables the representation of several stylized facts observed in stock return time series. Firstly, it addresses the likelihood of extreme returns that otherwise would not have been observed under the assumption of normal distribution. This leads to wider-tailed probability distributions of stock returns, a feature known as an excess of kurtosis. Secondly, it accounts for the leverage effect, characterized by a negative correlation between performance and volatility: as performance declines, volatility tends to increase. Finally, volatility exhibits temporal clustering, where volatility in one period depends on prior periods' volatility levels.

4.1. GARCH Modeling

Stylized facts regarding exchange rate returns are often explained through various models within the ARCH family. Engle (1982) proposed its use, and later, Bollerslev (1986) further developed its application. These models offer a framework for describing and analyzing exchange rate return features.

An extension of the ARCH modeling is the TGARCH model type that estimates the marginal density distributions of innovations associated with exchange rate returns.

The TGARCH model is also an extension of the traditional GARCH model that proposed Zakoian (1994). TGARCH

16 For a survey on volatility and its effects on the risk financial assessments, please see Flores-Sosa et al. (2022).

modeling allows the volatility of return series on period t, i.e., r_t, depend on the "news" arriving to the market (i.e., the lagged innovation u_{t-1}). This volatility is estimated with the following specification on the conditional variance of innovations, i.e., σ_t^2 :

$$r_t = \mu_t + u_t,$$

$$U_t = \sigma_t \varepsilon_t, \tag{8}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \gamma u_{t-1}^2 I\left(u_{t-1} < 0\right) + \beta \sigma_{t-1}^2,$$

Where μ_t is the conditional mean of returns and u_t are the lowered returns or innovations. We assume that the standardized disturbances or innovations ε_t have a t-student probability distribution with a shape parameter v. Likewise, parameters α_0, α_1, and β are assumed as non-negative; $\alpha + \gamma > 0$, and I is defined as an indicator function that takes the following values:

$$I = \begin{cases} 1 \; if \;\; u_{t-1} < 0 \\ 0 \;\; if \;\; u_{t-1} \geq 0 \end{cases}$$

Notably, the specification of the conditional variance given in equation (8) allows us to analyze the effects of qualitative news on the current volatility of the series of returns r_t[17].

Unlike the stock market, in the case of exchange rate returns, we must consider whether we are following the consensus that, for all purposes, an exchange rate represents the price of a foreign currency in terms of a domestic currency. If that is the case, we should expect that $\gamma > 0$; however, having $\gamma > 0$, corresponds with the reciprocal of the exchange rate that it would represent the price of a domestic currency in terms of the foreign currency.

Likewise, from the point of view of a Mexican investor "good news" mean that $u_{t-1} > 0$, and it has an effect equal to α_1 on σ_t^2. For the same reason, "bad news" means that $u_{t-1} < 0$, and it has an effect equal to $\alpha_1 + \gamma$ on σ_t^2. Thus, when $\gamma \neq 0$ "bad news" has measurable effects on the series' volatility. When "bad news" occurs and $\gamma > 0$, the series exhibits the "leverage effect" i.e., the volatility caused by "bad news" is more significant than the one caused by "good news". Thus, γ could be considered as a measure of the sensitivity to the prevailing "bad news" in the market: "Bad news" for the Mexican investor who buys US dollars is "good news" for the foreign investor who buys Mexican pesos.

4.2. TGARCH-MIDAS Modeling

The GARCH-MIDAS model generally integrates macroeconomic variables as a volatility component, enhancing its capacity to capture the market dynamics. This long-run volatility component aligns with the frequency of quarterly macroeconomic observations. It operates in combination with a short-run component, which fluctuates daily, as the exchange rate returns do.

17 To review this study's specification of equation 8, see equation (1.16) in Bollerslev et al. (1994). For applying the Indicator Function and the Threshold ARCH (TARCH) model, Zakoian (1994).

The difference of variance in equation (8) that comes from a TGARCH modeling is that the lowered returns or innovations u_t have the following specification:

$$u_{it} = \sqrt{\tau_t g_{it}} \varepsilon_{it} \tag{9}$$

here ε_{it} represents the innovation term, g_{it} follows the TGARCH process (short-run component), and τ_t provides the slow-moving local level of volatility (long-run component) for the day of the period (month) t (with i = 1,…, N_t, where N_t is the number of days for period t). The short-run component is then obtained in equation (10) as follows:

$$g_{it} = \left(1 - \alpha - \frac{\gamma}{2} - \beta\right) + \left(\alpha + \gamma I\left(u_{t-1} < 0\right)\right) \frac{{u_{i-1t}}^2}{\tau_t} + \beta g_{i-1t} \tag{10}$$

While the long-run component of the GARCH-MIDAS modeling is the following:

$$\tau_t = \exp\left(m + \theta \sum_{j-1}^{K} \delta_j\left(\omega\right) X_{t-j}\right) \tag{11}$$

Where X_t is the quarterly variable in period t, and $\delta_j\,(\omega)$ is a weighting function, which can be the Beta or Exponential Almon functions. For this work, the beta function (12) was used.

$$\delta_j\left(\omega\right) = \frac{\left(j/K\right)^{\omega_1 - 1}\left(1 - j/K\right)^{\omega_2 - 1}}{\sum_{j=1}^{K}\left(j/K\right)^{\omega_1 - 1}\left(1 - j/K\right)^{\omega_2 - 1}} \tag{12}$$

In this paper, volatilities of the macroeconomic variables ($\sigma^2_{(m-m^*)t}$, $\sigma^2_{\left(y-y^*\right)t}$, and $\sigma^2_{\left(i-i^*\right)t}$) and the volatility of the monetary approach obtained in (6), will be taken for the long-run volatility component, X_t.

For the estimation of the parameters, we used the following likelihood function in logarithms (LLF):

$$LLF\left(\Theta\right) = -\frac{1}{2}\sum_{t=t_s}^{T}\sum_{i=1}^{N_t}\left[\log\left(2\pi\right) + \log\left(g_{it}\tau_t\right) + \frac{u_{it}^2}{g_{it}\tau_t}\right] \tag{13}$$

where $\Theta = \{\alpha,\beta,\gamma,m,\theta,\omega_2,v\}$ and t_s is taken sufficiently large to ensure that different models will have the same information set.

As a benchmark model to compare the performance of every GARCH-MIDAS model, we follow Engle et al. (2013) and use for the long-run component X_t, the realized volatility (RV). We calculated the RV component as the sum of daily squared exchange rate returns such that $RV_t = \sum_{i=1}^{N_t} r_{it}^2$ where N_t is the number of trading days at time t, on a quarterly basis.

4.3. Forecast Evaluation

To conduct the forecast assessment, we generate out-of-sample volatility forecasts to evaluate the predictive performance of the GARCH-MIDAS models featuring various long-run components. We denote by $\hat{\sigma}_i$ the expected volatility obtained one day ahead for the day i. In this context, σ_i represents the proxy for the actual volatility dynamics for the same day i. To calculate $\hat{\sigma}_i$ we obtain the square of the daily exchange rate returns[18].

The evaluation metrics employed to compare the forecasting accuracy encompass the root mean squared error (RMSE), the mean absolute percentage error (MAPE), and the mean absolute error (MAE). These metrics are defined as follows:

$$RMSE = \sqrt{\frac{1}{T}\sum_{i=1}^{T}\left(\hat{\sigma}_i^2 - \sigma_i^2\right)^2}, \tag{14}$$

$$MAPE = \frac{100}{T}\sum_{i=1}^{T}\left|\frac{\hat{\sigma}_i^2 - \sigma_i^2}{\sigma_i^2}\right| \tag{15}$$

$$MAE = \frac{1}{T}\sum_{i=1}^{T}\left|\hat{\sigma}_i^2 - \sigma_i^2\right| \tag{16}$$

Where is the number of days in the out-of-sample period.

In addition, we implemented the Diebold and Mariano (2002) test (DM test) to determine whether the differences in forecasting power between the GARCH-MIDAS models with different long-run components and the GARCH-MIDAS model with quarterly realized volatility are statistically significant. This test consists of a pair-wise comparison between two alternative models. The t-statistic is defined as follows:

$$DM = \frac{\bar{d}}{\sqrt{2*\pi\hat{f}_d\left(0\right)/T}} \tag{17}$$

Where $\bar{d}$ is the mean of the differential loss process $d_{i(i=1)}^{T}$, is the number of days in the out-of-sample period, and $\hat{f}_d\left(0\right)$ is the spectral density estimate of d_i at the frequency .

For our study, the alternative hypothesis suggests that forecasting based on the GARCH-MIDAS model using RV as a benchmark is more accurate than forecasting with the GARCH-MIDAS model incorporating macroeconomic fundamental variables.

5. DATA AND RESULTS

The study uses daily closing prices of the peso-dollar nominal exchange rate exchange spanning from June 25, 1991, to December 31, 2022, and the Consumer Price Index (CPI), obtained from the Central Bank of Mexico (BdeM) and the National Institute of Statistics (INEGI). Mexican and US macroeconomic variables spanning from the third quarter of 1988 to the fourth quarter of 2022, obtained from (BdeM), the Bureau of Economic Analysis (BEA), and the Central Bank of the US (USFR).

We selected four macroeconomic variables as fundamentals: Gross Domestic Product (GDP), Consumer Price Index (CPI), M2 Money Stock (M2), and interest rate (IR 3-month Treasury Bill for the US and 91-day Cetes for Mexico) quarterly.

The in-sample period spans from 25 June 1991 to 31 December 2021, and the out-of-sample period extends from 1 January 2022 to 31 December 2022. Table 1 presents descriptive statistics of daily exchange rate returns and macroeconomic quarterly rates that summarize the mean (Mean), maximum (Max), minimum (Min), standard deviation (Stdev), skewness, kurtosis, and the number of observations (Obs.) for the exchange rate in Panel A (ER), Mexican macroeconomic variables in Panel B, and US macroeconomic variables in Panel C.

We estimated the regression model outlined in equation (5) while considering the restrictions imposed to determine the linear combination of conditional variances of the monetary approach variables. The resulting adjustment (with corresponding P-values in parentheses) is presented below:

$$\Delta s_t = \Delta\left(m_t - m_t^*\right) - \underset{(0.000)}{0.8781}\Delta\left(y_t - y_t^*\right) + \underset{(0.044)}{5.0861}\Delta\left(i_t - i_t^*\right) + e_t. \tag{18}$$

Then, the linear combination for the exchange rate to be used as in (11) is:

$$\sigma_{st}^2 = \sigma_{(m-m^*)t}^2 + 0.7711\sigma_{\left(y-y^*\right)t}^2 + 25.869\sigma_{\left(i-i^*\right)t}^2 \tag{19}$$

Table 2 presents the results of volatility estimation using the TGARCH-MIDAS model. A term of $K = 12$ (twelve quarters) is set for all the variables, corresponding to a 3-year lag period. Columns 1 to 6 report the results of the TGARCH-MIDAS model with the realized volatility (RV), Mexican and US gap of macroeconomic volatilities (GDP, M2, IR, CPI), and the volatility of the Monetary Approach (MA). P-values are reported in parentheses, the log-likelihood function (LLF) and the Akaike Information Criterion numbers of results are also shown.

All the parameters of the TGARCH model are statistically significant, i.e., $\hat{\alpha} + \hat{\gamma}/2 + \hat{\beta} < 1$, confirming a finite unconditional variance, and $\hat{\beta}$ complies with volatility clustering, so the typical characteristics of the financial time series are satisfied. The fact that the parameter $\gamma < 0$, indicates that the leverage effect confirms an economic agent that invests in Mexican pesos.

Figure 1 shows exchange rate returns volatility obtained from the estimation of equation (8), where the conditional mean was obtained through the traditional analysis of time series using the Box and Jenkins methodology (Box and Jenkins, 1976), resulting in an autoregressive model AR(1), and, for the variance equation, a TGARCH(1,1) model. The realized volatility, computed as the sum of daily squared exchange rate returns for each quarter, is also shown. Finally, we obtained the long-run component of the TGARCH-MIDAS model with the realized volatility. The last model will work as a benchmark.

Figure 1 shows the conditional volatility of an AR (1)-TGARCH (1,1) for the exchange rate returns (blue line), quarterly aggregate

18 We use the daily exchange rate to build the series of exchange rate returns, i.e., $r_t = (lnP_t - lnP_{t-1})$ 100.

Table 1: Summary statistics

	Mean	Max	Min	Stdev	Skewness	Kurtosis	Obs.
Panel A							
ER	0,02356	20,11368	-15,97125	0,84285	2,81294	97,25174	7903
Panel B							
GDP	0,00576	0,11051	-0,17126	0,03763	-0,78545	5,60099	138
M2	0,03437	0,14905	-0,23563	0,04190	-1,43496	14,38463	138
IR	-0,00039	0,11593	-0,05203	0,01463	3,49929	33,13409	138
CPI	0,02238	0,14886	-0,00983	0,02355	2,45591	11,71619	138
Panel C							
GDP	0,01171	0,08423	-0,09242	0,01293	-2,63933	38,75041	138
M2	0,01440	0,12006	-0,01277	0,01406	3,24394	24,70934	138
IR	-0,00004	0,00412	-0,00437	0,00118	-0,38767	5,45237	138
CPI	0,00702	0,02839	-0,03345	0,00783	-0,61800	7,38290	138

Source: Own calculations based on data from INEGI, BdeM, BEA and USFR.

Table 2: Parameter estimation for the TGARCH-MIDAS models

	RV	*GDP*	M2	IR	CPI	MA
α	0,1755	0,1400	0,1393	0,1332	0,1772	0,1795
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
γ	-0,0765	-0,0658	-0,0653	-0,0630	-0,0768	-0,0813
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
β	0,8582	0,8920	0,8923	0,8974	0,8562	0,8569
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
m	-3,0871	-7,3057	-7,4246	-6,9222	2,9285	2,8961
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
θ	0,3844	0,1223	0,1157	-0,4025	-3,8714	-0,8577
	(0,000)	(0,718)	(0,285)	(0,020)	(0,000)	(0,000)
$\omega 2$	1,0320	2,0198	2,0713	6,3915	1,1384	1,2564
	(0,000)	(0,116)	(0,118)	(0,000)	(0,000)	(0,000)
v	(5,888)	(5,986)	(5,991)	(6,007)	(5,738)	(5,631)
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
LLF	-1067,98	-1052,32	-1052,09	-1045,93	-1059,35	-1046,82
AIC	2149,97	2118,64	2118,18	2105,85	2132,70	2107,65

Source: Own calculations based on data from INEGI, BdeM, BEA and USFR.

realized volatility (grey line), and the long-run component of the conditional volatility of the GARCH-MIDAS with realized volatility (red line).

The estimates of θ are significant in all cases, except in the gaps of the Gross Domestic Product (GDP) and M2, which shows the impact of the interest rate gap (IR), inflation gap (CPI), and the monetary approach (MA) in the long-run component of volatility. The Akaike Information Criterion (AIC) and the Log-Likelihood Function (LLF) confirm that IR and MA models best adjust the variables.

Likewise, the value of θ is positive for the GARCH-MIDAS model with realized volatility, as the long-term component of real exchange rate volatility positively influences short-run exchange rate volatility.

In all other models where the coefficient of θ achieves statistical significance, it consistently carries a negative sign. Thus, significant increases in macroeconomic gap volatilities are regularly linked with a decrease in short-term exchange rate volatility.

Abreu (2021) suggests that these findings indicate a connection between the uncertainty stemming from monetary policies and the search for information. With information searching becoming faster and less costly, economic agents can immediately update their expectations regarding interest rates and inflation, amplifying these variables' volatility, and exhibiting a long memory process. Economic agents can utilize up-to-date information to learn and form beliefs following an information shock. Subsequently, they may act upon these beliefs, potentially avoiding behaviors that contribute to short-term exchange rate volatility.

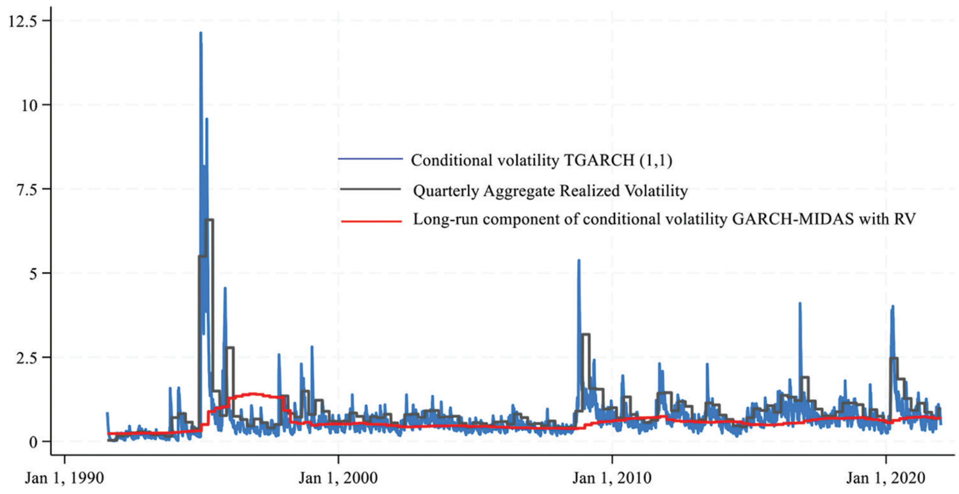
To further evaluate the performance of the GARCH-MIDAS models, we compared one-day out-of-sample forecasts incorporating macroeconomic variables with forecasts generated from one-day out-of-sample data using the GARCH-MIDAS benchmark specification with the realized volatility (RV).

Table 3 reports three performance statistics, root mean square error (RMSE), mean absolute percentage error (MAPE), and mean absolute error (MAE), shown in equations (14) to (16). It summarizes the one-day ability of the TGARCH-MIDAS model with variables of the long-run component, the Mexican and US gap of macroeconomic volatilities (GDP, M2, IR, CPI), and the volatility of the Monetary Approach (MA) relative to the benchmark model, TGARCH-MIDAS-RV, for the exchange rate. Table 3 also presents the P-value of the DM test (Diebold and Mariano 2022) pairwise comparison between forecasts from the benchmark and those from the augmented models. The alternative hypothesis is that the forecast with the TGARCH-MIDAS model with RV is more accurate than the TGARCH-MIDAS model with the macroeconomic volatility gap.

Accordingly, the TGARCH-MIDAS model with macroeconomic gap volatilities produces more accurate forecasts than the TGARCH-MIDAS model with RV in all cases except for the CPI. The P-values of the DM test does not reject the null hypothesis that the forecast errors are less than or equal in the models with macroeconomic gap volatilities, except for CPI significantly better than 5% for MAPE.

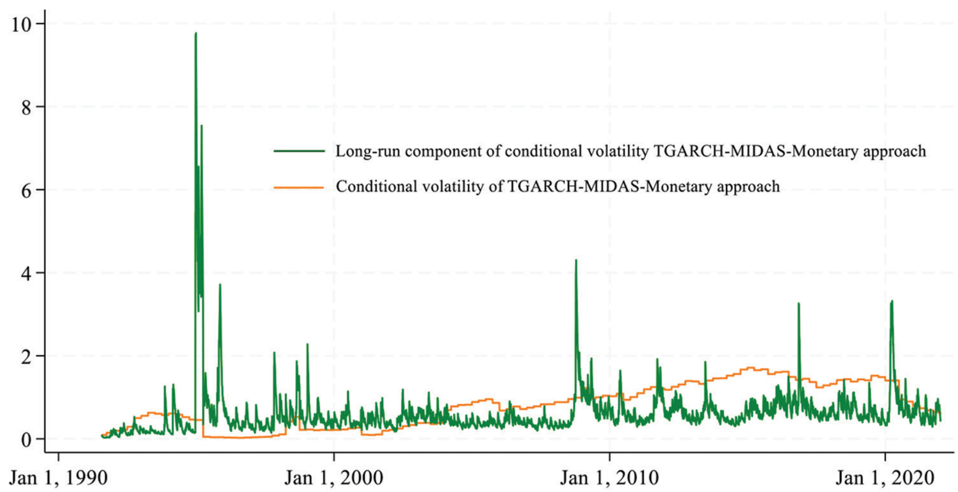
The superior forecasting capability of TGARCH-MIDAS is robust across all macroeconomic gap volatilities. Finally, we note that no macroeconomic gap volatilities dominate (the exception is CPI) regarding the forecasting ability.

Figure 1: Cobditional volatility AR(1)-TGARCH(1,1)



Source: own calculations based on the data under study.

Figure 2: Cobditional volatility and the monetary approach (TGARCH-MIDAS)



Source: own calculations based on the data under study.

Table 3: One-day ahead volatility forecast

	RMSE	DM P-value	MAPE	DM P-value	MAE	DM P-value
Benchmark	0,757		12086,352		0,432	
GDP	0,752	0,116	11378,079	0,871	0,420	0,837
M2	0,752	0,118	11400,074	0,871	0,421	0,836
IR	0,751	0,120	11318,081	0,872	0,420	0,848
CPI	0,763	0,903	12478,372	0,088	0,445	0,006
MA	0,756	0,746	11858,813	0,855	0,428	0,741

Source: Own calculations based on data from INEGI, BdeM, BEA and USFR.

Figure 2 shows exchange rate returns volatilities and long-run components obtained from the TGARCH-MIDAS model with the monetary approach, i.e., the conditional volatility (red line) and the long-run component of the conditional volatility of the GARCH-MIDAS with the monetary approach (orange line).

Previous results suggest that the macroeconomic approach is a good determinant of the volatility of the peso-dollar exchange rate in the long term and influences the short-term volatility.

6. CONCLUSION

This paper models peso-dollar exchange rate volatility in Mexico using the GARCH-MIDAS approach, which combines long-run volatility with macroeconomic variables of the monetary approach.

The statistical analyses suggest that the TGARCH-MIDAS models exchange rate returns series exhibit specific stylized facts of financial time series (volatility clusters, excess kurtosis, and leverage effect). The long-run volatility is driven by information on the volatility of the Mexico-US gap in inflation, the interest rate, and the basic monetary model.

The uncertainty stemming from monetary policies often arises from informational shocks, which economic agents can leverage to adapt their financial outlook. Consequently, they may adjust their behaviors to avoid actions that contribute to short-term exchange rate volatility.

Our study reveals that the GARCH-MIDAS model incorporating macroeconomic variables following the monetary approach outperforms the benchmark GARCH-MIDAS model with realized volatility (RV). Moreover, these volatility forecasts offer a more accurate description of exchange rate volatility returns, thereby holding significant implications for portfolio theory, risk analysis, and monetary policy.

For future lines of research, we recommend incorporating additional macroeconomic variables that offer a more comprehensive explanation of price fluctuations while remaining within the framework of the monetary approach. Despite the acknowledged limitations in the relationship between the evolution of the nominal exchange rate and the currently modeled macro-fundamental variables, the monetary approach remains an attractive paradigm. Exploring the integration of supplementary variables can enhance our understanding of the complex dynamics driving price and exchange rate variations under high volatility conditions.

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