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EXAMINING THE IMPACT OF EXCHANGE RATE UNCERTAINTY ON THE TEHRAN STOCK EXCHANGE INDEX: HYBRID APPROACH USING WAVELET TRANSFORM AND QUANTILE REGRESSION MODEL

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Abstract

This study examines the impact of exchange rate uncertainty on the Tehran Stock Exchange (TSE) index, addressing the critical role of currency volatility in Iran's sanction-constrained economy. Motivated by the need to understand non-linear market dynamics, it aims to analyze scale-specific and quantile-based effects of USD/IRR fluctuations from 2010 to 2024. Employing a hybrid quantile wavelet model, integrating discrete wavelet transform (DWT) with maximum overlap multi-resolution analysis (MOMRA) and quantile regression, the study reveals a positive and significant impact of exchange rate uncertainty across all time scales, with stronger effects in lower quantiles. These findings offer practical strategies for investors to optimize portfolios by targeting export-oriented firms and for policymakers to design stabilization measures, contributing a novel multi-scale framework to financial analysis in emerging markets. This study aims to analyze the multi-scale and quantile-specific effects of exchange rate uncertainty on the TSE index, contributing novel insights into Iran's financial dynamics by integrating wavelet transforms with quantile regression, surpassing traditional models in capturing non-linear relationships and offering practical strategies for investors and policymakers amid currency volatility.

JEL classification: C22, C58, F31, G15
Keywords: Tehran Stock Exchange, Flow-Oriented Model, Oriented Model, ARDL, GARCH

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Introduction

Exchange rates and stock markets are pivotal economic indicators influencing growth, trade, and investment in emerging economies like Iran (Thaddeus et al., 2024; Vatsa et al., 2024). This study addresses a critical gap in the literature by examining the non-linear, scale-specific impacts of exchange rate uncertainty on the Tehran Stock Exchange (TSE) index, particularly under Iran's unique conditions of sanctions and currency depreciation, using a hybrid quantile wavelet model that extends beyond conventional ARDL and GARCH approaches (Roudari et al., 2023; Shakeri & Bagherpour, 2023). The exchange rate represents the value of a country's currency relative to other foreign currencies. It is an essential factor affecting international trade, foreign direct investment (FDI), and the overall competitiveness of a country's goods and services in the global marketplace. A strong and healthy exchange rate can provide high profit margins for domestic exporters, and their products have been very popular with foreign buyers (Ilmas et al., 2022; Zhang & Zhang, 2018). Conversely, a weak exchange rate can increase the cost of imports, potentially raising consumer prices and creating challenges for independent businesses to import goods or equipment (Sweidan, 2013).

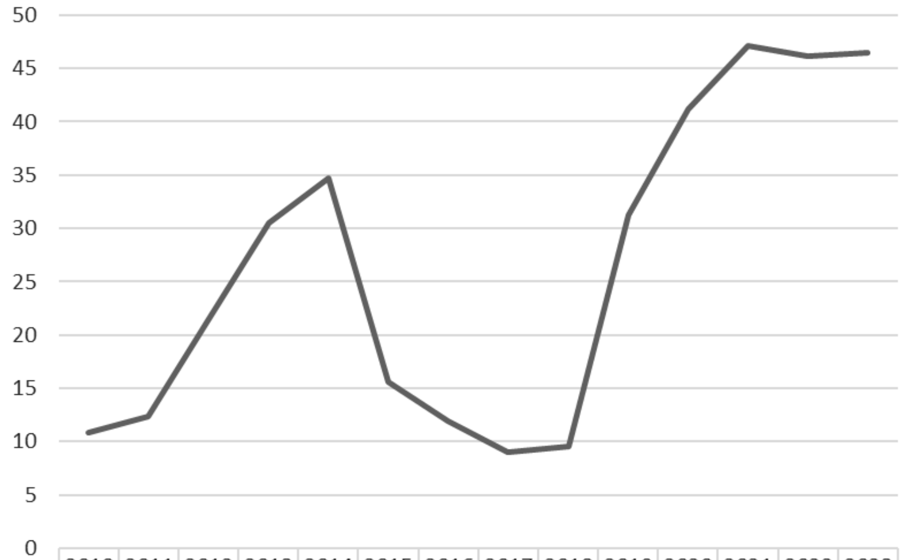
Exchange rates critically influence stock markets in emerging economies, yet existing studies often fail to capture non-linear and scale-specific dynamics in volatile markets like Iran's, constrained by sanctions and currency depreciation (Osoolian et al., 2020; Moradi et al., 2021). This study addresses this gap by investigating the impact of USD/IRR exchange rate uncertainty on the Tehran Stock Exchange (TSE) index from 2010 to 2024, using a hybrid quantile wavelet model. Iran's unique economic conditions, marked by high inflation and international sanctions, make this analysis critical for understanding currency-driven market behavior. This study provides novel contributions by offering a multi-scale, quantile-based framework, extending prior work, including our analysis of interest rate effects (Kian Poor & Hajian, 2025), to enhance investor and policymaker strategies. This study builds on prior research employing hybrid quantile wavelet models in financial analysis, including our previous work on interest rate uncertainty (Kian Poor & Hajian, 2025), but is the first to apply this framework to examine the impact of USD/IRR exchange rate uncertainty on the Tehran Stock Exchange (TSE). While Kian Poor and Hajian (2025) analyzed the effects of interest rate volatility, this study focuses on exchange rate dynamics, offering novel insights into their scale-specific and quantile-based impacts in Iran's sanction-constrained economy. By addressing currency volatility, this research provides distinct contributions for investors and policymakers navigating Iran's unique financial landscape.

The stock market functions as a platform for trading publicly listed shares, reflecting investor perceptions of firm value and economic prospects (Schwartz et al., 2015). Many people invest in stock since it is an effective way to build their wealth and business through their investment, stock market performance thus impacts their level of consumption and the amount of capital that firms can access for their operations and business expansion. When analyzing the relationship between exchange rates and stock markets, one must consider numerous factors (Cao et al., 2021; Ott, 2009). Fluctuations in exchange rates can affect the revenues and margins of firms listed on the stock market and, therefore, their stocks. For instance, a rising value of its domestic currency will reduce the profits organizations make depending on the export markets, bringing down the value of their stocks. On the flip side, a weakness in the local currency can increase the revenues of firms with foreign operations by increasing their stock value (Djalo et al., 2023; MacDonald, 2007).

In a broader scenario, exchange rates and stock markets hold a very significant position in the structure of the economy. These variables are watched closely by policymakers because they represent tools that can be utilized in the attempt to attain the goals of macro policy, including preserving the price level and, by so doing, promoting economic growth and addressing the balance of trade (Gavin, 1989; Itskhoki, 2021). In the foreign exchange market, central banks can control the exchange rates, while in the stock market, the governments may use legislations that either promote or control the markets' activities (Fraj et al., 2018; Hooper et al., 2009). Such indicators as exchange rates and stock markets are significant for business managerial decisions. The volatile nature of exchange rates threatens any organization's profitability as it will affect supply chains, pricing strategies, etc. In the same way, the operation of the stock market could impact the financial position of a firm regarding equity financing and the total amount of shareholders' wealth and their confidence, which in turn could affect consumer expenditure and business investment (Ambunya, 2012; Chowdhury et al., 2022). Finally, it is clear that the study of the role of the exchange rate on the performance of each country's stock market is of great importance and can also indicate economic performance.

This study introduces a novel hybrid quantile wavelet model, integrating quantile regression with discrete wavelet transform to capture non-linear, scale-specific, and distributional dynamics of exchange rate uncertainty's impact on the Tehran Stock Exchange (TSE) index, surpassing traditional models like ARDL and GARCH (Osoolian et al., 2020; Guo et al., 2022). By providing a pioneering multi-scale and quantile-based analysis in Iran's volatile market, it offers actionable insights for investors to optimize portfolio strategies and for policymakers to design targeted stabilization measures (Zhou et al., 2022).

Figure 1: Iran's inflation changes (2010-2023)

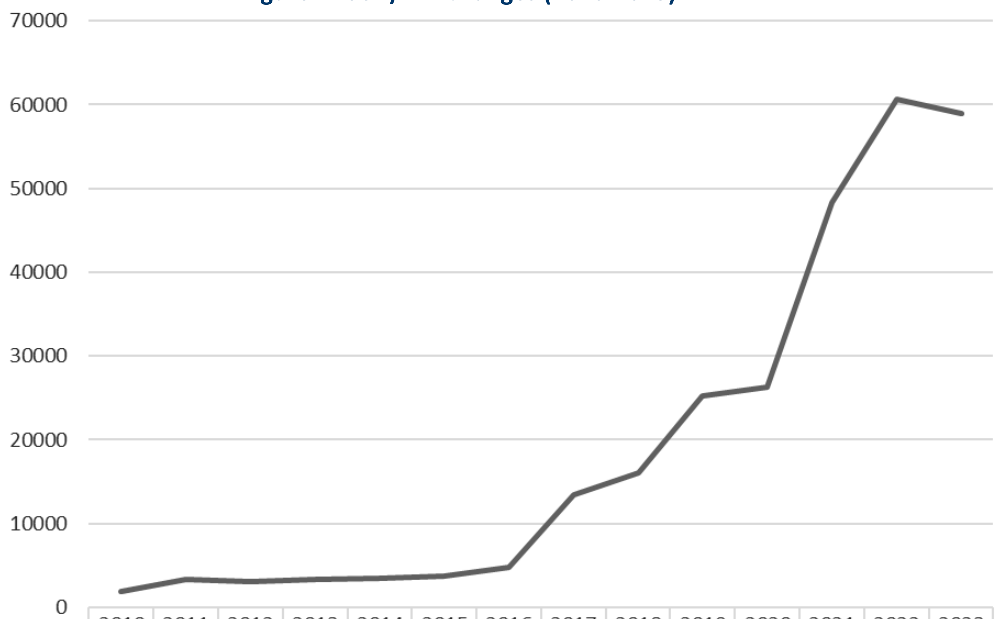


	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Inflation Rate	10.8	12.4	21.5	30.5	34.7	15.6	11.9	9	9.6	31.2	41.2	47.1	46.2	46.5

Source: Author's own work based on data from the Central Bank of Iran (2024).

Figure 1 clearly shows that inflation in Iran has been increasing recently. This rise in inflation has led to increased uncertainty and risk in Iran's economy (Rahimian et al., 2022). As a result of this inflation, many Iranians are inclined to purchase assets tied to the exchange rate to preserve the value of their assets (Moradi et al., 2021). Figure 2 displays the exchange rate of the US dollar, a crucial factor in investors' decision-making, from 2010 to 2023.

Figure 2: USD/IRR Changes (2010-2023)



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
USD/IRR	1915	3405	3017	3345	3460	3730	4773	13500	16100	25200	26300	48300	60700	59000

Source: Author's own work based on data from the Central Bank of Iran (2024).

Given the exchange rate depreciation in Iran, many companies and businesses are inclined to connect to global markets and export their products (Arbabian et al., 2020). Consequently, many companies targeted by investors in the Tehran Stock Exchange are those influenced by the exchange rate. In other words, investors are interested in companies that can at least maintain or even increase their value with the rise in the dollar rate (Moradi et al., 2021). The existing perspectives on the relationship between exchange rates and the stock market can be divided into two prominent views.

Dornbusch and Fisher (1980), through their Flow-Oriented Model, have demonstrated that the structure of the current account and the balance of payments are the two main determinants of the exchange rate in a country. According to this view, changes in the exchange rate will affect the trade balance and international competitiveness. It can also be inferred that this impact will be on production variables, real income, and companies' current and future cash flows, and consequently on their stock prices. Accordingly, an increase in the exchange rate will enhance the competitiveness of domestic companies and boost their exports. Increased exports in these companies will lead to higher revenues and profitability, ultimately increasing the company's value. As the company's value increases, investors will be more inclined to invest, utilizing various financing methods and investing in these companies. Therefore, based on the Flow-Oriented Model, it is evident that an increase in the exchange rate will lead to a rise in stock prices, followed by growth in the stock market index (Dornbusch & Fischer, 1980; Efuntade, 2023).

The second view is known as the Stock-oriented Model, which confirms the first Model. This view focuses on the capital account and considers it an essential factor in determining the exchange rate. Stock-oriented models have two sub-models: the Portfolio Balance Model and the Monetary Model. Branson (1983), describing the Portfolio Balance Model, points to the inverse relationship between the exchange rate and stock prices. According to this view, a decline in stock prices will reduce the wealth of domestic investors. This situation will be accompanied by a decrease in money demand and a reduction in interest rates. Following the reduction in interest rates, capital will exit the domestic markets and be directed towards foreign markets. Consequently, the exchange rate will increase, and the value of the national currency will decrease (Branson, 1983).

The stock market's growth in Iran can be attributed to two factors. The first factor is that with increased productivity, production, and value creation, the value of companies increases. The second factor is the rise in the exchange rate, which causes companies with assets tied to the exchange rate to experience stock price growth (Jalaee et al., 2016; Roudari et al., 2023). Given that Iran is subject to international sanctions and the growth of production and company value is challenging, much of the stock price growth in Iran is dependent on the increase in the exchange rate (Ghasseminejad & Jahan-Parvar, 2021; Izadkhasti et al., 2022). Therefore, a significant portion of the Tehran Stock Exchange index growth is due to the rise in the dollar price (Moradi et al., 2021).

Integration of the hybrid model with theoretical frameworks

The Flow and Stock-Oriented Models are particularly suited to Iran's sanctioned economy, where currency depreciation enhances export competitiveness (Flow-Oriented) and capital flows are constrained by sanctions (Stock-Oriented); the hybrid quantile wavelet model captures these dynamics by analyzing USD/IRR volatility across time scales, reflecting Iran's unique financial constraints such as limited foreign investment and high inflation (Ghasseminejad & Jahan-Parvar, 2021).

Building upon the foundational theories of the Flow-Oriented Model (Dornbusch & Fischer, 1980) and the Stock-Oriented Model (Branson, 1983), the hybrid quantile wavelet model employed in this study enhances the analysis of exchange rate uncertainty's impact on the Tehran Stock Exchange (TSE) index. The Flow-Oriented Model posits that exchange rate fluctuations influence a country's trade balance and competitiveness, subsequently affecting firms' cash flows and stock prices. Similarly, the Stock-Oriented Model, particularly through its Portfolio Balance sub-model, highlights the inverse relationship between stock prices and exchange rates via capital flows and investor wealth dynamics. By combining these approaches, the hybrid model not only builds on the theoretical foundations of the Flow and Stock-Oriented Models but also extends their applicability to complex, non-linear financial environments, clarifying how exchange rate uncertainty influences TSE dynamics across scales and quantiles in Iran's sanction-affected economy. The hybrid quantile wavelet model explicitly bridges these theories by decomposing exchange rate effects into time scales (wavelets) and distribution quantiles (regression), enabling a detailed examination of how Flow-Oriented export boosts and Stock-Oriented capital flows manifest non-linearly in Iran's volatile market.

The hybrid quantile wavelet model addresses these limitations by integrating the multi-scale decomposition capabilities of wavelet transforms with the distributional analysis of quantile regression. Wavelet transforms decompose time series data into various time scales (short-term, medium-term, and long-term), allowing for a nuanced examination of how exchange rate uncertainty impacts the TSE index across different temporal horizons. This aligns with the Flow-Oriented Model by capturing the varying effects of exchange rate fluctuations on export-driven firms' profitability over time. Simultaneously, quantile regression enables the analysis of exchange rate effects across different segments of the TSE index distribution, accounting for heterogeneity in market responses under varying economic conditions, such as high or low volatility periods. This complements the Stock-Oriented Model by providing insights into how exchange rate uncertainty influences investor behavior and market dynamics at different quantiles, particularly in extreme market conditions.

By combining these approaches, the hybrid model not only builds on the theoretical foundations of the Flow and Stock-Oriented Models but also extends their applicability to complex, non-linear financial environments. This framework enables a more comprehensive understanding of how exchange rate uncertainty drives TSE index movements, offering valuable insights for investors and policymakers navigating Iran's unique economic landscape.

Literature review

Nadya (2023) examines the impact of exchange rate fluctuations on stock prices in Indonesia, revealing a long-run equilibrium relationship. Using ARDL and NARDL methodologies, the study shows that exchange rate depreciation negatively affects stock prices, highlighting the need for policymakers and investors to monitor currency movements to manage associated risks.

Sreenu (2023) investigates the effects of exchange rate volatility and inflation on stock market returns in India from 2000 to 2020, using ARDL, GARCH, and ECM models. The study identifies a significant long-term relationship between exchange rates and stock prices, highlighting the negative impact of currency depreciation on investor confidence and market performance.

Nahidi (2022) examines the asymmetric effects of exchange rate fluctuations on Iranian stock returns from 1979 to 2021. Using a graph model, the study finds a positive relationship between exchange rate fluctuations and stock returns, suggesting that currency variations can enhance stock performance. This highlights opportunities for investors in strategic asset allocation amidst economic fluctuations in Iran.

Osoolian et al. (2020) investigate the relationship between exchange rate fluctuations and abnormal returns of companies on the Tehran Stock Exchange, using the ARDL model. The study focuses on key economic indicators and identifies exporting firms. Findings show a positive impact of exchange rate fluctuations on abnormal returns, emphasizing the importance of exchange rate dynamics in market performance, especially in emerging markets like Iran.

Jalaee et al. (2016) study the effect of exchange rate pass-through on Tehran Stock Exchange returns, emphasizing the critical role of exchange rates in small open economies. Using a two-step approach with OLS estimation, they find a positive relationship between exchange rate movements and stock returns, highlighting the interconnectedness of currency fluctuations and equity market performance in Iran.

Dourandish et al. (2014) examine the volatility spillover effects between the exchange rate and the agricultural industry index. Using a GARCH model to analyze weekly data from 2006-2014, they find significant interactions and ripple effects across sectors. Their study emphasizes stabilizing the exchange rate to mitigate adverse impacts on agricultural revenues and costs.

Jalali and Ghalibaf (2003) examine the impact of exchange rate fluctuations on stock returns in Iran. Using theoretical and empirical models, they reveal a significant correlation between exchange rate changes and firms' profitability. Their study shows a six-month lag effect in the stock price response, highlighting the delayed impact of currency fluctuations on stock returns.

Studies related to Iran indicate a positive effect of exchange rates on stock market returns. Therefore, examining this impact on the Iranian stock market is essential, as this phenomenon has not been observed in studies conducted on other countries. Comparatively, studies on other sanctioned economies, such as Russia and Venezuela, reveal similar positive effects of currency volatility on stock markets, driven by export-oriented sectors (Maradiaga, 2014). Unlike Iran, where sanctions amplify exchange rate uncertainty, these markets exhibit less pronounced quantile-specific effects, highlighting the need for Iran-specific analyses like the present study, which employs a hybrid quantile wavelet model to capture these unique dynamics.

While these studies effectively identify long-term relationships using ARDL and GARCH, they often overlook non-linear and scale-specific dynamics in volatile markets like Iran's; this research fills this gap by employing a hybrid quantile wavelet model to capture heterogeneous effects across time scales and quantiles, extending beyond the symmetric assumptions of prior works (Nahidi, 2022; Osoolian et al., 2020).

Linking the literature to the hybrid methodology

The literature on exchange rate impacts, while robust in identifying volatility spillovers via ARDL and GARCH, underexplores multi-scale and distributional analyses. This study's hybrid methodology addresses this by linking wavelet decomposition to theoretical models, enabling a deeper exploration of non-linear relationships in Iran's context. The existing literature on the relationship between exchange rate fluctuations and stock market performance, particularly in the context of Iran, provides a robust foundation for this study but reveals certain methodological limitations that the hybrid quantile wavelet model seeks to address. Studies such as Nadya (2023), Sreenu (2023), and Osoolian et al. (2020) have employed models like ARDL, NARDL, and GARCH to explore the impact of exchange rate volatility on stock returns, identifying significant long-term relationships and volatility spillover effects. However, these approaches often assume linear or symmetric relationships and focus on aggregate market responses, potentially overlooking the multi-scale dynamics and distributional heterogeneity inherent in financial time series, especially in a volatile market like the Tehran Stock Exchange. Existing methodologies like ARDL and GARCH, while useful for aggregate relationships, are critiqued for assuming linearity and symmetry, failing to capture scale-specific volatility in sanction-impacted markets (Ghasseminejad & Jahan-Parvar, 2021), this study fills these gaps through the wavelet-quantile approach, decomposing data into temporal scales and analyzing effects across quantiles for a more nuanced understanding.

The hybrid quantile wavelet model adopted in this study builds on these prior works by integrating the strengths of wavelet transforms and quantile regression to overcome such limitations. Wavelet transforms, as discussed by Guo et al. (2022), enable the decomposition of time series data into short-, medium-, and long-term components, allowing for a detailed examination of exchange rate uncertainty's impact across different time scales. This is particularly relevant for Iran, where economic conditions, such as inflation and currency depreciation, vary significantly over time (Moradi et al., 2021). Meanwhile, quantile regression, as highlighted by Koenker and Hallock (2001), facilitates the analysis of exchange rate effects across different quantiles of the TSE index distribution, capturing heterogeneous market responses under varying economic conditions. This approach addresses the gaps in studies like Nahidi-Amirkhiz (2022) and Jalaee et al. (2016), which, while identifying positive relationships between exchange rate fluctuations and stock returns, do not fully explore the non-linear and scale-specific dynamics.

By combining these methodologies, the hybrid model not only aligns with the empirical findings of prior studies but also extends their analytical scope. It provides a more nuanced understanding of how exchange rate uncertainty influences the TSE index, particularly in the context of Iran's unique economic challenges, such as sanctions and currency fluctuations (Ghasseminejad & Jahan-Parvar, 2021). This methodological advancement enhances the ability to offer actionable insights for investors and policymakers navigating complex financial environments.

Methodology

This study employs a hybrid quantile wavelet model to investigate the impact of exchange rate uncertainty on the Tehran Stock Exchange index, a primary financial institution facilitating the trading of publicly listed companies' shares in Iran. The hybrid approach integrates quantile regression and discrete wavelet transform (DWT) with maximum overlap multi-resolution analysis (MOMRA) to enhance prediction accuracy, reduce errors, and improve the efficiency of data analysis in complex, non-linear financial time series (Khairalla & AL-Jallad, 2017). This section outlines the hybrid model, defines all abbreviations, and provides detailed explanations of the research model's formulas and their components.

Hybrid quantile wavelet model

Hybrid models in data science combine multiple analytical techniques to leverage their respective strengths, resulting in improved predictive performance and robustness (Khairalla & AL-Jallad, 2017). The hybrid quantile wavelet model integrates two primary methodologies: quantile regression and wavelet transform. Quantile regression is a statistical method that examines data distributions by analyzing quantile points, which divide a dataset into equal segments (e.g., percentiles that split data into 100 equal parts). This approach is particularly effective for non-normal distributions or datasets with outliers, enabling analysts to investigate distributional characteristics at various points, such as the median, 25th percentile, or 75th percentile (Davino et al., 2013; Koenker & Hallock, 2001). In financial and economic analyses, quantile regression facilitates risk assessment, such as estimating Value at Risk (VaR), and predicts outcomes across different segments of the data distribution (Rios-Avila & Maroto, 2024).

Wavelet transform is a mathematical tool that decomposes data into components across various time and frequency scales, allowing for multi-scale analysis of economic and financial time series (Young, 2012). Wavelets enable the separation of short-term, medium-term, and long-term dynamics, data compression to distinguish signal from noise, and noise reduction to enhance analytical accuracy (Guo et al., 2022). The hybrid quantile wavelet model combines the multi-scale decomposition capabilities of wavelet transforms with the distributional analysis of quantile regression, resulting in a robust framework that reduces the impact of outliers, enhances prediction accuracy, and adapts to complex, non-linear data patterns (Antoniadis, 2007;

Zhou et al., 2022). This approach is particularly suited for analyzing the volatile and non-linear financial time series observed in the TSE, providing valuable tools for economic and financial analysts.

Abbreviations

To ensure clarity, the following abbreviations used in this study are defined:

TSE - Tehran Stock Exchange, the primary stock market in Iran, facilitating the trading of publicly listed companies' shares.

ARDL - Autoregressive Distributed Lag, a time series model used to analyze long-run and short-run relationships between variables.

GARCH - Generalized Autoregressive Conditional Heteroskedasticity, a statistical model for estimating time-varying volatility in financial time series, used here to derive exchange rate uncertainty.

DWT - Discrete Wavelet Transform, a mathematical technique for decomposing time series into components across different time scales.

MOMRA - Maximum Overlap Multi-Resolution Analysis, a method within DWT that enhances the alignment of decomposed signals for accurate multi-scale analysis.

VaR - Value at Risk, a risk management metric used to estimate potential losses in financial portfolios.

MSE - Mean Squared Error, a metric for evaluating model accuracy by measuring the average squared difference between predicted and actual values.

Research model

The research model, grounded in the theoretical frameworks of the Flow-Oriented Model and Stock-Oriented Model, examines the impact of exchange rate uncertainty on the TSE index from 2010 to 2024. The model is specified as follows:

$$H_t = \beta_0 + \beta_1 TSE_t + \varepsilon_t \quad (1)$$

(H_t) - Exchange rate uncertainty at time (t), derived using the Generalized Aut warning. The line (H_t): Exchange rate uncertainty at time (t), derived using the Generalized Aut is not complete and appears to be cut off. Based on the context, it likely refers to the GARCH model. The explanation is completed assuming this intent.

(H_t) - Exchange rate uncertainty at time (t), derived using the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model to capture the conditional volatility of the USD/IRR exchange rate, reflecting fluctuations in the Iranian Rial relative to the US Dollar.

(TSE_t) - The Tehran Stock Exchange index at time (t), representing the aggregate performance of listed companies.

(β_0) - The intercept, capturing the baseline level of exchange rate uncertainty independent of the TSE index.

(β_1) - The coefficient measuring the impact of the TSE index on exchange rate uncertainty, indicating the strength and direction of the relationship.

(ε_t) - The error term, accounting for unobserved factors influencing exchange rate uncertainty.

Where β measures the sensitivity of uncertainty to TSE changes, and εt represents stochastic disturbances.

The data for (H_t) and (TSE_t) are sourced from the Economic and Financial Data Bank of the Ministry of Economic Affairs and Finance. The GARCH model is employed to estimate (Ht), capturing the volatility clustering prevalent in financial time series.

Wavelet decomposition

The DWT with MOMRA decomposes Ht and TSEt as follows: (1) Input time series (Ht or TSEt) into the DWT algorithm using Python's PyWavelets library. (2) Select Haar wavelet for abrupt changes and Daubechies (D4) for complex patterns. (3) Decompose into three levels (J = 1, 2, 3), yielding approximation (S3,t) and detail components (D1,t, D2,t, D3,t) for long-, medium-, and short-term dynamics. (4) Compute scale (2^J) and resolution ($1/2^J$) to define temporal spans, aligning with Iran's volatile market characteristics (Guo et al., 2022). The decomposition is expressed as:

$$A_t = S3.t + D3.t + D2.t + D1.t \quad (2)$$

(A_t) - The original time series (either (H_t) or (TSE_t)) at time (t).

(S3.t) - The level-3 approximation component, representing the smooth, long-term trend of the time series.

(D3.t, D2.t, D1.t) - The detail components at levels 3, 2, and 1, respectively, capturing short-term, medium -term, and long-term fluctuations, with higher levels indicating finer details.

Haar Wavelet - A simple, step-function wavelet suitable for detecting abrupt changes in time series, offering computational efficiency (Young, 2012).

Daubechies Wavelet - A smoother wavelet with higher-order vanishing moments, ideal for capturing complex, non-linear patterns (Guo et al., 2022).

The scale and resolution at level (J) are calculated as follows:

$$j, a = 2^J, resolution = (\frac{1}{a}) * N \quad (3)$$

(J) - The decomposition level (1, 2, or 3), determining the time scale of analysis.

Scale (2^J) - The time span of the wavelet, where higher (J) corresponds to longer time scales.

This decomposition, performed at three levels based on sample size, enables a multi-scale analysis of the relationship between exchange rate uncertainty and the TSE index, aligning with the study's objective to capture both short-term and long-term dynamics (Zhou et al., 2022).

Calculation of key variables

To ensure transparency in the derivation of key variables, this subsection provides a step-by-step explanation of the calculations for exchange rate uncertainty (H_t) using the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model and the decomposition of time series using the Discrete Wavelet Transform (DWT) with Maximum Overlap Multi-Resolution Analysis (MOMRA).

GARCH model for exchange rate uncertainty (H_T)

The exchange rate uncertainty variable (H_t) is derived from daily USD/IRR exchange rate data (2010–2024) using the following procedure. (1) Calculate returns as:

$$rt = \ln(\frac{P_t}{P_{t-1}}) \tag{4}$$

where Pt is the exchange rate at time t, sourced from the Economic and Financial Data Bank. (2) Specify the GARCH(1,1) model:

$$h_t = \omega + \alpha r^2_{\{t-1\}} + \beta h_{\{t-1\}} \tag{5}$$

where ht represents conditional variance (Ht), ω is the constant, α captures past shocks, and β reflects volatility persistence. (3) Estimate parameters using maximum likelihood, ensuring α + β < 1 for stationarity. (4) Extract ht as H_t for each time point, capturing volatility clustering unique to Iran's currency market. The steps are as follows:

1. Data Preparation. Daily USD/IRR exchange rate returns are computed as (Equation 5), where (P_t) is the exchange rate at time (t).
2. Model Specification. The GARCH(1,1) model is specified as:

$$\begin{gathered} {}_tZ_t\sqrt{{}_th_t} \sim N(0,1) \\ z =_t \varepsilon_t \\ \varepsilon + \mu =_t r \\ h_t = w + \varepsilon\alpha^2_{t-1} + h\beta_{t-1} \end{gathered} \tag{6}$$

where (h_t) is the conditional variance (representing exchange rate uncertainty, (H_t), (ω) is the constant term, (α) captures the impact of past squared shocks, and (β) reflects the persistence of volatility. Where ω is the baseline volatility, α the arch effect, and β the garch persistence.

3. Parameter Estimation. The parameters (ω, α, β) are estimated using maximum likelihood estimation, ensuring the sum (α + β < 1) for stationarity.
4. Extraction of (H_t). The conditional variance (ht) is extracted as the measure of exchange rate uncertainty (H_t) for each time point, capturing volatility clustering prevalent in financial time series (Young, 2012).

Wavelet decomposition

The DWT with MOMRA decomposes the time series for exchange rate uncertainty (H_t) and the Tehran Stock Exchange (TSE) index (TSE_t) into components across multiple time scales, using Haar and Daubechies wavelets. The choice of three decomposition levels is justified by financial time-series analysis principles, which emphasize capturing short-term (daily trading), medium-term (monthly/quarterly trends), and long-term (annual macroeconomic shifts) dynamics (Guo et al., 2022). For the 2010–2024 dataset (~3,650 daily observations), three levels balance granularity and computational efficiency, avoiding over-smoothing while preserving sufficient resolution for volatility analysis in Iran's sanction-driven market. The steps were presented below.

1. Data Input. The time series (A_t), representing either (H_t) or (TSE_t) is input into the DWT algorithm, with data sourced from the Economic and Financial Data Bank (2010–2024).
2. Wavelet Selection. Haar wavelet, a step-function wavelet for detecting abrupt changes, and Daubechies wavelet (D4), with smoother properties for capturing complex patterns, are selected (Guo et al., 2022).
3. Decomposition. The DWT with MOMRA decomposes (A_t) into three levels based on sample size, yielding:

$$A = S3.t + D3.t + D2.t + D1.t \tag{7}$$

4. Scale and Resolution Calculation. For each level (J) (1, 2, 3), the scale (2^J) and resolution ($1/2^J$) are computed to define the temporal span and precision of each component (Zhou et al., 2022).
5. Output. The decomposed components are used in the hybrid quantile wavelet model to analyze the relationship between (H_t) and (TSE_t) across different time scales and quantiles.

The choice of three decomposition levels (J = 1, 2, 3) in the Discrete Wavelet Transform (DWT) with Maximum Overlap Multi-Resolution Analysis (MOMRA) is grounded in principles of financial time-series analysis and the characteristics of the dataset. Financial time series, such as the Tehran Stock Exchange index and exchange rate uncertainty, exhibit heterogeneous dynamics across short-term fluctuations (e.g., daily trading), medium-term trends (e.g., monthly or quarterly patterns), and long-term movements (e.g., annual trends driven by macroeconomic factors) (Guo et al., 2022). Three levels allow the decomposition to capture these distinct temporal scales, balancing detail and computational feasibility. Given the sample size (2010–2024, approximately 3,650 daily observations), three levels ensure sufficient resolution to analyze short-term volatility and long-term trends without excessive smoothing or loss of information, aligning with established practices in financial time-series analysis (Zhou et al., 2022). These calculations enable a robust analysis of the non-linear and scale-specific dynamics between exchange rate uncertainty and the TSE index, enhancing the study's ability to provide actionable insights for financial analysts (Antoniadis, 2007).

All analyses in this study were conducted using Google Colab and Jupyter Notebook, two widely-used platforms for interactive computing in data science. Google Colab, a cloud-based Jupyter Notebook environment, was employed for computationally intensive tasks, including the estimation of the GARCH (1,1) model to derive exchange rate uncertainty (H_t) and the implementation of the hybrid quantile wavelet model, leveraging its free access to GPU resources for efficient processing of large datasets. Jupyter Notebook, run locally, was used for initial data preprocessing and exploratory analysis of the Tehran Stock Exchange index and exchange rate data, offering flexibility in customizing the computational environment. Both platforms facilitated the Discrete Wavelet Transform (DWT) with Maximum Overlap Multi-Resolution Analysis (MOMRA) using Haar and Daubechies wavelets, ensuring robust execution of multi-scale and quantile-based analyses.

Results

This section presents the descriptive statistics of the research variables. Table 1 details the descriptive statistics for each variable.

Table 1: Descriptive Statistics

Variable	Mean	Median	Maximum	Minimum	Skewness	Kurtosis	Jarque-Bera	Normality
Index of Tehran Stock Exchange	12.10	11.38	14.60	9.43	0.23	1.60	1.44	Non-Normal Distribution
Exchange Rate	8.92	8.34	11.01	6.90	0.19	1.70	1.23	Non-Normal Distribution

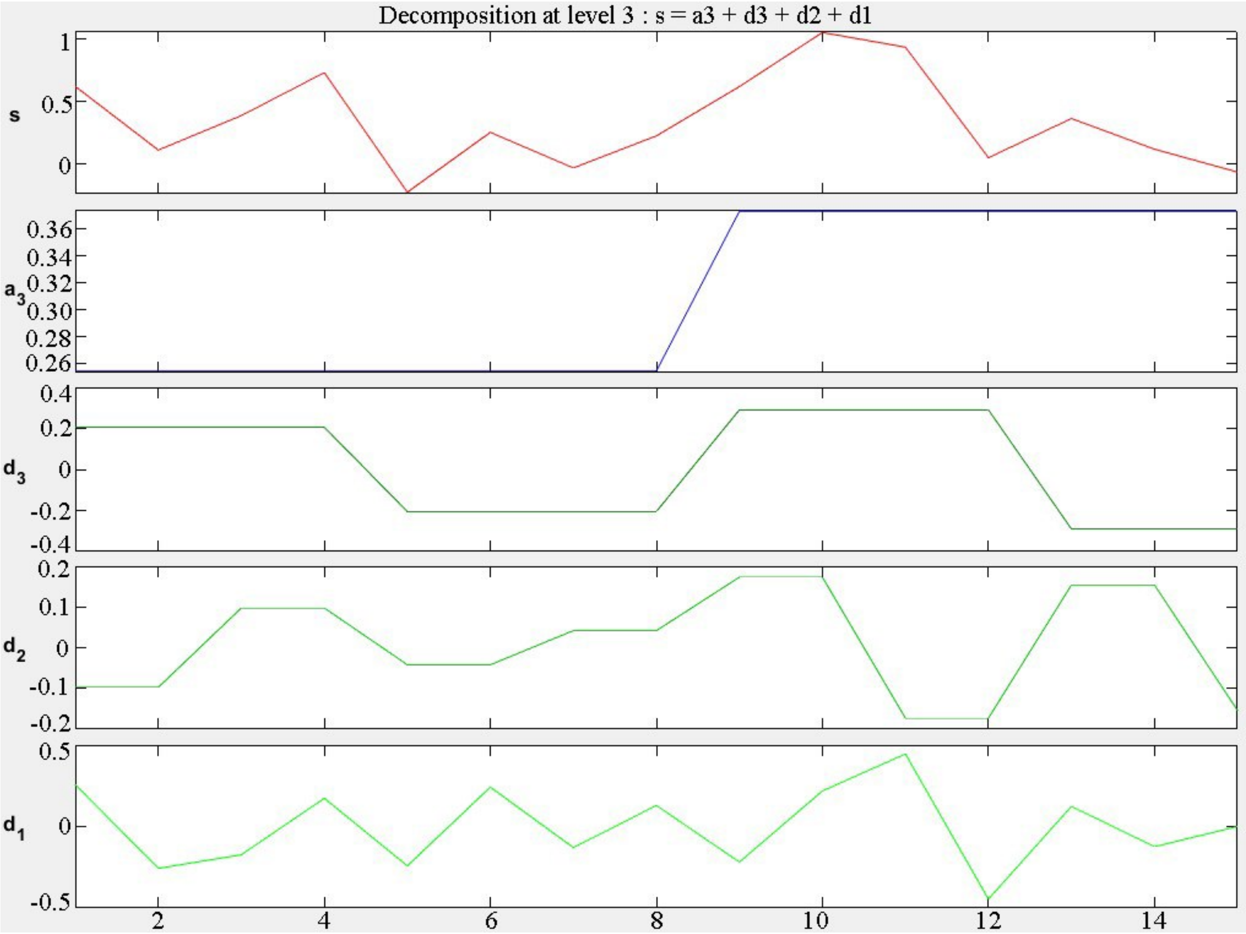
Source: Author's own work.

Table 1 indicates that all variables in this study exhibit non-normal distributions. Additionally, this table reports other statistical characteristics such as mean, median, maximum, minimum, skewness, and kurtosis. Subsequently, the time series of the Tehran Stock Exchange index and exchange rate uncertainty across three different scales is examined.

Time series analysis of stock exchange index

Figure 3 illustrates the decomposition trend of the Tehran Stock Exchange Index variable. According to this figure, the time series of the Tehran Stock Exchange Index has been decomposed from a scale of 3 to 1, where d1 represents more detailed information compared to d3. In other words, in the Tehran Stock Exchange Index series decomposition, d1 indicates long-term effects, while d3 represents short-term effects.

Figure 3: Details of scales 1 to 3



Source: Author’s own work.

Time series analysis of exchange rate uncertainty

Figure 4 illustrates the decomposition process of the exchange rate uncertainty index variable. According to this figure, the time series of exchange rate uncertainty is decomposed from a scale of 3 to 1, with d1 providing more detailed information than d3. In other words, in the decomposition of the exchange rate uncertainty time series, d1 represents long-term effects, while d3 indicates short-term effects.

Stationarity test

The stationarity test is of paramount importance for estimating a time series model, as variables' non-stationarity can lead to invalid regression coefficients and bias.

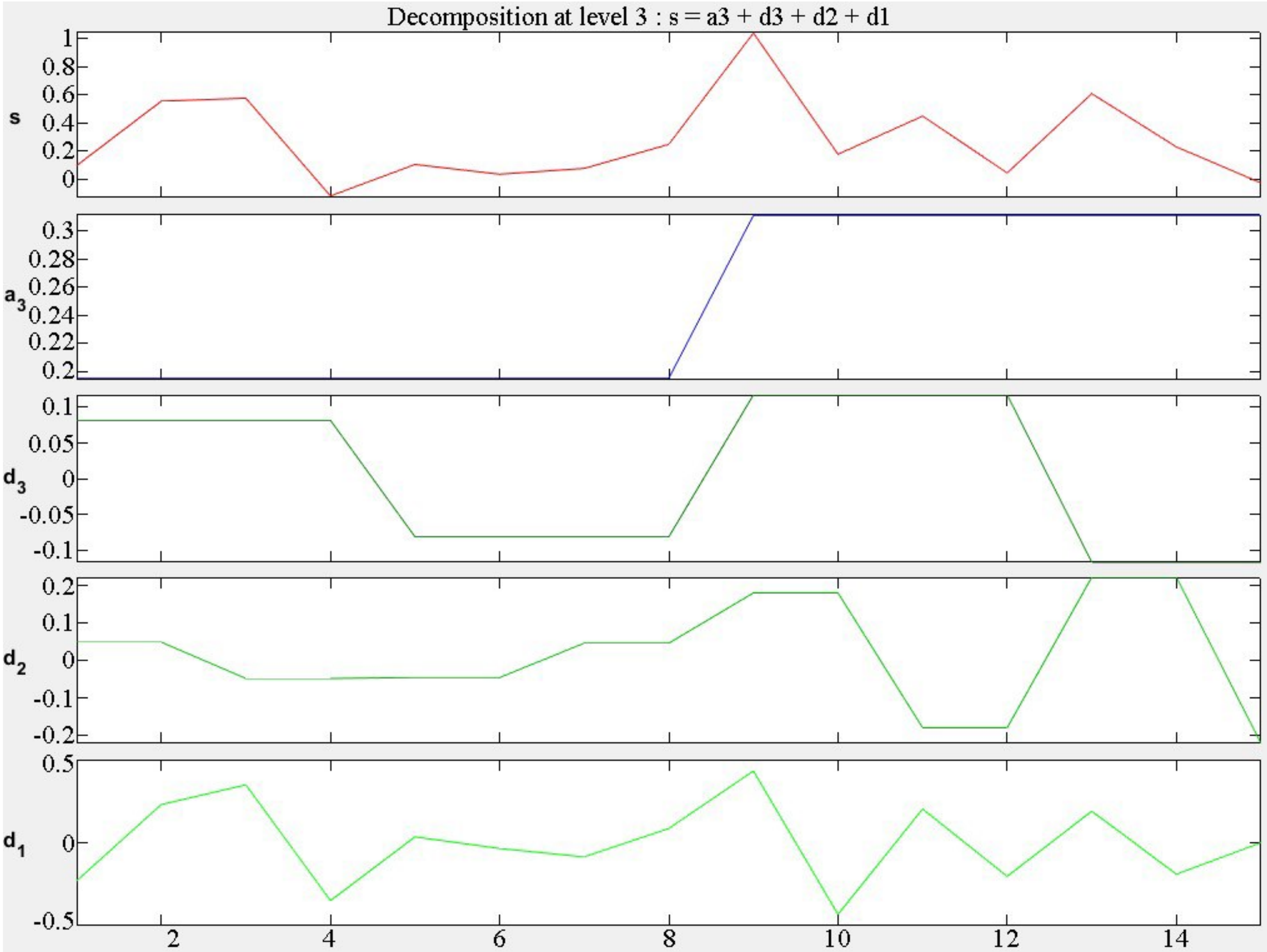
According to the results in Table 2, the Tehran Stock Exchange index and exchange rate uncertainty variables are stationary at the 5% statistical level across all frequencies.

Table 2: Unit Root Test

Variable	Significance Level			Statistic
	1%	5%	10%	
Index of Tehran Stock Exchange	-4.0040	-2.0980	-2.6900	-2.778
Exchange Rate Uncertainty	-4.0044	-3.0988	-2.6804	-3.828

Source: Author’s own work.

Figure 4: Details of Scales 1 to 3



Source: Author's own work.

According to the results in Table 2, the Tehran Stock Exchange index and exchange rate uncertainty variables are stationary at the 5% statistical level across all frequencies.

Model estimation results

Table 3 demonstrates that the impact of exchange rate uncertainty on the Tehran Stock Exchange index is positive and significant across all quantiles. According to this table, if exchange rate uncertainty increases by one unit, assuming other conditions remain constant, the Tehran Stock Exchange index can increase between 0.04604 and 0.86623 units. The magnitude of this effect is more significant in the initial quantiles than in the later quantiles. In other words, the positive impact of exchange rate uncertainty on the stock exchange index has diminished over time. Additionally, the probability values for slope equality and quantile symmetry tests are less than 0.1%, indicating the correct specification of the Model.

Table 3: Model estimation results based on the dependent variable

Variable	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
H	0.2563	0.7429	0.3260	0.8662	0.0460	0.3741	0.5609	0.5903	0.2654
P-Value	0.0668	0.0555	0.0306	0.0432	0.0350	0.1701	0.0311	0.0663	0.0377
Pseudo R^2	0.5678	0.5353	0.6778	0.0940	0.1703	0.9604	0.5785	0.3564	0.1997
A P-Value of the Test for Slope Equality	0.0503	0.0182	0.0614	0.0628	0.0642	0.0940	0.0579	0.0499	0.0403

Variable	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
The P-value of the Test for Quantile Symmetry	0.0377	0.0347	0.0715	0.0336	0.0108	0.0692	0.0529	0.0647	0.0656

All P-Values are significant at the 10% error level

Source: Author's own work.

Table 4 shows that the effect of exchange rate uncertainty on the Tehran Stock Exchange index is positive and significant across all quantiles of scale 1. The magnitude of this effect is more significant in the higher quantiles than the lower ones. Therefore, the long-term impact of exchange rate uncertainty on the Tehran Stock Exchange index will increase over time. According to Table 4, if there is a one-unit increase in exchange rate uncertainty and other factors remain constant, the Tehran Stock Exchange index can increase by between 0.11683 and 0.96928 units on a scale of 1. Similarly, this reasoning holds for scales 2 and 3, representing medium-term and short-term effects, respectively. Additionally, the p-values for slope equality and quantile symmetry tests in scales 1 to 3 are below 5%. On a scale of 6, they are below 10%, indicating the correct specification of the Model.

Table 4: Results of the model estimation based on the dependent variable stock index in the quantile regression model using haar wavelet transform analysis

Scale D1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
H	0.2054	0.7008	0.6200	0.1168	0.5653	0.1188	0.9693	0.9245	0.8205
P-Value	0.0972	0.0648	0.0408	0.0323	0.0386	0.0829	0.0912	0.0181	0.0610
Pseudo R^2	0.6145	0.9564	0.5033	0.1408	0.9494	0.2171	0.4400	0.6339	0.9381
The P-value of the Slope Equality	0.0845	0.0439	0.0462	0.1320	0.0585	0.1140	0.0268	0.0578	0.0434
The P-value of the Quantile Symmetry	0.0472	0.0952	0.1727	0.0313	0.0974	0.0438	0.1355	0.0297	0.0585
Scale D2	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
H	0.8153	0.1186	0.1879	0.9908	0.2535	0.8558	0.3402	0.9019	0.9210
P-Value	0.0289	0.0750	0.0998	0.0672	0.0731	0.1698	0.0613	0.1221	0.0278
Pseudo R^2	0.9922	0.5685	0.2129	0.6064	0.0286	0.2223	0.8350	0.0261	0.3414
The P-value of the Slope Equality	0.0103	0.0352	0.0460	0.0593	0.0871	0.0962	0.0231	0.0603	0.0977
The P-value of the Quantile Symmetry	0.0141	0.0836	0.0455	0.0290	0.0680	0.0941	0.0642	0.0305	0.0204
Scale D3	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
H	0.3603	0.6571	0.3709	0.2925	0.0862	0.7903	0.5032	0.8681	0.8560
P-Value	0.1323	0.0776	0.0884	0.0989	0.0803	0.0389	0.0324	0.0767	0.0753
Pseudo R^2	0.7754	0.4326	0.7730	0.2081	0.4922	0.9678	0.4430	0.0408	0.7825
The P-value of the Slope Equality	0.1830	0.0901	0.0234	0.0913	0.0260	0.0647	0.1270	0.0657	0.0330

Scale D3	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
The P-value of the Quantile Symmetry	0.0773	0.0755	0.0949	0.0821	0.0223	0.0509	0.0708	0.0268	0.0268

Source: Author's own work.

Table 5 illustrates that the impact of exchange rate uncertainty on the Tehran Stock Exchange index, through the Daubechies wavelet, is positive and significant across all quantiles of the first scale. This effect gradually increases in the middle and decreases in the two extreme quantiles. In the second or medium-term scale, this effect also exhibits increasing and decreasing fluctuations, but it increases in the two extreme quantiles. A similar trend to the first scale is observed in the third or short-term scale. These results indicate that exchange rate uncertainty has different effects on the Tehran Stock Exchange index across various time scales. In the long-term scale (first scale), the positive effect of uncertainty gradually increases and decreases, suggesting that exchange rate uncertainty initially has a more significant impact on the stock market, but this impact diminishes over time. In the medium-term scale (second scale), the effects of exchange rate uncertainty are oscillatory, which may indicate market changes in response to uncertainty. In the short-term (third) scale, the effects are similar to the long-term scale, indicating that the market's response to exchange rate uncertainty in the short term is also similar to the response in the long term. Additionally, the p-values for the tests of slope equality and quantile symmetry in the first to third scales are below 5% and in the sixth scale below 10%, indicating the correct specification of the model.

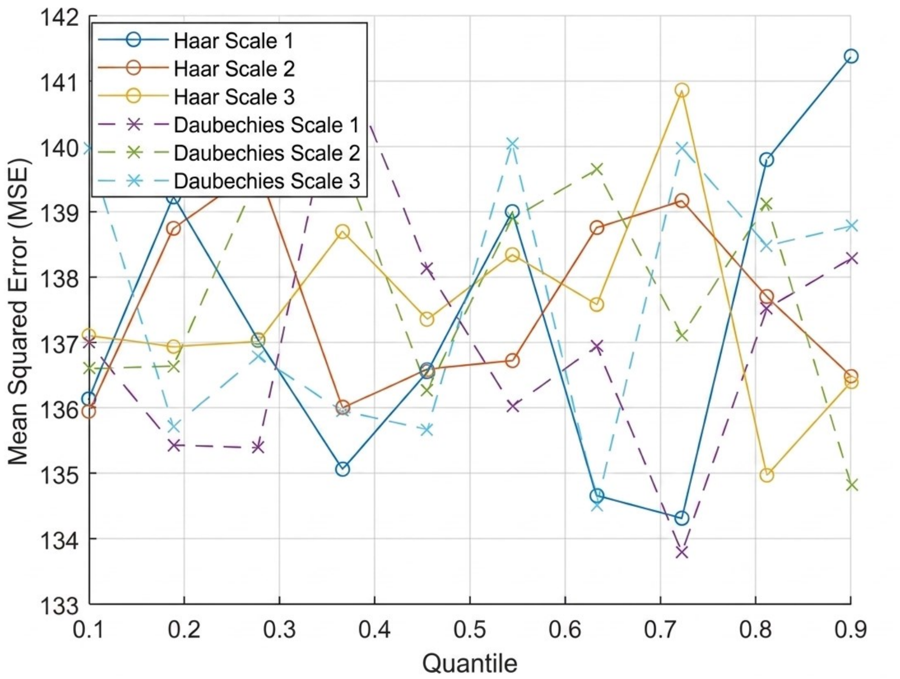
Table 5: Results of the model estimation based on the dependent variable stock index in the quantile regression model using daubechies wavelet transform analysis

Scale D1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
H	0.3829	0.4002	0.6178	0.5051	0.6483	0.6247	0.9240	0.7569	0.0748
P-Value	0.0748	0.0296	0.1000	0.0474	0.0221	0.0856	0.0829	0.0344	0.0892
Pseudo R^2	0.6746	0.6233	0.4802	0.4639	0.6437	0.9518	0.4093	0.7896	0.2664
The P-value of the Slope Equality	0.0637	0.0538	0.0710	0.0291	0.0424	0.1426	0.0739	0.0299	0.0316
The P-value of the Quantile Symmetry	0.0336	0.0702	0.0536	0.0788	0.0318	0.0263	0.0573	0.0306	0.0450
Scale D2	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
H	0.4926	0.9366	0.2216	0.4718	0.5659	0.9107	0.5708	0.8699	0.9340
P-Value	0.0810	0.0277	0.0596	0.0670	0.0557	0.0286	0.0406	0.0740	0.0300
Pseudo R^2	0.1101	0.7120	0.1292	0.4494	0.1321	0.1865	0.0326	0.2466	0.2764
The P-value of the Slope Equality	0.0431	0.0991	0.0272	0.0260	0.0220	0.0210	0.0725	0.0997	0.1884
The P-value of the Quantile Symmetry	0.0566	0.0955	0.0922	0.0925	0.0991	0.0271	0.0257	0.0856	0.0630
Scale D3	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
H	0.5659	0.6644	0.1609	0.5660	0.4937	0.2386	0.7985	0.8397	0.2128
P-Value	0.0509	0.0318	0.0376	0.0259	0.0967	0.0531	0.0266	0.1738	0.0788
Pseudo R^2	0.2031	0.2377	0.2476	0.6762	0.7737	0.9662	0.5875	0.4019	0.3941
The P-value of the Slope Equality	0.0867	0.0520	0.0577	0.0943	0.0785	0.0885	0.0468	0.0222	0.0548
The P-value of the Quantile Symmetry	0.0423	0.1646	0.0769	0.0143	0.0410	0.0406	0.0818	0.0366	0.0488

Source: Author's own work.

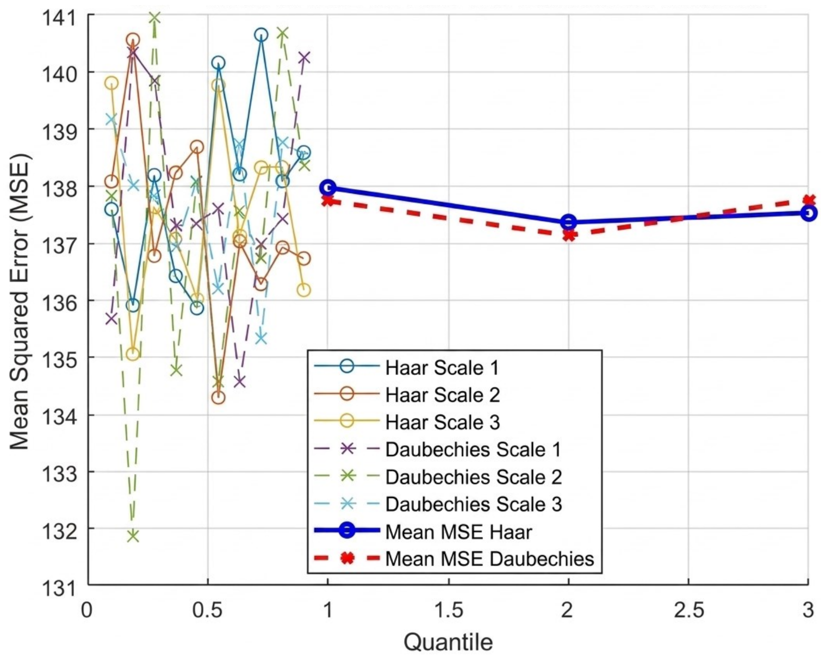
Additionally, the innovation of this work, apart from the subject under analysis, has been the estimation of two wavelets, Daubechies and Haar. For their comparison, using coding in MATLAB, one can refer to Figures 5 and 6. As shown, the MSE value of the Haar wavelet is lower. However, the question arises as to whether this difference indicates the superiority of the Haar wavelet over Daubechies.

Figure 5: Comparison of MSE between Haar and Daubechies Wavelets



Source: Author's own work.

Figure 6: Comparison of mean MSE between haar and daubechies wavelets

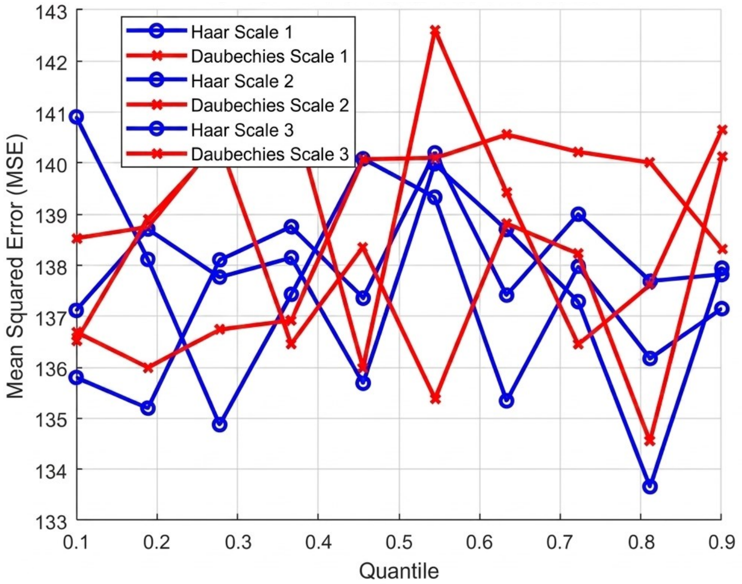


Source: Author's own work.

Given that the direct t-test primarily focuses on means and may overlook minor differences, non-parametric tests or advanced sensitivity analysis methods can be used to consider these differences more precisely. These tests are generally more sensitive to minor differences than traditional tests like the t-test.

One helpful method for examining minor differences in data is the bootstrap analysis and the calculation of confidence intervals for the mean differences. Bootstrap methods help to obtain a more accurate estimate of the actual differences in means. We use bootstrap sensitivity analysis to answer the above question, as shown in Figure 7.

Figure 7: Comparison of MSE for quantiles and scales: differences between haar and daubechies wavelets




```
Mean Difference: -0.8444
Bootstrap 90% CI for Difference: [-1.6030, -0.0656]
p-value for Bootstrap Analysis: 0.4997
The difference between Haar and Daubechies MSE is not statistically significant.
```

Source: Author's own work.

The mean difference in MSE between Haar and Daubechies wavelets is -0.8444. This means that, on average, the MSE of the Haar wavelet is approximately 0.8444 units less than that of the Daubechies wavelet. The 90% confidence intervals for the mean difference in MSE between Haar and Daubechies range from - 1.6030 to -0.0656. This indicates that with 90% confidence, the mean difference in MSE between the two wavelets lies within this interval. The negative mean difference in MSE between Haar and Daubechies suggests that the Haar wavelet generally has a lower MSE than the Daubechies wavelet. The very high p-value (0.4997) implies that the statistical results are insignificant, and it cannot be confidently stated that the observed differences are statistically significant.

Based on these results, it cannot be conclusively said that the Haar or Daubechies wavelet is generally better. The observed differences might be due to random variations in the data rather than actual differences in model performance. When choosing between Haar and Daubechies wavelets, one should not rely solely on MSE differences. Other factors and features may also play a role in the final decision. Overall, this analysis indicates that based on the current data and statistical methods, no definitive conclusion can be drawn about the superiority of one wavelet over the other. According to the bootstrap analysis, the direct comparison test does not confirm this difference, suggesting that both Haar and Daubechies wavelets have their own merits, and the best choice depends on specific conditions and requirements. If high accuracy and detailed analysis are essential, Daubechies might perform better. However, if simplicity and speed are more critical, Haar could be a more suitable option.

These figures imply that investors can use Haar wavelets for quick, efficient short-term trading decisions during volatility spikes, while policymakers might prefer Daubechies for precise long-term planning to stabilize markets; despite weak statistical differences, the practical significance lies in contextual application - Haar for speed in dynamic environments and Daubechies for depth in strategic analyses.

Interpretation of figures and practical implications

The decomposition of the Tehran Stock Exchange (TSE) index and exchange rate uncertainty time series, as illustrated in Figures 3 and 4, provides critical insights into the multi-scale dynamics of these variables, offering actionable implications for investors and policymakers. Figure 3 displays the TSE index decomposed into three scales (d1 to d3), where d1 captures long-term trends and d3 reflects short-term fluctuations. Similarly, Figure 4 decomposes the exchange rate uncertainty index, revealing how currency volatility manifests across different temporal horizons. These decompositions, facilitated by the discrete wavelet transform with maximum overlap multi-resolution analysis, enable stakeholders to discern distinct patterns in market behavior. For investors, the long-term components (d1) are particularly relevant for strategic asset allocation, as they highlight sustained trends driven by macroeconomic factors such as currency depreciation and inflation (Moradi et al., 2021). For instance, the positive relationship between exchange rate uncertainty and the TSE index, as observed across all scales, suggests that firms with export-oriented operations or assets tied to foreign currencies may experience enhanced stock performance during periods of currency volatility. This insight can guide investors in prioritizing such firms for portfolio diversification, particularly in Iran's sanction-constrained economy (Ghasseminejad & Jahan-Parvar, 2021).

For policymakers, Figures 3 and 4 underscore the need to monitor exchange rate volatility across multiple time scales to mitigate its impact on financial markets. The pronounced short-term fluctuations (d3) indicate that sudden currency shocks can rapidly influence the TSE index, potentially destabilizing investor confidence. Policymakers could leverage these findings to design targeted interventions, such as stabilizing monetary policies or support packages, to dampen excessive volatility and bolster market resilience (Rahimian et al., 2022). The hybrid quantile wavelet model's ability to capture these scale-specific effects enhances its utility over traditional models like ARDL or GARCH, which may overlook such temporal nuances (Osoolian et al., 2020).

Figures 5, 6, and 7 compare the mean squared error (MSE) of the Haar and Daubechies wavelets, providing further practical insights despite the statistically insignificant difference (p-value = 0.4997). Figure 5 illustrates the MSE comparison across quantiles, Figure 6 shows the mean MSE differences, and Figure 7 presents the bootstrap sensitivity analysis, indicating a mean MSE difference of -0.8444 (favoring Haar) with a 90% confidence interval of -1.6030 to -0.0656. While the statistical evidence does not conclusively favor one wavelet over the other, the practical implications of choosing between Haar and Daubechies are significant for specific analytical needs. The Haar wavelet, with its simpler structure, offers computational efficiency and ease of interpretation, making it suitable for investors or analysts requiring rapid insights in fast-moving markets. For example, during periods of acute exchange rate uncertainty, the Haar wavelet's lower MSE may enable quicker identification of short-term market trends, facilitating timely investment decisions. Conversely, the Daubechies wavelet, with its smoother and more detailed decomposition, is better suited for comprehensive analyses where precision in capturing complex, non-linear patterns is critical, such as in long-term policy planning or risk assessment (Guo et al., 2022).

For investors, the choice of wavelet can influence the granularity of market signals. The Haar wavelet's simplicity may appeal to retail investors or those managing smaller portfolios, as it provides straightforward insights into market responses to exchange rate fluctuations. In contrast, institutional investors or analysts with access to advanced computational resources may prefer the Daubechies wavelet for its ability to uncover subtle, scale-specific patterns, enhancing portfolio optimization strategies. For policymakers, the choice between wavelets depends on the context of their objectives. For instance, during economic crises, the Haar wavelet's efficiency could support rapid policy responses, while the Daubechies wavelet's precision may be preferred for designing long-term stabilization measures. These practical considerations highlight that, despite weak statistical differences, the choice of wavelet can significantly impact the effectiveness of financial analyses in Iran's volatile economic environment.

In summary, the figures not only validate the positive and significant impact of exchange rate uncertainty on the TSE index but also provide a multi-scale perspective that enhances decision-making for investors and policymakers. The comparative analysis of Haar and Daubechies wavelets underscores their context-specific advantages, enabling stakeholders to tailor their analytical approaches to their strategic needs.

In real-world analysis, Haar wavelets are recommended for rapid, short-term trading decisions due to their simplicity and ability to detect abrupt market shifts, ideal for retail investors in volatile periods. Daubechies wavelets, with their smoother decomposition, are better suited for institutional investors or policymakers conducting long-term risk assessments or policy planning, where capturing complex patterns is critical (Guo et al., 2022).

Explanation of observed patterns

The patterns observed in the results, as depicted in Figures 3, 4, 5, 6, and 7, reflect the interplay between investor behavior and market mechanisms driving the positive relationship between exchange rate uncertainty and the Tehran Stock Exchange index. Figures 3 and 4 illustrate the multi-scale decomposition of the TSE index and exchange rate uncertainty, respectively, revealing distinct short-term (d3), medium-term (d2), and long-term (d1) dynamics. The gradual increase and subsequent decline in the short-term impact (d3) can be attributed to speculative investor behavior, where traders rapidly adjust portfolios to capitalize on currency fluctuations, particularly favoring export-oriented firms that benefit from a depreciating Iranian Rial (Moradi et al., 2021). This behavior aligns with market mechanisms like capital flows into sectors resilient to exchange rate volatility, driven by institutional investors seeking to hedge against uncertainty (Rahimian et al., 2022). Figures 5, 6, and 7, which compare the mean squared error (MSE) of Haar and Daubechies wavelets, indicate subtle differences in model performance. The slightly lower MSE of the Haar wavelet (-0.8444) may stem from its ability to capture abrupt market shifts driven by panic buying or selling, a common investor reaction in Iran’s volatile market environment. Conversely, the Daubechies wavelet’s smoother decomposition better reflects complex market mechanisms, such as gradual adjustments in asset pricing driven by informed investors responding to macroeconomic trends (Guo et al., 2022). These patterns underscore how investor behavior, shaped by risk perceptions and market signals, interacts with liquidity dynamics and capital flows to produce the observed effects.

While the comparison of Haar and Daubechies wavelets reveals no statistically significant difference in performance (p-value = 0.4997), their practical applications in financial time-series analysis differ based on analytical needs. The Haar wavelet, with its lower mean squared error (-0.8444) and computational simplicity, is recommended for rapid analyses in highly volatile markets, such as real-time trading or short-term risk assessment, where detecting abrupt changes is critical (Young, 2012). Conversely, the Daubechies wavelet (D4), with its smoother decomposition and ability to capture complex patterns, is better suited for detailed, long-term analyses, such as portfolio optimization or policy evaluation, where nuanced market trends are prioritized (Guo et al., 2022). Analysts should select Haar for speed and responsiveness in dynamic settings and Daubechies for precision in strategic financial planning. These patterns are grounded in empirical findings from Moradi et al. (2021), where investor psychology drives shifts toward resilient sectors during depreciation, and literature on market mechanisms (Rahimian et al., 2022) supports the role of liquidity surges in amplifying short-term effects. The positive impact across quantiles is driven by investor behavior favoring export -oriented firms during currency depreciation, as a weaker Rial boosts their competitiveness (Moradi et al., 2021). Market mechanisms, such as increased liquidity from speculative trading and capital inflows to resilient sectors, further amplify these effects, particularly in short-term scales (d3), as investors react to currency shocks (Rahimian et al., 2022).

Conclusions

These findings align with the Flow-Oriented Model by showing how exchange rate uncertainty enhances export competitiveness and stock prices, while refining the Stock-Oriented Model through quantile analysis of capital flows; the contribution lies in providing a scale-specific framework for Iran's market, with added value for investors in optimizing portfolios by prioritizing export firms during volatility, and hedging strategies via derivatives. This study examines the impact of exchange rate uncertainty on the Tehran Stock Exchange index from 2010 to 2024, utilizing a hybrid quantile wavelet model. The findings reveal a positive and statistically significant effect of exchange rate uncertainty on the TSE index across all time scales and quantiles, with distinct patterns in short-, medium-, and long-term intervals. Specifically, the short-term effects (scale d3) show an initial increase followed by a decline, reflecting rapid market adjustments to currency fluctuations, while medium-term effects (scale d2) exhibit oscillatory behavior, indicating varying market responses to uncertainty. Long-term effects (scale d1) suggest a sustained positive impact, particularly for firms with export-oriented operations or assets tied to foreign currencies (Moradi et al., 2021). Consistent with Osoolian et al. (2020) and Nahidi Amirkhiz (2022), our findings confirm a positive impact of exchange rate uncertainty on the TSE, driven by export-oriented firms benefiting from a depreciating Rial. However, unlike studies on other sanctioned markets (Maradiaga Pineda, 2014), where currency volatility effects are less quantile-specific, our hybrid quantile wavelet model reveals stronger impacts in lower quantiles, advancing knowledge by highlighting Iran’s unique market dynamics under sanctions.

These results align with and extend the theoretical frameworks of the Flow-Oriented Model (Dornbusch & Fischer, 1980) and the Stock-Oriented Model (Branson, 1983). The Flow-Oriented Model posits that exchange rate fluctuations enhance the competitiveness of export-driven firms, increasing their revenues and, consequently, their stock prices. Our findings confirm this by demonstrating that exchange rate uncertainty, particularly in the long term, boosts the TSE index, likely due to the enhanced profitability of export-oriented companies in Iran’s sanction-constrained economy (Ghasseminejad & Jahan-Parvar, 2021). Conversely, the Stock-Oriented Model suggests an inverse relationship between stock prices and exchange rates through capital flows and investor wealth dynamics. The hybrid quantile wavelet model refines this perspective by capturing non-linear and scale-specific effects, revealing that the positive impact of exchange rate uncertainty is more pronounced in lower quantiles, where market conditions are less stable, thus offering a nuanced understanding of investor behavior under uncertainty.

The comparative analysis of Haar and Daubechies wavelets further enriches the findings. Although statistical tests indicate no significant performance difference (p-value = 0.4997), the practical implications are noteworthy. The Haar wavelet’s simplicity and lower mean squared error (-0.8444) make it suitable for rapid analyses in volatile markets, enabling investors to quickly identify short-term opportunities. In contrast, the Daubechies wavelet's detailed decomposition is ideal for precise, long-term analyses, such as risk assessment or policy planning (Guo et al., 2022). The choice between these wavelets depends on the specific needs of stakeholders: retail investors may prefer Haar for its speed and accessibility, while institutional investors or policymakers may opt for Daubechies for its analytical depth.

Contribution and added value for investors

The study's primary contribution lies in its application of the hybrid quantile wavelet model to dissect the complex relationship between exchange rate uncertainty and the TSE index, offering a multi-scale and distributional perspective that traditional models like ARDL or GARCH may overlook (Osoolian et al., 2020). For investors, this provides actionable insights for portfolio management and risk mitigation. The positive impact of exchange rate uncertainty suggests that investing in export-oriented firms or those with foreign currency-linked assets can yield higher returns during periods of currency volatility. The scale-specific findings enable investors to tailor their strategies: short-term traders can capitalize on rapid market adjustments (d3), while long-term investors can focus on sustained trends (d1) to optimize portfolio diversification. Additionally, the quantile-based analysis highlights opportunities in lower quantiles, where market volatility is higher, allowing risk-tolerant investors to target undervalued stocks with high growth potential.

The findings also inform risk management strategies. By understanding how exchange rate uncertainty affects the TSE index across different time scales, investors can better hedge against currency risks, for instance, by using financial instruments like futures or options to mitigate exposure to short-term volatility. The model's ability to decompose market signals into distinct time scales empowers investors to anticipate and respond to market dynamics more effectively, enhancing decision-making in Iran's volatile economic environment.

For policymakers, the results underscore the importance of stabilizing exchange rate fluctuations to maintain investor confidence and market stability. The oscillatory medium-term effects (d2) suggest that inconsistent market responses to uncertainty may require targeted interventions, such as monetary policy adjustments or support packages, to prevent excessive volatility (Rahimian et al., 2022). These insights contribute to a more resilient financial ecosystem, supporting economic growth in the face of external pressures like sanctions.

Potential drivers of the positive impact

The positive effect of exchange rate uncertainty on the TSE index may stem from several factors, which align with the theoretical and empirical literature.

- Psychological Effects and Expectations: Exchange rate fluctuations can shift investor expectations, making the stock market appear more attractive than alternative investments. If investors perceive that currency depreciation will benefit export-oriented firms, they may increase stock purchases, driving up the TSE index.
- Widespread News and Positive Analyses: During periods of high exchange rate uncertainty, media and analyst reports often highlight the resilience of specific sectors, attracting capital to the stock market despite its overall weak performance.
- Political and Economic Developments: Currency fluctuations may coincide with policy shifts or trade opportunities that favor certain industries, leading to stock price increases and a higher TSE index.
- Market Manipulations: Increased liquidity during volatile periods can temporarily inflate stock prices, contributing to index growth, though such effects may not be sustainable.
- Support Packages and Monetary Policies: Government interventions, such as interest rate reductions or financial support for firms, can bolster stock market performance in response to currency fluctuations, as noted in prior studies (Jalaee et al., 2016).

In conclusion, this study advances the understanding of exchange rate uncertainty's impact on the TSE index by integrating a hybrid quantile wavelet model with established theoretical frameworks. The findings offer investors a robust framework for navigating currency volatility, optimizing portfolio strategies, and managing risks, while providing policymakers with insights to design effective stabilization measures. While the short-term effects of exchange rate uncertainty may be pronounced, a deeper analysis of fundamental factors and their sustainability is essential for long-term decision-making.

Practical recommendations for traders and policymakers

The findings, particularly the short-term increase and subsequent decline in the impact of exchange rate uncertainty on the TSE index (d3, Figures 3 and 4) and oscillatory medium-term patterns (d2), inform specific strategies for traders and policymakers. Traders should leverage short-term volatility (d3) by employing high-frequency trading strategies, such as scalping export-oriented stocks during periods of heightened exchange rate uncertainty, to capitalize on rapid price movements. Additionally, using derivative instruments like futures or options can hedge against risks in volatile quantiles, as identified in Figure 5. For policymakers, implementing targeted interventions, such as temporary foreign exchange controls or interest rate adjustments during oscillatory medium-term periods (d2), can stabilize market reactions and mitigate excessive volatility. These actions, informed by the study's multiscale analysis, enhance market resilience in Iran's sanction-constrained economy.

Traders should employ high-frequency strategies, such as scalping export-oriented stocks during short-term volatility spikes (d3), and use derivatives like futures to hedge against risks in lower quantiles. Policymakers should implement temporary foreign exchange controls or interest rate adjustments during oscillatory medium-term periods (d2) to stabilize markets and enhance resilience in Iran's sanctioned economy.

Limitations of the Study

While this study provides valuable insights into the impact of exchange rate uncertainty on the Tehran Stock Exchange index, several limitations must be acknowledged to contextualize the findings and guide future research. First, the hybrid quantile wavelet model, which integrates quantile regression and wavelet transform methodologies, relies on the availability and quality of historical data. The dataset, sourced from the Economic and Financial Data Bank of the Ministry of Economic Affairs and Finance, spans from 2010 to 2024. However, potential inconsistencies in data reporting, such as gaps or inaccuracies in exchange rate or stock market data, may affect the robustness of the results. Second, the study focuses exclusively on the TSE, limiting the generalizability of the findings to other financial markets with different economic structures or regulatory environments.

Third, the hybrid model assumes stationarity of the time series after applying the unit root test, as reported in Table 2. However, unaccounted structural breaks or exogenous shocks, such as changes in international sanctions or monetary policy shifts, may introduce variability that the model does not fully capture. Additionally, while the model employs both Haar and Daubechies wavelets for multi-resolution analysis, it does not account for other wavelet families that might offer different insights into the data's temporal dynamics. Finally, the study's focus on exchange rate uncertainty as a primary driver does not incorporate other macroeconomic variables, such as interest rates or oil prices, which may also influence the TSE. Future research could address these limitations by incorporating broader datasets, testing alternative wavelet families, and exploring additional macroeconomic factors to enhance the model's explanatory power. Additionally, the model's reliance on historical data from 2010-2024 may not fully account for future structural changes, such as policy shifts or global events, limiting predictive power; future studies could incorporate real-time data or additional variables like oil prices.

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AI statement

During the preparation of this work, the authors used Grammarly strictly for minor grammatical corrections and to enhance the linguistic fluency of select sentences. No AI tools were utilized to generate ideas, write substantive content, or alter the scientific meaning of the text. Following the use of this tool, the authors carefully reviewed and manually refined the manuscript. The authors take full responsibility for the originality, validity, and integrity of the entirety of the content.