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# Assessing financial convergence in developing countries: The case of D-8 countries☆

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ABSTRACT

The European Union's regional integration serves as a model for blocs such as the D-8 Organisation for Economic Cooperation, which aims to enhance financial and economic integration. This study employs wavelet coherence analysis to examine the interrelations between exchange rates, bond yields, stock exchanges, the VIX, and oil prices in D-8 countries, utilizing daily data from 2010 to 2025 to assess financial convergence. The findings reveal dynamic and heterogeneous financial relationships. Türkiye, Indonesia, and Malaysia exhibit medium-term synchronisation between exchange rates and bond yields, while Bangladesh and Nigeria show inverse relationships. Stock markets also display varied interactions, with Indonesia and Malaysia demonstrating persistent negative correlations, while Türkiye shifts from synchronisation to an inverse relationship. More open economies, like Türkiye and Malaysia, demonstrate stronger coherence with global volatility (VIX), whereas controlled economies, such as Iran, show weaker responses. Although mid-to-long-term coherence suggests progress towards financial convergence, differences in market openness and policies hinder full integration. Policymakers should prioritize coordinating exchange rates, ensuring financial transparency, and harmonising regulations to strengthen stability in D-8 economies. Proactive risk management and regional policy coordination can mitigate the effects of global volatility. Enhancing financial linkages through cross-border investments and regional agreements will improve resilience and speed up convergence.

## 1. Introduction

Financial development can be defined as the growth and improvement of financial institutions, markets, and instruments within an economy. This indicates that economic growth is enhanced through the effective allocation of capital, the expansion of investment opportunities, and improved financial accessibility. The main components of financial development include financial institutions, financial markets, and financial instruments. While promoting economic stability and inclusivity, it is crucial to recognize that excessive or poorly regulated financial expansion can lead to financial crises, emphasising the need for balanced and well-regulated financial systems (Khan & Senhadji, 2003).

In recent decades, the world has undergone a wave of financial deregulation and globalisation. This transformation is expected to promote financial growth in developing nations, allowing them to bridge the gap with more advanced economies. Reducing financial disparities between these countries is crucial for diminishing income inequality, as financial development plays a vital role in the process of economic convergence (Aghion et al., 2005).

One of the challenges faced by policymakers and global investors is distinguishing between financial market fluctuations caused by contagion and those resulting from various factors (Bodart & Candelon, 2009; Kallberg & Pasquariello, 2008). If heightened volatility and cross-market linkages stem from contagion, they are likely to diminish after a few days. In contrast, if the increased fluctuations and co-movements arise from fundamental variables, they are expected to endure for a prolonged period. Therefore, analysing financial shocks, due to their detrimental effects on the global economy, is of paramount importance. This analysis provides insights into financial, economic, and monetary integration, encompassing the management of portfolio risks and devising monetary and fiscal policies (Yang et al., 2016).

Exchange rate volatility poses a threat to global financial stability,

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affecting trade, investment, and economic performance. Sudden fluctuations disrupt markets, increase import costs, and burden foreign debt. Managing volatility frequently requires adjustments in monetary policy, such as interest rate increases, which can stabilise exchange rates but may also deter investment and elevate unemployment. Monetary unions necessitate financial and economic convergence, as well as resilience to external shocks.

The formation of a monetary union depends on similar production structures and shared vulnerability to external shocks, facilitating coordinated economic and financial responses (Kenen, 1969). The optimum currency area (OCA) theory (Mundell, 1961) advocates for the adoption of a common currency to ensure stability. One approach involves pegging national currencies within the group while allowing a floating exchange rate externally. Key success factors include high resource mobility, which enables the free movement of labour and capital (Mundell, 1961), and trade openness, which promotes internal trade by reducing transaction costs and stabilising exchange rates (McKinnon, 1963). When member states demonstrate comparable financial and economic convergence, they tend to respond more consistently to a unified monetary policy, enhancing stability (Fleming, 1971; Ingram, 1962; Kenen, 1969). These elements contribute to the establishment of a flexible union. Therefore, OCA provides a framework for assessing the suitability of a region for a common currency, aiding policymakers in their decision-making.

As a cornerstone of economic stability, the financial sector plays a vital role in promoting economic integration by significantly contributing to overall economic growth (Khan & Senhadji, 2003). Consequently, the establishment of a single market for financial services has been a central aspect of European integration. To this end, various measures have been implemented since the latter half of the 20th century to advance the single market initiative (Kılınç et al., 2017). In 1999, the Economic and Monetary Union (EMU) was created, introducing the Euro, which has generated considerable interest (European Parliament, 2025). The choice to join the EMU and adopt the Euro represents a significant milestone that requires careful consideration and a thorough understanding of the potential benefits and challenges (Rose, 2017).

The success of the EMU has encouraged numerous regions, including countries in East and Southeast Asia, to explore the possibility of pursuing a similar trajectory. One such group consists of the Developing Eight (D-8) or D-8 Organisation for Economic Cooperation countries. Founded in 1997 by Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Türkiye, the D-8 aims to promote socio-economic development among its member countries based on the principles of peace, dialogue, cooperation, justice, equality, and democracy. The organisation plays a vital role in enhancing the global economic standing of developing nations by advocating for trade diversification, increasing participation in international decision-making, and improving living standards. To bolster economic integration among its members, the D-8 has established a Preferential Trade Agreement intended to strengthen intra-trade and economic relations, with the broader objective of raising living standards and contributing to global harmony and stability. The agreement also outlines key areas for collaboration and project development, including telecommunications, finance, rural development, science and technology, poverty alleviation, agriculture, energy, environment, and health (Hakim et al., 2015). As the organisation continues its efforts to attain sustainable economic growth and equitable development, understanding the dynamics between financial variables within the D-8 economies becomes ever more relevant (D-8, 2025).

This study, therefore, aims to examine the interrelations between the exchange rate, bond yield, stock market, VIX, and oil prices in each of the D-8 countries and to ascertain whether changes in these variables occur simultaneously and in the same direction across these eight nations. To achieve this, wavelet coherence analysis was employed to analyse daily data from 2010 to 2025.

The existing literature presents several studies that analyse, individually, the relationship between exchange rates, interest rates, and various equities of the OIC members. However, to date, no research has investigated financial convergence among the D-8 countries using wavelet coherence while controlling for similarities in relevant variables. This study addresses this gap by examining these similarities through wavelet coherence. Thus, it contributes to the literature regarding financial convergence among countries within a group, as well as bringing the experiences of D-8 countries to the academic agenda.

The remainder of the paper consists of three parts: the following section reviews the literature and the studies undertaken to date. The relevant literature suggests that this study is unique in terms of its topic. The second part examines the econometric methods and data, while the third section presents the empirical results. The conclusion represents the final section of the study.

## 2. Literature review

The concept of financial development convergence has been the subject of investigation from a variety of angles within existing literature. These angles encompass economic growth, banking, stock markets, informality, and credit markets. While the examination of countries is often conducted independently, the existing literature also explores how groups of countries converge and how this convergence can lead to deeper economic and financial integration. Researchers analyse whether similarities in financial structures, regulatory frameworks, and economic policies contribute to the harmonisation of financial systems across nations. It is, therefore, vital for policymakers seeking to encourage economic cooperation and integration among nations to understand the dynamics of regional and global financial convergence (Bahadir & Valev, 2015; Khan & Senhadji, 2003; Sever 2022, 2023).

Among others, Léon (2018) investigates the convergence of global credit structures using data from 143 countries (1995–2014). It finds distinct convergence in total, household, and firm credit, with household credit converging more rapidly, thereby reshaping its share of total credit. Convergence is more pronounced in low-income countries and those with initially lower credit levels, but it decelerates post-2008 financial crisis. The convergence trend of banking and stock market indicators in European Union (EU) countries is examined by Kılınç et al. (2017). The study assesses the effects of the transition from the European Monetary System to the Single Currency over the past five decades on financial market integration. The findings suggest a gradual alignment of banking and stock market metrics across the EU, with an improvement in convergence when considering institutional quality and key macroeconomic variables.

In a recent study, Sever and Yücel (2024) analysed panel data from 156 countries between 1991 and 2017 to explore the impact of the informal economy on the convergence of financial development. The findings indicate that financial development tends to equalise across countries over time. However, an increase in the size of the informal economy has been shown to slow this convergence. The findings suggest that reducing informality can facilitate the catch-up process of less financially developed countries with those that possess more advanced financial systems.

Numerous studies have investigated the cause-and-effect relationships among different currencies using various methods, including Markov switching, vector autoregressive (VAR) models, and Granger causality tests. Orlov (2009), Nikkinen et al. (2011), Antonakakis (2012), and Beirne and Gieck (2014) are among several notable figures who have conducted research in this area. Conversely, one of the primary issues identified with previous econometric analysis models, such as GARCH, was the challenge of heteroscedasticity in estimating time-varying conditional correlations. Recently, there has been an increased focus on advanced methodologies for analysing the interdependence between markets and the co-movement of financial asset returns and their volatilities (Maiti et al., 2020). This has involved a

particular emphasis on wavelet analysis (Haque et al., 2018; Khan et al., 2023; Vukovic et al., 2021).

The existing literature analyses variables using wavelet coherence analysis. Most studies provide separate evidence for the exchange rate, bond yield, and oil price across different countries. It is intriguing to connect these variables at various scales and highlight similarities between nations. For example, Kirik et al. (2023) examine the interrelated movement of bank deposit rates and their primary underlying determinants, including foreign exchange rates (FX), cross-currency swap rates, and implied forward rates from 2005 to 2020. The findings indicate cross-country interdependence, with stronger evidence of co-movement during adverse economic conditions and a higher correlation compared to other periods, such as the 2007–2009 US mortgage crisis, the 2010–2012 Euro crisis, and the 2019 pandemic. Furthermore, wavelet analysis reveals that the deposit rate lags behind the FX rate and leads the cross-country swap rate. Tsai and Chang (2018) employed the wavelet coherence phenomenon to investigate the causality of the lead-lag association between economic growth and money in 15 Asia-Pacific countries over three decades. The empirical results have significant policy implications for these countries that are implementing monetary policy to stimulate their economies.

Yang et al. (2016) analyse the co-movement of foreign exchange rates (GBP/USD, EUR/USD, and JPY/USD) using wavelet analysis during the global financial crisis and the European debt crisis. The empirical findings indicate a significant interdependence between the EUR and GBP across all frequency bands of scale over the sample period, with this interdependence being more pronounced during crises. Qureshi and Aftab (2023) examine the interdependence and contagion among the exchange rates of five major Asian emerging markets through wavelet decomposition to explore the diverse nature of interdependence and lead-lag relationships. The empirical results demonstrate co-movement among several exchange rate pairs, with a notable increase during the global financial crisis. Furthermore, there are moderate rises in co-movements, suggesting a regional market convergence in the long run.

Junior et al. (2019) employed the three-dimensional continuous Morlet wavelet transform methodology to investigate the co-movement of the returns of four major currencies in Ghana from May 1999 to February 2018. The results indicate that the interdependence of these currencies is time-varying and heterogeneous. The currencies are closely linked, and lead-lag relationships exist between the returns and the exchange rates. It reveals that the volatilities of the Euro and yen significantly influence movements in other currencies concerning daily and weekly exchange rate returns.

The analysis of time series that examine the interactions between energy markets in both time and frequency domains has gained popularity in the literature. Akoum et al. (2012) analysed the relationship between stock market returns and OPEC basket oil returns in GCC countries and two non-oil-producing nations (Egypt and Jordan) from 2002 to 2011. The study found no significant market dependency between the countries in the short term. However, in the long term, there is a strong correlation between oil returns and stock market returns. Yang et al. (2017) examine the relationship between crude oil prices and exchange rate markets by analysing their dynamics in the time and frequency domains using a wavelet coherence framework. The results suggest that the degree of co-movement between crude oil prices and exchange rates varies over time. Strong but not uniform links were found around 2008 for all countries included in the study and from 2005 onwards for oil-exporting countries. It has been observed that a negative relationship exists between crude oil price returns and exchange rates in oil-exporting countries. However, the relationships for oil-importing countries remain uncertain.

Several studies have investigated countries that are members of the OIC. The correlation between the Gulf Cooperation Council (GCC) and the United States stock market returns was analysed using the wavelet coherence method (Matar et al., 2021). The investigation examined the weekly stock index prices of the Dow Jones and S&P 500, alongside six GCC stock markets. It has been identified that there is a long-term, definitive co-movement between several GCC stock markets and those of the US.

Aloui et al. (2018) examined the relationship between the Sharia stock index and three Islamic bond yields within a global perspective of the Islamic financial markets in the GCC. The empirical findings suggest a significantly changing pattern in the dynamic association between Sharia stocks and Islamic bond yields in the time-frequency domain. Khan et al. (2023) investigated the effects of exchange rates, interest rates, and oil prices on the inflation rate for Türkiye and Pakistan during the period from January 2010 to December 2021 using the wavelet coherence model. The results demonstrate that currency depreciation increases inflation in both economies. The impact of interest rates on inflation is more pronounced in Pakistan than in Türkiye, while oil prices contribute to inflation solely in Pakistan.

Several papers assess the feasibility of establishing a monetary union among Muslim countries, investigating its potential benefits for bilateral trade, growth, and development (Fegheh, 2014). Monetary integration should be considered alongside other forms of economic and financial integration, including political, fiscal, and institutional integration. The countries exhibit diverse socio-economic and political structures, which may or may not facilitate the formation of a currency union. According to Kirchner (2006), the absence of democratic institutions could hinder integration among Muslim economies, as rulers may be reluctant to adopt a common policy. Arif and Shabbir (2019) explored the possibility of establishing a currency union among Islamic nations, concluding that such a union may not be beneficial due to differences in factors such as mobility, sources of income, and political and socio-economic conditions among Islamic countries.

## 3. Data and methodology

### 3.1. Data

The data utilised in this study is collected daily, ensuring a high-resolution analysis of temporal dynamics. To process and analyse this dataset, we employed R Studio's 'biwavelet' package, specifically designed for wavelet-based time series analysis. This package facilitates the exploration of time-frequency relationships and the identification of patterns and co-movements across various time scales. Table 1 displays the abbreviations and sources of the variables.

The daily data in this study covers the period from January 2010 to February 2025. When comparing financial variables across countries, variations in public holidays and the unavailability of daily data during certain periods for some nations can lead to discrepancies in the number of observations. This may pose challenges in the analysis process and result in differences in sample sizes across countries.

Iran does not have a bond rate as it does not issue conventional bonds due to Islamic finance principles, international sanctions, and a state-controlled economy that relies more on oil revenues and direct monetary policies rather than debt markets. Furthermore, daily stock exchange data for Iran was not accessible. Nevertheless, due to the lack of data, the relationship between the exchange rate and bond yield in Bangladesh was assessed only for the period from March 2015 to February 2025. Table 2 presents the descriptive statistics for the D-8 countries.

### 3.2. Methodology

The Fourier Transform (FT) is a widely used technique for analysing signals. However, it has limitations when addressing data that varies over time, such as non-stationary data. While the FT excels at identifying frequencies within a signal, it does not indicate when those frequencies occur. This limitation arises because it relies on sine and cosine waves, which are continuous over time.

**Table 1**
Abbreviations and sources.

| Abbreviations | Description | Source |
|---|---|---|
| Exchange rate | The exchange rate between the US dollar (USD) and domestic currency. | investing.com |
| Bond yield | 10-Year Government bond yield | investing.com |
| Stock exchange | Countries' stock market data | investing.com |
| VIX | The daily market volatility index | The Chicago Board options exchange (CBOE) |
| Oil price | Europe brent spot price FOB (dollars per barrel) | The U.S. Energy information administration |

Furthermore, FT assumes that the frequency content of the signal remains constant, which is often not the case. By providing time-frequency analysis, the Wavelet Transform (WT) overcomes these limitations. WT employs localised wavelets that identify both the frequency and location within the signal, offering a more nuanced understanding of the signal's behaviour. Additionally, WT can analyse non-stationary data, effectively identifying trends, abrupt changes, and non-linear relationships between frequencies—elements that FT might overlook. Therefore, WT is a valuable tool in circumstances where the frequency content of the data varies over time (Yilanci & Pata, 2023).

To analyse the data, we employed the Wavelet Coherence (WC) procedure. Cross-wavelet coherence analysis serves as a powerful tool for visualising the relationship between two signals in the time-frequency domain. Conventional correlation analysis provides a limited perspective on the relationship between variables, despite being a cornerstone of time series analysis. It overlooks the possibility that this relationship may vary over time or depend on frequency, yielding a single value. Wavelet coherence examines the co-movement of two signals in the time-frequency domain, offering a more nuanced understanding. Much like a time-varying correlation analysis, this technique illustrates how the strength and nature of the relationship between the variables change across different periods and frequency bands. This enables us to identify specific instances where the variables are interrelated and the frequencies at which these relationships are most significant. By investigating the 'when' and 'how' of the relationship, wavelet coherence transcends a simple correlation coefficient, providing a richer understanding of the dynamic interaction between variables (Ferrer et al., 2016).

One advantage of wavelet methods is their ability to present results without dividing the data into distinct sample periods. This technique allows for the examination of correlation patterns between financial data across various regimes. Wavelet coherence also facilitates three-dimensional analysis by simultaneously considering the time and frequency components, as well as the strength or weakness of the correlation between the time-series components (Rehman et al., 2023). Traditional econometric methods for time series analysis often isolate the time and frequency components (Aguiar-Conraria & Soares, 2011; Grinsted et al., 2004).

In summary, the wavelet coherence approach offers several significant advantages: measuring the dynamic relationship between variables instead of suggesting a static relation (Bodart & Candelon, 2009); identifying structural breaks when there is a complete breakdown in association or a shift in the specific frequency band; determining the causality relationship at various frequencies; and, while other estimation techniques require parameters, the wavelet model is free from such jargon (Vacha & Barunik, 2012).

In terms of formal expression, Torrence and Webster (1999) and Grinsted et al. (2004) articulated the wavelet coherence of two time series, x and y, as follows:

**Table 2**
Descriptive statistics for the D-8 countries.

| Countries | Obs. | | Exchange Rate | Bond Yield | Stock Exchange | VIX | Oil Price |
|---|---|---|---|---|---|---|---|
| **Türkiye** | 3384 | *Mean* | 8.46 | 13.36 | 2113.52 | 18.16 | 77.93 |
| | | *Minimum* | 1.51 | 6.02 | 498.37 | 9.01 | 9.12 |
| | | *Maximum* | 35.99 | 29.03 | 11172.75 | 82.69 | 133.18 |
| | | *Std. deviation* | 9.51 | 5.65 | 2678.78 | 6.99 | 25.53 |
| **Indonesia** | 3556 | *Mean* | 12870.15 | 7.22 | 5411.98 | 18.51 | 78.11 |
| | | *Minimum* | 8460.00 | 5.02 | 2475.57 | 9.01 | 9.12 |
| | | *Maximum* | 16575.00 | 10.05 | 7905.39 | 82.69 | 133.18 |
| | | *Std. deviation* | 2323.07 | 0.92 | 1237.24 | 6.97 | 24.66 |
| **Malaysia** | 3465 | *Mean* | 3.90 | 3.79 | 11200.61 | 18.43 | 77.99 |
| | | *Minimum* | 2.94 | 2.50 | 8179.73 | 9.01 | 9.12 |
| | | *Maximum* | 4.80 | 99.69 | 13124.11 | 82.69 | 133.18 |
| | | *Std. deviation* | 0.55 | 1.67 | 910.35 | 7.07 | 24.96 |
| **Pakistan** | 3285 | *Mean* | 149.12 | 11.42 | 38497.14 | 18.19 | 77.19 |
| | | *Minimum* | 83.60 | 7.59 | 9603.55 | 9.01 | 9.12 |
| | | *Maximum* | 307.75 | 16.83 | 117586.98 | 82.69 | 133.18 |
| | | *Std. deviation* | 64.57 | 2.26 | 17738.83 | 7.00 | 25.13 |
| **Nigeria** | 3043 | *Mean* | 411.31 | 13.83 | 41673.25 | 17.77 | 75.36 |
| | | *Minimum* | 156.00 | 0.00 | 20123.51 | 9.01 | 9.12 |
| | | *Maximum* | 1681.39 | 22.35 | 105933.03 | 82.69 | 133.18 |
| | | *Std. deviation* | 365.48 | 2.78 | 20653.40 | 6.71 | 24.53 |
| **Egypt** | 2528 | *Mean* | 16.63 | 17.17 | 12238.77 | 17.83 | 76.26 |
| | | *Minimum* | 5.69 | 12.70 | 3868.44 | 9.01 | 9.12 |
| | | *Maximum* | 51.03 | 33.34 | 33382.51 | 82.69 | 133.18 |
| | | *Std. deviation* | 11.28 | 3.45 | 6509.61 | 6.58 | 24.49 |
| **Bangladesh** | 1819 | *Mean* | 89.86 | 8.21 | 5528.15 | 18.06 | 67.33 |
| | | *Minimum* | 77.38 | 5.38 | 3603.95 | 9.01 | 22.79 |
| | | *Maximum* | 121.99 | 13.01 | 7351.04 | 80.62 | 133.18 |
| | | *Std. deviation* | 12.80 | 1.93 | 782.88 | 6.61 | 18.99 |
| **Iran** | 3278 | *Mean* | 29278.69 | – | – | 17.78 | 77.10 |
| | | *Minimum* | 9885.00 | – | – | 9.01 | 9.12 |
| | | *Maximum* | 44120.00 | – | – | 82.69 | 128.14 |
| | | *Std. deviation* | 12352.95 | – | – | 6.97 | 25.20 |

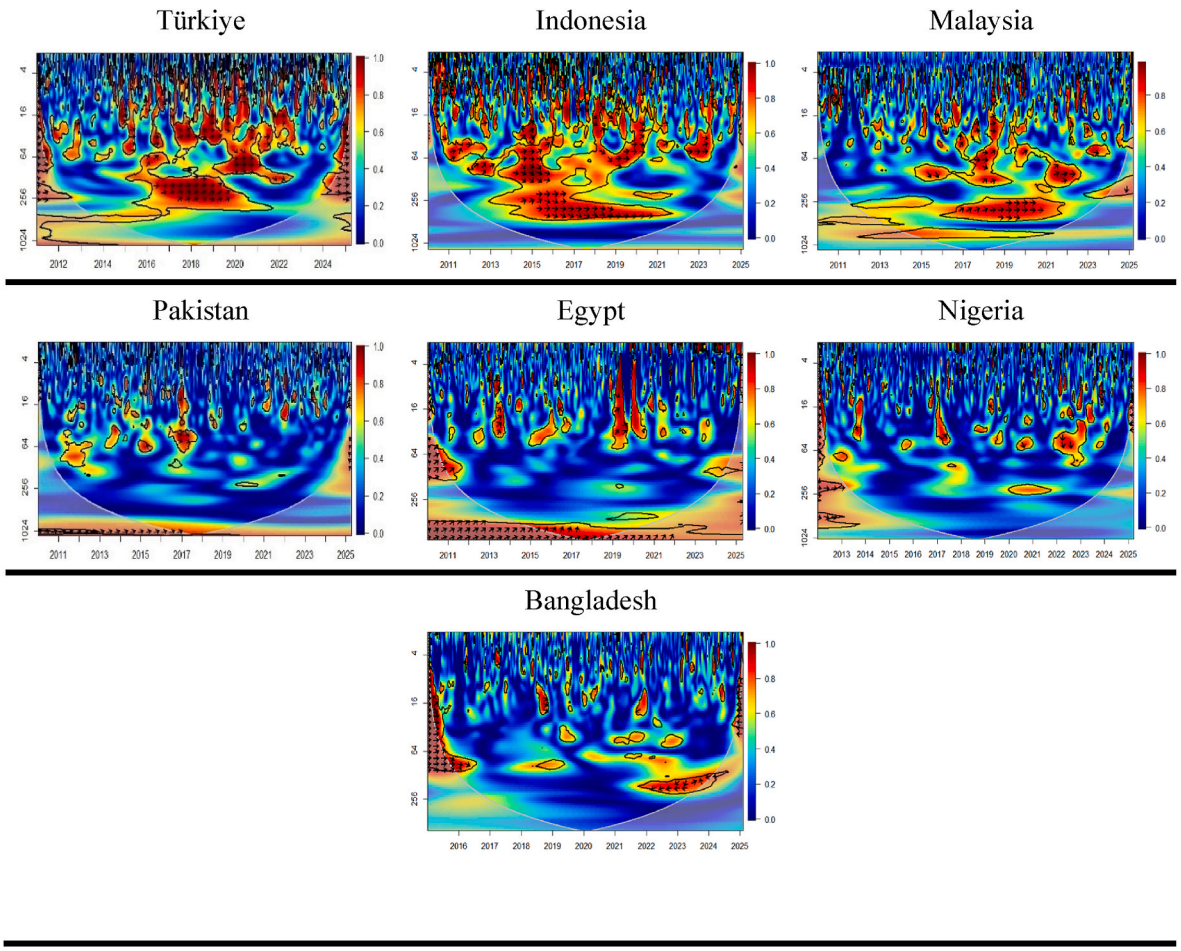


**Fig. 1.** The Results of Wavelet Coherence for Exchange Rate and Bond Yield
**Note:** Iran's financial system prohibits interest-bearing transactions due to Islamic principles. As a result, the bond yield cannot be analysed together with other variables.

$$R_n^2(s) = \frac{\left|S\left(s^{-1}W_n^{XY}(s)\right)\right|^2}{S\left(s^{-1}\left|W_n^X(s)\right|^2\right).S\left(s^{-1}\left|W_n^Y(s)\right|^2\right)} \quad (1)$$

where S represents a smoothing operator. Convolutions in scale and time will be used to achieve smoothness.

$$S(W) = S_{scale}(S_{time}(W_n(s))) \quad (2)$$

where $S_{time}$ and $S_{scale}$ explain the smoothness of time and scale in wavelet analysis respectively. Given the nature of our variables and data, we employ the smoothing operator proposed by Torrence and Webster (1999), namely the Morlet Wavelet:

$$S_{time}\ (W)|_s = \begin{pmatrix} \frac{-t^2}{2s^2} \\ W_n(s)^* c_1 \end{pmatrix} |_s;\ S_{time}\ (W)|_s = \left(W_n(s)^* c_2 \pi(0.6\ s)\right)|_n \quad (3)$$

where the normalization constants are $C_1$ and $C_2$, and rectangle functions are represented by $\pi$, similarly, 0.6 factor is considered for scale decorrelation length of Morlet wavelet following Torrence and Compo (1998). $0 \le R_n^2(s) \le 1$ is the range of Wavelet coherence two-time, which shows at each scale two time series linear association. The value of the wavelet squared coherence, $R_n^2(s)$, has a high value that reflects strong co-movement between time series, and *vice versa* $W_n^{XY}(s)$ denotes cross wavelet power and indicates the region time scale where time series demonstrate high common power, thereby reflecting the local covariance between two series at each scale. Thus, the two series y (t) and x(t), that is, cross wavelet power, is expressed as:

$$W_n^{XY}(s) = W_n^X(s) W_n^{*Y}(s) \quad (4)$$

In the above equation, $W_n^X(s)$ and $W_n^{*Y}$, show two continuous wavelet transform series correspondently where the * represents a complex conjugate.

According to Torrence and Compo (1998) and Madaleno and Pinho (2012), lead-lag associations can be depicted by the wavelet coherence of different phases, where the phase of wavelet coherence can be explained as:

$$\varnothing_n^{XY}(s) = tan^{-1}\left(\frac{I\left\{S\left(s^{-1}W_n^{XY}(s)\right)\right\}}{R\left\{S\left(s^{-1}W_n^{XY}(s)\right)\right\}}\right) \quad (5)$$

In equation 5, R and I represent the real and imaginary slices of the smooth power spectrum. By analysing these elements together, it is possible to uncover the links between the signals in terms of coherence, phase, and potential lead-lag relationships across different frequencies and times (Basdekis et al., 2022; Marín-Rodríguez et al., 2023). Consequently, wavelet approaches may be considered, following the studies of Yilanci and Pata (2023), Kirikkaleli (2021), and Lin et al. (2018).

## 4. Empirical results of the wavelet coherence

The figures below illustrate the WC order and directional findings for

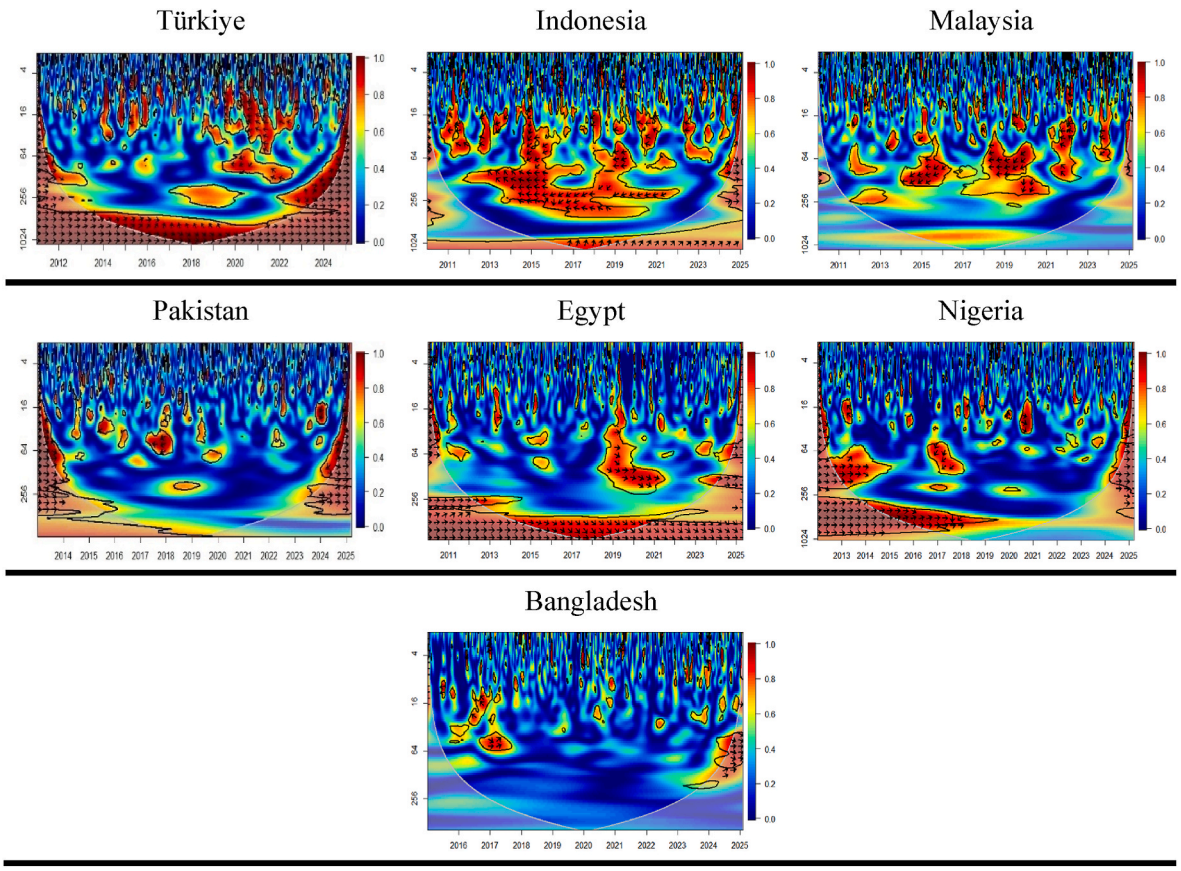


**Fig. 2.** The results of wavelet coherence for exchange rate and stock exchange.

the significant regions identified by the WC results. They summarise whether the underlying determinant leads or lags behind variables and whether pairs are in or out of phase. The horizontal axis (x-axis) represents the research period in days, while the vertical axis (y-axis) denotes the frequency domain.

The study analysed five frequency cycles: 1–4, 4–16, 16–64, 64–256, 256–512, and 512–1024 daily bands. To aid comprehension, the findings have been categorised into signals of short-term (ST), medium-term (MT), and long-term (LT). ST signals refer to those that fall within the 2–4 day and 4–16 day ranges, MT signals refer to those that fall within the 16–64 day and 64–256 day ranges, and LT signals refer to those that fall within the 512–1024 day range. To the right of each plot, a power colour code ranges from dark blue (signifying low power, near zero) to dark red (signifying high power, near one). Black arrows indicate the phase relationship. Arrows pointing to the right and left signify positive and negative correlation, respectively, while diagonal arrows demonstrate a leading effect. Dark contours emphasise the statistical significance of coherence. The time and frequency axes facilitate the tracking of changes throughout the data. A cone-shaped region designates areas where edge effects may influence the results, aiding in reliable interpretation.

Fig. 1 illustrates the interrelationships among exchange rates (USD/TRY, USD/IDR, USD/MYR, USD/PKR, USD/EGP, USD/NGN, USD/BDT, and USD/IRR) and bond yields for D-8 countries.

The wavelet coherence analysis for the D-8 countries reveals distinct patterns in the relationship between exchange rates and bond yields, showcasing varying lead-lag dynamics across different timeframes. In Türkiye, Indonesia, and Malaysia, the medium-term coherence (2015–2022) is characterised by predominantly rightward-pointing arrows, indicating a strong in-phase relationship where movements in exchange rates and bond yields are synchronised. In contrast, Bangladesh exhibits a leftward pattern from 2022 to 2024, suggesting an anti-phase relationship where bond yields and the USD move inversely or with a phase lag. Meanwhile, Pakistan displays significant medium-term coherence only in 2017. Nigeria shows minimal coherence except for 2023, where leftward-downward arrows indicate a negative correlation or a phase shift. The results demonstrate that exchange rate fluctuations played a dominant role in shaping bond market behaviour across most D-8 economies, albeit with different lead-lag relationships. Fig. 2 illustrates the results of wavelet coherence for exchange rates and the stock exchange.

The wavelet coherence analysis of D-8 countries highlights distinct time-frequency relationships between exchange rates and stock markets, featuring varying lead-lag effects. Indonesia (2013–2022) and Malaysia (2014–2022) display medium-term negative correlations, while Egypt (2015–2021) exhibits a mixed rightward and downward trend. Bangladesh shows synchronisation only in 2017, Nigeria presents a rightward-downward correlation (2013–2018), and Pakistan demonstrates an inverse relationship solely in 2018. In Türkiye, a long-term in-phase correlation (2015–2020) transitions to a medium-term inverse relationship (2020–2022).

These variations underscore the influence of economic cycles, monetary policies, and external factors on currency-stock market dynamics in emerging markets. The mixed lead-lag dynamics suggest possible spillover effects, where financial shocks in one country could impact others, highlighting the necessity for coordinated economic policies within the D-8 group. The notable presence of mid-to-long-term correlations further emphasises the interdependence of exchange rate stability and stock market performance, underscoring the significance of policy synchronisation and exchange rate risk management. Fig. 3 illustrates the results of wavelet coherence for exchange rate and VIX.

Türkiye's relationship in 2019 was characterised by a leftward trend, reflecting an inverse correlation. By 2020–2021, this shifted to a rightward trend, indicating synchronisation. In Indonesia (2014–2017) and

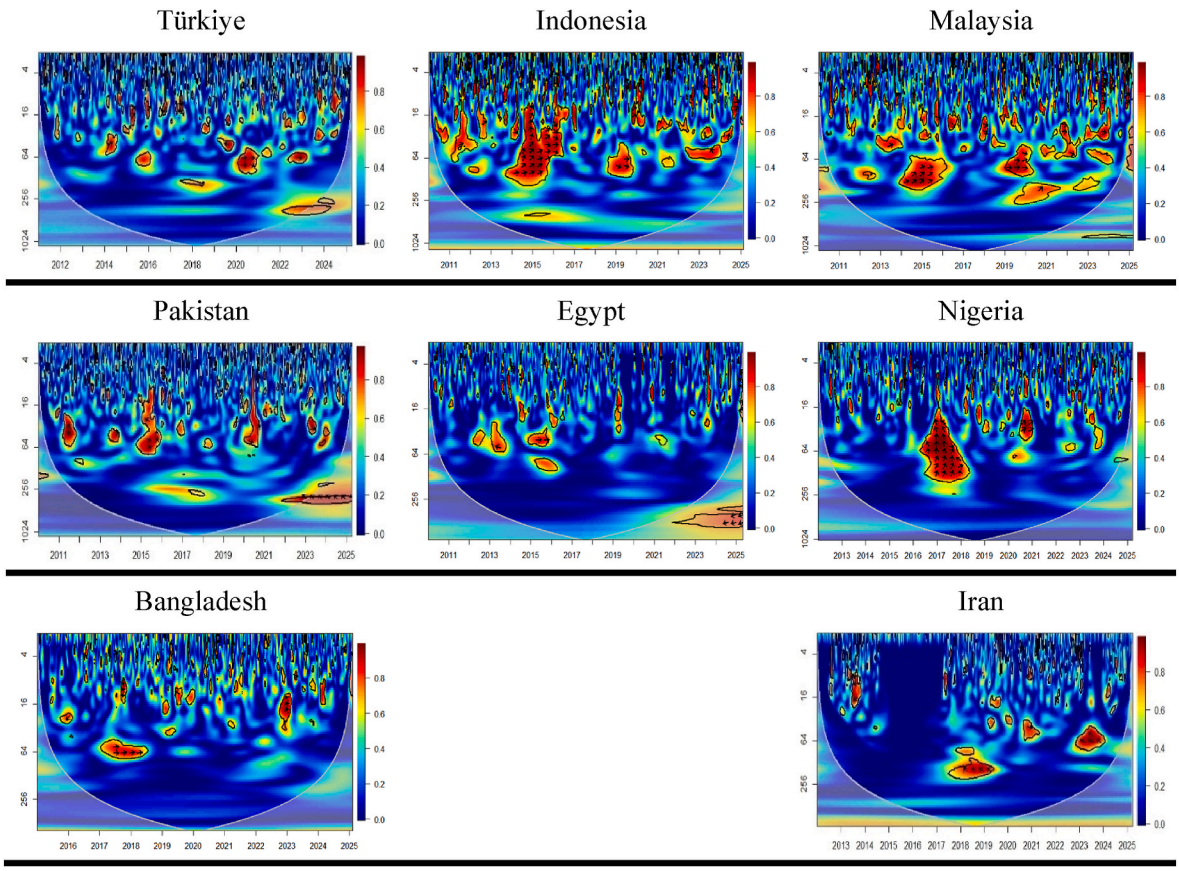


**Fig. 3.** The results of wavelet coherence for exchange rate and VIX

Nigeria (2016–2019, 2020), a medium-term rightward-upward pattern emerged, signifying a positive correlation with volatility. Malaysia exhibited rightward coherence in 2014–2016 and 2019–2020, while Egypt displayed a similar trend only in 2015. Bangladesh aligned with the VIX in 2017–2018, whereas Pakistan showed rightward-upward coherence in 2015 and 2020. Iran exhibited a leftward-upward relationship in 2018–2020 and 2023–2024, suggesting a delayed but inverse response to volatility.

These findings highlight the varied exchange rate responses to global market uncertainty among D-8 economies. Wavelet coherence analysis indicates that D-8 countries have differing levels of sensitivity to global risk sentiment, as reflected by the VIX. Nations with more open economies (e.g., Türkiye, Malaysia) exhibit stronger and more immediate correlations with the VIX, while more regulated economies (e.g., Iran) demonstrate weaker coherence. The findings emphasise the influence of external risk perception on exchange rate dynamics within these economies. Fig. 4 illustrates the results of wavelet coherence for the exchange rate and oil price.

In 2017, Türkiye exhibited a rightward-downward pattern, indicating synchronisation with a lag. Meanwhile, Indonesia and Malaysia displayed medium-term leftward patterns during 2014–2015, signifying an inverse correlation. Additionally, Malaysia showed a leftward-upward trend, further reinforcing this relationship. Egypt had a leftward pattern in 2015 but shifted to a rightward relationship from 2021 to 2023, reflecting changing dynamics over time. Bangladesh exhibited a leftward pattern in 2020 and 2023, while Nigeria showed leftward-downward coherence in 2016–2018 but a rightward pattern in 2022. Pakistan's medium-term relationship was leftward from 2015 to 2018 but shifted to rightward in 2020. Iran displayed a leftward-upward-down pattern only in 2012, with no consistent correlation over time. These findings highlight the varied exchange rate responses to oil price fluctuations across D-8 economies. Fig. 5 illustrates the results of wavelet coherence for bond yield and stock exchange.

The wavelet coherence analysis results indicate significant time-frequency relationships between bond yields and stock exchanges across D-8 countries. Bond yields and equity markets in Türkiye displayed a predominantly leftward and left-downward coherence between 2014 and 2022, suggesting an inverse or lagged relationship. Indonesia exhibited consistent leftward patterns in both the medium and short terms from 2014 to 2025, indicating a negative correlation. Malaysia showed medium-term leftward and leftward-upward coherence from 2019 to 2022, implying a changing phase relationship. Egypt had a leftward-down pattern in 2015 but transitioned to a leftward-up medium-term trend from 2016 to 2021, reflecting varying market dynamics. Bangladesh demonstrated medium-term leftward-up coherence in 2015 and 2021 but a rightward-down pattern in 2018–2019, illustrating alternating correlation phases. Nigeria exhibited a medium-term leftward-up trend from 2016 to 2020 but a leftward-downward pattern in 2021. Meanwhile, Pakistan recorded a medium-term rightward-upward trend from 2017 to 2019, indicating a positive correlation during this period.

These findings underscore the varied interactions between bond yields and the stock market across D-8 economies, shaped by domestic monetary conditions and global financial trends. Fig. 6 illustrates the results of wavelet coherence for bond yields and the VIX.

In Türkiye, bond yields moved in sync with market volatility in the medium term, demonstrating a rightward pattern in 2017 and 2019. Indonesia exhibited medium-term rightward-upward coherence in 2011 and 2014–2015, indicating a strong positive correlation. Malaysia and Egypt displayed similar rightward-upward medium-term trends in 2015, with Egypt also showcasing this pattern in 2019. Bangladesh showed a long-term rightward-downward trend between 2019 and 2021, suggesting an inverse or lagged response. Nigeria exhibited a long-term leftward-downward trend in 2016–2017, followed by a medium-term

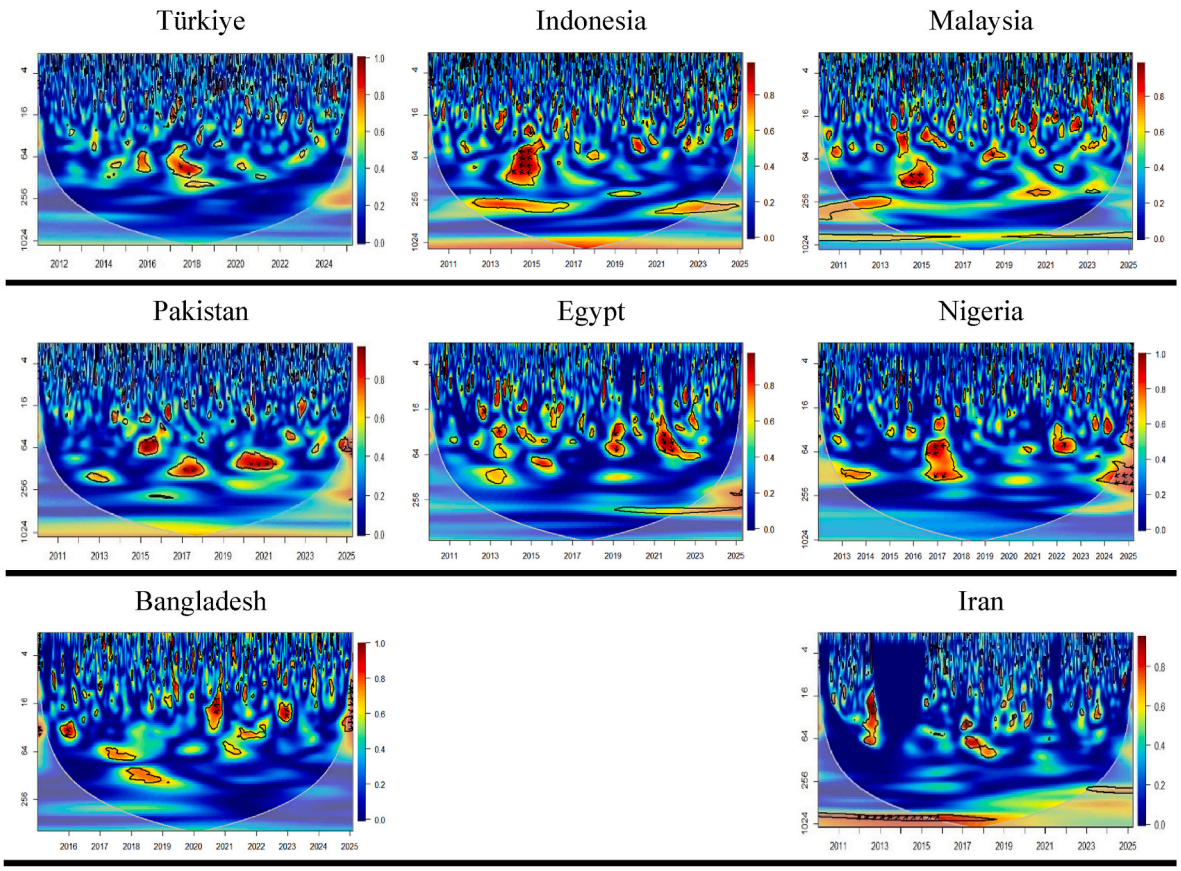


**Fig. 4.** The results of wavelet coherence for exchange rate and oil price.

rightward-upward pattern in 2017. Pakistan displayed a medium-term rightward and rightward-downward pattern between 2015 and 2018, reflecting mixed dynamics.

These findings highlight the varying responses of bond yields to market volatility across D-8 economies, influenced by local financial conditions and global uncertainty. Fig. 7 illustrates the results of wavelet coherence between bond yields and oil prices.

The wavelet coherence analysis of bond yields and oil prices among D-8 countries reveals distinct yet interconnected patterns. Bond yields in Türkiye exhibited a long-term rightward downward correlation from 2013 to 2016, followed by a medium-term leftward downward shift in 2017. Indonesia showed a medium-term leftward-downward relationship in 2014 but transitioned to a rightward-upward pattern in 2022. Malaysia displayed a long-term rightward-upward trend between 2015 and 2020, with a medium-term leftward-downward shift in 2020. Egypt demonstrated a medium-term rightward-downward correlation in 2018, followed by a leftward pattern from 2019 to 2021. Bangladesh primarily exhibited a medium-term leftward-downward trend from 2017 to 2019, while Nigeria showed a similar pattern during 2021–2022. Pakistan exhibited a long-term rightward-upward relationship from 2015 to 2020, which persisted in the medium term.

These findings underscore the differing levels of bond yield sensitivity to oil price fluctuations among D-8 economies, influenced by structural economic factors and external market conditions. Fig. 8 illustrates the results of wavelet coherence for the stock exchange and oil price.

The wavelet coherence analysis of stock exchanges and oil prices in D-8 countries reveals dynamic relationships that evolve over time and across frequency domains. In Türkiye, stock prices and oil prices exhibited a medium-term rightward correlation in 2014, indicating synchronisation. Indonesia displayed a medium-term rightward pattern in 2014 and a long-term rightward trend from 2016 to 2019, suggesting a sustained positive relationship. Malaysia experienced a medium-term rightward correlation between 2013 and 2016, with intermittent short-term synchronisation after 2016. Egypt showed a medium-term rightward-downward relationship in 2014–2015 and again in 2019, reflecting a mixed response to oil price fluctuations. Bangladesh demonstrated a long-term rightward-downward trend from 2019 to 2021, indicating a delayed negative impact. Nigeria exhibited a medium-term rightward correlation in 2016 and 2020–2022, suggesting periods of alignment. Pakistan showed a medium-term rightward-downward trend from 2017 to 2019, indicating phase shifts over time.

These findings underscore the diverse interactions between stock markets and oil prices across D-8 economies, shaped by structural dependencies and external market conditions. Collectively, these patterns indicate that while stock exchanges in D-8 countries were historically influenced by oil prices, recent years show growing complexity, with some markets exhibiting delayed or even inverse reactions to oil price changes. Fig. 9 illustrates the results of wavelet coherence for stock exchange and VIX.

Financial markets are highly susceptible to global uncertainty, and volatility indices such as the VIX serve as a crucial gauge of investor sentiment. The results indicate periods of strong coherence across various time scales, signifying that the stock markets of these economies exhibit significant synchronisation with global risk sentiment. Notably, Türkiye demonstrates medium-term leftward coherence in 2014–2016 and 2019, suggesting that market participants reacted to volatility with delayed adjustments. Similarly, Indonesia exhibits a strong medium-term leftward pattern in 2014 and 2019, while Malaysia shows persistent yet intermittent medium-term leftward coherence throughout the 2010–2025 period. Egypt's stock market follows a similar trend, particularly in 2013, 2015, and 2020. Bangladesh displays long-term leftward coherence between 2018 and 2022, implying that volatility spillovers have influenced its market over an extended duration.

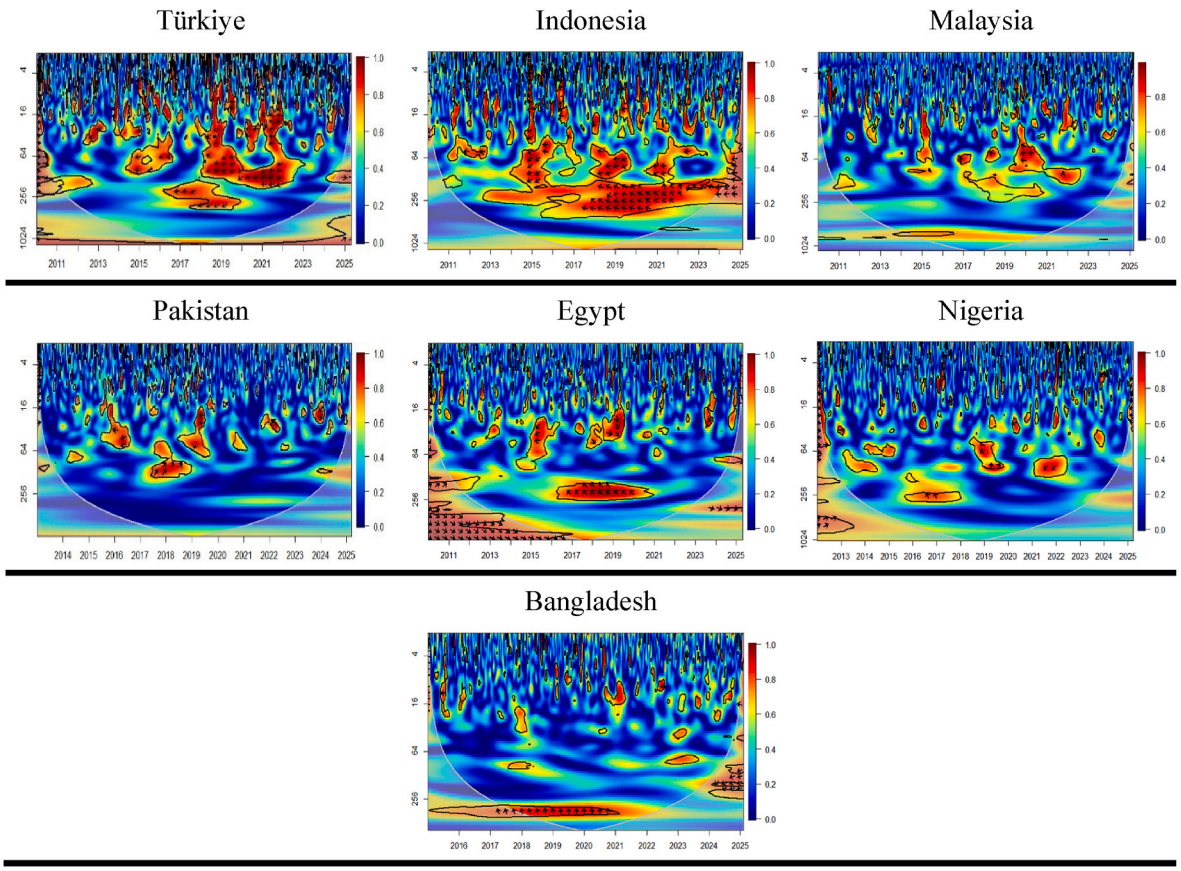


**Fig. 5.** The results of wavelet coherence for bond yield and stock exchange.

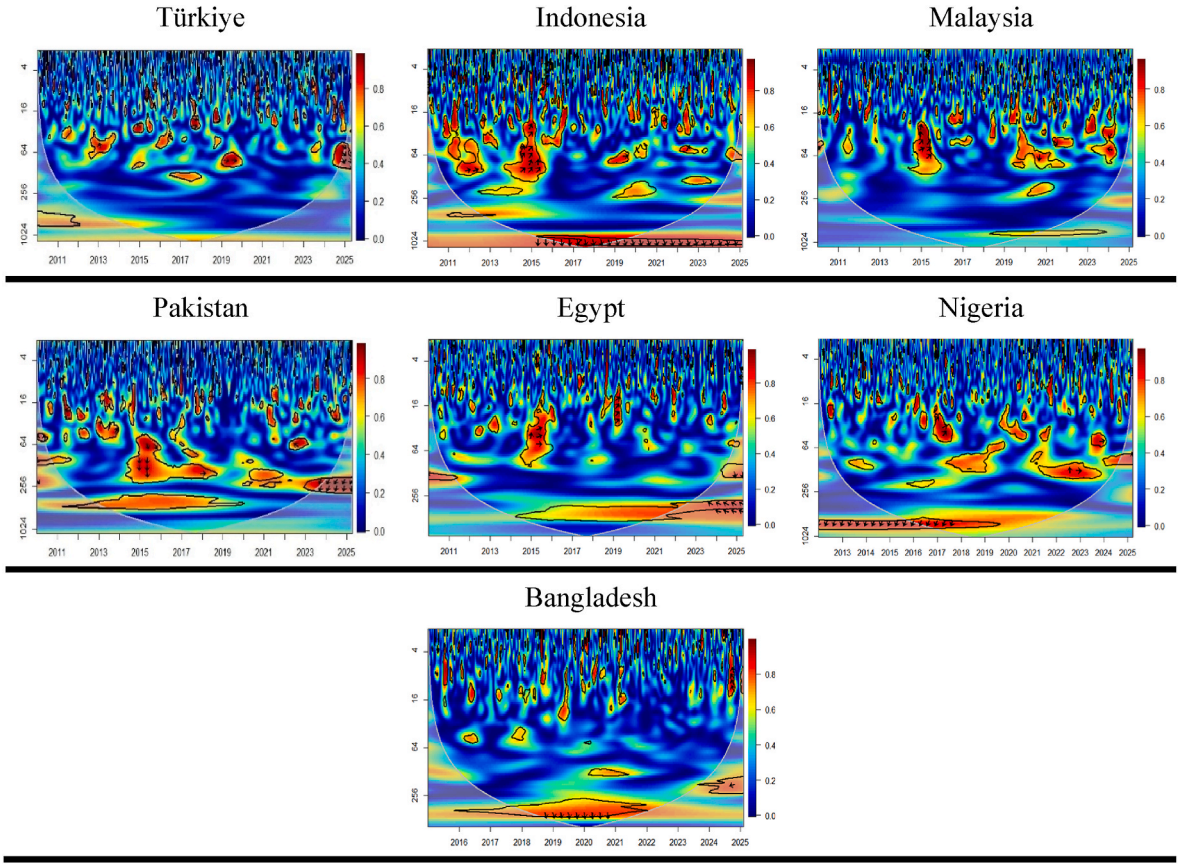


**Fig. 6.** The results of wavelet coherence for bond yield and VIX

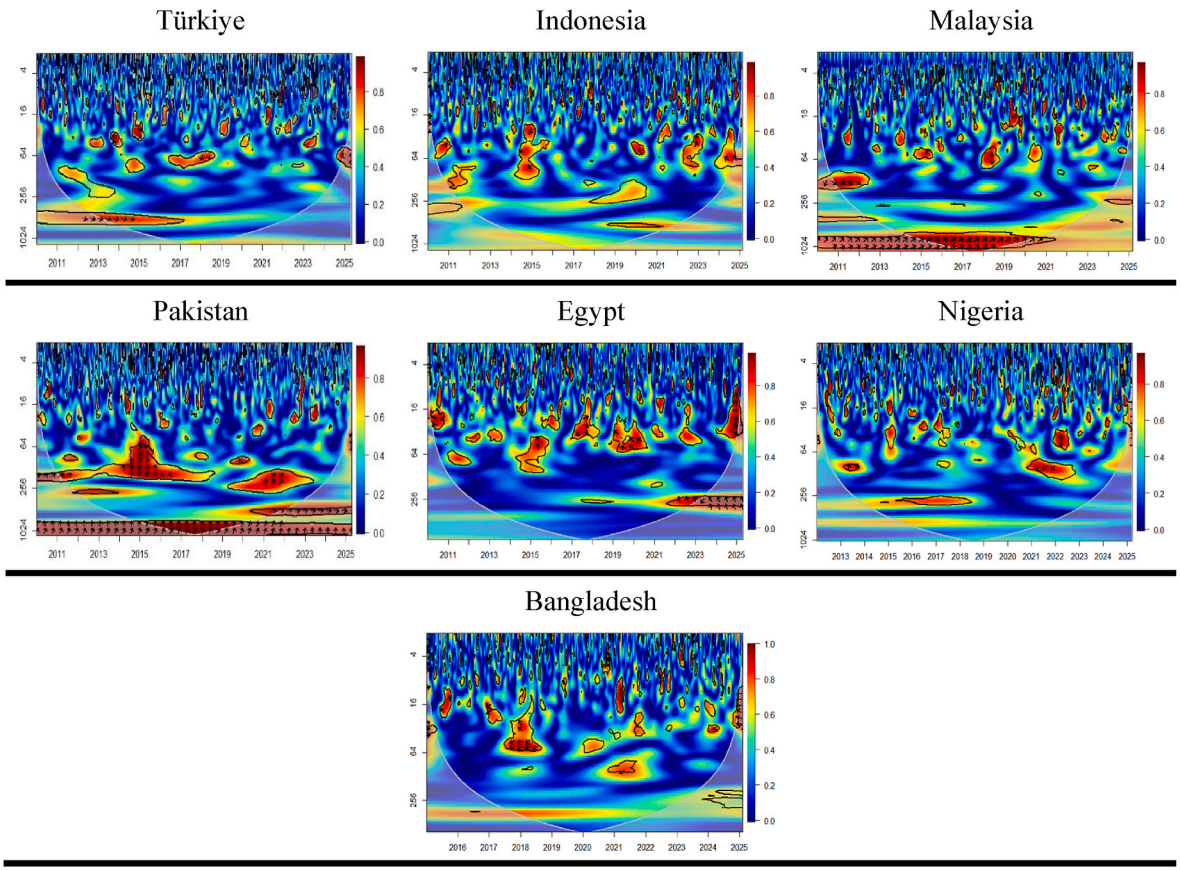


**Fig. 7.** The results of wavelet coherence for bond yield and oil.

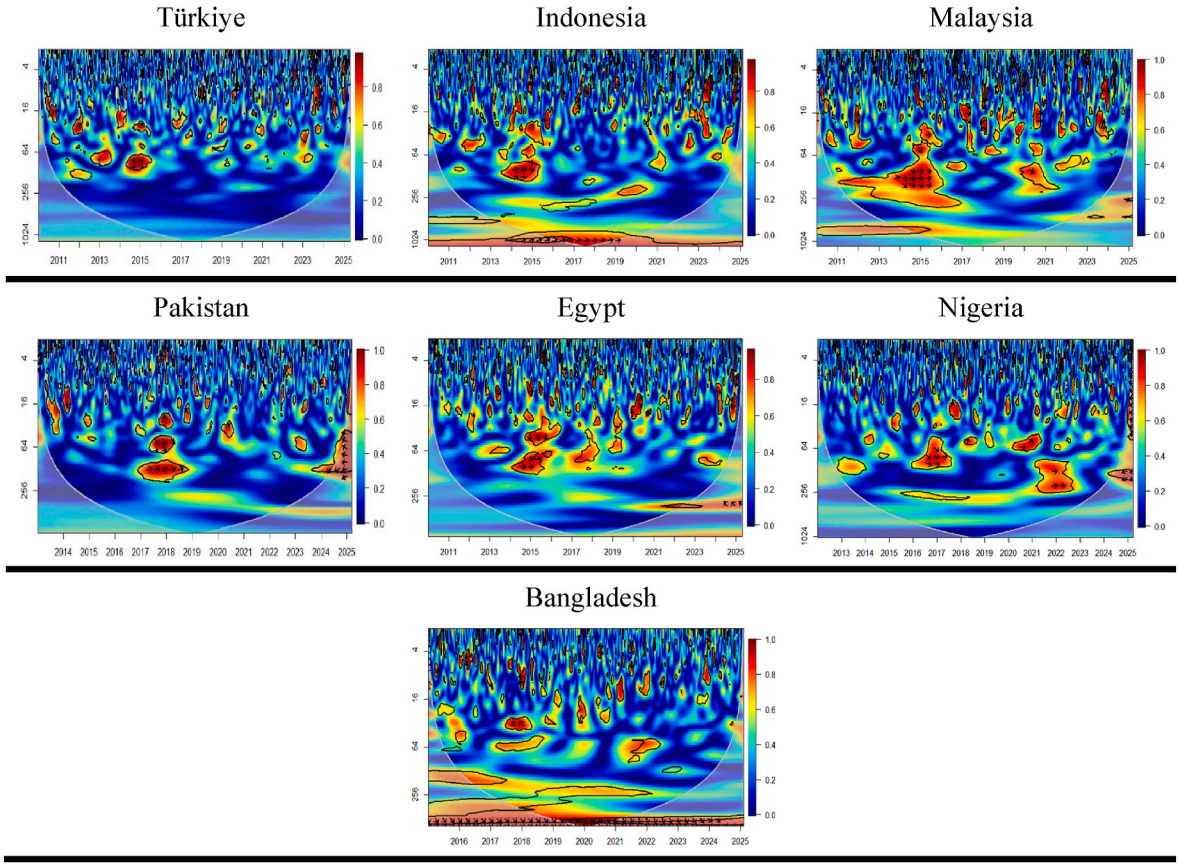


**Fig. 8.** The results of wavelet coherence for stock exchange and oil price.

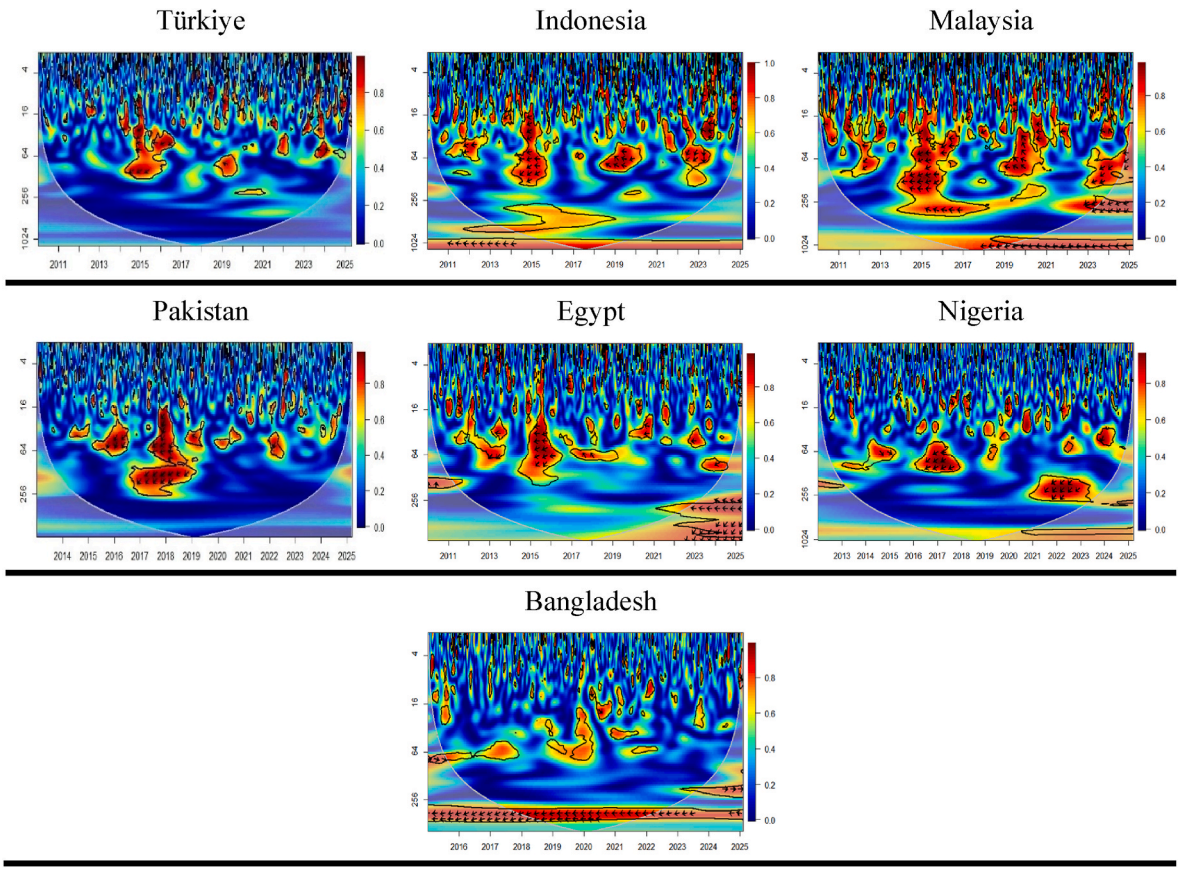


**Fig. 9.** The results of wavelet coherence for stock exchange and VIX

Nigeria's stock market reflects medium-term leftward coherence in 2016–2018 and 2021–2023, indicating susceptibility to external shocks during these periods. Lastly, Pakistan's market exhibits significant medium-term coherence between 2015 and 2020.

These findings indicate that the stock markets of D-8 countries are affected by global risk sentiment, although the degrees of responsiveness vary across different time horizons. The results offer critical insights for policymakers, investors, and financial regulators by illuminating the extent to which global risk perception impacts emerging market economies. Grasping these interlinkages is vital for devising risk mitigation strategies, enhancing market resilience, and promoting financial stability in these economies.

## 5. Conclusions

This study employs wavelet coherence analysis to investigate the time-frequency relationships among exchange rates, bond yields, stock markets, volatility (VIX), and oil prices in D-8 economies. The findings reveal significant yet heterogeneous interactions, with notable variations in lead-lag dynamics and correlation structures across different time horizons.

Exchange rate movements significantly influence bond yields, stock markets, and market volatility across the D-8 countries, although there are country-specific variations. Türkiye, Indonesia, and Malaysia show strong medium-term synchronisation between exchange rates and bond yields, while Bangladesh and Nigeria display inverse relationships in recent years. These findings indicate that currency fluctuations play a crucial role in shaping bond market behaviours, emphasising the necessity for robust exchange rate management policies. Likewise, the interactions between exchange rates and stock markets reveal diverse patterns, with some countries exhibiting prolonged negative correlations (e.g., Indonesia, Malaysia) and others transitioning from synchronisation to inverse relationships over time (e.g., Türkiye). These mixed dynamics suggest that external economic shocks and monetary policies are critical in influencing currency-stock market relationships.

The wavelet coherence analysis further highlights the differing sensitivity of exchange rates and bond yields to global volatility and fluctuations in oil prices. Countries with more open economies (e.g., Türkiye, Malaysia) demonstrate stronger and more immediate relationships with the VIX, while more controlled economies (e.g., Iran) display weaker coherence, suggesting variations in market integration and restrictions on capital flow. Furthermore, bond yield responses to oil price fluctuations vary significantly, with some countries (e.g., Türkiye, Malaysia) showing strong synchronisation, while others (e.g., Egypt, Nigeria) exhibit shifting dynamics over time. These results emphasise the structural economic differences within the D-8 group, where global risk sentiment and commodity price volatility affect financial markets in diverse ways.

Stock markets in the D-8 economies also display diverse relationships with volatility and oil prices, showing evidence of both immediate and lagged responses. While some markets (e.g., Indonesia, Nigeria) show long-term positive correlations with oil prices, others (e.g., Pakistan, Bangladesh) display delayed or inverse reactions. Furthermore, financial markets across the D-8 are highly sensitive to global uncertainty, as indicated by their medium-to-long-term coherence with the VIX. These findings underscore the significance of investor sentiment and global financial conditions in shaping market behaviour in emerging economies.

The results also provide insights into the extent of financial convergence among D-8 economies. While some countries demonstrate strong synchronisation in financial variables—such as exchange rates, bond yields, and stock markets—others remain more insulated from global market dynamics. The presence of mid-to-long-term coherence in financial indicators, particularly between exchange rates and stock/

bond markets, suggests a degree of financial integration within certain D-8 economies, notably Türkiye, Indonesia, and Malaysia. However, the variability in lead-lag relationships across different financial variables indicates that complete financial convergence within the D-8 group has yet to be realised.

To promote greater financial convergence, D-8 countries should enhance policy coordination, particularly in managing exchange rate risks, improving financial market transparency, and harmonising regulatory frameworks. Strengthening financial linkages through better cross-border investments, regional financial agreements, and coordinated economic policies could reduce financial vulnerabilities and bolster market resilience.

While evidence of mid-to-long-term coherence in financial variables suggests progress towards regional financial convergence, variations in market openness, monetary policies, and external dependencies indicate that complete financial integration within the D-8 remains unfinished. Enhancing policy coordination, strengthening exchange rate management, and harmonising regulatory frameworks could aid in accelerating financial convergence. Future research should investigate policy interventions that promote financial stability and integration within the D-8 region.

Future research might further examine the role of specific policy interventions and macroeconomic factors in shaping these financial linkages, thereby offering deeper insights into effective risk management strategies for emerging economies. Furthermore, exploring the potential for increased financial convergence through policy harmonisation and regional financial integration could provide valuable guidance for economic cooperation within the D-8 framework.

## Author contribution statements

Mehmet Asutay and Mervan Selcuk conceived of the presented idea.
Mehmet Asutay and Mervan Selcuk developed the theory.
Mervan Selcuk performed the computations.
Mehmet Asutay and Mervan Selcuk verified the analytical methods.
Mehmet Asutay supervised the findings.
Mervan Selcuk wrote the initial draft.
Mehmet Asutay finalised the writing.
Mehmet Asutay and Mervan Selcuk discussed the results and contributed to the final manuscript.

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