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Re-Investigating the UIP Hypothesis: Recent Evidence From BRICS Economies

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ABSTRACT

The study re-investigates the existence of the Uncovered interest parity (UIP) hypothesis and substantially adds to the literature by offering the most recent evidence during the period from 2000 to 2022 from developing and emerging economies. The study further augments the literature by extending the standard UIP hypothesis to account for the monetary policy stance and risk premium. The estimates of nonlinear autoregressive distributed lag (NARDL) and component generalised autoregressive conditional heteroscedasticity (C-GARCH) show that the UIP hypothesis does not exist in any of the BRICS economies. Nevertheless, after accounting for the risk premium and monetary policy stance using inflation levels, the interest rate differential significantly and positively influences the expected changes in the spot exchange rates. This indicates three important aspects: first, the necessity of risk premium to make up for the higher risk that comes with holding the foreign bond for the benefit of domestic investors. Second that the UIP puzzle does not hold, such that higher interest differential depreciates the domestic currency. Third, the analysis underscores the substantial and direct impact of US inflation level, particularly for Brazil, Russia and India, in determining the changes in the spot exchange rate. These insights hold crucial implications for policymakers and regulators.

JEL Classification: C22, E43, F31, F41

1 | Introduction

Uncovered interest parity (UIP) is one of the widely researched issues in the literature of international finance. Indeed, UIP has been widely used phenomenon in the theoretical framework and model construction of various International finance and open-economy macroeconomic models (see, for instance, Mundell Fleming model, and Dornbusch Overshooting Model, among others). The theory of UIP, initially proposed by Fisher (1930), suggests that interest rate differential should be equal to the differences in the expected spot exchange rates between the two countries. It implies that lower-yielding currency should appreciate against the higher-yielding currency to cancel out the losses from the interest rate differential and eradicating all prospects of profitability of uncovered interest arbitrage, which is also known as *carry trade speculations* (Moosa and Halteh 2012; La Marca 2007). In other words, in a perfectly competitive world, the existence of the UIP hypothesis implies that there exists no possibility of arbitrage condition between investing in domestic and foreign currency-denominated assets, driving the alignment of country-specific interest rates over the long term. It also suggests that the integration of domestic and foreign interest rates will result in the domestic country relinquishing control over its monetary policy. Therefore, the prevalence of UIP indicates an efficient capital market as the interest rate differentials lead to capital flows and, therefore, impact the exchange rate, which lowers the arbitrage possibility (Obstfeld and Rogoff 1995). While the failure of UIP indicates an inefficient capital market, and encourage currency managers to engage in carry trade speculations (Cook 2009). Thus, monetary authorities of each country will hold the ability to control their short-term interest rates (Lavoie 2000).

The empirical literature provides ample studies exploring the role of UIP in the context of both developed and developing economies. A few studies provided evidence in favour of UIP (see, for instance, Bhatti 2014; Coleman 2012; Lothian and Wu 2011; Mehl and Cappiello 2009; among others), while there are others that reflect the rejection of the UIP hypothesis (see, for instance, Živkov et al. 2016; Chu 2015; Jiang et al. 2013; Li, Ghoshray, and Morley 2012; Mehl and Cappiello 2009; Tai 2001). Indeed, numerous studies have provided evidence for the tendency of currencies in high-interest countries to appreciate rather than to depreciate as suggested by UIP hypothesis (see, for instance, Burnside et al. 2007; Chinn and Meredith 2004; Gyntelberg and Remolona 2007). This UIP puzzle is commonly known as *forward premium puzzle*. Thus, there is no consensus over the existence of UIP hypothesis.

According to the neo-classical framework, the time-varying foreign exchange risk premium is a significant explanation for UIP's failure that is also frequently mentioned in the literature (Lewis 1995; MacDonald 2000). This is due to the fact that every country's currency carries a risk premium. As a result, even in equilibrium, investments in riskier countries should be anticipated to yield higher rates of return than those in less risky countries. But risk premia are unobserved and this has led to a great deal of research on how to model these currency risk premia (Graham and Harvey 2010). Another important factor that explains the deviation from UIP hypothesis often correlates with changes in interest rates or monetary policy stance. For instance, when US interest rates increase relative to those of India, the uncovered interest rate deviation tilts in favour of US interest-bearing assets, leading to a higher expected rate of return on these assets. Conversely, when US interest rates decrease in relation to India, the opposite effect is observed. It is intriguing to note that it is not uncommon for higher interest rates in one country to be linked to the anticipation of that country's currency appreciating relative to another country's currency, contradicting the prediction of uncovered interest rate parity (McCallum 1994).

In this context, the empirical literature has attempted to empirically examine the failure of the UIP hypothesis, which includes nonlinearities (Cho 2018; Jiang et al. 2013; Li, Ghoshray, and Morley 2013; Samimi et al. 2009; Mark and Moh 2007; Cavoli and Rajan 2006), failure of rational expectations and monetary policy regime (Engel et al. 2019; Park and Park 2017; Linnemann and Schabert 2015; Moore and Roche 2012), risk premium (Adewuyi and Ogebe 2019; Živkov et al. 2016; Chu 2015; Jiang et al. 2013; Li, Ghoshray, and Morley 2012; Mehl and Cappiello 2009; Tai 2001), and currency bias (Lee 2013). However, most of these studies are focused on developed economies (Engel 2016; Fukuda and Tanaka 2017; Park and Park 2017; Lothian and Wu 2011; Tai 2001), with very few focusing on emerging economies, especially from Asia region (Moore and Roche 2012; Mehl and Cappiello 2009). Nevertheless, we do not find any study specifically focussing on BRICS economies and examining their interest parity against US dollar (USD). Moreover, the recent dynamic scenario of the pandemic and developing geopolitical tensions worldwide have not been covered so far in the extant literature, as most of the existing studies cover the study period till 2016 (cf. Table 1 for more details). Additionally, there is lack of comprehensive analysis of UIP hypothesis that accounts for the two factors: risk premium and monetary policy, along with the statistical properties like nonlinearity and asymmetry that may explain the failure of UIP hypothesis.

In light of this brief background, the purpose of this research is to update the analysis by comprehensively examining the existence of UIP in the context of the BRICS economies across a longer time series spanning 2000 M01 to 2022 M12. Our study produces various novel findings and thus makes noteworthy contributions to the UIP literature. First, this study substantially adds to this field of research by examining the existence of UIP hypothesis in the context of BRICS economies. The BRICS nations hold a noteworthy position in the world economy because of their considerable share in world growth, investment, and capital mobility (Mensi et al. 2014; Jiang, Fu, and Ruan 2019). However, the financial and nonfinancial turbulences, such as the pandemic and geopolitical tensions, highlight the possible crisis contagion that weighs severely on the growth outlook of the BRCIS economies.

Second, the research on UIP has yielded conflicting and equivocal results. This is because many UIP-related concerns have been addressed using wide methodological approaches (cf. Table 1). Consequently, further investigation is needed that provides a comprehensive and robust analysis of the issues in interest parity research. Thereby, we utilise a variety of advanced econometric techniques to thoroughly investigate the UIP hypothesis while accounting for nonlinear time varying risk premium and monetary policy regime. We first employ a Linear Auto Regressive Distributed Lag (ARDL) regression model to establish a direct relationship between expected exchange rates and interest rate differentials. Next, a nonlinear ARDL regression model was applied to account for nonlinearities and asymmetries explicitly in the relationship. The role of time-varying risk premium in the UIP hypothesis is assessed using the component generalised autoregressive conditional heteroscedasticity (C-GARCH) model, which helps control heteroscedasticity and distinguishes between long-run volatility trends and short-run deviations. Finally, the study performs the analysis using the extended UIP hypothesis by controlling for the monetary policy stance in both domestic and foreign economies. Therefore, by conducting a comprehensive analysis that accounts for factors such as structural breaks, asymmetries, nonlinearities, risk-premium, and monetary policy stance, this study significantly enriches the existing literature. The significance of selecting the appropriate method, and accounting for the risk premium, and domestic and foreign inflation levels is thus highlighted by these findings. Additionally, the recent dynamic scenario of the pandemic and developing geopolitical tensions worldwide have not been covered so far in the extant literature, as most of the existing studies cover the study period till 2016 (cf. Table 1 for more details).

Third, the study substantially adds to the existing literature by unveiling the important results, for which there was no consensus in the literature. Our estimates show that after controlling for the risk premium and domestic and foreign monetary policy

TABLE 1 | Details on the extant literature on the applicability of UIP hypothesis.

Study (Year)	Sample nations	Sample years	Methodology	Conclusion
Studies producing evidence in favour of UIP				
Lee (2013)	36 countries	1999–2004	Ordinary least squares	Short-term UIP holds well, and UIP puzzle holds due to the key currency bias.
Jiang et al. (2013)	Ten Central and Eastern European	1997–2011	Smooth transition regression and Exponential smooth transition regression	UIP holds for seven economies.
Linnemann and Schabert (2015)	The United States, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Portugal, Spain, the United Kingdom and Euro	1975–2013	Panel-vector autoregressive model	Changes in the interest rate of a small open economy led to exchange rate responses that are consistent with UIP predictions
Lothian (2016)	17 countries	217 years	Regression analysis	UIP holds in the long run
Lothian and Wu (2011)	France, the United Kingdom and the United States	1791–1999	Regression analysis	UIP holds true over the long period, and large interest-rate differentials have significantly stronger forecasting powers for currency movements than small interest-rate differentials.
Mehl and Cappiello (2009)	18 mature and emerging economies	1980–2006	Regression analysis	UIP holds for mature economies but not for emerging economies
Bhatti (2014)	Commonwealth of independent states (CIS)	1995–2010	Engle and Granger (1987) and Phillips and Ouliaris (1990) cointegration tests	UIP holds in the long run for Azerbaijan, Kazakhstan and Kyrgyzstan
Moore and Roche (2012)	42 countries	1983–2010	Simulation exercise	The degree of monetary volatility explains whether uncovered interest parity holds. The high monetary volatility is associated with UIP.
Studies producing evidence against UIP				
Adewuyi and Ogebe (2019)	Algeria, Nigeria, Angola and South Africa	1990-2017	ARDL, NARDL and C-GARCH	UIP fails to hold in African nations, which is attributable to capital mobility restrictions and currency risk
Baharumshah, Haw and Fountas (2005)	10 Asian economies	1977–2001	Panel unit root tests	Real interest parity is not supported, and interest rate differentials exhibit mean reverting behaviour

(Continues)

TABLE 1 | (Continued)

Study (Year)	Sample nations	Sample years	Methodology	Conclusion
Fukuda and Tanaka (2017)	Australian Dollar and NZ Dollar	2009–2016	GARCH	Monetary policy plays a significant role in explaining the deviations from covered interest parity on the forward contract
Engel et al. (2019)	Euro and Non-Euro Zone	1973–2016	Regression analysis	UIP does not hold, and inflation significantly leads to dollar appreciation
Park and Park (2017)	12 developed economies	2000-2016	Structural break tests	The UIP puzzle becomes more pronounced when the monetary policy rule is stricter against inflation
Chu (2015)	Home and foreign countries	2008–2009	DSGE	The policy shocks widen the uncovered interest parity deviations, and UIP does not hold true during the global financial crisis.
Li, Ghoshray, and Morley (2012)	10 developed and emerging economies	1986–2008	CGARCH-M	The study finds that risk is an important part of modelling exchange rates and needs to be considered in both empirical and theoretical models.
Tai (2001)	Japan, Hong Kong, Singapore, Malaysian and United States	1988–1988	GARCH-M	Deviations from UIP are due to a risk premium and not to irrationality among market participants
Živkov et al. (2016)	Seven East European transition countries	2003–2013	C-GARCH	UIP principle does not hold in any country and exchange rate volatility is driven by economic fluctuations.
Cuestas, Filipozzi, and Staehr (2015)	Czech Republic, Croatia, Hungary, Poland and Romania	2007–2014	Bai and Perron (1998) break approach	Exchange rate forecasts deviated from UIP during the crisis period of 2008–2009

Abbreviations: ARDL, autoregressive distributed lag; C-GARCH, component GARCH; GARCH, generalised autoregressive conditional heteroskedasticity; GARCH-M, GARCH in-mean; NARDL, nonlinear ARDL.
Source: Author compilation.

stance, the interest rate differential significantly and positively influences the expected changes in the spot exchange rates of all the BRICS economies. Though the relation between exchange rate and interest rate differential is not one-to-one, yet our estimates clearly show the rejection of UIP puzzle and provide evidence that higher yielding currencies tend to depreciate in comparison to lower yielding currency. Furthermore, it is observed that the inflation level plays a significant role in determining the changes in the exchange rate. Thus, our study highlights the need for incorporating time-varying risk-premium and monetary policy stance in both theoretical and empirical UIP models. Additional findings illustrate that the domestic and foreign currencies are not close substitutes of each other such that monetary integration between the two nations has not been achieved. Thus, our findings depict that previous studies showing the negative impact of interest rate differential might be due to econometric misspecification and inappropriate econometric method of analysis. This way, our study also contributes to the empirical literature examining the determinants of exchange rate (Pershin, Molero, and de Gracia 2016; Chowdhury 2012; Basher, Haug, and Sadorsky 2012; Yuan 2011).

The structure of the study is discussed as follows. Section 2 presents the trend analysis of exchange rate and interest rate in BRICS economies. Section 3 describes the literature review on the exploration of the UIP hypothesis. Section 4 provides the details on the database and econometric specification of the models. Section 5 produces the preliminary analysis that includes unit root and cointegration analysis. Section 6 presents the regression methods and their respective estimates. And the final section is concluding in nature.

2 | Trend Analysis of Exchange Rate and Interest Rate

The trend analysis of the spot exchange rate and domestic and foreign interest rates of BRICS nations for the period from January 2000 to December 2022 is provided in Figure 1. It is noted that for Brazil, the exchange rate with the United States has almost remained stable during the study period, with a considerable appreciation of the currency during the 2020–2021 period. This might owe to Brazil's central bank's action of increasing the foreign exchange liquidity by introducing global dollar-denominated bond repo agreements, in which only foreign exchange dealers could participate (IMF 2021). This has also resulted in a decline in Brazil's rate of interest, thereby reducing the interest differential with the United States.

For Russia, it is noted that Rubel depreciated slowly during the period from 2000 to 2013, but in early 2014, it considerably depreciated against USD owing to the confidence shock experienced at the end of 2014. Additionally, the world oil market shock and the expectation of a rise in the US interest rate led to the depreciation pressure on the Russian currency. While it again slowly depreciated during the post-2015 period, except for a significant spike in the initial months of 2022, which can be explained by the alarming geopolitical tensions between Ukraine and Russia. The rate of interest has also shown a likewise trend, with a decline during the initial years while a spike in 2015, then remained stable before rising again in 2022. Russia adopted a tight monetary policy in 2015 that led to a higher rate of interest to stabilise the domestic foreign exchange market (IMF 2016). Likewise, the world outlook and the Fed's expectations of increasing interest rate led the Russian central bank to increase the interest rate for stabilisation purposes. For India, the trend shows a constant depreciation of the Indian Rupees to the USD during the study period. A higher exchange rate between INR and USD in the initial years is explained by the Asian economic crisis that led to ~50% fall in the domestic currencies of Asia against the dollar. There have been moderate fluctuations till 2007, followed by sharp depreciation and substantial instability from 2008 to 2013. While the currency showed little appreciation during 2013–2017, followed by substantial depreciation in more recent years. India has been an inflation-targeting economy and has adopted a tight monetary policy to control the rising price level that led to comparatively higher interest rates, particularly during the 2011–2017 period. During the Covid period (2020–2021), there was a decline in the interest rate, followed by an extensive increase during the 2022 period. This might be explained by the ongoing geopolitical tensions around Ukraine and Russia, which hiked the oil and other commodity prices, thereby leading to world inflationary pressures. Finally, South African currency has slowly depreciated during the initial years of the study. While the controversial land reform in 2001 led to its currency's depreciation, which also led the interest rate to rise. The currency further depreciated owing to the widening current account deficit, high inflation, and subprime crisis. The situation has gotten worse in recent years, primarily in response to the pandemic and geopolitical tensions. A similar trend is also observed in the interest rates of South Africa. However, the interest rate differential has been narrowed down during 2022, which pertains to the high inflationary pressure and tight monetary policy being adopted by the Federal Reserve Bank. This gives us preliminary indication of a relationship between exchange rate and interest rates.

3 | Theoretical Framework and Relevant Literature Review

According to the UIP hypothesis, the expected changes in the exchange rate are fully adjusted in the interest rate differentials between the domestic and foreign economies, making the expected speculation profits to be zero. This hypothesis has implications for the investors, making them indifferent between domestic and foreign investments. Accordingly, the hypothesis can be represented as follows:

$$(1 + R) = \frac{\mathrm{SER}^e}{\mathrm{SER}}(1 + R^*), \tag{1}$$

where $R(R^*)$ is the domestic (foreign) rate of interest, and SER (SER^e) is the current (future) spot exchange rate between domestic and reference currency.

Equation (1) implies that the current and future spot exchange rate and the foreign interest rate determine the domestic interest rate. Thus, the appreciation (or depreciation) of the domestic currency should be in line with the

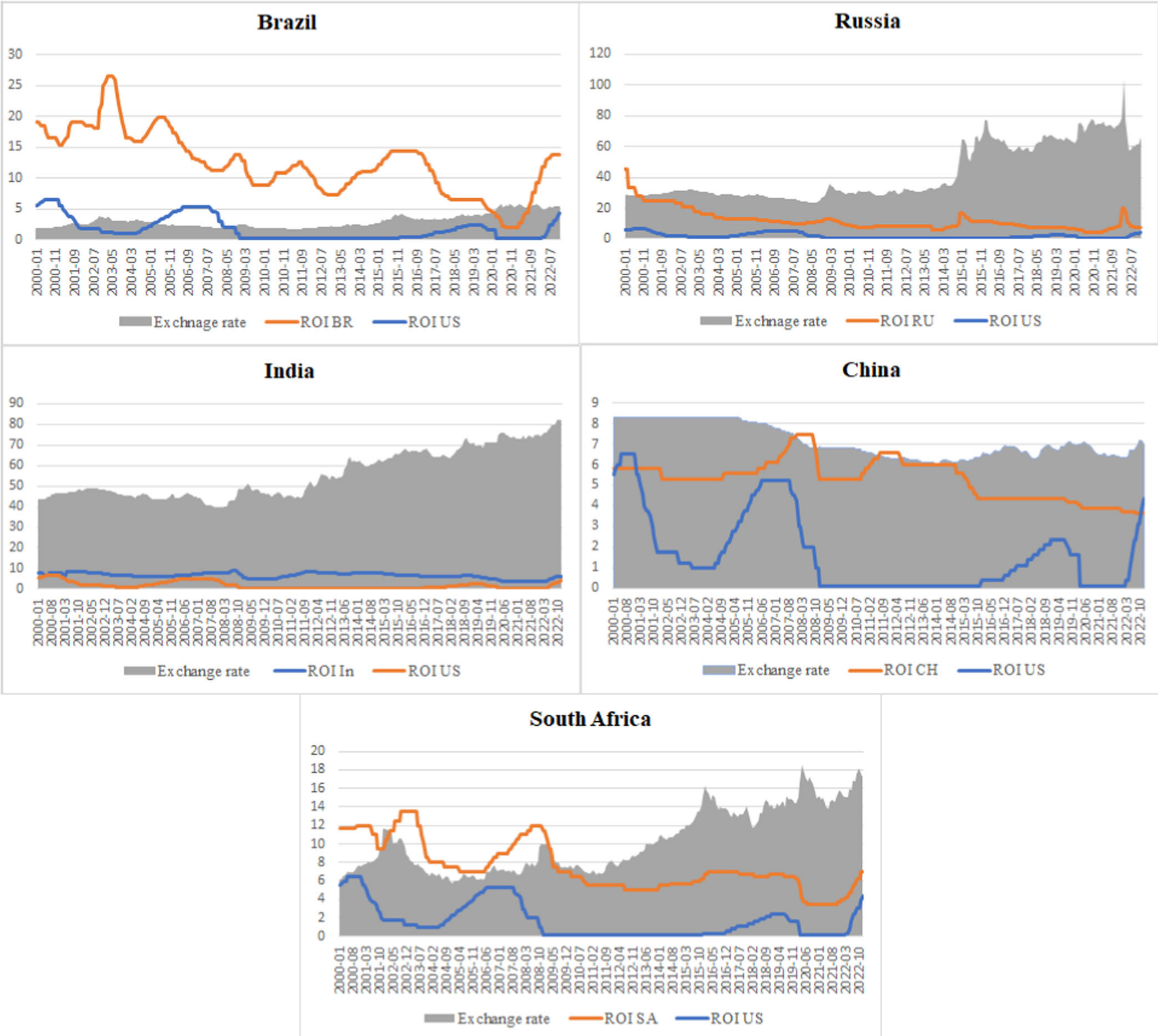

FIGURE 1 | Trends of the spot exchange rate, and domestic and foreign interest rates in the BRICS economies.

interest differential between the domestic and foreign currencies, which is the essence of the UIP hypothesis. It implies that foreign and domestic bonds are perfect substitutes, and capital is perfectly mobile. Accordingly, a higher domestic interest rate will cause the domestic currency to depreciate by the same amount, therefore eliminating the prospect of carry trade profit and vice versa. If the UIP does not hold, there would be room for the speculators (carry traders) to make profits by investing in high-interest currency and borrowing in low-interest currency. It is indeed argued that investors take a short position on low-interest currency while a long position on a high-interest currency (Moosa and Halteh 2012). Thereby, short-term capital moves from a low-interest country to a high-interest country, lowering the latter interest rate and increasing the former interest rates. This makes high-interest currency to depreciate and another one to appreciate, and the process continues until the UIP hypothesis is re-established.

A significant number of empirical studies have emerged in the literature analysing the issue of UIP in the context of different countries, time periods, and methods employed. However, there is no consensus over the validation or invalidation of the UIP condition. For instance, Bhatti (2014) provided evidence in favour of UIP for six countries of the Commonwealth of Independent States (CIS), such that CIS currencies depreciate following significant interest rate differentials. Likewise, Mehl and Cappiello (2009) demonstrated that UIP performs well in predicting exchange rate movements for mature economies but not for emerging economies. Using ultra-long time series on dollar-sterling and franc-sterling, Lothian and Wu (2011) also documented the existence of UIP conditions especially during ultra-long series data. Cuestas, Filipozzi, and Staehr (2015) provided evidence for UIP hypothesis. However, forecasts are rejected during the period of global financial crisis for five economies. Likewise, Chu (2015) demonstrated that policy shocks during the global financial crisis widen the UIP deviations. Indeed, some of the studies have provided evidence for forward premium puzzle, asserting that unlike the prediction of UIP hypothesis, countries with higher rate of interest witness a stronger currency (see, for instance, Cumby and Obstfeld 1982; Fama 1984; Gaab, Granziol, and Horner 1986; McCallum 1994; Baillie and Bollerslev 2000; Burnside et al. 2007; Chinn and Meredith 2004; Gyntelberg and Remolona 2007).

In the past decade, several studies have surfaced, yielding results that call into question the widespread examination on whether to outrightly accept or reject the UIP hypothesis. For instance, Adewuyi and Ogebe (2019) investigated the validity of UIP in the context of African countries and non-members of OPEC countries. However, the study showed that failure of UIP in African countries can be attributed to capital mobility restrictions and currency risk. Likewise, Fukuda and Tanaka (2017) analysed the relationship between monetary policy and covered interest parity from 2009 to 2016. The estimates from GARCH regression indicate the significant role of monetary policy in explaining the deviations from covered interest parity on the forward contract. Engel et al. (2019) revealed that the inflation rate largely impacts exchange rate changes for Euro and non-Euro regions that explain the failure of UIP hypothesis. Park and Park (2017) investigated the UIP puzzle while accounting for the monetary policy rules for the 12 advanced economies from 2000 to 2016. The study shows that for nations, which reduced the policy rates in response to the crisis, the UIP condition holds true after the global financial crisis. Moore and Roche (2012) examined the prevalence of UIP in the context of monetary volatility for 42 countries. The estimates of Fama regression suggest UIP holds true when monetary volatility is high, while in low monetary volatility, UIP does not hold true. Analysing the role of structural breaks, Živkov et al. (2016) showed that the UIP principle does not hold in any of the sample countries of the East European region, yet economic fluctuations significantly determine the variations in exchange rate. Lee (2013) estimates the slope parameters in the UIP regression model and shows that short-term UIP holds true, and UIP puzzle hold when key currency offers higher return on capital. Linnemann and Schabert (2015) demonstrate the validation of the UIP when foreign interest rates follow the US monetary policy rate. Jiang et al. (2013) provided evidence of nonlinear UIP for seven CEE nations. By employing a multivariate GARCH approach, Tai (2001) provides evidence for the deviations from UIP, which are explained by the risk premium for Asia Pacific foreign exchange markets.

To summarise, the following are the important research gaps in the literature on UIP. To our knowledge, no study examines and compares the existence of UIP in the context of the BRICS trade bloc. Though there are a few studies conducting the analysis for some of the BRICS nations, there is no consensus over the existence of UIP, given the varied issues and methodologies adopted in the extant studies. Additionally, there is no study that accounts for the recent time period encompassing pandemic and other structural and geo-political developments across the world. Though Neo-classical framework asserts the significant role of risk premium (Lewis 1995) and monetary policy (Taylor 1993) in explaining the failure of UIP hypothesis, there is lack of empirical studies accounting for both these factors along with statistical properties of nonlinearity and asymmetry simultaneously in the UIP hypothesis.

Thus, this paper intends to fill these gaps in the literature by investigating the applicability of UIP in the context of BRICS economies during 2000 to 2022 and using the appropriate methodologies that account for nonlinearity and asymmetry. Specifically, the study first employs Linear Auto Regressive Distributed Lag (ARDL) regression model to establish a direct relationship between expected exchange rates and interest rate differentials. Second, a nonlinear ARDL regression model was applied to account for non-linearities and asymmetries explicitly in the relationship. We set the following hypotheses:

H1: *UIP hypothesis holds true in BRICS nations.*

H1a: *UIP puzzle (forward premium puzzle) holds true in BRICS nations.*

Additionally, we are taking into account the monetary policy regime by including the inflation level in the UIP equation, as it is considered to be a good indicator of the monetary policy stance and provides information that may not be captured by interest rates alone (Engel et al. 2019). This is because tight monetary policy can help reduce inflation levels and strengthen a nation's currency. However, changes in interest rates also depend on the relative liquidity of short-term interest-bearing assets. The Taylor rule (1993) also specifies that interest rate changes are based on inflation and output gap. Thus, Taylor rule has been widely used in the literature to determine the changes in exchange rate (Molodtsova and Papell 2009; Engel et al. 2019). The study performs the analysis using the extended UIP hypothesis by controlling for the monetary policy stance in both domestic and foreign economies using C-GARCH model. As a result, we propose the following hypothesis:

H2: *Inflation level plays significant role in determining relation between exchange rate and interest rate differential.*

We expand this study to further investigate whether the relationship between exchange rate changes and interest rate differential is influenced by risk premium. It's important to consider the risk premium as each country's currency carries a different level of risk. Therefore, even in equilibrium, investments in riskier countries are expected to yield higher returns compared to less risky countries. The time-varying risk premium is one of the most frequently cited reasons leading to the failure of UIP (see Lewis 1995, MacDonald 2000; Flood and Marion 2000; McCallum 1994; Chinn and Meredith 2004; Tai 2001; Li, Ghoshray, and Morley 2012). Thus, if investors are risk-averse, forward rate will equal the expected spot exchange rate and risk premium, which compensates for the prospective risk associated with holding foreign assets (Chinn 2006). The role of time-varying risk premium in the UIP hypothesis is assessed using the component generalised autoregressive conditional heteroscedasticity (C-GARCH) model, which helps control heteroscedasticity and distinguishes between long-run volatility trends and short-run deviations. Based on this, we have the following hypothesis:

H3: *Risk premium plays significant role in determining relation between exchange rate and interest rate differential.*

4 | Database and Econometric Specification

4.1 | Database

The study investigates the validity of the UIP hypothesis in the context of BRICS economies. For this, the study employs monthly data on the spot foreign exchange rate of five BRICS economies, Brazil, Russia, India, China and South Africa, against the USD. The interest differential is computed as the difference between the domestic interest rate and the foreign interest rate. The domestic and foreign interest rates are measured by the money market interest rates. We further extend the analysis by incorporating the domestic and foreign inflation levels (measured by the percentage change of the Consumer Price Index over the corresponding period of the previous year) into the UIP hypothesis to account for the monetary policy stance. The data on all these variables have been taken from the International Financial Statistics (IFS) database of the International Monetary Fund (IMF). The sample period spans from January 2000 to December 2022. The sample period comprises various important events that happened across the world; thereby, it would allow us to account for the changing monetary policy stance by incorporating the inflation levels in the UIP hypothesis. In our sample, except China, all other BRICS economies are inflation-targeting nations (International Monetary Fund's Annual Report on Exchange Arrangements and Exchange Restrictions 2021).

The descriptive statistics of the variables are provided in Table 2. The table shows that the average log of spot foreign exchange rates for Brazil, Russia, India, China and South Africa are noted to be 0.996, 3.665, 3.99, 1.958 and 2.275. This depicts that Brazil has the strongest foreign exchange rate relative to the USD, while India has the weakest foreign exchange rate. The average rate of interest is noted to be 12.29%, 11.97%, 6.63%, 5.30% and 7.48%, for Brazil, Russia, India, China and South Africa, respectively. The log of interest rate differential is observed to be the highest for Brazil, followed by Russia, India, South Africa and China. While the average inflation level is noted to be highest in Russia and lowest in China during the sample period. The statistically significant statistic on the ARCH LM test in almost all the cases rejects the null hypothesis of no ARCH effects in the series, justifying the application of the C-GARCH method.

4.2 | Econometric Specification

The UIP hypothesis can be econometrically tested using the following model:

$$\mathrm{ser}_{t+1} - ser_t = \beta_0 + \beta_1 (r - r^*)_t + \varepsilon_{t+1}, \tag{2}$$

where, ser_{t+1} is the log of the spot exchange rate at time $t+1$; ser_t is the log of the spot exchange rate at time t; $(r - r^*)_t$ is the interest rate differential between the domestic economy and foreign economy at time t, and is computed as a natural log of $\frac{(1+R)}{(1+R^*)}$; and ε_{t+1} is the error term at time $t+1$. β_0 and β_1 are the parameters to be estimated, whereby β_0 denotes the constant risk premium and β_1 represents the slope coefficient on the interest rate differential.

Literature spells two main conditions for the UIP hypothesis to hold true (Jiang et al. 2013; Bhatti 2014): First, interest rate differential should be an unbiased and efficient predictor of future changes in the exchange rate, that is, the estimated value of β_0 should be 0, and that of β_1 should be close to 1. And second, the interest rate differential and the risk premium should be stationary, that is, their mean should revert towards the equilibrium situation. The risk premium (λ) is computed as follows:

$$\lambda_t = (r - r^*)_t - \frac{\mathrm{ser}_{t+1} - \mathrm{ser}_t}{\mathrm{ser}_t}. \tag{3}$$

5 | Preliminary Analysis

5.1 | Unit Root Tests

As noted in the econometric specification for the UIP hypothesis to hold, the interest rate differential should be an unbiased and efficient predictor, thereby, the interest rate differential and risk premium should be stationary. Therefore, the first step to test our econometric model is to check for the stationarity of the variables. For this, the study adopts both linear and nonlinear unit root tests. First, the linear tests (including ADF and PP) have been employed. However, these tests do not account for the possible structural breaks and nonlinearity (Hasanov and Telatar 2011). Thus, to account for structural breaks endogenously, we employ Perron (2006) unit root test that examines the stationarity while endogenously accounting for the structural breaks. And finally, to account for the nonlinearities, the study applies Kapetanios, Shin, and Snell (2003) (KSS) and Kruse (2011) unit root tests. These tests are shown to have relatively good power in the case of nonlinear series.

The estimates of all the unit root tests are provided in Table 3. It is observed that for the difference in current and future spot exchange rates, the conventional tests, structural break, and nonlinear unit root tests reject the null hypothesis of unit root at a 1% level of significance. Thus, the variable $(s_{t+1} - s_t)$ is noted to be integrated of order (0). For interest rate differential, most of the tests do not reject the null hypothesis of unit root, and thereby the series is not stationary at the level (except the KSS test for Brazil and Russia). Thus, the stationarity of the first difference of interest rate differential $(r - r^*)$ is found to be integrated of order (1). For inflation (ϕ), it is noted that for the US, all tests except the Perron test depict the stationarity at the level. Likewise, the inflation levels of Brazil, Russia and South Africa followed I(0) as per nonlinear tests, while according to other tests, they are noted to be I(1). While, Indian inflation is noted to be I(0) according to all other tests, except for the Perron test, and for China, PP and Perron test depict it to be I(0), while ADF, KSS and Kruse test reveal it to be I(1). And finally, risk premium for all nations are integrated of order (1). However, the non-stationarity of risk premium denotes that the mean of risk premium does not revert towards the UIP equilibrium in the long run. It suggests non-convergence in the risk premium of the BRICS economy.

5.2 | Linear and Nonlinear Cointegration Tests

The existence of a long-run relationship between variables in Equation (2) is examined through both linear and nonlinear

TABLE 2 | Summary statistics.

	Obs.	Mean	Median	Min	Max	Std dev.	Skewness	Kurtosis	ARCH LM (1)	ARCH LM (5)	ARCH LM (10)
R^*	276	1.649	1	0.125	6.5	1.861	1.158	3.181	166.256*	102.682*	109.293*
ϕ^*	276	2.495	2.160	−2.097	9.059	1.797	1.172	5.607	5.707*	8.997	9.453
India											
R	276	6.635	6.75	4	9	1.327	−0.461	2.329	3.505*	9.833*	18.685*
$r - r^*$	276	1.258	1.329	0.064	2.133	0.611	−0.270	1.885	11.121*	11.447*	11.595
ser_t	276	3.998	3.893	3.670	4.412	0.208	0.322	1.616	7.402*	31.581*	37.971*
ser_{t+1}	276	4.001	3.895	3.670	4.412	0.209	0.312	1.610	5.894*	25.941*	31.457*
ϕ(I)	276	5.661	5.504	−0.707	11.245	2.298	0.155	2.975	0.175	7.512	13.794
Brazil											
R	276	12.299	12	2	26.5	5.168	0.265	2.992	10.773*	63.410*	66.641*
$r - r^*$	276	1.739	1.957	0.693	2.606	0.616	−0.304	1.579	22.132*	22.679*	22.531*
ser_t	276	0.996	0.904	0.448	1.731	0.363	0.468	2.139	16.833*	22.347*	23.965*
ser_{t+1}	276	1.000	0.913	0.448	1.731	0.364	0.457	2.121	16.871*	16.871*	23.986*
ϕ(B)	276	6.438	6.126	1.877	17.235	2.796	1.382	5.723	1.575	7.125	11.927
Russia											
R	276	11.976	10	4.25	45	6.707	1.931	7.428	74.512*	105.863*	102.782*
$r - r^*$	276	1.703	1.871	0.458	2.926	0.557	−0.458	2.206	57.325*	75.132*	76.573*
ser_t	276	3.665	3.445	3.150	4.644	0.395	0.590	1.650	83.772*	100.474*	99.670*
ser_{t+1}	276	3.668	3.447	3.150	4.644	0.396	0.574	1.629	83.427*	99.985*	99.440*
$\phi(R)$	249	9.009	8.384	2.175	19.035	4.210	0.251	1.981	89.595*	0.597	0.847
China											
R	276	5.302	5.31	3.65	7.47	0.958	0.067	2.422	23.541*	24.064*	23.836*
$r - r^*$	276	1.071	1.148	−0.144	1.905	0.624	−0.274	1.782	16.085*	16.024*	15.861*
ser_t	276	1.958	1.922	1.800	2.114	0.108	0.361	1.593	7.290*	30.125*	41.282*
ser_{t+1}	276	1.958	1.922	1.800	2.114	0.108	0.373	1.610	7.818*	30.063*	41.423*
ϕ(C)	275	2.185	1.900	−1.799	8.803	1.958	0.783	3.990	12.053*	16.348*	16.714*
South Africa											
R	276	7.488	7	3.5	13.5	2.644	0.686	2.525	1.584*	25.771*	30.449*
$r - r^*$	276	1.331	1.450	0.287	2.407	0.510	−0.450	2.045	22.256*	39.471*	42.160*
ser_t	276	2.275	2.203	1.746	2.922	0.327	0.255	1.633	0.633	1.626	8.949
ser_{t+1}	276	2.279	2.213	2.279	2.922	0.328	0.250	1.629	0.621	1.653	8.808
ϕ(SA)	276	5.532	5.385	0.154	13.019	2.300	0.717	4.357	7.046*	28.109*	35.794*

Note: *Denote the statistical significance at 1% level. $\boldsymbol{R}$ and $\boldsymbol{R^*}$ is the foreign (US) and domestic rate of interest; $\boldsymbol{r}$ and $\boldsymbol{r^*}$ denote the log of domestic and foreign rate of interest; ser_t and ser_{t+1} signify the spot exchange rate at time t and $t+1$; and ϕ and ϕ^* denote the inflation levels in domestic and foreign country, respectively. Abbreviation: ARCH LM, autoregressive conditional heteroscedasticity LM test.

Source: Author calculations.

TABLE 3 | Estimates of traditional and nontraditional unit root tests.

		Conventional tests		Structural break test	Nonlinear test		
		ADF	PP	Perron test	KSS test	Kruse test	Final decision
$s_{t+1} - s_t$							
India	Level	−12.218***	−12.083***	−12.38***	−3.853***	−3.613***	I (0)
Brazil	Level	−11.496***	−11.473***	−11.70***	−3.835***	−3.754***	I (0)
Russia	Level	−12.092***	−11.648***	−12.07***	−9.754***	−7.975***	I (0)
China	Level	−9.027***	−8.883***	−12.59***	−5.656***	−5.655***	I (0)
South Africa	Level	−12.372***	−12.264***	−22.51***	−4.197***	−4.151***	I (0)
$r - r^*$							
India	Level	−0.201	−0.739	1.858	−1.596	−0.844	I (1)
	Diff	−15.349***	−15.787***	15.25***	−3.058**	−3.122***	
Brazil	Level	−1.258	−1.841	−2.62	−3.066**	−1.856	I (1)
	Diff	−13.095***	−13.730***	−1.316***	−4.303***	−4.380***	
Russia	Level	−1.283	−1.976	−2.80	−2.681*	−1.394	I (1)
	Diff	−13.560***	−13.791***	−13.80***	−6.786***	−7.083***	
China	Level	0.018	−0.660	−2.24	−1.050	−1.004	I (1)
	Diff	−15.523***	−16.090***	−15.59***	−2.722*	−2.767**	
South Africa	Level	−0.749	−1.883	−3.00	−2.369	−2.007	I (1)
	Diff	−12.953***	−13.922***	−12.94***	−2.908*	−2.880***	
	Diff	−12.327***	−12.263***	−12.55***	−3.945***	−3.747**	
λ_t							
India	Level	−0.229	−0.755	−1.68	−1.614	−0.841	I (1)
	Diff	−15.392***	−15.818***	−15.57***	−2.896*	−2.964***	
Brazil	Level	−1.492	−1.927	−2.62	−3.122**	−1.848	I (1)
	Diff	−14.810***	−15.209***	−1.490***	−3.825***	−3.822***	
Russia	Level	−1.281	−1.985	−2.82	−2.553	−1.369	I (1)
	Diff	−13.178***	−13.353***	−13.41***	−5.781***	−6.037***	
China	Level	−0.004	−0.678	−2.27	−1.097	−1.005	I (1)
	Diff	−15.505***	−16.073***	−15.57***	−3.413**	−3.451***	
South Africa	Level	−6.624***	−6.505***	−6.62***	−1.615	−1.485	I (1)
	Diff	−22.090***	−25.869***	−22.05***	−1.976	−3.163**	
ϕ							
United States	Level	−1.669	−2.449	−4.34*	−1.254	−1.464	I (1)
	Diff	−10.360***	−10.003***		−3.296**	−3.272***	
India	Level	−3.050	−4.077***	−3.39	−4.233***	−3.584***	I (0)
	Diff			−12.32***			
Brazil	Level	−1.734	−2.912	−3.46	−3.132**	−3.436***	I (1)
	Diff	−7.857***	−7.873***	−7.79***	−2.990**	−3.433***	
Russia	Level	−1.306	−2.246	−3.74	−3.541***	−0.901	I (1)
	Diff	−9.409***	−9.329***	−9.62***	−7.640***	−7.588***	
China	Level	−2.817	−3.290*	−5.14***	−2.332	−1.739	I (1)
	Diff	−14.952***	−15.048***		−6.060***	−4.514***	
South Africa	Level	−2.164	−3.111	−2.71	−3.74***	−2.879***	I (1)
	Diff	−10.696***	−10.937***	−11.09***	−4.276***	−4.871***	

Note: *,**,*** denote the statistical significance levels at 10%, 5% and 1%, respectively.
Source: Author's calculations.

TABLE 4 | Estimates of linear cointegration test.

Nations	*F*-statistics	No. of lags	Decision
Model:			
Brazil	64.866***	(1, 1)	Co-integrated
Russia	91.837***	(1, 1)	Co-integrated
India	75.196***	(1, 1)	Co-integrated
China	39.915***	(1, 1)	Co-integrated
South Africa	59.032***	(1, 1)	Co-integrated

Note: *,**,*** denote the statistical significance levels at 10%, 5% and 1%, respectively.
Source: Author calculations.

tests. Autoregressive distributed lag (ARDL) cointegration is used for the linear relation. The estimates are provided in Table 4, which shows statistically significant *F*-statistics for all the BRICS countries. Thus, it rejects the null hypothesis of no cointegrating relation between exchange rate and interest rate differential for BRCIS countries during the sample period.

However, the test might not produce adequate estimates in the presence of structural break and nonlinearity. Thus, we also employ Gregory and Hansen's (1996) test to account for the structural breaks. The test has a null hypothesis of no cointegrating relation in the presence of an endogenous structural break. The method tests cointegration using three structural change forms: level, trend and regime shifts. We provide the estimates of the test in the context of all three shifts for robustness purposes. These are demonstrated in Table 5. The findings are consistent with the linear cointegration test, suggesting a rejection of the null hypothesis of no cointegration relation in the context of all the shifts. Thus, based on Gregory and Hansen's (1996) test, we conclude that a cointegrating relation exists between exchange rate and interest rate differential in all the BRICS countries, even in the presence of the endogenous structural break.

6 | Regression Analysis

The traditional and nontraditional unit root tests depict that variables are integrated of either order (0) or (1). Further, the estimates of linear and nonlinear cointegration tests depict the presence of a long-run relationship between exchange rate and interest rate differential for all the BRICS economies. Therefore, we now estimate Equation (2) to investigate the validity of UIP in the context of the BRICS trade bloc using the linear and nonlinear regression models. First, following Adewuyi and Ogebe (2019), and Aftab, Ahmad, and Ismail (2018), the study employs the Linear Auto Regressive Distributed Lag (ARDL) of Pesaran, Shin, and Smith (2001). The method helps to explain the speed of adjustment in the changes in the spot exchange rate following the changes in the interest rate differential. Therefore, we specify the Equation (2) as follows:

$$\Delta(s_{t+1} - s_t) = \gamma_0 + \gamma_1(s_t - s_{t-1}) + \gamma_2(r - r^*)_t + \sum_{i=1}^{M} \delta_i \Delta(s_{t+1-i} - s_{t-i}) + \sum_{i=1}^{N} \rho_i \Delta(r - r^*)_{t-1} + \varpi_1 ect_1 + \mu_{1t+1}. \tag{4}$$

However, the method has an assumption of linearity and cannot control for the asymmetric relationship between spot exchange rate changes and interest rate differential. Therefore, to account for the asymmetric and nonlinear relation in both the long run and short run, following previous studies (Adewuyi and Ogebe 2019), the study further adopts Shin, Yu, and Greenwood-Nimmo (2014)'s method of the nonlinear autoregressive distributed lag (NARDL) model[1]. Accordingly, our UIP hypothesis is represented in the following form:

$$\Delta(s_{t+1} - s_t) = \gamma_0 + \gamma_1(s_t - s_{t-1}) + \gamma_2(r - r^*)_t^+ + \gamma_3(r - r^*)_t^- + \sum_{i=1}^{M} \delta_i \Delta(s_{t+1-i} - s_{t-i}) + \sum_{i=1}^{N} \rho_i \Delta(r - r^*)_{t-1}^+ + \sum_{i=1}^{P} \omega_i \Delta(r - r^*)_{t-1}^- + \varpi_2 ect_2 + \mu_{2t+1}. \tag{5}$$

Here, in Equation (5), the asymmetric effects of interest rate differential are captured by positive changes in $(r - r^*)_t^+$ and negative changes in $(r - r^*)_t^-$ on changes in the spot exchange rate. The long-run effect is computed as follows: Positive effects: $\varsigma_1^{r-r^*} = -\frac{\gamma_2}{\gamma_1}$ and Negative effects: $\varsigma_2^{r-r^*} = -\frac{\gamma_3}{\gamma_1}$. While the short-run effects are given by $\sum\rho_i$ and $\sum\omega_i$ for positive and negative effects, respectively.

Further, to investigate the role of time-varying risk premium in the UIP hypothesis, the study employs the component generalised autoregressive conditional heteroscedasticity (C-GARCH) model. Literature shows the role of risk premium in explaining the failure of the UIP hypothesis. Thus, given the nonexistence of UIP in BRICS economies (cf. to Section 5.3), we further investigate the UIP hypothesis while controlling for the time-varying risk premium. For this, following previous literature (Li, Ghoshray, and Morley 2012; Živkov et al. 2016; Wei 2009; Tai 2001), the study employs the C-GARCH model, which helps control for heteroscedasticity and distinguishes between long-run volatility trends and short-run deviations that describe volatility better than the other methods (Christoffersen, Heston, and Jacobs 2006)[2].

We express our UIP hypothesis under the C-GARCH model as follows:

$$s_{t+1} - s_t = \gamma_0 + \gamma_1(r - r^*)_t + \gamma_2\phi_t + \gamma_3\phi_t^* + \xi\sigma_{t+1} + \mu_{t+1}, \tag{6}$$

$$l_{t+1} = \eta_1 + \eta_2(l_1 - \eta_1) + \eta_3(\varepsilon_t^2 - \sigma_t^2), \tag{7}$$

$$\sigma_{t+1}^2 = l_{t+1} + \eta_4(\varepsilon_t^2 - l_t) + \eta_5(\sigma_1^2 - l_t), \tag{8}$$

where ξ is the coefficient on standard deviation represents the time-varying risk premium (cf. Equation 6). Equation (7) is a long-term equation that reflects the permanent component of

TABLE 5 | Estimates of Gregory and Hansen's method for cointegrating relationship.

Nations	Variables	Model C	Model C/T	Model C/S	Decision
Brazil	ADF statistic	−11.67***	−11.89***	−11.73***	Co-integrated
	Break date	2011m4	2011m4	2015m11	
	Zt	−11.69***	−11.94***	−11.75***	Co-integrated
	Break date	2011m4	2011m4	2015m11	
	Zc	−183.36***	−188.13***	−184.57***	Co-integrated
	Break date	2011m4	2011m5	2015m11	
Russia	ADF statistic	−11.00*	−11.23*	−11.23*	Co-integrated
	Break date	2008m3	2015m10	2015m10	
	Zt	−12.65*	−12.80*	−12.93*	Co-integrated
	Break date	2008m4	2016m2	2016m2	
	Zc	−201.44*	−204.44*	−207.42*	Co-integrated
	Break date	2008m4	2016m2	2016m2	
India	ADF statistic	−12.44*	−12.63*	−12.57*	Co-integrated
	Break date	2007m11	2007m11	2006m6	
	Zt	−12.53*	−12.73*	−12.66*	Co-integrated
	Break date	2007m11	2007m11	2006m6	
	Zc	−205.53*	−209.23*	−206.98*	Co-integrated
	Break date	2007m11	2007m11	2006m6	
China	ADF statistic	−9.12*	−9.26*	−9.08*	Co-integrated
	Break date	2018m2	2015m5	2005m4	
	Zt	−9.74*	−9.91*	−9.74*	Co-integrated
	Break date	2013m10	2013m10	2018m2	
	Zc	−144.00*	−146.68*	−146.50*	Co-integrated
	Break date	2013m10	2013m10	2018m2	
South Africa	ADF statistic	−12.51*	−12.58*	−12.73*	Co-integrated
	Break date	2011m4	2011m4	2003m11	
	Zt	−12.65*	−12.73*	−13.31*	Co-integrated
	Break date	2011m4	2011m4	2003m7	
	Zc	−202.31*	−203.93*	−215.4*	Co-integrated
	Break date	2011m4	2011m4	2003m7	

Note: *,**, *** denote the statistical significance levels at 10%, 5% and 1%, respectively.
Source: Author calculations.

exchange rate volatility, and Equation (8) is a short-run equation that represents the transitory component of the exchange rate volatility. Thereby, l_{t+1} is the long-term component of conditional variance and η_2 measures the long-term persistence and the impact of shocks on the permanent component of volatility is captured by η_3. Likewise, η_4 in Equation (8) represents the initial impact of shocks and η_5 shows the transitory (short-run) component of the conditional variance.

The findings are discussed as follows.

6.1 | Testing UIP Hypothesis With Linear and Nonlinear ARDL Regression Models

The estimates of linear ARDL models are provided in Table 6.[3] Panel A produces the estimates for Equation (2), which tests for the direct UIP hypothesis. It is to be noted that the UIP hypothesis holds true in case the intercept value is equal to 0 and the slope coefficient on the interest rate differential is equal to 1. The UIP puzzle is that many studies in the literature provide evidence that interest rate differentials hold significant forecasting power, but its coefficient is negative, that is, opposite of what is suggested by the UIP hypothesis.

From Panel A of Table 6, it is observed that the long-run estimates show statistically insignificant coefficients on slope parameters, and it differs from 1. Additionally, the intercept value is almost equal to 0, but it is not significant at conventional levels of significance across all the BRICS economies. It illustrates that domestic and foreign financial assets are not the perfect substitutes for each other. This shows that the UIP hypothesis does not hold true in any of the BRICS economies, providing evidence for *Hypothesis H1a*. This finding lends

TABLE 6 | Estimates of ARDL regression.

	Panel A: UIP hypothesis					Panel B: Extended UIP hypothesis				
Variables	**Brazil**	**Russia**	**India**	**China**	**South Africa**	**Brazil**	**Russia**	**India**	**China**	**South Africa**
Long run										
$r - r^*$	−0.003	−0.005	0.002	0.0008	−0.029	−0.0002	−0.0008	0.004*	0.001	0.012
ϕ^*	—	—	—	—	—	0.001	0.001	0.001**	0.0008	0.004***
ϕ	—	—	—	—	—	−0.001	−0.0007	0.0004	−0.0008*	−0.0009
Short run										
$D(r - r^*)$	0.011	0.102***	0.005	−0.0002	0.047	0.011	0.111***	0.009	0.001	−0.554
$D(\phi^*)$	—	—	—	—	—	−0.002	0.0007	0.001	−0.0005	−0.004
$D(\phi)$	—	—	—	—	—	0.00001	−0.020***	−0.0006	0.00088	0.004
Constant	0.006	0.011	−0.0006	−0.0008	0.00003	0.005	0.004	−0.007**	−0.001	−0.001
ECM	−0.658***	−0.794***	−0.731***	−0.477***	−0.719***	−0.666***	−0.688***	−0.759***	−0.520***	−0.748***
Adj. R^2	0.320	0.397	0.350	0.222	0.353	0.312	0.478	0.362	0.233	0.362
Ramsey reset test	1.01	44.57***	1.32	2.66	1.37	1.50	25.36***	1.23	2.75	1.43
BP test	42.36***	420.34***	2.76	35.68***	10.41***	42.95***	147.19***	0.75	26.99***	7.10***
JB test	53.76***	266.25***	34.71***	40.99***	23.62	83.94 ***	228.66 ***	70.01***	91.01***	48.79

Note: *,**,*** denote the statistical significance level at 10%, 5% and 1%, respectively.
Source: Author calculations.

support to the findings of Adewuyi and Ogebe (2019), and Mehl and Cappiello (2009).

Next, we apply the nonlinear ARDL approach for possible nonlinear asymmetric effects. The impact of positive and negative changes in interest rate differentials on changes in exchange rates is provided in Table 7. The estimates show that long-run asymmetry is not present in any of the BRICS economies, and the long-run slope coefficient is also different from 1, thereby providing evidence for nonexistence of the UIP hypothesis. Moreover, the estimates portray that long-run asymmetry is present in the case of Russia, India and China. However, none of the slope coefficients are equal to 1 and statistically significant. Further, the short-run asymmetry is present in the case of South Africa, but the slope coefficient is not statistically significant. Therefore, both linear and nonlinear ARDL regression models produce evidence for the nonexistence of the UIP hypothesis in the BRICS economies. This finding is consistent with the strand of the empirical literature that produces evidence against the UIP hypothesis (Engel et al. 2019; Adewuyi and Ogebe 2019; Fukuda and Tanaka 2017; Park and Park 2017; Živkov et al. 2016).

6.2 | Testing Extended UIP Hypothesis

This section analyses the extended version of the UIP hypothesis by incorporating the domestic and foreign inflation levels, following Taylor rule. Specifically, we estimate the following equation:

$$ser_{t+1} - ser_t = \beta_0 + \beta_1(r - r^*)_t + \beta_2\phi_t + \beta_3\phi_t^* + \varepsilon_{t+1}, \tag{9}$$

where ϕ_t and ϕ_t^* represent the domestic and foreign inflation levels, respectively.

This equation helps to account for the monetary policy stance of the domestic and reference nations, as four out of five BRICS economies are inflation-targeting economies (IMF 2021). Indeed, the inflation level is considered to be a good indicator of the monetary policy stance and reveals information that might not be captured by the interest rates (Engel et al. 2019). This might be because tight monetary policy helps to lower inflation levels and appreciates the nation's currency, but the movement of the interest rates also depends on the relative liquidity of the short-term interest-bearing assets. Additionally, given the dominance of the USD in the international market, we also control the United States inflation levels. It also helps in evaluating the role of relative monetary policy stance in the domestic country vis a vis reference country. Consistent with our previous estimates, the coefficient on interest rate differential is not statistically significant. Nevertheless, given the long-run asymmetry in South Africa and China, it is found that positive changes in interest rate differentials have a negative impact on the changes in the spot exchange rates for both China and South Africa, and negative changes in interest rate differentials have a positive impact on the changes in the spot exchange rate of South Africa. This finding supports the applicability of NARDL regression approach. Further, the long-run estimates of linear ARDL and NARDL depict that foreign inflation levels have a positive and significant impact on the exchange rate of Brazil, India and South Africa (rf. Panel B of Tables 6 and 7, respectively). It suggests that as US inflation increases, the exchange rate also increases, implying the depreciation of the domestic currency. Indeed, US monetary policy seems to have a more significant impact on exchange rates compared to the domestic inflation level. This shows the dominance of US monetary policy in determining the exchange rates (Rey 2013). While, for China, domestic inflation has a more significant and negative impact, depicting that as domestic inflation increases, the domestic currency of China appreciates in comparison to the reference currency (USD). These findings support our *hypothesis H2* that inflation rate plays significant role in determining variations in exchange rate, and is consistent with those of Engel et al. (2019).

6.3 | Testing UIP Hypothesis and Extended UIP Hypothesis for Time-Varying Risk Premium

The estimates of C-GARCH using generalised error distribution are provided in Table 8. Panel A provides the estimates of the C-GARCH model for the UIP hypothesis, and Panel B provides the estimates for the C-GARCH model for the extended UIP hypothesis. The diagnostic test of ARCH (LM) is produced, which has a null hypothesis of no ARCH effects in the estimated model. The test statistics accept the null hypothesis at a conventional level of significance in all the estimated models. This implies that all the models are robust to the heteroscedasticity issues. The estimates provided in Table 8 show that the intercept term (α) is not statistically significant at the conventional significance levels. However, the β coefficient (i.e., the coefficient on interest rate differential) is positive and statistically significant across all the economies, and the coefficient is even greater than 1 for all economies, except Brazil (cf. extended UIP model estimates). Thus, the estimates validate our *hypothesis H3* that risk premium plays significant role in determining the positive relation between expected exchange rate and interest rate differential. However, the coefficient being different from unity depicts that domestic and foreign bonds are not perfect substitutes for each other. This finding aligns with those of previous studies (Adewuyi and Ogebe 2019; Bhatti 2014; Park and Park 2017). But it also refutes the previous literature (Burnside et al. 2007; Chinn and Meredith 2004; Gyntelberg and Remolona 2007) on the UIP hypothesis puzzle that the coefficient on interest differential is negative. Thus, our estimates clearly reject hypothesis *H1a* that there exists forward premium puzzle.

Furthermore, the positive coefficient depicts that as the interest differential increases, the exchange rate increases, that is, the domestic currency depreciates relative to the foreign currency (USD), and this depreciation is more than the increase in interest rates for Russia, India, China and South Africa. It is found that the higher domestic rate of interest leads to a more substantial depreciation of the domestic currency in the case of Russia, India, China and South Africa, while the depreciation of the domestic currency of Brazil is less than the increase in the rate of interest. This finding improves upon the previous estimates when the coefficient on interest differential was not

TABLE 7 | Estimates of NARDL models.

Variables	Brazil	Brazil	Russia	Russia	India	India	China	China	South Africa	South Africa
Long run										
$(r{-}r^{*})^{+}$	−0.002	−0.009	−0.0003	−0.008	0.002	0.002	0.0006	−0.002	−0.079	−0.716**
	(0.003)	(0.008)	(0.004)	(0.008)	(0.001)	(0.003)	(0.0007)	(0.001)	(0.149)	(0.317)
$(r{-}r^{*})^{-}$	−0.003	0.00009	−0.001	0.004	0.002	0.005	0.0008	0.004***	−0.056	0.431**
	(0.003)	(0.009)	(0.004)	(0.007)	(0.002)	(0.004)	(0.0009)	(0.001)	(0.086)	(0.185)
$(\phi)^{+}$	—	−0.00097	—	0.00099	—	−0.0002	—	-0.0003	—	−0.001
		(0.001)		(0.001)		(0.0007)		(0.0003)		(0.001)
$(\phi)^{-}$	—	0.0007	—	0.002	—	0.0001	—	-0.0007**	—	−0.0009
		(0.001)		(0.001)		(0.0005)		(0.0003)		(0.001)
$(\phi^{*})^{+}$	—	0.004*	—	0.003	—	0.002**	—	0.0003	—	0.008***
		(0.002)		(0.001)		(0.001)		(0.0004)		(0.002)
$(\phi^{*})^{-}$	—	0.001	—	−0.0008	—	0.001	—	0.0004	—	0.004***
		(0.001)		(0.001)		(0.0009)		(0.0004)		(0.001)
Constant	0.005	0.020**	0.0005		−0.001	0.002	−0.001		0.003	0.137**
	(0.005)	(0.008)	(0.004)		(0.002)	(0.003)	(0.001)		(0.004)	(0.067)
Short run										
$D(s_t\text{-}s_{t-1})$	0.044	0.063	0.162***	0.054	0.078	0.058	0.130**	0.148**	0.083	−1.787
	(0.062)	(0.066)	(0.059)	(0.072)	(0.063)	(0.065)	(0.064)	(0.065)	(0.061)	(1.096)
$d(r{-}r^{*})^{+}$	−0.044	−0.027	0.136***	0.138***	0.013	0.024	-0.000	0.004	−1.36	0.692
	(0.031)	(0.033)	(0.025)	(0.026)	(0.015)	(0.016)	(0.005)	(0.006)	(0.972)	(1.207)
$d(r{-}r^{*})^{+}$	0.032	0.053	−0.113***	−0.003	0.013	0.027*	0.0009	0.007	0.741	−0.106
	(0.030)	(0.033)	(0.027)	(0.031)	(0.015)	(0.016)	(0.005)	(0.006)	(1.004)	(0.782)
$d(r{-}r^{*})^{-}$	0.124***	0.108	0.055	0.005	0.0006	0.007	0.002	0.002	0.366	0.188
	(0.047)	(0.051)	(0.035)	(0.039)	(0.023)	(0.024)	(0.009)	(0.010)	(0.750)	(0.825)
$d(r{-}r^{*})^{-}$	−0.052	−0.063	0.004	−0.031	−0.021	−0.021	−0.022**	0.026**	1.277*	−0.003
	(0.048)	(0.052)	(0.033)	(0.038)	(0.023)	(0.024)	(0.009)	(0.010)	(0.751)	(0.008)
$d(\phi)^{+}$	—	−0.004	—	−0.04***	—	−0.001	—	0.001	—	0.0001
		(0.009)		(0.005)		(0.002)		(0.001)		(0.008)
$d(\phi)$	—	−0.006	—	−0.005	—	0.002	—	−0.001	—	0.012
		(0.009)		(0.006)		(0.002)		(0.001)		(0.008)
$d(\phi^{*})^{+}$	—	0.001	—	0.021***	—	0.00001	—	−0.0004	—	−0.0007
		(0.008)		(0.007)		(0.002)		(0.001)		(0.008)

(Continues)

TABLE 7 | (Continued)

Variables	Brazil	Brazil	Russia	Russia	India	India	China	China	South Africa	South Africa
$d(\phi^*)^+$	—	−0.001 (0.008)	—	−0.0008 (0.007)	—	0.001 (0.002)	—	0.001 (0.001)	—	−0.001 (0.010)
$d(\phi^*)^-$	—	−0.007 (0.010)	—	−0.001 (0.010)	—	−0.001 (0.004)	—	-0.001 (0.001)	—	−0.006 (0.010)
$d(\phi^*)^-$	—	0.00005 (0.010)	—	−0.0042 (0.010)	—	−0.005 (0.004)	—	0.002 (0.001)	—	−0.001 (0.009)
$d(\phi^*)^-$	—	0.004 (0.009)	—	0.011 (0.009)	—	0.008* (0.004)	—	0.0004 (0.001)	—	0.002 (0.009)
$d(\phi^*)^-$	—	0.006 (0.009)	—	0.0007 (0.009)	—	0.0052 (0.004)	—	0.0002 (0.001)	—	0.015 (0.010)
ECM	−0.655 (0.072)	−0.717*** (0.078)	−0.828*** (0.079)	−0.624*** (0.082)	−0.797*** (0.077)	−0.815*** (0.082)	−0.557*** (0.066)	−0.638*** (0.070)	−0.771*** (0.073)	−0.903*** (0.085)
R^2	0.351	0.381	0.475	0.612	0.363	0.409	0.253	0.313	0.381	0.432
Adj. R^2	0.332	0.332	0.459	0.578	0.344	0.362	0.230	0.258	0.362	0.387
F-stat.	17.98***	7.79***	30.03***	17.87***	18.95***	8.77***	11.25***	5.74***	20.41***	9.63***
Ramsey Reset test	0.434	0.5013	44.23***	15.09***	1.856	2.217	3.296**	2.366	1.095	1.035
BP test	40.7***	38.33***	505.1***	40.96***	4.632**	1.955	23.86***	8.925***	9.723***	4.578
JB test	28.86***	38.69***	2638***	436.1***	49.36***	36.46***	387.8***	376.7***	96.0***	104.4***
Long run asymmetry	0.096	0.431	0.513	1.228	0.001	0.382	0.162	6.553**	0.088	8.061***
		1.95		1.308		0.475		1.081		0.007
		4.297**		6.63**		0.722		0.0152		8.255***
Short run asymmetry	1.077	0.040	0.432	4.847**	1.392	2.141	1.847	4.316**	1.496	0.285
		0.548		32.29***		0.0522		0.425		0.726
		0.935		0.881		5.85**		0.004		0.258
T_BDM	−9.083	−9.151	−10.390	−7.561	−10.313	−9.920	−8.447	−9.122	−10.484	−10.534
F_PSS	27.641	12.342	36.178	9.693	35.543	14.236	24.076	12.554	36.810	16.357

Note: *,**,*** denote the statistical significance levels at 10%, 5% and 1%, respectively.
Source: Author calculations.

TABLE 8 | Estimates of C-GARCH model.

	Brazil	Russia	India	China	South Africa	Brazil	Russia	India	China	South Africa
	UIP hypothesis					Extended UIP hypothesis				
α	0.0003 (0.0006)	0.005*** (0.0008)	0.000002 (0.00006)	0.00003 (0.00003)	−0.0002 (0.0009)	0.002*** (0.001)	0.005*** (0.001)	0.0006*** (0.0001)	0.00006 (0.00004)	0.001 (0.001)
β	0.788*** (0.008)	3.971*** (0.026)	3.961*** (0.010)	1.902*** (0.004)	2.097*** (0.011)	0.792*** (0.008)	3.971*** (0.013)	3.964*** (0.00001)	1.900*** (0.004)	2.119*** (0.012)
γ	−0.222*** (0.062)	−1.501*** (0.300)	−0.275** (0.121)	−0.610*** (0.174)	−0.165 (0.134)	−0.314*** (0.060)	−1.503*** (0.448)	−0.519*** (0.158)	−1.048*** (0.280)	−0.206 (0.144)
ϕ	—	—	—	—	—	−0.00001 (0.0001)	−0.000004 (0.00004)	−0.000007 (0.00001)	−0.00001* (0.000007)	−0.00009 (0.00008)
ϕ^*	—	—	—	—	—	0.0004*** (0.0002)	0.0001** (0.00008)	0.00008*** (0.00002)	0.00001 (0.000007)	−0.0001 (0.0002)
C(4)	0.00001 (0.00003)	0.00001*** (0.000001)	0.000006 (0.0000006)	0.00000001 (0.0000002)	0.005 (0.003)	0.0007 (0.0004)	0.00001*** (0.000001)	0.0000009 (0.0000005)	0.00000003*** (0.000000008)	0.004*** (0.003)
C(5)	1.014*** (0.018)	0.507 (0.457)	0.936*** (0.051)	0.988*** (0.019)	0.999*** (0.000003)	0.999*** (0.000006)	0.352 (0.394)	0.946*** (0.0000005)	0.930*** (0.018)	0.999** (0.000004)
C(6)	0.419*** (0.043)	0.186 (0.144)	0.398*** (0.112)	0.196*** (0.064)	0.160** (0.068)	0.414*** (0.030)	0.158 (1.831)	0.278** (0.079)	0.139** (0.050)	0.144*** (0.070)
C(7)	0.005 (0.079)	0.197 (1.463)	−0.097 (0.101)	0.182*** (0.064)	0.415*** (0.078)	−0.021 (0.041)	0.166 (1.827)	0.260*** (0.082)	0.113** (0.050)	0.409*** (0.082)
C(8)	1.037*** (0.076)	0.026 (0.372)	0.914*** (0.239)	0.372* (0.222)	0.285*** (0.110)	0.162 (2.071)	0.034 (0.605)	−0.220 (0.207)	0.061 (0.343)	0.236** (0.113)
Wald	6.363***	17/96***	4.896***	15.91***	1.556	19.37***	6.745***	15.91***	9.89***	1.041
ARCH LM (5)	0.279	0.164	0.176	0.515	0.221	0.599	0.196	0.157	1.251	0.232
ARCH LM (10)	0.216	0.109	0.565	0.287	0.284	0.596	0.389	0.248	0.788	0.348
ARCH LM (20)	0.386	0.122	1.910*	0.205	0.335	0.576	0.278	2.289*	0.528	0.422

Note: *,**,*** denote the statistical significance levels at 10%, 5% and 1%, respectively.
Source: Author calculations.

playing any significant role in determining the changes in spot exchange rates. Our estimates show that after controlling for the risk premium that is required to compensate domestic investors for the extra risk involved in holding the foreign bond, the expected appreciation of the foreign currency is equal to the interest rate differential and the extra risk involved. This finding is consistent in case of extended UIP hypothesis.

Additionally, the statistically significant coefficient on the Wald test rejects the null hypothesis of no risk premium in all the models. Therefore, this finding confirms the presence of risk premium and plays a significant role in determining the variations in exchange rate, which is noted to be the primary reason for the failure of the UIP hypothesis. Moreover, this coefficient on risk premium (γ) is statistically significant and negative across all the models. It suggests that as the risk premium increases, the domestic currencies of all BRICS economies depreciate relative to the USD. It illustrates that the domestic and foreign currencies are not close substitutes of each other such that monetary integration between the two nations has not been achieved. This finding highlights the need of incorporating risk premium in theoretical and empirical models and is in line with those of Adewuyi and Ogebe (2019), Li, Ghoshray and Morley (2012), Tai (2001), Lee (2013) and Mehl and Cappiello (2009).

Furthermore, consistent with the findings of Engel et al. (2019) and our previous estimates, the findings indicate that the monetary stance plays a significant role in determining the changes in the exchange rate (rf. Panel B of Table 8). It is noted that the coefficient on domestic inflation (ϕ) is negative and statistically significant for China, while the foreign inflation level is positive and statistically significant for Brazil, Russia and India. This implies that the domestic monetary policy stance has a significant implication for the changes in the exchange rate for China, while US monetary policy has a more significant implication for Brazil, Russia and India. The significance of selecting the appropriate method, and accounting for the risk premium, and monetary policy stance is thus established by these findings, which complement our prior estimates of the linear and nonlinear ARDL method.

7 | Conclusions

The study investigates the existence of the UIP hypothesis in the context of BRICS economies during 2000 M01 to 2022 M12. The study further expands the standard UIP hypothesis to an extended version by accounting for the monetary policy stance in both domestic and foreign economies. Additionally, the study analyses the role of risk premium in explaining the impact of interest rate differential on the expected changes in exchange rates. The study adopts various conventional and nonconventional methods of unit root tests, cointegration and regression tests to achieve these objectives. These tests also consider various statistical issues, such as potential nonlinearities and asymmetries in the relationship between exchange rate changes and interest rate differentials.

The estimates of ARDL and NARDL suggest that the UIP hypothesis does not exist in any of the BRICS economies. However, the C-GARCH estimates that accounts for risk premium and monetary policy stance, the interest rate differential positively and significantly influences the expected changes in the spot exchange rates of all the BRICS economies, which is consistent with our *hypotheses H2* and *H3*. Though the relation between exchange rate changes and interest rate differential is not one-to-one, yet our estimates clearly show the rejection of UIP puzzle in the context of BRICS economies and provide evidence that higher yielding currencies tend to depreciate in comparison to lower yielding currency. This finding is consistent across all econometric models used in this study. This also depicts that previous studies showing the negative impact of interest rate differential might be due to econometric misspecification and inappropriate econometric method of analysis. Our study indicates the necessity of accounting for risk premium to make up for the higher risk that comes with holding the foreign bond for the benefit of domestic investors. Though the coefficient on interest rate differential is not equal to 1, the coefficient is positive in all the models, as predicted by the UIP hypothesis. Thus, this finding partially supports our *hypothesis H1*. Further, consistent with our *hypothesis H2*, the study shows the significant role of US monetary policy in determining the changes in the spot exchange rate, specifically for Brazil, Russia and India. This shows the dominance of US monetary policy in determining the exchange rates. While, for China, domestic inflation has a more significant and negative impact, depicting that as domestic inflation increases, the domestic currency of China appreciates in comparison to the reference currency (USD). This finding indicates that inflation level has a more direct impact on the exchange rate changes.

The results of this study have significant implications for policymakers and regulators. To begin with, the study provides evidence that risk premium is an important factor in accounting for the extra risk involved in holding bonds in foreign currency. The estimates demonstrate that the projected appreciation of the foreign currency is equal to the interest rate differential and the additional risk involved after controlling for the risk premium that is necessary to reimburse domestic investors for the greater risk involved in holding the foreign bond. It has considerable implications for the investors, such that investors may borrow from the US economy, which has a lower interest rate, and may invest in any of the economies, which have a higher interest rate. Thus, there is higher tendency for investors to engage in carry trade speculations. Second, the study shows that US monetary policy has a positive and significant influence on the expected changes in the exchange rates of Brazil, Russia and India. It indicates that expansionary monetary policy in the US widens the interest rate differential, causing an inflow of capital in the domestic country and leading to a higher exchange rate, resulting in the depreciation of the domestic currency. Thus, India, Brazil and Russia should be attentive of the US monetary policy. In contrast, for China, domestic monetary policy plays more crucial role, indicating that expansionary monetary policy of China leads to lower interest rate in China, leading capital outflow and thus causing decline in exchange rate, that is, the appreciation of the domestic currency. Third, the study substantially adds to the existing literature by unveiling the important results, for which there was no consensus in the literature. These findings underscore the significance of selecting the appropriate method, and accounting for the risk premium, and domestic and foreign inflation levels. Our results have significant implications for theoretical models, emphasising the necessity of considering statistical properties such as nonlinearity and asymmetry, and incorporating the risk premium and monetary policy regime using inflation rates, when empirically evaluating the prevalence of the UIP hypothesis.

The study also has a few limitations, which essentially provide a direction for future research. First, the findings are based on a single trade bloc, that is, BRCIS. Further research can produce evidence from other developing economies, for which there is comparatively lesser evidence. Second, the study does not account for the extended portfolio balance approach that also considers the role of wealth and real GDP level in determining the expected exchange rates. Nevertheless, these limitations do not overshadow the crucial conclusions that this study brings to the forefront.

Ethics Statement

The author has followed the required ethical standards and declares hereby that the work submitted is original and is not submitted or published elsewhere.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The data used in the study is publicly available on the website of the International Financial Statistics (IFS) database of the International Monetary Fund (IMF). The data is available at: International Financial Statistics (imf.org).

Endnotes

[1] We confirm the presence of nonlinear dependency of the variables in all BRICS economies using Brock, Dechert, and Scheinkman (BDS) test, developed by Broock et al. (1996). The test has a null hypothesis that data are independently and identically distributed (IID), depicting that time-series is linearly dependent. However, in all cases, our estimates reject the null hypothesis and confirm the presence of nonlinearity in the UIP hypothesis. We have applied BDS test to each individual variable as well as to the residual of the regression model. The estimates are not presented in the paper for brevity purpose; however, they are available from the corresponding author upon request.

[2] The large body of research provides evidence that C-GARCH performs better in comparison to other GARCH models (Wei 2009; Black and McMillan 2004; Ghysels, Santa-Clara, and Valkanov 2005; Guo and Neely 2008; Guo and Whitelaw 2006).

[3] The ARDL is applied using lag structure of (1,1), which is chosen using the standard Akaike Information Criterion (AIC).

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