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ORIGINAL ARTICLE

Analyzing a New Portfolio Balance Model with Micro and Macro Determinants of Exchange Rate when Expectations are Rational

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Abstract

The current study incorporates a modified version of Kouri's (1983) portfolio balance rational expectations model to determine and forecast the bilateral exchange rate between India and the US for the period 1996:Q2-2019:Q3. The assumption of rational expectations enables us to analyse the factors representing current and capital account as macroeconomic determinants of exchange rates. The most significant contribution of the current study is however the inclusion of the microstructure theory within Kouri's (1983) framework, which permits us to determine the role of micro factors and macro factors, in influencing exchange rate. The use of the novel econometric tool, the Nonlinear Auto-Regressive Distributed Lag (NARDL) model, combined with various post-estimation tests, allows us to conclude in favour of asymmetric relationship between some of the exogenous variables and the exchange rate, with both micro and macro factors being important determinants of the exchange rate in the short-run. While evaluating the forecasting accuracy of the modified Kouri's (1983) model, we compare it to the Random Walk Model (RWM) across three forecast horizons: 6-months, 1-year, and 2-years. The results show that the modified Kouri (1983) model outperforms the RWM for all the forecast horizons considered.

Keywords Indian rupee · Portfolio balance model · Depreciation · Rational expectations · Microstructure theory · NARDL approach · Forecasting · Random walk model

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Introduction

The exchange rate plays a crucial role in global trade and financial markets, impacting investment portfolios, current accounts, and foreign reserves of a country. Therefore, knowledge about the factors causing fluctuations in the exchange rate and the ability to forecast these fluctuations is essential for confidence, stability, and informed decision-making in investments, trade, and policymaking, particularly in an emerging economy like India.

India has experienced a substantial rise in international financial flows and a widening positive interest differential with the world since 1991. During this period, the Indian Rupee has steadily depreciated against the US Dollar, accompanied by short-run fluctuations (Dua & Ranjan 2010). Hence, understanding the determinants of the exchange rate is essential to comprehend the role of the exchange rate in India's economic interactions with the rest of the world, especially with the US, as the US is India's largest trading partner.

Following the breakdown of the Bretton-Woods System in 1971, which marked a shift from fixed to flexible exchange rate regimes, several theoretical models have been developed to determine and forecast exchange rates. Notable among these are the Purchasing Power Parity (PPP) model, the monetary model, the sticky-price monetary model, and the Portfolio Balance Model (PBM) of exchange rate determination. However, empirical analysis and forecasting by Meese and Rogoff (1983) found the PPP model, the monetary model, and the sticky-price monetary model to be inefficient in explaining and forecasting the short-run dynamics of exchange rates. Furthermore, these models are based on the assumption of perfect asset substitutability which states that domestic and foreign assets are perfect substitutes and there is no risk associated with holding foreign assets. However, holding foreign assets entails certain risks in the form of political or economic instability of the foreign nation. This risk factor is ignored by the aforementioned models. Given these limitations, the PBM emerges as a more effective model, as it analyzes the short-run dynamics of exchange rates and assumes imperfect asset substitutability. This study will, therefore, employ the PBM to determine and forecast the bilateral exchange rate between India and the US.

The fundamental PBM was developed by Branson (1972, 1976). He relied on the assumption that investors' expectations are stationary, meaning the exchange rate is expected to remain constant over time. However, investors base their decisions on various factors, such as human rationality, past experiences, and the best available information in the market (Kouri 1983). Investors' expectations are therefore, not stationary but rational. Given this context, the model developed by Branson (1972, 1976) is limited to fully explain exchange rate variations because it does not account for rational expectations and focuses solely on stock transactions in the capital account to explain changes in the exchange rate. To address this shortcoming, Kouri (1983) introduced the Portfolio Balance Rational Expectation Model. This model suggests that, in the short-run, exchange rates deviate from equilibrium due to unexpected current changes or anticipated future changes in the determinants of current and capital account balances. These transactions in the current and the capital account balances signify the macroeconomic fundamentals of an economy. Given the comprehensive approach adopted by rational expectations model, the present study will utilize Kouri's (1983) PBM to identify the factors responsible for changes in the bilateral exchange rate between India and the US.

The theoretical model of Kouri (1983) has been empirically investigated by Branson (1984), Engel & Flood (1985), Doukas & Lifland (1994) and Itskhoki & Mukhin (2021). However, the model failed to effectively explain the dynamics of exchange rate in the short-run. Exclusive reliance of the model on macroeconomic variables to determine the exchange rate could be the possible reason for this failure (Meese 1986). In the short-run, the macroeconomic variables like money supply, income, prices remain fixed, while microeconomic factors such as behavior, beliefs, and preferences of individual investors in the foreign exchange market play a more active role (Evans & Lyons 2002). Hence, in this paper, we develop a hybrid model by integrating micro behavior of investors with Kouri's (1983) PBM based on macroeconomic fundamentals. The adopted approach is new to the literature on PBM.

Since we are determining and forecasting the bilateral exchange rate of India and the US, the role of Reserve Bank of India (RBI) in the foreign exchange market is accounted for by means of a variable on capital control of India. Further, the model's assumption of imperfect asset substitutability is explicitly addressed by the use of Economic Policy Uncertainty (EPU) Index of the US.

A major contribution of the current study is the use of a novel econometric method in determining and forecasting the bilateral exchange rate of India and the US. The existing empirical contributions of Kouri (1983) have considered a linear relationship among the exchange rate and the exogeneous variables. However, there may be an asymmetric relationship among these variables on account of the positive and the negative shocks of the exogeneous variables having different impacts on the exchange rate. The current study aims to explore this potential asymmetry in determining the bilateral exchange rate between India and the US. To investigate the asymmetry, the study employs the Non-Linear Autoregressive Distributed Lag (NARDL) methodology, developed by Shin et al. (2014). NARDL is an extension of the linear Autoregressive Distributed Lag (ARDL) model of Pesaran and Shin (1999).

The NARDL approach is particularly well-suited for our theoretical model for several reasons. First, it allows us to capture both the positive and the negative shocks of exogenous variables on the exchange rate (Shin et al. 2014). Second, it effectively models both short-run and long-run relationships among variables (Simran & Sharma 2024). Third, it avoids the convergence issues that often arise when estimating a large number of model parameters (Ugurlu-Yildirim, et al. 2021). Fourth, NARDL is robust against endogeneity issues and performs well even with small sample sizes (Hemrit & Nakhli 2021). Finally, it can accommodate variables with different orders of integration, specifically I(0) and I(1), which eliminates the requirement for all variables to have the same orders of integration, as is necessary in other error correction models (Shin et al. 2014).

By using the NARDL approach, we noticed asymmetric effects with some macro determinants of exchange rate in the short-run. The micro determinant of exchange rate though observed to significantly influence the exchange rate only in the short-run, its asymmetric effects could not be ascertained due to technical constraints. Other variables like capital control and EPU index reported significant effects in few instances, with asymmetry observed only for EPU index in the long-run. Our hybrid model with micro and macro determinants of exchange rate upholds the relevance of short-run, and makes an important contribution to the literature by suggesting that the incorporated variables play crucial roles in determining exchange rates, especially when they are effectively incorporated into a model.

The current study also attempts to compare the out-of-sample forecasting accuracy of the modified model of Kouri (1983) with the Random Walk Model (RWM). The findings indicate that the modified model outperforms the RWM when predicting outcomes for all the forecast horizons considered. Thus, our modification identifies a robust model of exchange rate determination which can reliably be used for forecasting purposes.

The rest of the paper is organized as follows. In Sect. 2, we briefly discuss the reason for analyzing the bilateral exchange rate between India and the US, employing Kouri's (1983) PBM. The theoretical foundation of our model is developed in Sect. 3, where we also discuss all the relevant literature. The econometric methods are discussed in Sect. 4. Section 5 lists the secondary sources of data used for the analysis. We provide and analyze the study's findings in Sect. 6. Section 7 summarizes and concludes the paper.

The Indian Scenario and Kouri's (1983) Model

The movement of the relative interest rate, capital flows, and exchange rate of India with respect to the US can validate the use of Kouri's (1983) PBM in the current study.

As per Fig. 1, the US has recorded real interest rates below Indian rates for most of the period observed. Accompanying this behavior is a rising trend in net capital flows into India, as demonstrated in Fig. 2. A rise in capital inflows into India should cause the Indian rupee to appreciate, which, however, is not evident from Fig. 3. Thus, it is difficult to establish a direct association between interest rate differentials and exchange rate movements. Multiple factors may have contributed towards

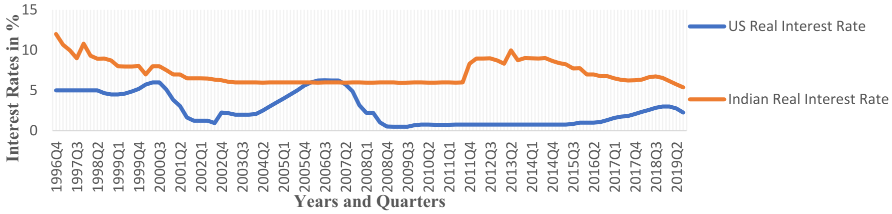

Fig. 1 Real Interest Rates of India and the US

Fig. 2 Net Capital Flows

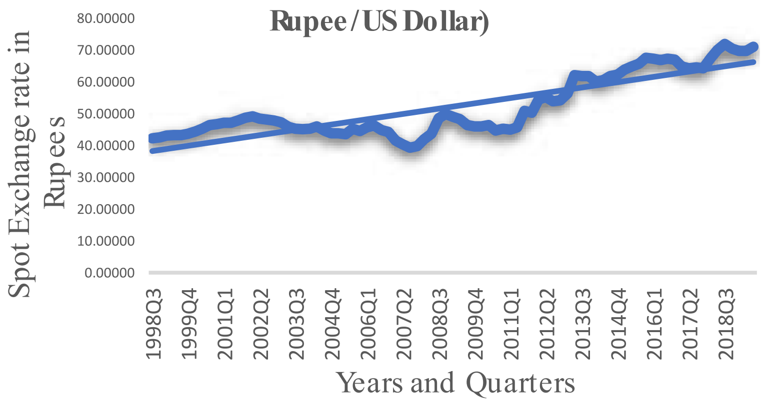

Fig. 3 Spot Exchange Rate (Indian rupee/US dollar)

the observed exchange rate movement in India, and the PBM of Kouri (1983) by identifying the role of current and capital accounts, provide a framework for analyzing how different factors (including interest rates) may have influenced the exchange rate changes.

Theoretical Framework and Discussion of Relevant Literatures

Kouri (1983) has emphasized the role of current and capital account in determining the exchange rate both in the short and the long-runs by highlighting the role of expectations.[1]

According to Kouri (1983), when expectations are stationary, the short-run exchange rate is determined by the interactions in the asset market (representing capital account transactions) only, as illustrated in Fig. 4.

In Fig. 4, net foreign currency holdings are measured along the horizontal axis and the exchange rate is measured along the vertical axis. The downward sloping FF curve represents the stock demand for foreign currency while, the upward rising GG curve represents the stock supply of foreign currency. The demand for foreign

[1] For a detailed analysis of the model, one can refer to Kouri (1983).

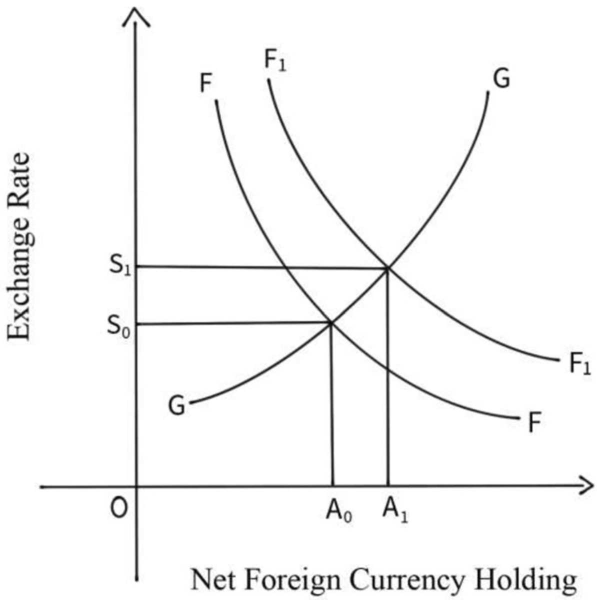

Fig. 4 Short-run Equilibrium of Kouri (1983) under Stationary Expectations

currency is driven by domestic investors seeking more foreign assets, while the supply of foreign currency originates from foreign investors' interest in domestic assets. The equilibrium in the short-run is achieved at the exchange rate S_0. At S_0, net foreign currency holding is OA_0. Any point above S_0 will lead to excess supply of foreign currency, resulting in appreciation of domestic currency to S_0, and vice-versa. If the domestic investor wants to increase their holding of foreign assets, it will lead to a shift in the FF schedule to F_1F_1. Given the increase in demand for foreign assets, the short-run equilibrium will now be achieved at S_1, i.e., the domestic currency will depreciate from S_0 to S_1. At S_1, net foreign currency holding is OA_1.

The role of current account in the stationary expectations model is highlighted by Kouri (1983) in the long-run. Kouri (1983) made two assumptions before investigating the model: that there is no economic inflation and that all interest income from foreign assets is spent on imports. The first assumption implies that the current account is zero in the long-run. The second assumption implies that the current account is independent of the changes in the international investments. Given these two assumptions, Kouri (1983) stated that the current account is an increasing function of the exchange rate, as represented by the BB schedule in Fig. 5A.

Figure 5A reveals that at S_0 the current account is in surplus by the amount C_0, while at S_4 current account is in deficit by C_1. The current account is balanced at S_1, representing the long-run equilibrium exchange rate.

According to Kouri (1983), the stock of foreign assets would change in response to current account deficit or surplus. Thus, in Fig. 5B, if the short-run equilibrium is achieved at A_0 with exchange rate S_0 due to increase in demand for foreign assets, the corresponding current account surplus from Fig. 5A will cause stock of foreign

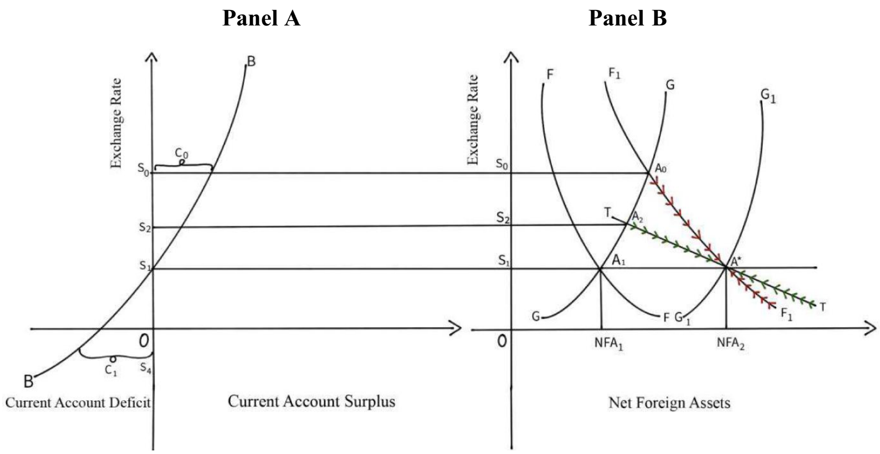

Fig. 5 Dynamic Partial Equilibrium of Kouri (1983)

assets to increase, inducing a movement down along the F_1F_1 schedule. The resulting fall in current account surplus must be matched by foreign capital inflow (represented by shift of GG curve to G_1G_1) to restore BOP equilibrium. Thus, the long-run equilibrium will be achieved at A^* with the exchange rate S_1, where both the current and capital accounts are in balance.

Hence it follows, given the short-run equilibrium exchange rate S_0, the exchange rate per unit of time must change in such a way as to equilibrate the current account with marginal net outflow of capital (Kouri 1983). This is known as the dynamic balance of payment condition. From the dynamic balance of payment condition, the expression of acceleration hypothesis is derived which states that the rate of change in the exchange rate is determined by the ratio of the current account to the sum of domestic holding of foreign assets and foreign holding of domestic assets.

The preceding discussions thus illustrates, with stationary expectations, the short-run exchange rate is determined by the changes in demand and supply of foreign assets, or by transactions in the capital account only. The equilibrium exchange rate in the long-run is however determined by the interactions between the current and the capital account.

This distinction is however eradicated if rational expectations is assumed in the model. Rational expectations, also known as perfect foresight, is an expectations theory where individuals base their decisions on human rationality, the best available information in the market, and their past experiences. According to rational expectations, people on average will make the best guess about the future.

Hence in Fig. 5B, due to an anticipated increase in the demand for foreign assets by domestic investors in some future date, t, the exchange rate will not immediately depreciate to S_1 on F_1F_1 schedule. Instead, the investors will anticipate that although in the short-run the exchange rate is depreciating, it will be appreciating in the long-run due to current account effects. Therefore, the investors tend to change both the current account and capital account determinants in the short-run. As a result, the short-run equilibrium is attained at A_2 along the TT schedule with the exchange rate S_2. The TT schedule is hence, the rational expectations path. Thereafter, the exchange rate will continue to appreciate along the TT schedule, with corresponding changes in the foreign capital inflows, till the long-run equilibrium is achieved at A^*. When the increase in demand for foreign asset actually occurs at time T, there will be no effect on the exchange rate at all. Therefore, according to Kouri (1983), any changes in the short-run exchange rate will arise only as a result of current unanticipated events or anticipated future events. These changes will be influenced by the determinants of both the current account and the capital account. The determinants of current account are the past exchange rate, incomes and price levels of countries.[2] The determinants of capital account are the money supply and bonds of countries.

Following this notion, Branson (1984) and Diebold & Pauly (1988) developed a model where the exchange rate is a function of its own lagged values, relative money supply, relative price levels, and relative income of both countries. Branson (1984) and Diebold & Pauly (1988) suggested the use of relative values in the analysis to avoid the loss in degrees of freedom arising from the inclusion of several variables in the model. Also, we may conjecture that relative values offer a better comparative framework than absolute values. Diebold and Pauli (1988) however, refrained from including purchase and sale of bonds as a determinant of the capital account due to high degree of unreliability associated with data on bonds. Further they observed, separate inclusion of bonds need not be necessary as the interest income from bonds is a part of total income, and hence a determinant of current account balance.

Thus, following Diebold and Pauli (1988), the reduced form equation for exchange rate determination in the short-run can be given as:

$$e_t = f\left(e_{t-i}, \frac{M_t}{M_t^*}, \frac{P_t}{P_t^*}, \frac{Y_t}{Y_t^*},\right) + V_t \tag{1}$$

In Eq. (1), e_t represents the spot exchange rate. e_{t-i} represents the lagged exchange rate. M_t and M_t^* represent the money supply of the domestic and the foreign nations respectively. P_t and P_t^* represent the general price level of the domestic and the foreign nations respectively. Y_t and Y_t^* represent the gross domestic product or income of the domestic and the foreign nations respectively. v_t represents the random error term.

It is evident from the above discussion that Kouri's (1983) model depends on macroeconomic fundamentals to explain exchange rate movements but overlooks the role of microeconomic factors. In response, Evans and Lyons (2002) developed the microstructure theory of exchange rate determination, which incorporates both microeconomic and macroeconomic factors in explaining exchange rate dynamics.

[2] The current account is a function of past or lagged exchange rate and not current exchange rate because any current events does not affect the current exchange rate under rational expectation. Moreover, according to the definition of rational expectations, people make expectations about the future based on all the available information. Now, as the past exchange rate incorporates information about the stochastic elements of the previous year, lagged values of the exchange rate need to be considered.

The key determinants of microstructure approach are (1) order flows, (2) bid-ask spreads, and (3) turnover in the foreign exchange market (Moosa & Bhatti 2010). (1) Order flow is the cumulative flow of transactions, which can be positive or negative depending on whether participants in the foreign exchange market are buying or selling when the foreign exchange transaction is first initiated. Order flow represents only actual signed transactions undertaken in the foreign exchange market. It does not consider booking and cancellation of foreign currency in the foreign exchange market (Moosa and Bhatti 2010). The order flow reflects the beliefs and preferences of the investors in the sense that if a large number of traders believe that a particular currency will appreciate, they are likely to buy that currency, leading to positive order flows. Conversely, if they anticipate depreciation, they might sell, resulting in negative order flows. Thus, aggregate beliefs and preferences drive the direction and magnitude of order flows in the foreign exchange market. (2) The bid-ask spread is the difference between the highest price a buyer is willing to pay for an asset (the bid price) and the lowest price a seller is willing to accept (the ask or offer price). Traders' beliefs about future currency movements can affect their willingness to trade and their risk perceptions. If traders are uncertain or expect high volatility, they may demand a larger bid-ask spread as compensation for the risk, leading to a wider spread. On the other hand, if traders have strong, shared beliefs about a currency's future value, they might be more willing to trade at narrower spreads, reducing the bid-ask spread. (3) Turnover, in contrast, serves as a broader gauge of trading activity in the foreign exchange market. It includes all transactions related to buying, selling, booking, and cancelling foreign currencies or related instruments, hence representing order flows (Dua & Ranjan 2010). Turnover also offers insight into the bid-ask spread, as higher trading volumes generally lead to a narrower spread. This is because increased trading activity lowers transaction costs and reduces disparities in knowledge and inventory holdings among market participants (Dua & Ranjan 2010). If market participants are actively buying and selling based on their beliefs and preferences, turnover increases. Conversely, low turnover might indicate a lack of strong convictions or preferences among traders.

The microstructure approach acknowledges that macroeconomic fundamentals still play a crucial role in determining exchange rates (Evans & Lyons 2002). Reflecting on this perspective, Evans and Lyons (2002) developed a hybrid model that combines interest rate differentials to represent macroeconomic factors and order flows to capture microeconomic influences on exchange rate fluctuations. However, their model has been critiqued as incomplete because it does not explicitly address all macroeconomic fundamentals, such as changes in income, money supply, and money demand (Moosa & Bhatti 2010). Hence, in this paper, recognizing the significance of both macroeconomic and microeconomic factors in determining the exchange rate, the PBM of Kouri (1983) and its representation by Diebold and Pauli (1988) is modified to incorporate microstructure theory. The determinants of exchange rate in the PBM of Kouri (1983) will signify macroeconomic fundamentals, while turnover in the foreign exchange market of India, being a more comprehensive measure of microstructure approach, will determine microeconomic fundamentals.[3]

Before proceeding with the estimation of the modified model, the existing exchange rate regime in India must be taken into account. The exchange rate in India is determined mainly by the market forces, but with careful intervention and monitoring of the RBI (Dua & Ranjan 2010). RBI intervenes in the Indian economy to reduce volatility from sudden surges or deficits in capital flows. As evident from Figs. 1 and 2 in Sect. 2, an interest differential between India and the US, is accompanied by rising capital inflows into India. But a sudden surge in the capital inflows will increase the supply of foreign currency, leading to an appreciation of the Indian rupee. Appreciation however is not preferred in a developing country like India, as appreciation may reduce exports and enhance imports, thus, creating a deflationary situation in the economy. Hence, to avoid such a scenario, RBI carries out sterilized intervention by capping the government securities and corporate bonds, to subdue the effects of capital inflows on the exchange rate (Raj et al. 2018). Such sterilized intervention may partly explain the unexpected movement in exchange rate in Fig. 3 in Sect. 2, and hence need to be considered in the current study by means of a variable on capital control of India.[4]

Given the assumption of imperfect substitutability between domestic and foreign assets, and the associated risks with foreign investments, the Economic Policy Uncertainty (EPU) Index of the US developed by Baker et al., (2016) is incorporated into the modified model to assess the effect of risk premium on changes in exchange rate between Indian Rupee and US Dollar. The EPU Index plays a crucial role in determining exchange rates by influencing investor sentiment and confidence. A high EPU Index value for the US indicates greater uncertainty regarding its economic policies, which can lead to reduced investor confidence and capital outflows from the US, thus affecting the exchange rate. Increased policy uncertainty of the US can also affect expectations about future economic conditions and interest rates, further impacting the exchange rate as market participants adjust their positions based on these expectations. Thus, the EPU Index serves as a significant indicator of exchange rate movements by reflecting the overall economic policy landscape and its associated risks. The use of EPU Index as a determinant of exchange rate is supported by Beckmann & Czudaj (2017), Kido (2016), Li et al., (2020) and Simran & Sharma (2024).

The model to be finally considered for analysis in this paper, is thus represented by the reduced form Eq. (2) determining the bilateral exchange rate between India and the US:

[3] The use of turnover is supported by Berger et al. (2008), and Dua & Ranjan (2010).

[4] Variable on capital control of India is constructed by following Fernandez et al. (2016). Based on IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER), Fernandez et al. (2016) presents capital control restrictions on both inflows and outflows for 100 countries between 1995 and 2019.

$$e_t = f\left(e_{t-i}, \frac{M_t}{M_t^*}, \frac{P_t}{P_t^*}, \frac{Y_t}{Y_t^*}, MB_t, CC_t, EPU_t\right) + W_t. \quad (2)$$

Here, MB_t represents the turnover in the foreign exchange market of India. CC_t represents the capital control variable of India. EPU_t represents the Economic Policy Uncertainty Index of the US. Wt represents the random error term.

If the lagged exchange rate (e_{t-i}) depreciates i.e., it increases, there will be an excess supply in the asset market and simultaneous current account surplus leading to appreciation of the exchange rate in the short-run. In the long-run however, the lagged exchange rate does not affect the current exchange rate, as with rational expectations, the stochastic element present in the lagged exchange rate will be eventually anticipated by the investors. Therefore, the effect of lagged value of the exchange rate is not included in our long-run analysis.

An increase in the Indian money supply (M_t) will induce a current account deficit on one hand and an increase in demand for foreign assets on the other. In both the cases, exchange rate will depreciate in the short-run. In the long-run, however, the ultimate effect on the exchange rate will depend upon the relative strength of current account deficit and the excess demand for foreign asset. Similar impacts on the US economy will arise from an increase in the US money supply (M_t^*). As a result, the changes in relative money supply ($\frac{M_t}{M_t^*}$) may have a dual impact on the exchange rate, both in the short-run and in the long-run.

An increase in Indian income (Y_t) will also induce a current account deficit and an increase in demand for foreign assets. Therefore, the effects of an increase in domestic income in both short and long-runs can be analyzed in a manner similar to the increase in domestic money supply. Similar repercussions on the US economy will result from an increase in the US income (Y_t^*). Therefore, the exchange rate's response to the relative income ($\frac{Y_t}{Y_t^*}$) may likewise be dual in both short and long-runs.

An increase in the Indian price level (P_t) will increase the demand for imports given the exports, and therefore a current account deficit in the domestic economy. This will result in immediate depreciation of the Indian Rupee vis-à-vis US Dollar in the short-run. As the price level does not affect the asset market, given the current account deficit, the exchange rate will depreciate in the long-run as well to maintain the acceleration hypothesis. An increase in the US price level (P_t^*) will have similar effects on the US economy. Hence, the effect of relative price level ($\frac{P_t}{P_t^*}$) on the exchange rate could also be dual in both short and long-runs.

The exchange rate may rise or fall in response to an increase in turnover in the foreign exchange market of India (MB_t). An increase in the sale of foreign currency will cause the Indian Rupee to appreciate, while an increase in the purchase of foreign currency will cause the Indian Rupee to depreciate. The short-run exchange rate will be determined by the relative strength of foreign currency purchases compared to sales. However, in the long-run, the exchange rate is expected to appreciate if a current account surplus occurs as a result of higher purchases of foreign currency compared to sales in the short-run, and vice versa.

The demand for and supply of foreign currency would decline if RBI tightens controls on capital inflows and outflows (CC_t). A currency will depreciate (appreciate) if the decline in supply outweighs (falls behind) the decline in demand. The consequent impact on the exchange rate will thus depend on the relative fall in the supply and demand for foreign currency in the short-run. In the long-run as well, exchange rate will appreciate if the fall in the supply outweighs the demand for foreign assets in the short-run, and vice versa.

The value of the EPU Index (EPU_t) will rise with an increase in risk perception or economic uncertainty in the US. This heightened uncertainty can lead Indian investors to become more cautious, reducing their demand for US Dollar as they hesitate to invest in US markets. Simultaneously, uncertainty in US markets may reduce income of the US investors. As the US markets underperform due to economic instability, US investors earn lower profits or may even incur losses. Consequently, with reduced income, US investors have less capital to invest in Indian assets, which decreases the supply of US Dollar into India. If the decrease in demand for US Dollar is greater (lesser) than the decrease in supply, the Indian currency will appreciate (depreciate) in the short-run. In the long-run, the exchange rate will appreciate if the decline in the supply of US Dollar outweigh the decline in demand in the short-run, and vice versa.

Econometric Methods

For analysis, the variables are transformed using natural logarithms to stabilize variance and achieve a more normal distribution. This enhances the reliability and interpretability of the model results. Additionally, to mitigate the impact of seasonality and prevent spurious correlations, the variables are seasonally adjusted using the moving average method in EViews before estimating the model.

To determine the order of integration of the variables, we use the Augmented Dickey–Fuller (ADF) Test. If the variables are integrated of mixed orders i.e., of orders 0 and 1, then the NARDL model will provide the best fit (Simran & Sharma 2024). However, this model will not be applicable if any of the variables are integrated of order 2. In the current study, we employ the NARDL technique since we found our variables to be integrated of orders 0 and 1.[5]

As discussed in Section I, the NARDL technique separately considers the effects of positive and negative shocks of the exogenous variable to analyse the dependent variable. Based on this approach, Shin et al. (2014) developed a long-run non-linear regression equation, as represented by Eq. (3):

$$
\begin{aligned}
\ln(e_t) = {} & \pi_0 + \pi_1{}^{+}\ln\left(\frac{M_t}{M_t^*}\right)^{+} + \pi_1{}^{-}\ln\left(\frac{M_t}{M_t^*}\right)^{-} + \pi_2{}^{+}\ln\left(\frac{Y_t}{Y_t^*}\right)^{+} + \pi_2{}^{-}\ln\left(\frac{Y_t}{Y_t^*}\right)^{-} \\
& + \pi_3{}^{+}\ln\left(\frac{P_t}{P_t^*}\right)^{+} + \pi_3{}^{-}\ln\left(\frac{P_t}{P_t^*}\right)^{-} + \pi_4{}^{+}\ln(MB_t)^{+} + \pi_4{}^{-}\ln(MB_t)^{-} + \pi_5{}^{+}\ln(CC_t)^{+} \\
& + \pi_5{}^{-}\ln(CC_t)^{-} + \pi_6{}^{+}\ln(EPU_t)^{+} + \pi_6{}^{-}\ln(EPU_t)^{-} + \varepsilon_{1t}
\end{aligned}
\tag{3}
$$

[5] The results for the ADF test are reported in the Appendix, Table 6.

In Eq. (3), the independent variables are decomposed into their partial sums of positive and negative changes to obtain the asymmetric long-run equilibrium i.e.,

$$\ln\left(\frac{M_t}{M_t^*}\right) = \ln\left(\frac{M_t}{M_t^*}\right)^+ + \ln\left(\frac{M_t}{M_t^*}\right)^- \tag{4}$$

$$\ln\left(\frac{Y_t}{Y_t^*}\right) = \ln\left(\frac{Y_t}{Y_t^*}\right)^+ + \ln\left(\frac{Y_t}{Y_t^*}\right)^- \tag{5}$$

$$\ln\left(\frac{P_t}{P_t^*}\right) = \ln\left(\frac{P_t}{P_t^*}\right)^+ + \ln\left(\frac{P_t}{P_t^*}\right)^-. \tag{6}$$

$$\ln\left(MB_t\right) = \ln\left(MB_t\right)^+ + \ln\left(MB_t\right)^-. \tag{7}$$

$$\ln\left(CC_t\right) = \ln\left(CC_t\right)^+ + \ln\left(CC_t\right)^-. \tag{8}$$

$$\ln\left(EPU_t\right) = \ln\left(EPU_t\right)^+ + \ln\left(EPU_t\right)^-. \tag{9}$$

In Eq. (3), $\pi_1{}^+$, $\pi_1{}^-$, $\pi_2{}^+$, $\pi_2{}^-$, $\pi_3{}^+$, $\pi_3{}^-$, $\pi_4{}^+$, $\pi_4{}^-$, $\pi_5{}^+$, $\pi_5{}^-$, $\pi_6{}^+$, $\pi_6{}^-$ represent the asymmetric long-run parameters. ln(.) represents the logarithmic operator. ε_{1t} is the disturbance term representing unobserved factors that affect the exchange rate, but are not accounted for by the included variables. The other variables in the model have been explained in the previous section.

Equation (3) when combined with the unrestricted linear ARDL (p, q) specification, allows us to obtain a general form of the NARDL model. The following general form of the model is used to study both the long-run and the short-run association of the variables:

$$\begin{aligned}\Delta\ln(e_t) =& \beta_0 + \beta_1\ln(e_{t-1}) + \beta_2^+\ln\left(\frac{M_t}{M_t^*}\right)^+ + \beta_2^-\ln\left(\frac{M_t}{M_t^*}\right)^- + \beta_3^+\ln\left(\frac{Y_t}{Y_t^*}\right)^+ + \beta_3^-\ln\left(\frac{Y_t}{Y_t^*}\right)^- + \beta_4^+\ln\left(\frac{P_t}{P_t^*}\right)^+\\ &+ \beta_4^-\ln\left(\frac{P_t}{P_t^*}\right)^- + \beta_5^+\ln\left(MB_t\right)^+ + \beta_5^-\ln\left(MB_t\right)^- + \beta_6^+\ln\left(CC_t\right)^+ + \beta_6^-\ln\left(CC_t\right)^-\\ &+ \beta_7^+\ln\left(EPU_t\right)^+ + \beta_7^-\ln\left(EPU_t\right)^- + \sum_{i=1}^{p}\tau_{1i}\Delta\ln(e_{t-i}) + \sum_{i=0}^{q_1}\tau_{2i}^+\Delta\ln\left(\frac{M_{t-i}}{M_{t-i}^*}\right)^+ + \sum_{i=0}^{q_2}\tau_{2i}^-\Delta\ln\left(\frac{M_{t-i}}{M_{t-i}^*}\right)^-\\ &+ \sum_{i=0}^{q_3}\tau_{3i}^+\Delta\ln\left(\frac{Y_{t-i}}{Y_{t-i}^*}\right)^+ + \sum_{i=0}^{q_4}\tau_{3i}^-\Delta\ln\left(\frac{Y_{t-i}}{Y_{t-i}^*}\right)^- + \sum_{i=0}^{q_5}\tau_{4i}^+\Delta\ln\left(\frac{P_{t-i}}{P_{t-i}^*}\right)^+ + \sum_{i=0}^{q_6}\tau_{4i}^-\Delta\ln\left(\frac{P_{t-i}}{P_{t-i}^*}\right)^- + \sum_{i=0}^{q_7}\tau_{5i}^+\Delta\ln(MB_{t-i})^+\\ &+ \sum_{i=0}^{q_8}\tau_{5i}^-\Delta\ln(MB_{t-i})^- + \sum_{i=0}^{q_9}\tau_{6i}^+\Delta\ln(CC_{t-i})^+ + \sum_{i=0}^{q_{10}}\tau_{6i}^-\Delta\ln(CC_{t-i})^- + \sum_{i=0}^{q_{11}}\tau_{7i}^+\Delta\ln(EPU_{t-i})^+ + \sum_{i=0}^{q_{12}}\tau_{7i}^-\Delta\ln(EPU_{t-i})^- + \varepsilon_{2t}\end{aligned} \tag{10}$$

In Eq. (10), Δ represents the difference operator. The lag length of the dependent variable is represented by p, while $q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10}, q_{11}$ and q_{12} represent the lag lengths of the independent variables. The lag lengths of the dependent and the independent variables in the current study are selected by means of Bayesian Information Criterion (BIC). BIC is a statistical measure that balances the goodness of fit of the model with its complexity. The lag length that minimizes the BIC is selected as the optimal lag length. According to Pesaran and Shin (1999), BIC performs better than the Akaike Information Criterion (AIC) when the sample size is small, which is the case in the current study. Our lag selection criteria report an NARDL (2, 2, 3, 1, 1, 0, 0, 1, 0, 1, 0, 0, 1) model suitable for analysis. Thus, we consider 2 lags for the exchange rate, 2 lags for the partial sums of positive relative money supply, 3 lags for the partial sums of negative relative money supply, 1 lag each for the partial sums of positive and relative income, 0 lag each for partial sums of positive and negative relative price level, 1 lag for partial sum of positive turnover in the foreign exchange market of India, 0 lag for partial sum of negative turnover in the foreign exchange market of India, 1 lag for partial sum of positive capital control variable of India, 0 lag for partial sum of negative capital control variable of India, 0 lag for partial sum of positive EPU Index of the US and 1 lag for partial sum of negative EPU Index of the US. ε_{2t} is the disturbance term.

In Eq. (10), β_2^+, β_2^-, β_3^+, β_3^-, β_4^+, β_4^-, β_5^+, β_5^-, β_6^+, β_6^-, β_7^+, β_7^- are the long-run parameters of the model. The coefficients of the differenced variables i.e., $\tau_{1i}, \tau_{2i}^+, \tau_{2i}^-, \tau_{3i}^+, \tau_{3i}^-, \tau_{4i}^+, \tau_{4i}^-, \tau_{5i}^+, \tau_{5i}^-, \tau_{6i}^+, \tau_{6i}^-, \tau_{7i}^+, \tau_{7i}^-$ represent the short-run parameters of the model.

Equation (10) also permits the examination of cointegration relationships of variables. Cointegrated variables suggest existence of a long-run relationship among them. The Bounds Tests for Cointegration is used for this purpose. After estimating Eq. (10), we test the null hypothesis that there is no cointegration among the variables using F-bounds and t-bounds tests. The F-bounds test is a statistical test that evaluates the joint significance of the coefficients on the one-period lagged levels of the variables, while the t-bounds test used to evaluate the significance of the coefficients on the lagged values of the dependent variable, (Narayan 2005). At a particular significance level, Shin et al. (2014) proposed two sets of critical values for the test, identified as upper and lower bounds. The lower bound assumes that all variables in the NARDL model are integrated of order 0. The upper bound assumes they are integrated of order 1. If the absolute values of the F and t statistics are lower than the lower bound, we cannot reject the null hypothesis, indicating no cointegration between the variables. If the values are higher than the upper bound, we can reject the null hypothesis and confirm the presence of cointegration. If the values fall between the lower and upper bounds, the results are inconclusive. Our Bounds test result reports the presence of cointegration among the variables.[6]

The short-run association amongst the variables is represented by Eq. (11), which includes the short-run parameters to be estimated and an Error Correction Term (ECT). The co-efficient of $ECT_{t-1}(\tau_8)$ is the speed of adjustment, which assesses how quickly the exchange rate returns to its long-run equilibrium value. τ_8 must be negative and significant to ensure a long-run convergence of the variables. The log transformation of variables enables us to assess the elasticity of exchange rate due to changes in independent variables. ε_{3t} is the disturbance term.

[6] Result of bounds test is reported in the Appendix, Table 7.

$$\begin{aligned}\Delta \ln(e_t) =& \tau_0 + \sum_{i=1}^{2} \tau_{1i}\Delta \ln(e_{t-i}) + \sum_{i=0}^{2} \tau_{2i}^{+}\Delta \ln\left(\frac{M_{t-i}}{M_{t-i}^{*}}\right)^{+} \\ &+ \sum_{i=0}^{3} \tau_{2i}^{-}\Delta \ln\left(\frac{M_{t-i}}{M_{t-i}^{*}}\right)^{-} + \sum_{i=0}^{1} \tau_{3i}^{+}\Delta \ln\left(\frac{Y_{t-i}}{Y_{t-i}^{*}}\right)^{+} + \sum_{i=0}^{1} \tau_{3i}^{-}\Delta \ln\left(\frac{Y_{t-i}}{Y_{t-i}^{*}}\right)^{-} \\ &+ \sum_{i=0}^{0} \tau_{4i}^{+}\Delta \ln\left(\frac{P_{t-i}}{P_{t-i}^{*}}\right)^{+} + \sum_{i=0}^{0} \tau_{4i}^{-}\Delta \ln\left(\frac{P_{t-i}}{P_{t-i}^{*}}\right)^{-} + \sum_{i=0}^{1} \tau_{5i}^{+}\Delta \ln(MB_{t-i})^{+} \\ &+ \sum_{i=0}^{0} \tau_{5i}^{-}\Delta \ln(MB_{t-i})^{-} + \sum_{i=0}^{1} \tau_{6i}^{+}\Delta \ln(CC_{t-i})^{+} + \sum_{i=0}^{0} \tau_{6i}^{-}\Delta \ln(CC_{t-i})^{-} \\ &+ \sum_{i=0}^{0} \tau_{7i}^{+}\Delta \ln(EPU_{t-i})^{+} + \sum_{i=0}^{1} \tau_{7i}^{-}\Delta \ln(EPU_{t-i})^{-} + \tau_8 \mathrm{ECT}_{t-1} + \varepsilon_{3t}\end{aligned} \tag{11}$$

To account for any heteroscedasticity and autocorrelation in the data, the model is estimated with a robust estimate of standard errors. We then test for the presence of autocorrelation, stability of the model, and the normality of the residuals using the Breusch–Godfrey LM test, Cumulative Sum of Squares of Recursive Residuals (CUSUMQ) Test, and Jarque–Bera Normality Test respectively. The current study also checked for the endogeneity of the variables. Although Hemrit & Nakhli (2021) asserts that the NARDL model addresses the endogeneity of the regressors, we still apply the Ramsey RESET test to our model to confirm that there are no specification errors. Ramsey RESET test is a general test of specification errors that considers omitted variables, incorrect functional forms, and simultaneity issues while testing for specification errors (EViews 12, 2020). According to Shabbir et al. (2019), the degree of data differencing used in the ARDL model tends to decompose model residuals and eliminate multicollinearity. Since, NARDL is an extension of the ARDL model, therefore, we assume that our results are robust with respect to the presence of multicollinearity in our model.

After estimation of the model and verification of its robustness through comprehensive diagnostic checks, the study proceeds to evaluate its out-of-sample forecasting accuracy in comparison with the RWM with drift. The RWM with drift suggests that the most reliable forecast for the current exchange rate is the previous rate, adjusted by a constant drift term to capture any long-term trends, along with a random error component to account for short-term fluctuations (Gujarati & Porter 2009). This drift term is particularly relevant in this analysis due to the observed upward trend in the exchange rate, as illustrated in Fig. 3. The mathematical representation of the model is as follows:

$$\mathrm{x_t} = \theta + \mathrm{x_{t-1}} + \varepsilon_{4\mathrm{t}} \tag{12}$$

Here, $\mathrm{x_t}$ is the current exchange rate. $\mathrm{x_{t-1}}$ is the previous exchange rate. θ is the drift term. $\varepsilon_{4\mathrm{t}}$ is the random error term.

To rigorously assess the forecasting performance of the models, the dataset is divided into two distinct periods. The period from the second quarter of 1996 to third quarter of 2017 is employed for estimating the model. The forecasts are then generated for the subsequent period, spanning from the fourth quarter of 2017 to the third quarter of 2019. The study evaluates the forecasts over three different time horizons: 6 months, 1 year, and 2 years following Meese & Rogoff (1983). The choice of these time horizons reflects the need to assess the model's performance across short-term, medium-term, and long-term forecasting scenarios. By evaluating these horizons, the study aims to provide a comprehensive understanding of the model's robustness and reliability in predicting exchange rates over varying time frames.

Forecast accuracy of the models are measured using error metrics such as Root Mean Square Error (RMSE), Mean Squared Error (MSE), and Mean Absolute Error (MAE). These metrics, recommended by Meese & Rogoff (1983), Mark (1995), and Faust & Rogers (2003), are critical for determining how closely the model's predictions align with actual outcomes. Kouri's (1983) model will be considered to exhibit superior forecasting accuracy, if a comparison of these error metrics across Kouri's (1983) model and RWM reveals lower values from the former. Lower error values indicate that the modified Kouri's (1983) model provides more precise forecasts, thereby positioning it as a more reliable model for exchange rate prediction in this context.

The measures of MSE, MAE and RMSE are given in Eqs. (13), (14) and (15) respectively:

$$\mathrm{MSE} = \sum_{i=1}^{n} \frac{\left(x_i - \widehat{x}_i\right)^2}{n} \tag{13}$$

$$\mathrm{MAE} = \sum_{i=1}^{n} \frac{\left|x_i - \widehat{x}_i\right|}{n} \tag{14}$$

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} \tag{15}$$

Here, x_i represent actual value of the exchange rate. $\widehat{x}_i$ represent the predicted value of the exchange rate. n is the number of observations.

Data

The study uses quarterly time series data from 1996Q2 to 2019Q3. To construct the variables required for the analysis, the necessary data have been collected from various sources, a summary of which is presented in Table 1.

The trends in relative money supply, relative income, relative price level, turnover in the foreign exchange market of India, capital control of India and the EPU index of the US, over the observed period, can be determined from the following figures (Figs. 6, 7, 8, 9, 10, 11).

Table 1 Summary of data sources

Variable	Definition	Source
e_t	Indian rupee/US dollar spot exchange rate	Handbook of statistics published by RBI
M_t	Money supply of India (M3)	Federal reserve economic data (FRED)
M_t^*	Money supply of the US (M3)	FRED
Y_t	Gross domestic product of India at current prices	FRED
Y_t^*	Gross domestic product of the US at current prices	FRED
P_t	Consumer Price Index of India (Base Year = 2015)	FRED
P_t^*	Consumer Price Index of the US (Base Year = 2015)	FRED
MB_t	Turnover in the foreign exchange market of India	Handbook of statistics published by RBI
CC_t	Capital control variable of India	FKRSU dataset prepared by Fernandez et al. (2016)
EPU_t	Economic policy uncertainty of the US	Dataset prepared by Baker et al. (2016)

An increasing trend in relative money supply, relative price level and turnover in the foreign exchange market of India are evident from the Figs. 6, 8 and 9. Relative income and the EPU index of the US in Figs. 7 and 11, do not represent any steadily rising or declining trends. The movement of capital control of India is determined by the availability of annual data.[7]

Results and Discussion

Table 2 displays the estimated short-run and the long-run coefficients with associated p values from the considered NARDL model.

The short-run and long-run results reported in Table 2, are discussed in Subsects. 6.1 and 6.2 respectively.

Discussions on Short-Run Results

The speed of adjustment parameter coefficient, ECT(− 1) is significant at the 1% level and negative, indicating the presence of a long-run relationship among the variables. The value of the coefficient for ECT(− 1) is − 0.285, which suggests that at least 28.5% of the deviations from equilibrium caused by shocks in the previous quarter will be corrected, causing the model to return back to the equilibrium in the current quarter.

[7] The values are same for every quarter in a year when quarterly data are calculated from annual data using frequency changing method in EViews.

Table 2 The estimated short-run and the long-run coefficients

Variable	Co-efficient	P value
Short-run estimates		
c	1.0269***	< 0.001
$\Delta\ln\left(e_{t-1}\right)$	− 0.2138***	0.0001
$\Delta\ln\left(\frac{M_t}{M_t^*}\right)^+$	− 0.3217***	< 0.001
$\Delta\ln\left(\frac{M_{t-1}}{M_{t-1}^*}\right)^+$	− 0.3389***	< 0.001
$\Delta\ln\left(\frac{M_t}{M_t^*}\right)^-$	− 0.4014***	< 0.001
$\Delta\ln\left(\frac{M_{t-1}}{M_{t-1}^*}\right)^-$	− 0.2708***	0.0002
$\Delta\ln\left(\frac{M_{t-2}}{M_{t-2}^*}\right)^-$	− 0.1353***	0.0025
$\Delta\ln\left(\frac{Y_t}{Y_t^*}\right)^+$	− 3.4283***	< 0.001
$\Delta\ln\left(\frac{Y_t}{Y_t^*}\right)^-$	− 5.5820***	< 0.001
	− 0.0334***	0.0027
	0.4283**	0.0411
$\Delta\ln\left(EPU_t\right)^-$	− 0.0008	0.2757
T(− 1)	− 0.2851***	< 0.001
Long-run estimates		
$\ln\left(\frac{M_t}{M_t^*}\right)^+$	− 0.2511	0.3358
	0.1689	0.6252
	− 1.8644	0.6062
$\ln\left(\frac{Y_t}{Y_t^*}\right)^-$	− 8.8334***	0.0005
	0.2836	0.1224
	0.0151	0.9787
$\ln\left(MB_t\right)^+$	− 0.0003	0.9959
$\ln\left(MB_t\right)^-$	0.0481	0.4798
$\ln\left(CC_t\right)^+$	− 2.1935*	0.0604
$\ln\left(CC_t\right)^-$	0.9349**	0.0283
	− 0.0107	0.7262
	− 0.1125*	0.0767

R-squared = 0.9608

Adjusted R-squared = 0.9547

F statistic = 157.4995 (p-value: < 0.001)

Jarque–Bera statistic = 1.471 (p-value: 0.479)

Note: *** Indicates significance at 1% level, ** indicates significance at 5% level and * indicates significance at 10% level. 90 observations are included after adjustments. Source: Authors' contribution

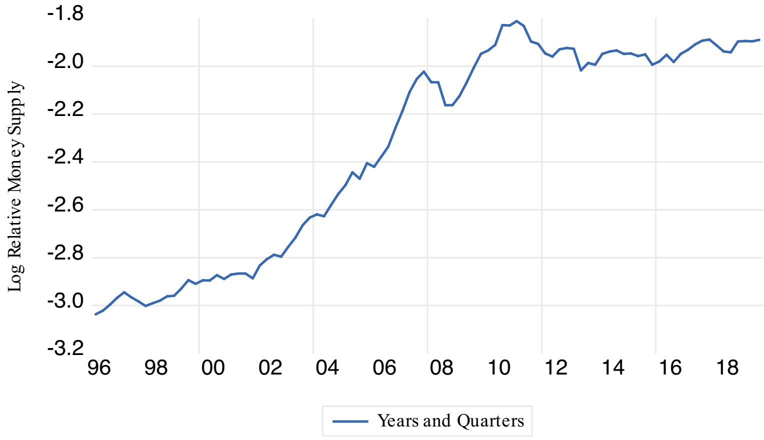

Fig. 6 Relative Money Supply of India and the US

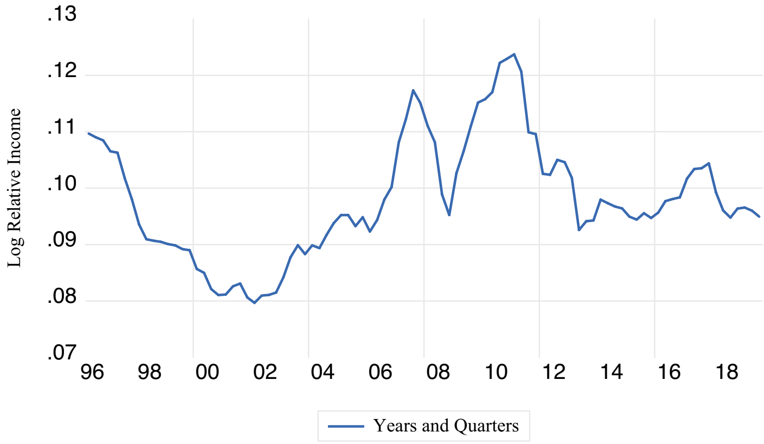

Fig. 7 Relative Income of India and the US

The coefficient for exchange rate demonstrates significance at the first lag, showing a negative association. This implies that a 1% increase in exchange rate changes from the previous period leads to a 0.21% appreciation in the short-run exchange rate.

The effects of positive shocks of relative money supply in the current period have negative effect on the exchange rate. This implies that as the relative money supply increases, the exchange rate appreciates. The negative significance of positive shocks of relative money supply may be intuitively explained by referring to the policy measures of the RBI. If there are sudden surges in capital inflows there is a tendency of the exchange rate to appreciate. Thus, to reduce the tendency of appreciation, RBI may intervene in the foreign exchange market by purchasing US Dollar and thereby, increasing the Indian money supply. But this increase in Indian money

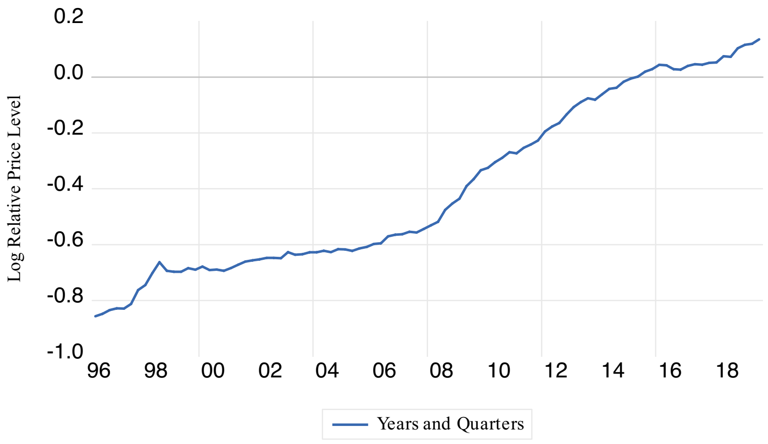

Fig. 8 Relative Price Level of India and the US

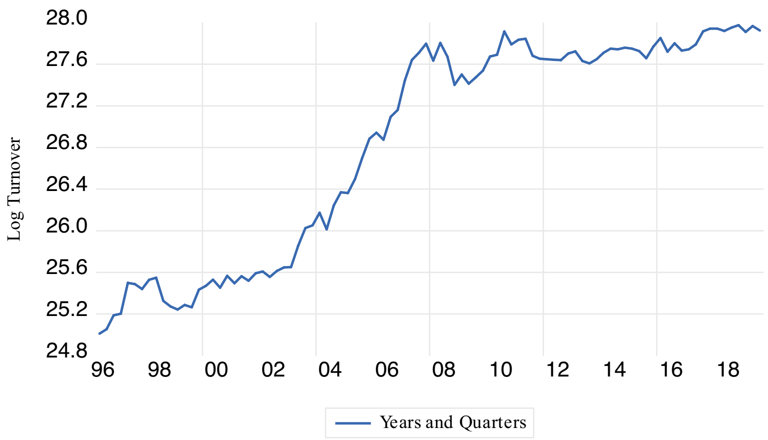

Fig. 9 Turnover in the Foreign Exchange Market of India

supply could result in inflationary pressure in the Indian economy. To counteract this, RBI may conduct open market sales of government securities to partially sterilize the excess money supply (Raj et al. 2018). Consequently, in the current period, even if there is an increase in the Indian money supply and a resultant increase in the relative money supply, the effect is partially nullified. Thus, the appreciation of the Indian Rupee in the current period is mainly driven by the increase in the US money supply, even if the increase in the US money supply is less than the increase in the Indian money supply. Positive shock from the previous period will also have the similar effect on the exchange rate. The effects of negative shocks of relative money supply on the exchange rate is also negative for its current period. This implies that when the relative money supply falls, the exchange rate rises, leading

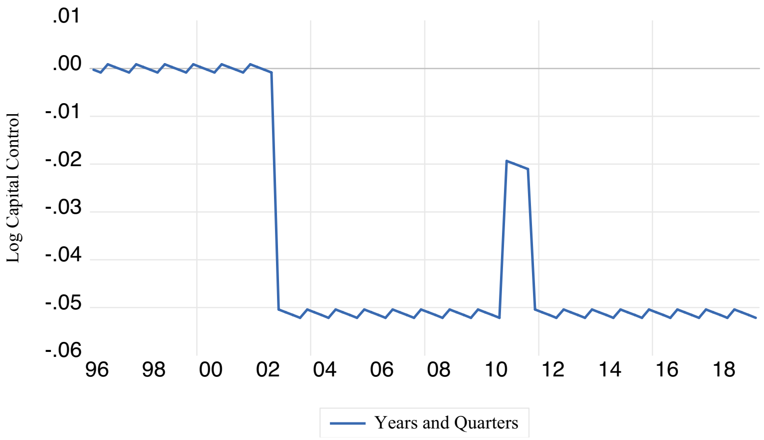

Fig. 10 Capital Control of India

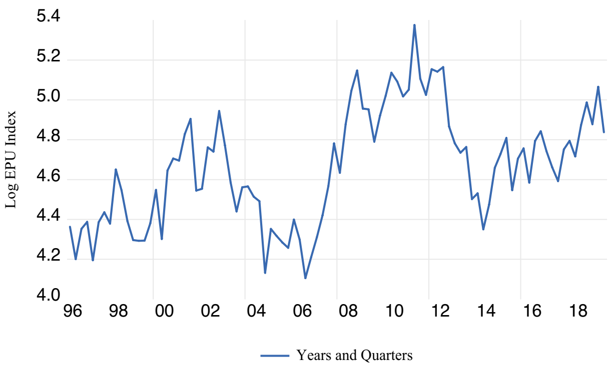

Fig. 11 EPU Index of the US

to a depreciation of the Indian Rupee. This could occur if there is a capital outflow, prompting the RBI to intervene by selling foreign currency, which decreases the Indian money supply. However, a reduction in the Indian money supply could lead to deflationary pressures in the Indian economy. To counteract this, the RBI might sterilize its intervention by open market purchase of government securities, partially offsetting the impact of reduced money supply. Consequently, even if there is a fall in the Indian money supply and a resultant decrease in the relative money supply, the effect is partially nullified. As a result, the depreciation of the Indian Rupee in the current period is mainly driven by a fall in the US money supply, even if the fall in the US money supply is less than the decrease in the Indian money supply. Negative shocks from the previous two periods will similarly affect exchange rate. Therefore, positive and negative shocks to the money supply have differing effects on the exchange rate.

Current positive and negative shocks of relative income negatively influence the exchange rate in the short-run generating differing effects on the exchange rate. The policy implications align with those related to money supply, given that an increase in money supply generally results in higher income and vice-versa.

The positive shocks of turnover in the foreign exchange market of India negatively influences the short-run exchange rate, suggesting an appreciation of Indian Rupee due to an increase in turnover. Hence, the sale of foreign currency outweighs the purchase of foreign currency in the short-run. The effects of negative shocks in turnover could not be assessed because the optimal lag lengths for these shocks were zero, which prevented their coefficients from being reported by EViews. However, the effect of negative shocks is indirectly reflected in the constant term of the model, which remains statistically significant. This implies that while positive turnover shocks have a clear and substantial effect on the exchange rate, the impact of negative shocks remains ambiguous and not precisely measurable within this context.

Positive shocks in capital control of India increase the exchange rate. Thus, reduction in the supply of foreign currency due to increased capital controls, outweighs the decrease in demand. The effects of negative shocks in capital control of India could not be assessed due to their zero optimal lag lengths, resulting in non-disclosure of their coefficients by EViews. Consequently, while positive capital control shocks have a distinct and significant impact on the exchange rate, the effects of negative shocks are less clear and not exclusively quantifiable in this context.

The effect of a positive shock of the EPU index of the US could not be ascertained due to its zero optimal lag length. The coefficient for negative shocks of the EPU index of the US is not statistically significant in the short-run.

EViews did not report the difference coefficients for positive and negative shocks of relative price-level due to their zero optimal lag lengths. Similar to other variables with unreported coefficients, their effects are reflected in the constant term, which is statistically significant.

Discussions on Long-Run Results

The effects of positive shocks of relative income on the long-run exchange rate are not found to be significant.[8] Negative shocks of relative income, on the other hand, negatively influences the exchange rate in the long-run i.e., as relative income falls, exchange rate depreciates in the long-run. This outcome suggests that changes in relative income in the short-run might have led to a current account deficit. To maintain the BOP in the long-run, this deficit must be reduced and the capital account surplus must increase following Fig. 5. As a result, the Indian Rupee depreciates in the long-run.

[8] Positive shocks in relative income were significant in the short-run but not in the long-run, possibly because such shocks mainly affect short-run dynamics, with their long-run impact fading as prices or wages adjust over time.

The other macroeconomic variables such as relative money supply and price levels are found to have no notable effects on exchange rates.[9] Thus contrary to expectations, macroeconomic variables have limited role in long-run. The coefficient for turnover in India's foreign exchange market is also not statistically significant confirming with the relevance of the variable in short-run.

The coefficient for positive shocks of capital control of India negatively influences the long-run exchange rate i.e., as capital control increases, the exchange rate appreciates in the long-run. This suggests that as the exchange rate depreciates in the short-run as a result of increase in capital control by the RBI (relevant from the short-run results), there may be current account surplus. To achieve the BOP equilibrium in the long-run, this surplus needs to decrease and the capital account surplus must rise following Fig. 5. Hence, the Indian Rupee will appreciate in the long-run. The coefficient for negative shocks of capital control of India positively affects the long-run exchange rate i.e., as capital control falls, exchange rate appreciates in the long-run. It could be because if the exchange rate depreciates in the short-run due to decrease in capital control by the RBI, there may be current account surplus and to maintain the BOP in the long-run, the appreciation of the Indian Rupee is witnessed in the long-run following Fig. 5. Thus, positive and negative shocks to capital control of India have uniform impacts on the long-run exchange rate as both results in long-run appreciation of the exchange rate.

The coefficient for positive shocks of the EPU index of the US is not significant. The coefficient for negative shocks of the EPU index is negatively significant implying that as EPU index decreases, the exchange rate depreciates in the long-run. Thus a decrease in the risk perception in the US economy may have led to a current account deficit in the short-run. To maintain the BOP in the long-run, this deficit must be reduced and the capital account surplus must decrease following Fig. 5. Hence, Indian Rupee will depreciate in the long-run.[10]

The error correction regression model is well-fitted, with R-squared and adjusted R-squared values around 96%. The overall model is significant at the 1% level, as reported by the F test. The Jarque–Bera statistic is not significant which implies that the residuals are normally distributed and thus, the inferences based on t and F statistics are reliable.

[9] The coefficients for positive and negative shocks in relative money supply were significant in the short-run but became insignificant in the long-run, likely because, as relative money supply is a policy-driven variable, investors eventually anticipate its effects under rational expectations. According to Kouri's (1983) rational expectations model, current and capital account transactions influence the exchange rate, therefore in the long-run, any price changes are already anticipated, leading to no noticeable impact of relative price changes on the exchange rate.

[10] In the short-run, the coefficient of positive shocks of the EPU index could not be ascertained while the coefficient of negative shocks of the EPU index of the US was not statistically significant, likely due to the influence of positive capital controls during this period. However, in the long-run, the coefficient of negative EPU index becomes significant, even with effective capital controls. With ongoing capital controls, the Indian economy may stabilize, making it more appealing to US investors. As risks in the US economy decrease (i.e., as the EPU index falls), US investors might seek opportunities in India despite the capital controls, which could account for the negatively significant coefficient for EPU index in the long-run.

Post Estimation Tests

As a part of post estimation tests, CUSUMQ test is performed to determine if the estimated model is stable. The CUSUMQ test result is presented in Fig. 12.

Based on the information presented in Fig. 12, it can be concluded that the estimated coefficients are stable. The stability of the estimated coefficients is indicated by the CUSUMQ statistic plot, which shows that the deviations of the actual data from its expected value fall within 5% confidence interval for parameter stability. As a result, if the model experiences any shocks, it can eventually return back to its equilibrium state. Thus, shocks will be absorbed by the model over time.

The model is also assessed for autocorrelation using the Breusch–Godfrey LM Test, and the findings are presented in Table 3.

According to the information presented in Table 3, there is no autocorrelation up to 3 lags. This is supported by the fact that both the F-statistic and the Chi-square statistic are not significant.

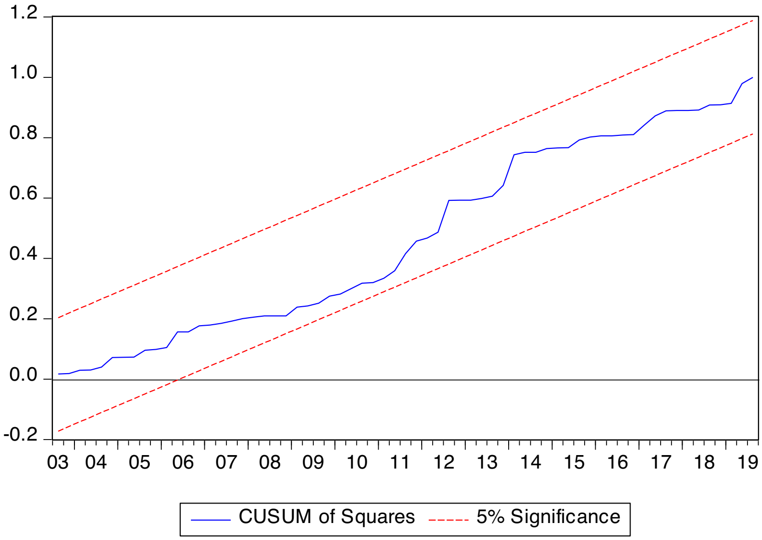

Fig. 12 CUSUMQ Test for Model Stability

Table 3 Breusch-Godfrey LM Test for Autocorrelation

Breusch–Godfrey LM Test for Autocorrelation			
Lags	F-statistic	p-value of F statistic	p-value of chi-square
1	0.4908	0.486	0.408
2	0.3455	0.709	0.614
3	0.5625	0.642	0.497

Null hypothesis: There is no autocorrelation upto lag 3. ***Indicates significance at 1% level, **indicates significance at 5% level and * indicates significance at 10% level. Source: Authors' contribution

Table 4 Ramsey RESET test

Ramsey RESET Test	Value	p value
t-statistic	0.3014	0.764
F-statistic	0.0908	0.764

Null hypothesis: There is no specification error. ***Indicates significance at 1% level, **indicates significance at 5% level and * indicates significance at 10% level. Source: Authors' contribution

We, then, use the Ramsey RESET test to assess the possibility of specification errors that could result in regressor endogeneity. Table 4 reports the outcome of this test.

Table 4 shows that the coefficients for t and F statistics are not significant, indicating that the model is correctly specified and does not have issues related to endogeneity.

Forecasting Results

Table 5 reports the forecasting accuracy metrics for the RWM and the modified Kouri's (1983) model across three different forecast horizons, specifically, at 6-months, 1-year, and 2-years.

It is evident from Table 5 that across all the forecast horizons, the modified Kouri (1983) model reports MSE, MAE, and RMSE lower than that reported by the RWM. Hence, the modified model of Kouri (1983) exhibits stronger forecasting capabilities in predicting exchange rates over 6-months, 1-year, and 2-years. The finding is a significant contribution to the existing literature involving the Meese and Rogoff puzzle.

Meese and Rogoff (1983) demonstrated that the exchange rate forecasts based on models such as Bilson's (1978) flexible-price monetary model, Dornbusch's (1976) sticky-price monetary model, and Hooper and Morton's (1982) portfolio balance model were generally outperformed by the naive RWM across 6-months, 1-year, and 2-years forecast horizons. This phenomenon, widely known as the Meese-Rogoff puzzle, has sparked extensive research and discussion over the years. Several studies have attempted to address this puzzle by refining existing models or introducing new variables. For instance, Chinn and Meese (1995) explored the potential of out-of-sample forecasting improvements by introducing new variables into the model. Kilian & Taylor (2001), Neely and Sarno (2002), and Cushman (2007) found that their models could surpass the RWM for 2-years and longer forecast horizons using cointegration analysis. However, none of these models managed to outperform the RWM in 6-months and 1-year forecast horizons.

The results of the current study are particularly noteworthy because they demonstrate that the modified Kouri (1983) model not only surpasses the RWM in 2-years forecast horizons but also outperforms it in 6-months and 1-year forecast horizons. This is a significant achievement, as it challenges the long-standing Meese-Rogoff puzzle and suggests that the modifications made to the Kouri's (1983) model, provide a robust framework for exchange rate forecasting across various time horizons.

Table 5 Comparing forecasting accuracy metrics

Random walk model			
Error metrics	Forecast Horizons		
	6-months	1-year	2-years
MSE	0.0009	0.0044	0.0052
MAE	0.0222	0.0552	0.0662
RMSE	0.0305	0.0665	0.0722
Modified Kouri's (1983) model			
Error metrics	Forecast horizons		
	6-months	1-year	2-years
MSE	< 0.0000	< 0.0000	0.0002
MAE	0.0024	0.0036	0.0108
RMSE	0.0024	0.0050	0.0155

Source: Authors' contribution

In light of this outcome, it is crucial to explore why the modified Kouri's (1983) model performs so effectively. One possible explanation is that the model incorporates the micro-behaviour of investors in determining and forecasting the short-run exchange rate, allowing it to better reflect the realities of market dynamics. Additionally, the model effectively captures the complex interactions between exchange rates and underlying economic variables in both the short and long-runs. Moreover, the use of the novel NARDL approach in determining and forecasting the bilateral exchange rate further enhances its accuracy, contributing to its superiority over existing exchange rate determination models.

Summary and Conclusion

In the current study, we use Kouri's (1983) PBM to explain and forecast the bilateral exchange rate between India and the US. Kouri (1983) improves upon the PBM of Branson (1972, 1976) by assuming expectations to be rational, and allowing for the simultaneous role of current and capital account towards determining exchange rate. We have analysed quarterly time series data from 1996Q2 to 2019Q3 to study the exchange rate, after making significant changes to the original model. The original model, despite being a short-run model, is based only on the macroeconomic determinants of exchange rate. However, microeconomic factors may have greater influence than the macroeconomic factors in the short-run. Hence, we modify the original model by introducing heterogeneous micro behaviour of investors in the foreign exchange market in the form of turnover in the foreign exchange market of India, as a representation of microeconomic factor. Thus, our model significantly contributes to the literature by analysing both micro and macroeconomic determinants of exchange rate. To account for the role of RBI, a variable on capital control of India is further considered in our model. The risk associated with foreign investments is explicitly considered in our model by the EPU index of the US. We analyse our modified model by means of NARDL approach, which enables us to ascertain both the positive and negative shocks of the exogeneous variables on the exchange rate. It also allows us to analyse the long-run and short-run behaviours of our model. Our analysis reveals that asymmetric effects are observed with some of the considered exogenous variables both in the short and long-runs. However, the significance of both macro and micro determinants of exchange rate in the short-run upholds the relevance of the model for short-run analysis.

Upon testing the forecasting abilities of the modified model, it is observed that our model performs better than the RWM over all the forecast horizons under consideration, contradicting the observations made by Meese and Rogoff (1983). Thus, we conclude by noting that our modified model based on the interactions between capital account and current account, highlights the significance of macro and micro determinants of exchange rate primarily in the short-run, and establishes itself as a reliable model for forecasting over the short, medium and longer time periods. For future analysis, financial analysts should incorporate microeconomic factors, such as market turnover, alongside macroeconomic variables, and closely monitor capital control measures and the EPU index. Effective management of capital controls and reducing economic policy uncertainty are essential for stabilizing exchange rates. Therefore, policymakers should consider adopting this modified Kouri (1983) model to enhance decision-making and improve exchange rate management.

Appendix

See Tables 6, 7.

Table 6 Augmented-Dickey Fuller Test for Stationarity of Variables

Variables	Level			1st difference		
	SC lag	t-Statistic	p value	SC lag	t-Statistic	p value
$\ln\left(e_t\right)^{\$\$}$	1	– 2.03	0.579	0	– 6.87***	< 0.001
$\ln\left(\frac{M_t}{M_t^*}\right).^{\$\$}$	2	– 1.25	0.893	0	– 7.37***	< 0.001
$\ln\left(\frac{Y_t}{Y_t^*}\right).^{\$}$	1	– 2.28	0.180	0	-6.36***	<0.001
$\ln\left(\frac{P_t}{P_t^*}\right)^{\$\$}$	2	– 1.47	0.832	1	– 4.84***	< 001
$\ln(\mathrm{MB}_t)^{\$\$}$	0	– 0.86	0.955	0	– 9.83***	< 0.001
$\ln(CC_{t}.)^{\$}$	0	– 1.79	0.385	0	– 9.49***	< 0.001
$\ln\left(EPU_t\right)^{\$}$	0	– 2.79*	0.067	–	–	–

Note: $ represents model with intercept but no trend, $$ represents model with intercept and trend. The use of trend is justified by the figures shown in Section 5. *** p < 0.01, ** p < 0.05, * p < 0.10. The Schwarz Criterion (SC) or BIC is used for appropriate lag selection in order to conduct the test. Null hypothesis: the variable is non-stationary. Source: Authors' contribution

Table 7 NARDL Bounds Test for Cointegration

F-bounds test and t-bounds test						
F statistic	Critical value at 1%		t statistic	Critical Value at 1%		Decision
	Lower Bound value, I(0)	Upper bound Value, I(1)		Lower Bound Value, I(0)	Upper Bound Value, I(0)	
5.66	2.54	3.86	– 9.34	– 3.43	– 5.68	Cointegration

The lower and upper bound critical values are considered from Shin et al. (2014). Source: Authors' contribution

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Data Availability The data that support the findings of this study can be downloaded from the following publicly accessible sites:

https://fred.stlouisfed.org/graph/?g=SFhn

https://fred.stlouisfed.org/graph/?g=SFhD

https://fred.stlouisfed.org/graph/?g=SFhR

https://fred.stlouisfed.org/graph/?g=SFi5

https://dbie.rbi.org.in/BOE/OpenDocument/opendoc/openDocument.jsp?sIDType=CUID&iDocID=1EpV5CsABfKyQZsBVgHpwPzZDcwrQQ&sType=wid&sRefresh=Yes&token=DWPRODAPP1:6400@114617165JMvpByxJCYszpeCaQOcaCZO114617163JKn2jwLB4kX3fBjapxZQdERONEOFF.

https://dbie.rbi.org.in/DBIE/dbie.rbi?site=redirectURL&r=%2FBOE%2FOpenDocument%2Fopendoc%2FopenDocument.jsp%3FrbiApp%3Dtrue%26sIDType%3DCUID%26iDocID%3DM1fjqvMABeX2AIMAQAAAOkIAAqwYEx8AAAA%26sType%3Dwid%26sRefresh%3DYes%26token%3DDWPRODAPP1%3A6400%40114617

http://www.columbia.edu/~mu2166/fkrsu/2021-FKRSU-Update-12-08-2021.xlsx

https://www.policyuncertainty.com/us_monthly.html

The data in a consolidated format can also be made available from the authors upon request.

Code Availability The Eviews commands used to run the statistical analysis can be made available upon request.

Declarations

Conflict of Interest The authors declare that there is no conflict of interest.

Ethics Approval Not applicable.

Consent to Participate Not applicable.

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