Facing the Quadrilemma:

Reserve Accumulation, Exchange Rates and Monetary Policy in Large Emerging Markets

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Abstract

This paper investigates interest rate and foreign exchange market intervention policy rules in large emerging markets, evaluating the effectiveness of these rules in navigating the constraints of the quadrilemma to achieve macroeconomic and financial stability objectives. We estimate extended Taylor rules and foreign exchange intervention functions, together designed to stabilize output, inflation, and exchange rates as well as accumulate international reserves to targeted levels, for India and Brazil. We also consider how greater capital account openness has impacted policy rules. We find that the specific policy rules followed in India and Brazil differ sharply. Output stabilization is a dominant characteristic of interest rate policy in India, as is inflation targeting in Brazil. Both countries actively use intervention policy to achieve exchange rate stabilization and, at times, stabilizing reserves around a target level tied to observable economic fundamentals. The relative emphasis these policy objectives, and the impact of capital control liberalization, shifted after the Global Financial Crisis.

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1. Introduction

The traditional "trilemma" set of policy constraints, where a country needs to balance tradeoffs between degrees of monetary independence, exchange rate stability and controlled capital account openness, has in the recent literature been extended to a "quadrilemma" with a fourth policy goal of financial stability (Aizenman, 2017). The later consideration for emerging markets is frequently focused on stability from international financial shocks in the form of sharp movements in capital flows, exchange rate instability and U.S. interest rate fluctuations. Emerging markets have always looked beyond the domestic objectives of inflation and output gaps, emphasized in large advanced economies and embodied in interest rate Taylor Rules, toward external objectives.

In attempting to achieve these external objectives, emerging markets frequently complement policy interest rates with foreign exchange market intervention and capital controls as additional policy instruments. Given that four policy objectives are combined with only three policy instruments (policy interest rate, intervention and capital controls), the "Tinbergen Principle" doesn't hold (i.e. equal instruments and objectives) and policy makers may at times face tradeoffs in achieving all their goals. In this context, the IMF (2012) finds that the number of countries actively managing their exchange rates has increased substantially since the Global Financial Crisis and that Brazil, Chile, Colombia, Turkey, and other emerging markets with announced inflation targeting regimes have increased both the frequency and the size of their interventions. In tandem with active intervention operations, the use of capital controls continues to be a powerful macroeconomic management tool in many emerging markets (Fernandez et al. 2016).

Theoretical work has investigated the tradeoffs associated with domestic and external policy objectives, and where intervention and capital controls may contribute to macroeconomic and financial stability (e.g. Gonçalves (2008), Cavallion (2019), Farhi and Werning (2012), Jeanne (2012), Schmitt-Grohé and Uribe (2012), and Benigno and others (2014)). For example, the theoretical framework of Gonçalves (2008) argues that official accumulation of foreign reserves may be perceived as interventions to influence the exchange rate, undermining the credibility of floating exchange rates and inflation targets. He develops a theoretical framework to study the

interaction between reserve accumulation and monetary policy, and highlights the trade-off between the speed of reserve accumulation and anti-inflationary credibility.

In related work, Cavallion (2019) develops a New Keynesian small open economy model that characterizes the optimal use of foreign exchange intervention in response to exchange rate fluctuations driven by capital flows. In his model, an increase in foreign demand for domestic assets appreciates the domestic currency and generates a boom-bust cycle in the economy. In response to such a shock, the optimal foreign exchange intervention in his model is to lean against the wind and stabilize the path of the exchange rate. By leaning against the wind, the central bank reduces the real appreciation (and the consumption boom triggered by the inflow of capital) and reduces the output gap. It is not optimal for the central bank to fully stabilize the exchange rate in this framework since it reduces some of the benefits of portfolio capital flows.

Most empirical work on macroeconomic policy functions, especially for advanced economies, emphasize policy interest rates as reflected in Taylor Rules. Taylor rules for emerging markets often recognize external objectives and include an include an exchange rate objective, e.g. Aizenman, Hutchison and Noy (2011. Our work empirically contributes to this literature by combining the investigation of interest rate and foreign exchange market intervention policy rules in large emerging markets, evaluating the effectiveness of these rules in navigating the constraints of the quadrilemma to achieve their macroeconomic and financial stability objectives. We extend previous work investigating modified Taylor rules that to consider a second policy rule linking foreign exchange market intervention to exchange rate stability and an objective to accumulate reserves to a target level.

We investigate how large emerging-market economies have in practice managed to accumulate very large reserve levels over time (for precautionary purposes, reducing the likelihood of financial instability), despite substantial cyclical variation, while at the same time following monetary policy rules designed to stabilize inflation, output and the exchange rate. We focus on two policy instruments, interest rates and change in international reserves (through foreign exchange market intervention), and four policy objectives—inflation, output, exchange rates and trend buildup of reserves. Against this background, we also control for changes in the intensity of capital controls, though this instrument is only infrequently cyclically applied.

Our choice to study Brazil and India is based both on their similarities and contrasts. First, both are large market-oriented emerging market economies. Most theoretical and empirical work in this area focuses on small open economies (SOEs) and attempts to measure where each country lies on a spectrum of policy tradeoffs. However, large emerging markets should display somewhat different characteristics than SOEs in reserves-exchange rate-monetary policy nexus. In particular, large EM interest rates should not in principle be completely determined by the "center country" (some inherent monetary independence compared with the SOEs) and potential foreign capital inflows are not infinite (as in the SOE model).

Second, Brazil and India use capital controls extensively as a macroeconomic management tool. While India has been gradually reducing capital controls over the past two decades, it continues to have quite strict international capital controls. Brazil is much more open financially but continues with fairly extensive controls. According to the Fernandez et al. (2016) data set on capital control restrictiveness using the IMF Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) for base data source, India and Brazil placed 0.95 and 0.65, respectively in 2016. Net liberalization has occurred over the past two decades as corresponding values for India and Brazil in 2000 were 1.0 and 0.85, respectively. (The U.S. had a restrictiveness index of 0.16 in 2016 and 0.13 in 2000 using this methodology). This allows us to explore whether variations in this instrument has impacted the effectiveness of other instrument of macroeconomic management.

Third, both Brazil and India have experienced very large reserve accumulations, motivated at least in part by the desire to reduce the likelihood or severity of financial crises. This fact, in combination with active foreign exchange policies, is an important element of macroeconomic and macro-prudential management in these countries. Fourth, these countries are very diverse in terms of their macroeconomic policies and outcomes, exchange rate regimes and intensity of capital controls. Although both have all seen large buildups in international reserves over two decades, with the exception of recent reductions (or slower growth), Brazil and India vary in terms of their monetary regimes, capital controls and success in moderating inflation. In particular, the Central Bank of Brazil has had an explicit inflation targeting regime since 2001 while the Reserve Bank of India is characterized by substantial discretion in policy actions. These contrasts allow us empirically to test differences in policy reactions and test for

quadrilemma constraints in a more robust manner than for each country individually. We use time-series methods for our methodology and employ quarterly data. Additional features of our analysis are the incorporation of a measure of "adequate" reserves, calculated by the IMF, into our intervention equation, and a measure of capital account openness, based on the work of Pasricha et al. (2015) and Pasricha (20176), into the interest rate rule (Taylor Rule) and intervention rule equations.

The remainder of the paper is organized as follows. Section 2 presents some background on macroeconomic management and external considerations in Brazil and India. Section 3 presents the basic model in the context of the quadrilemma policy-tradeoff constraints. Section 4 presents the empirical results and section 5 concludes.

2. Macroeconomic Management in Brazil and India

India and Brazil have experienced challenges to macroeconomic and financial stability similar to other emerging markets and advanced economies. Managing domestic output and inflation objectives in tandem with exchange rate and balance of payments stability has frequently been a balancing act between multiple targets and limited policy instruments.

India has alternated between an emphasis on output and inflation in pursuing domestic macroeconomic stability (Hutchison et al. 2013; Gupta and Sengupta, 2014; Kaur, 2016), and maintaining orderly conditions in the foreign exchange markets as an official objective of the Reserve Bank of India (RBI) (Hutchison and Pasricha, 2016). RBI is the manager of the foreign exchange regulation act (FEMA, 2004), which also gives it the power to impose capital controls. In practice, this objective has meant very active management of controls on international capital movements and frequent foreign exchange market intervention operations, as well as at least one episode of interest rate defense of the exchange rate in 2013. These considerations make understanding the linkages between monetary policy, capital controls and foreign exchange market intervention operations central to a study of macroeconomic management in India.

Hutchison and Pasricha (2016) find that India has followed active foreign exchange market intervention and capital control policies. They argue that intervention policy is mainly directed toward limiting exchange rate appreciation, during which times dollar purchases were generally

large, and *not* directed toward limiting depreciation. This policy may have allowed relative stability in the real exchange rate, hence maintaining India export competitiveness, as the exchange rate depreciated over longer-periods to offset relative high inflation in India. Intervention policy and exchange rate depreciation also allowed greater monetary autonomy, especially during a period associated with increased financial liberalization of the international capital account. Moreover, reserve accumulation—through USD purchases on the foreign exchange market—is a desirable objective to the extent that it provides a stock of precautionary reserves in the event of a balance of payments/currency crisis or sudden stop in private capital inflows that generally finance persistent current account deficits in India. On the other hand, the exchange rate did not play the role of a "nominal anchor" of monetary policy and high inflation in India as a consequence has been a recurring problem.

Control of international financial capital movements is another policy instrument that has been frequently employed to influence financial flows in and out of India and the exchange rate (Hutchison, Pasricha and Singh, 2012; Patnaik and Shah, 2012; Hutchison and Pasricha, 2016). Although the overall trend was towards financial liberalization of the capital account, capital control actions (i.e. tightening and easing of restrictions on capital flows) have been actively used as an instrument to "lean against the wind" of exchange rate pressures in both directions. Whether or not capital controls policies have been effective is evaluated by Patnaik and Shah (2012).

Tradeoffs between domestic and external objectives have also confronted the Central Bank of Brazil. The country is the largest emerging market to adopt an inflation targeting regime (IT), starting in July 1999 and formally continuing to date. Cortes and Paiva (2017) argue that the Central Bank of Brazil (BCB) succeeded in anchoring inflation expectations and gaining credibility until 2011, when a new discretionary-based policy was adopted despite a formal IT rule. Aizenman, Hutchison and Noy (2011) find that commodity-based emerging markets with an IT regime such as Brazil are still very likely to smooth exchange rates as part of their Taylor Rule interest rate setting policy.

The Central Bank of Brazil has been found to intervene in the foreign exchange market to smooth excessive exchange rate volatility and to manage the level of international reserves

(Gnabo et al., 2010). Although intervention activity varies over time, spot-market interventions and the sale of exchange swaps are predominantly against the wind in terms of USD. In terms of the effectiveness of intervention, several studies find that FX intervention, including through swaps, can affect the exchange rate, e.g. Kohlscheen and Andrade (2014), Barroso (2014), Chamon et al. (2017), Novaes and Oliveira (2007), and Verlot (2010). Novaes and Oliveira (2007), for example, find that in periods of relative tranquility the level of the exchange rate is affected more strongly by interventions (in both the spot and the derivatives markets) than the stance of monetary policy, while interventions appear ineffective during episodes of high exchange rate volatility.

3. Model

Our empirical model is based on the basic quadrilemma policy tradeoff and research in this area. The basic analytical framework consists of two policy rules: a modified Taylor Rule and a foreign exchange intervention policy function. Policy is directed toward achieving two domestic objectives, output and inflation stabilization, and two international macroeconomic objectives, exchange rate stabilization and a target level of international reserves to reduce the risk of capital stops and financial instability. Two instruments are associated with policy functions, and one instrument, fluctuations in capital controls, is taken as a pre-determined variable. In addition to the two policy reaction functions, foreign exchange market is directly linked to changes in international reserves through an accounting identify

The Taylor rule is modified to capture the central bank's objective of reducing output variations around trend, inflation variations from target, and stabilize the nominal exchange rate. Given hysteresis found in policy actions we include a lagged interest rate as is standard in most studies. The modification of the Taylor rule to include an exchange rate target is standard in the emerging markets literature (e.g. Aizenman, Hutchison and Noy, 2011). This formulation takes the form:

$$(1) \qquad i_t = \alpha_1 + \alpha_2 (y_t - y*) + \alpha_3 (\pi_t - \pi^*) + \alpha_4 (e_t - e_{t-1}) + \alpha_5 i_{t-1} + \varepsilon_t$$

Where i_t is the central bank interest rate operating instrument, $(y_t - y*)$ is (log) output less (log) output trend (i.e. percentage deviation from trend output) , $(\pi_t - \pi^*)$ is inflation deviation from target, $(e_t - e_{t-1})$ is the (log) nominal exchange rate change, and ε_t is the error term.

Stabilizing objectives ("leaning against the wind") of output, inflation and the exchange rate suggests that $\alpha_2 > 0, \alpha_3 > 0, and\ \alpha_4 > 0$.

The foreign exchange management fund is postulated to intervene in the foreign exchange market (foreign exchange purchases are positive values) to stabilize the exchange rate and to management foreign reserves around the target level. Hence, there are potentially two instruments focused on exchange rate management. In addition, the target level may itself vary over time as suggested by the very rapid buildup of international reserves by emerging market economies during the period prior to the Global Financial Crisis (GFC) . The intervention equation takes the form:

$$(2) \qquad I_t = \beta_1 + \beta_2\ (e_t - e_{t-1}) + \beta_3\ (R_t - R_t^*) + \mu_t$$

Where I_t is foreign exchange market intervention (USD purchases (purchases of foreign exchange are positive values and sales are negative values, as a percent of last quarter's stock of international reserves), $(R - R*)$ is the (log) stock of international reserves less the (log) of the target reserve level (i.e. percentage deviation from target reserves) and μ_t is the error term. Foreign exchange sales intervention to slow or reserve exchange rate depreciation $(e_t - e_{t-1}\ > 0)$ suggests $\beta_2 < 0$. A rise in the stock of reserves above the target value also suggests foreign exchange sales intervention, $\beta_3 < 0$.

Intervention is linked to international reserves through an accounting identify, i.e. the rise (fall) in international reserves equals foreign exchange intervention purchases (sales) plus interest earnings on foreign reserves and valuation changes:

$$(3)\ R_t - R_{t-1} = I_{t-1} + i_{t-1}^* R_{t-1} + VAL_{t-1}$$

where i_{t-1}^* is the interest rate on foreign exchange reserves and $VAL_{t-1}$is valuation changes on international reserve holdings. Hence, intervention is directly linked to the target for international reserves. Our assumption is that i_{t-1}^* and VAL_{t-1} are exogenous variables.

In addition to the linkages across the two policy equations and the accounting identity, we also investigate the extent to which U.S. interest rates (i_t^*) and capital account openness $(openness_t)$ constrain domestic interest rate policy (Taylor Rule) and, for $openness_t$, enters into decisions to intervene in the foreign exchange market. We would expect U.S. interest rates to enter directly

into interest rate policy decisions, in addition to the indirect channel via the exchange rate, especially in the post-GFC period when greater movement of international capital was generally allowed in both Brazil and India. The effect of greater capital market openness (liberalization) on both interest rate and intervention policies would depend on the directional response of net private capital flows, which in turn on market conditions and whether institutional measures liberalized controls on inflows or outflows most.

3. Data and Methodology

3.1 Data

We employ quarterly data over the period 1998-2018 in our analysis. The exact sample period varies slightly between regression specifications due to data availability. Descriptions of each variable and the date range over which they are available are explained in the appendix.

Macroeconomic developments for both countries are detailed in the summary statistics of Table 1 and Figures 1-7. Panel A of Table 1 shows the full sample period, Panel B shows the pre-GFC crisis sample period and Panel C shows the post-GFC crisis period. India generally has a much more stable macro-economy than Brazil, with lower interest rates, lower inflation and more stable (lower standard deviation) exchange rates, intervention and reserves (relative to required reserves). Figure 1 shows the output gap; Figure 2 inflation (and, for Brazil, evolution of the inflation target); Figure 3 money market interest rates; Figure 4 exchange rates (left panel, level of the domestic currency per USD; right panel, percent change); Figure 5, left column, is the level of international reserves and the "adequate reserves" level (estimated by the IMF) and right column is the net spot foreign exchange market intervention; Figure 6 is the reserve gap (difference between actual reserves and adequate reserves as a percent of adequate reserves; Figure 7 is the measure of cumulative step of external capital account openness (cumulative net changes).

We use a standard measure of the output gap given by the cyclical deviation of industrial production from its trend. We seasonally adjusted both series using the U.S. Census Bureau X-13 procedure. HP filter estimates of the logged series are employed to obtain trend and cyclical output measures. The cyclical portion is multiplied by 100, yielding an output gap measure that

can be interpreted as the percent deviation of industrial production from its trend level. The output gap measures are shown in Figure 1. This series has been employed in other studies investigating monetary policy in both Brazil and India. (Kaur, 2016; Gupta and Sengupta, 2014; De Almeida, 2003). It is evident from the figure that output gap volatility has been much larger in Brazil than India.

Brazil has had an inflation target since 1999. This target has changed several times over the sample period, shown in Figure 2, but for most of the sample the midpoint target was 4.5%. India does not have an announced inflation target. For purposes of econometric estimation, we assume the target is constant and therefor subsumed in the constant term of the estimated Taylor Rule for India. We follow other studies (e.g. Guta and Sengupta, 2014; Modenesi, 2013) and use the WPI index to construct the inflation rate in India and the IPCA index for Brazil. Inflation averaged 4.7% in India and 5.2% in Brazil over the sample period, with similar volatility, shown in Table 1. Brazil has been slightly above its inflation target over the sample period (0.4% above).

Money market interest rates are employed in both studies, shown in Figure 3. Despite similar inflation rates, Brazil has almost double the nominal (and real) interest rates than India. This may reflect both real growth equilibrium factors (determining equilibrium real interest rates), risk premium differences, institutional features of the two economies, and that Brazil is more financially open. The stance of monetary policy is measured with the money market interest rate. For India, this is the 3-month interbank lending rate. For Brazil, we use the SELIC rate, which is the overnight interbank lending rate. The nominal exchange rate employed in the study, shown in Figure 4, is the value of local currency against the USD. Brazil has experienced higher average depreciation (1.0% quarterly average) over the sample than India (0.7% quarterly average), shown in Table 1, and much higher exchange rate volatility.

Foreign exchange market intervention is defined as foreign currency purchases (domestic currency sales) in the foreign exchange market, valued in millions USD, shown in the right panels of Figure 5. This data is obtained from the Central Banks of Brazil and India, respectively. Negative values represent foreign currency sales (domestic currency purchases) in the foreign exchange market. The advantage of this measure is that it only reports active intervention in the foreign exchange market and excludes interest earnings and valuation effects on reserves. (Many studies proxy intervention by changes in reserves). Both countries actively

intervened in the foreign exchange market during most of the sample period, though Brazil ceased its intervention activity in recent years.

Reserves are defined as international reserves less gold but including SDRs, shown in the left panels of Figure 5. Reserve data for Brazil and India are obtained from the central bank of each country. No reserve targets are announced in either country. As a proxy, we use the IMF series on reserve adequacy for both Brazil and India. The IMF defines international reserve adequacy (RA) for emerging market economies with floating exchange rates as $RA = 5\% \times Exports + 5\% \times Broad\ Money + 30\% \times Short\ Term\ Debt + 15\% \times Other\ Liabilities$. The IMF measure of reserve adequacy is only available at the annual level. An approximate quarterly series is estimated using a cubic spline interpolation. The resulting quarterly series are also plotted in the left panels of Figure 5. It is apparent that both countries grew reserves very substantially since the early 2000s, pausing at the time of the GFC. After that period, reserve growth in reserves continued in India and flattened out in Brazil.

The reserve "gap," measured by the difference between actual reserves and reserve adequacy (as a percentage of reserve adequacy), is shown in Figure 6. This figure shows that India exceeded its "reserve adequacy" metric from around 2002, peaking at almost 100% just before the GFC. Since that time, the reserve gap declined before stabilizing at about 30%. Brazil's reserve gap was negative until 2007 but has been consistently positive since 2010, fluctuating around 50% from 2014 until 2018.

Capital Openness Index, shown in Figure 7, is taken by accumulating net capital account liberalization or restrictiveness changes based on the Pasricha et al. (2015) dataset, updated in Pasricha (2017). This is a dataset of capital control actions for 16 emerging market economies, where country-level measures of capital control changes are based on a weighted sum of the capital account changes for a given year, where the weights are given by the share of the country's international investment position that are affected by the policy change. We take the cumulative sum of these changes so that they can be interpreted as the level of capital openness for a given country, albeit not comparable across countries in level form. The resulting time series for Brazil and India is shown in Figure 7. This index has been used in Pasricha et al. (2015), Pasricha (2017), and Aizenman and Binici (2016). Some of the advantages of this series are that it results in a

measure of capital openness that varies more regularly than several measures such as the Chinn-Ito index (Chinn and Ito, 2006) or Fernandez et al. (2016). This is because it presumably takes into account all regulatory changes for a given country and weights them according to their estimated impact on capital flows.

3.2 Methodology

Turning to methodology, our baseline time series models for Brazil and India are estimated over the 1999q1-2018q4 period. We allow for sample shifts before and after the Global Financial Crisis, as the external environment changed markedly at this time, likely impacting policy behavior. We employ a methodology that considers the endogeneity of the reserve gap. The contemporaneous reserve gap is influenced by the scope of intervention operations. Consequently, we treat the reserve gap variable as endogenous and instrument for it with its lagged value. Depreciation is likely to suffer from a two-way causality issue as well. However, we do not employ an instrumental variables method and instead treat depreciation as exogenous. There are two reasons for this decision. First, depreciation is notoriously difficult to forecast and thus finding a strong instrument is a daunting task. Weak instruments lead to results that perform poorer than OLS estimates (Stock, Wright, and Yogo 2002), and so it isn't clear that instrumenting for depreciation will lead to improved estimates. The second reason is that the bias of the depreciation coefficient works against our hypothesis. This is because lower interest rates and foreign currency purchases lead to depreciation, whereas we expect depreciation to cause higher interest rates and purchases of domestic currency. That said, our results for depreciation can be interpreted as a lower bound on the true effect of depreciation on interest rate and intervention policy Both inflation and the output gap are assumed to respond to interest rate changes only with a lag and are treated as pre-determined variables. We estimate HAC Newey-West standard errors to account for potential autocorrelation and heteroskedasticity in the error term.

4. Results

4.1 Baseline Full Sample Results

Table 2 shows the full-sample baseline results for Brazil and India (column 1), together with the possibility of asymmetric responses associated with exchange rate appreciation and depreciation (column 2). Panel A reports the extended Taylor rule model estimations and Panel B the intervention functions. Spot intervention operations are employed in the intervention function estimates reported in Panel B.

The results shown in Panel A indicate very different monetary policies pursued by India and Brazil over the full sample period. India has systemically pursued output stabilization, raising domestic interest rates on average by 11 basis points in response to a one percentage point rise in the output gap. We find no evidence that the Reserve Bank of India systematically responds to inflation or exchange rates in setting money market rates over the full sample period. Brazil, on the other hand, responds strongly to deviations from its inflation target, confirming the central bank's commitment to an IT regime, increasing the interest rate by 71-73 basis points for every 1 percentage point above the inflation target. No output stabilization is suggested for Brazil over the full sample period. Interest rate policy is highly persistent in both countries, especially in Brazil (lagged dependent variable coefficient equals 0.97 in Brazil and 0.81 in India).

India and Brazil are similar in foreign exchange market intervention policy responses to exchange rate changes, shown in Panel B. Both countries respond strongly to exchange rate movements in "leaning against the wind" intervention operations, selling (buying) about 0.24-0.26% in Brazil and 0.48-%-0.63% in India, of the stock of international reserves in response to a one percent depreciation of the domestic currency against the USD. However, only India appears to systematically target reserves around a level associated with observable economic fundamentals. A rise (fall) in actual reserves above (below) the target induces a significant sale (purchase) in foreign exchange (as a percent of last period's total reserves).

Both India and Brazil built significant foreign exchange reserve positions during the sample period. This is reflected in the significant constant terms in the intervention regressions, indicating average foreign exchange purchases of about 3% per quarter (as a percentage of existing reserves).

4.2 Policy Shifts and the Global Financial Crisis

We address whether policy shifts occurred at the time of the GFC in Table 3. It is evident that output stabilization was important in India's interest rate policy both before and after the GFC, with similar estimated interest rate responses. There is also evidence in the post-GFC evidence of an inflation response for India, unlike the pre-GFC period (or the full sample period). In Brazil, inflation targeting dominates the central bank interest rate policy in both sub-periods, as it did in the full sample period, but with a substantially lower estimated response n the post-GFC period. This finding is consistent with concerns that Brazil is adhering less to inflation targeting in recent years (Cortes and Paiva, 2017). Using interest rate policy to stabilize the exchange rate is also evident in Brazil during the pre-GFC, where a 1% depreciation is met with a 10-basis point rise in the money market rate, but not in the post-GFC period. No clear evidence that the central bank is adjusting interest rates in response to exchange rate movements is evident in India.

Exchange rate stabilization is a dominant feature of intervention policy for both countries pre- and post-GFC as for the full sample period. All the coefficient estimates are significant at the 5% level or better. However, the Reserve Bank of India appears to consistently respond more actively to exchange rates in its intervention operations than does the Central Bank of Brazil. Moreover, the estimated responses are weaker for both India and Brazil after the GFC, with estimated sales of foreign exchange in response to a 1% depreciation from 0.66% to 0.35% in India and from 0.48% to 0.09% in Brazil.

While intervention responses to exchange rates appear weaker in the post-GFC, stronger responses are suggested in the management of foreign exchange reserves. In India, the response of selling foreign exchange when reserves are above target is consistent with a stabilizing role and statistically significant in all periods, but the magnitude jumps by a factor of three between the pre- and post-GFC. The response for Brazil is not statistically significant in the pre-GFC (nor in the full sample period), but is significantly negative (stabilizing) in the post-GFC period.

4.3 Transmission of U.S. Interest Rates and Capital Controls

In this section we explore the extent to which policy interest rates in India and Brazil are directly tied to U.S. interest rates in addition to the indirect link via the exchange rate. We also consider the impact of external financial account openness on policy interest rates and foreign exchange market intervention policy.

The results are reported in Table 4. U.S. interest rates did not move enough during the post-GFC, encompassing the zero-lower-bound period, to warrant inclusion in the sample so only the pre-GFC period is presented in our Taylor Rule equation estimates. Column (1) in Panel A for India and Brazil include the U.S. interest rate in the baseline Taylor Rule regression, while column (2) reports estimates with the U.S. interest rate and openness. The estimates indicate that domestic money market rates move about 18-27 (Brazil) to 24-25 (India) basis points for a 1 percentage point move in U.S. interest rates, though only the estimates for India are statistically significant.

The results in Table 4 suggest quite different policy responses to capital account liberalization in India and Brazil. For India, in the pre-GFC period, an increase in openness led to lower money market interest rates (8 basis points, Panel A) and sales of foreign exchange (0.97 percent of reserves) by the central bank (Panel B). No significant impact on intervention policy from greater openness is seen in the post-GFC. In Brazil, steps toward greater openness (restrictiveness) also is associated with lower (higher) domestic interest rates (61 basis points), but prompted the purchase of foreign currency by the central bank in the pre-GFC (6.17 percent of reserves) and sales of foreign currency in the post-GFC (1.5 percent of reserves).

These differences may be explained in part to how the pattern of financial market liberalization/openness and market conditions affected net capital flows in the two periods and across the two countries, leading to varying policy responses. Shown in Figure 7, India—though much more financially closed generally than Brazil—set out on a gradual process of external financial liberalization over the sample period. The number of liberalization measures (positive steps in the figure) far exceeded the number of restrictive measures (negative steps in the figure), so that over 50 net liberalization steps were taken between 2001 and the end of 2015. Brazil, on the other hand, used capital control more as a cyclical policy instrument, at times loosening and at times tightening controls. The number of net liberalization steps (positive) only slightly outnumbered the number of restrictive (negative) steps over course of the full sample.

For India, it appears that a rise in openness led to net capital outflows in the pre-GFC, perhaps because of a tendency to liberalize outflows more than inflows, indirectly creating incipient pressure for currency depreciation, and in turn prompting the central bank to “absorb” the impact on the foreign exchange market by selling foreign exchange (an official capital inflow). Less private capital inflow may also have adversely impacted domestic investment, leading the

Reserve Bank of India to respond by lowering the policy rate. The effect of liberalization of inflows and outflows may have been more balanced post-GFC as no impact on intervention operations is found.

The results for Brazil, on the other hand, suggest that an increase in openness led to a surge in net private capital inflows during the pre-GFC period, leading the central bank to offset the impact on the foreign exchange market by making large USD purchases. The capital inflow associated with greater openness during pre-GFC was also associated with lower money market rates, suggesting that the central bank allowed private capital inflows to loosen domestic financial market conditions. The contrasts with post-GFC, where a net increase in openness was associated with net capital outflows and official sales of foreign exchange reserves. Liberalization in this period may have been more directed to relaxation of controls on outflows than inflows or attributable to adverse market conditions.

5. Conclusion

We find that India and Brazil follow on very different interest rate policies, with India emphasizing output stabilization and Brazil adhering to inflation targeting over most of 1999-2018. Intervention policies appear focused on external stabilization, with both countries attempting to stabilize the exchange rate with "leaning against the wind" foreign change purchases and sales. In terms of an external financial stability objective, India uses intervention operations to target reserves at a level justified by economic. Brazil, on the other hand, did not appear to target a specific level of reserves until after the Global Financial Crisis (GFC). Controlling for the exchange rate and international reserves gap, both countries still made large net purchases of foreign exchange each quarter on average over the sample period, allowing them to accumulate reserves in pursuit of their external financial stability objective.

Policies in both countries shifted with the GFC. Inflation became an important target of India's interest rate policy post-GFC, alongside the traditional emphasis on output stabilization. This contrasts with the overarching goal of output stabilization in India pre-GFC. India's intervention policy became less focused on the exchange rate post-GFC, with more weight placed on stabilizing international reserves around the target level.

Brazil's policies also shifted. Interest rate policy in Brazil pre-GFC was dominated by the inflation target, with the exchange rate as an important secondary objective. Although the exchange rate doesn't enter significantly into the post-GFC Brazilian Taylor rule, we also find less response to inflation target deviations. This may point to a more discretionary and diffuse policy agenda in Brazil after the GFC. Less emphasis on the exchange rate is also noted for Brazil's intervention operations post-GFC, while international reserves grew in importance.

The role of exchange rate stabilization receded considerably in post-GFC intervention policy for both countries, in tandem with greater emphasis in maintaining foreign exchange reserves around a target level justified by economic fundaments. India appears more active than Brazil in using an activist intervention policy to achieve exchange rate and financial stability objectives in both periods. It is evident, however, that both countries focused on rapidly building international reserves regardless of underlying fundamentals pre-GFC, following a pattern seen in many emerging market economies at the time. After the GFC a more systematic policy approach to stabilizing reserves around a targeted level is clearly discernable.

Overall, the results point to a pattern where India is more activist than Brazil on the external dimension of policy aiming to achieve exchange stability and a set reserve target, while its interest rate instrument is mainly focused on output stabilization. Brazil's inflation targeting regime combined with greater international financial openness than India, led interest rate policy to focus more on inflation generally. Exchange rate stabilization policy in Brazil pre-GFC was strongly supported by intervention operations but with little or no systemic use of intervention to achieve a specific target for international reserves. Stabilizing international reserves around a target level played a much larger role after the GFC in Brazil.

The impact of the liberalization of international capital controls on policy is complex, depending on market conditions and the specific actions taken to lift restrictions on capital inflows or outflows. We find that greater financial openness affected India and Brazil differently, depending on the sequence of measures taken. This led to varying private capital movements and intervention policy responses.

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Table 1: Descriptive Statistics

Panel A: Entire Sample, 1999Q1 - 2018Q4

	India					Brazil			
Statistic	N	Mean	St. Dev.	Min	Max	N	Mean	St. Dev.	Min	Max
i	84	6.98	1.62	3.35	10.52	76	13.447	4.579	6.5	26.500
$\hat{Y}$	84	0.00	2.24	−6.46	6.61	76	−0.207	9.554	−18.712	16.250
π	80	4.56	3.19	−5.68	10.47	76	5.242	3.385	3.025	11.153
$\pi - \pi^*$	80	4.56	3.19	−5.68	10.47	76	0.419	1.023	−1.025	5.685
Δe	83	0.73	3.04	−6.91	10.86	76	1.019	8.498	−17.857	28.557
$R - R^*$	84	33.12	27.68	−34.01	93.13	76	1.244	49.978	−92.475	69.608
I_{spot}	84	1.56	3.89	−8.30	10.14	76	2.63	6.769	−8.816	32.000
I_{total}	84	0.01	11.64	−34.76	26.66	76	2.581	7.12	−11.292	32.000
openness	60	20.76	15.84	0.15	53.73	60	1.802	1.193	0.000	3.490

Panel B: Pre Crisis, 1999Q1 - 2008Q4

	India					Brazil			
Statistic	N	Mean	St. Dev.	Min	Max	N	Mean	St. Dev.	Min	Max
i	44	6.93	1.63	4.19	10.23	36	16.931	3.775	11.25	26.500
$\hat{Y}$	44	0.25	2.61	−3.43	6.61	36	−0.624	10.049	−17.035	16.250
π	40	4.56	3.19	−5.68	10.47	36	6.268	3.870	3.025	11.153
$\pi - \pi^*$	40	5.15	1.87	1.51	10.47	36	0.546	1.254	−1.025	5.685
Δe	43	0.50	2.87	−6.91	10.86	36	−0.148	8.109	−17.857	20.815
$R - R^*$	44	29.68	36.78	−34.01	93.13	36	−42.709	33.72	−92.475	28.552
I_{spot}	44	2.32	4.79	−8.30	10.14	36	4.263	9.358	−8.816	32.000
I_{total}	44	0.14	11.37	−25.35	23.40	36	3.988	9.801	−11.292	32.000
openness	32	8.07	5.67	0.15	20.36	32	1.409	1.346	0.000	3.490

Panel C: Post Crisis, 2009Q1 - 2018Q4

	India					Brazil			
Statistic	N	Mean	St. Dev.	Min	Max	N	Mean	St. Dev.	Min	Max
i	40	7.04	1.63	3.35	10.52	40	10.312	2.5	6.5	14.250
$\hat{Y}$	40	−0.27	1.74	−6.46	3.41	40	0.168	9.198	−18.712	14.710
π	40	3.97	4.05	−5.68	10.12	40	5.057	2.908	3.625	8.741
$\pi - \pi^*$	40	3.97	4.05	−5.68	10.12	40	0.305	0.755	−0.905	2.705
Δe	40	0.98	3.24	−3.86	10.72	40	2.069	8.801	−16.717	28.557
$R - R^*$	40	36.91	10.51	19.07	62.61	40	40.802	19.869	−11.280	69.608
I_{spot}	40	0.72	2.34	−4.56	9.12	40	1.161	2.199	−1.775	8.490
I_{total}	40	−0.16	12.08	−34.76	26.66	40	1.315	2.794	−2.743	8.959
openness	28	35.27	10.11	22.32	53.73	28	2.252	0.798	0.578	3.490

Panel A: Interest Rate Policy	Dependent Variable: i_t	
	India	Brazil
c	1.1277^{***}	1.30^{*}
	(0.3943)	(0.7100)
$\hat{Y}$	0.1150^{***}	-0.0000
	(0.0342)	(0.0203)
$\pi - \pi^*$	0.0194	0.7307^{***}
	(0.0194)	(0.2300)
Δe	0.0348	0.0377
	(0.0646)	(0.0345)
i_{t-1}	0.8170^{***}	0.9740^{***}
	(0.0498)	(0.0498)
R^2	0.8321	0.9215
Num. obs.	80	76

Panel B: Spot Intervention	Dependent Variable: I_t	
	India	Brazil
c	3.2275^{***}	2.93^{**}
	(0.7114)	(1.2802)
Δe	-0.4766^{***}	-0.2662^{***}
	(0.1496)	(0.0801)
$R - R^*$	-0.0402^{***}	-0.0311
	(0.0120)	(0.0291)
R^2	0.1319	0.1368
Num. obs.	83	76

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 2: Baseline Results

Panel A: Interest Rate Policy	Dependent Variable: i_t			
	India		Brazil	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
c	1.4799^{***}	0.8609	2.51^{**}	1.07
	(0.4983)	(0.5315)	(1.20)	(0.76)
$\hat{Y}$	0.1207^{*}	0.1611^{***}	-0.0000	0.0120
	(0.0651)	(0.0225)	(0.0203)	(0.0112)
$\pi - \pi^*$	-0.0236	0.0353^{**}	0.70^{**}	0.48^{**}
	(0.0537)	(0.0145)	(0.34)	(0.22)
Δe	-0.0242	0.0818	0.10^{**}	-0.01
	(0.0334)	(0.0820)	(0.04)	(0.01)
i_{t-1}	0.7863^{***}	0.8555^{***}	0.91^{***}	0.95^{***}
	(0.0528)	(0.0756)	(0.05)	(0.07)
R^2	0.8486	0.858	0.8515	0.8732
Num. obs.	40	40	36	40

Panel B: Spot Intervention	Dependent Variable: I_t			
	India		Brazil	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
c	3.5684^{***}	4.6347^{**}	2.36	3.87^{***}
	(1.1493)	(1.8151)	(2.58)	(0.90)
Δe	-0.6624^{**}	-0.3476^{**}	-0.48^{***}	-0.09^{***}
	(0.2975)	(0.1517)	(0.13)	(0.03)
$R - R^*$	-0.0315^{*}	-0.0969^{**}	-0.04	-0.06^{***}
	(0.0170)	(0.0378)	(0.04)	(0.01)
R^2	0.1503	0.1437	0.1016	0.4107
Num. obs.	43	40	36	40

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 3: Pre and Post Global Financial Crisis

Panel A: Interest Rate Policy - Pre GFC	Dependent Variable: i_t			
	India		Brazil	
	(1)	(2)	(1)	(2)
c	1.987^{***}	3.2289^{***}	6.4176^{*}	8.8692^{**}
	(0.3249)	(0.8176)	(3.4913)	(4.1772)
$\hat{Y}$	0.1277^{**}	0.2475^{***}	-0.0176	0.0041
	(0.0691)	(0.0578)	(0.0390)	(0.0416)
$(\pi - \pi^*)$	-0.0276	.0909	0.5248	0.5183
	(0.0489)	(.0849)	(0.3105)	(0.3798)
Δe	0.0323	0.0590	0.0089	0.0006
	(0.0336)	(0.0373)	(0.0294)	(0.0279)
i_{t-1}	0.5994^{***}	0.4054^{***}	0.5103^{*}	0.4080
	(0.0455)	(0.1175)	(0.2598)	(0.3249)
i_{US}	0.2474^{***}	0.236^{***}	0.1872	0.2717
	(0.0511)	(0.0473)	(0.2306)	(0.3268)
openness		-0.0809^{***}		-0.6089^{*}
		(0.0284)		(0.3550)
R^2	0.8908	0.8766	0.8198	0.8369
Num. obs.	40	32	32	32

Panel B: Spot Intervention	Dependent Variable: I_t			
	India		Brazil	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
c	4.78^{***}	-2.09	-9.39^{***}	8.06^{***}
	(1.35)	(4.51)	(2.14)	(1.77)
Δe	-0.26^{**}	-0.27^{*}	-0.27	-0.00
	(0.11)	(0.16)	(0.20)	(0.02)
$R - R^*$	0.12	-0.02	-0.14^{***}	-0.08^{***}
	(0.10)	(0.05)	(0.03)	(0.02)
openness	-0.97^{**}	0.11	6.17^{***}	-1.50^{***}
	(0.42)	(0.09)	(0.81)	(0.51)
R^2	0.66	0.30	0.49	0.41
Num. obs.	32	28	32	28

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Table 4: Intervention and Capital Account Liberalization (Openness)

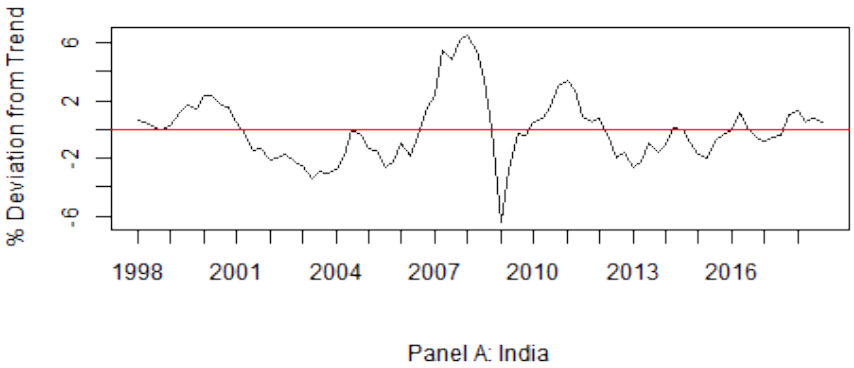
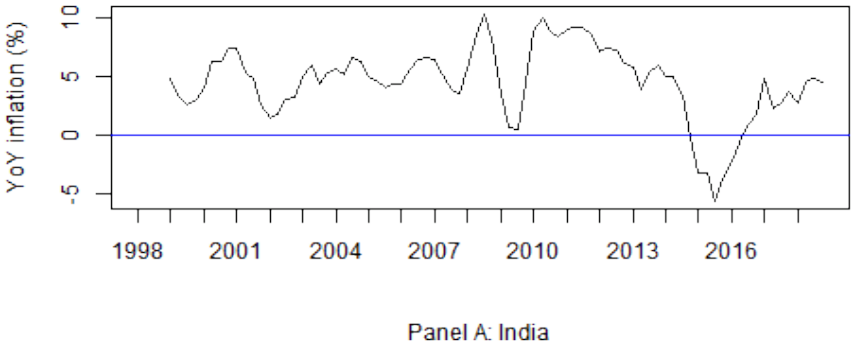
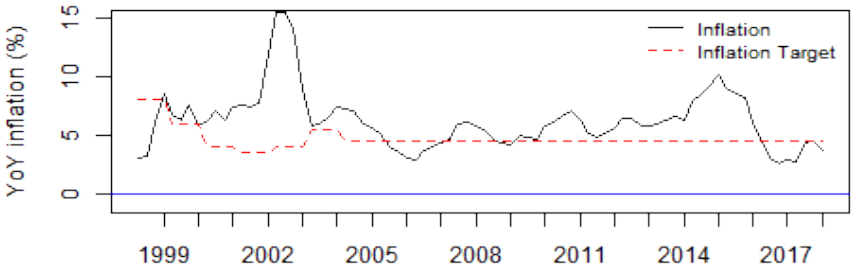


Figure 1: Output Gap



Panel A: India



Panel B: Brazil

Figure 2: Inflation

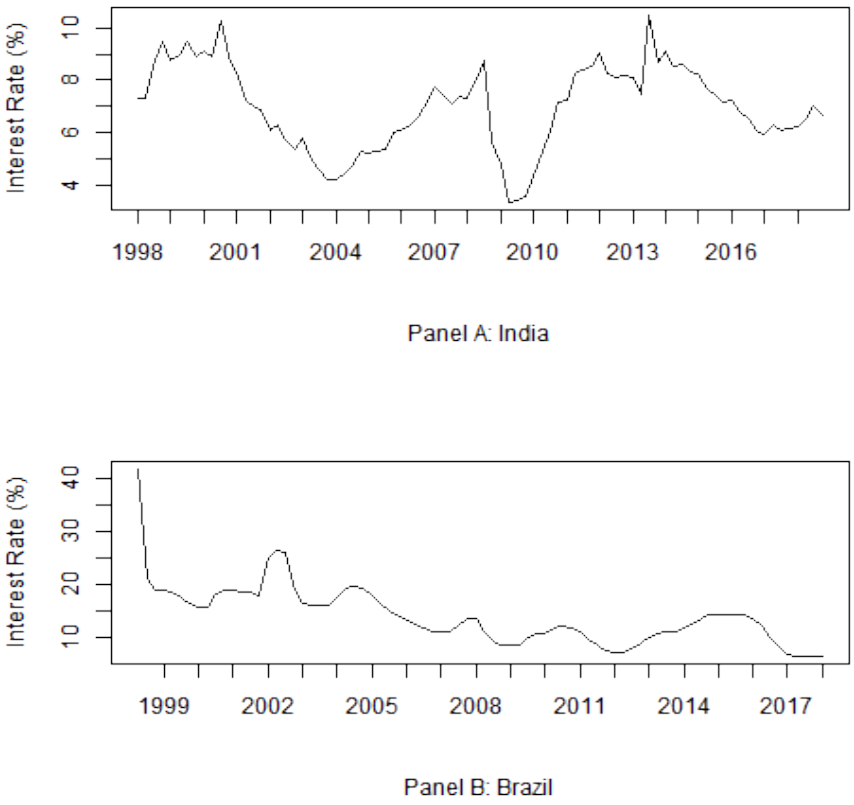


Figure 3: Money Market Interest Rates

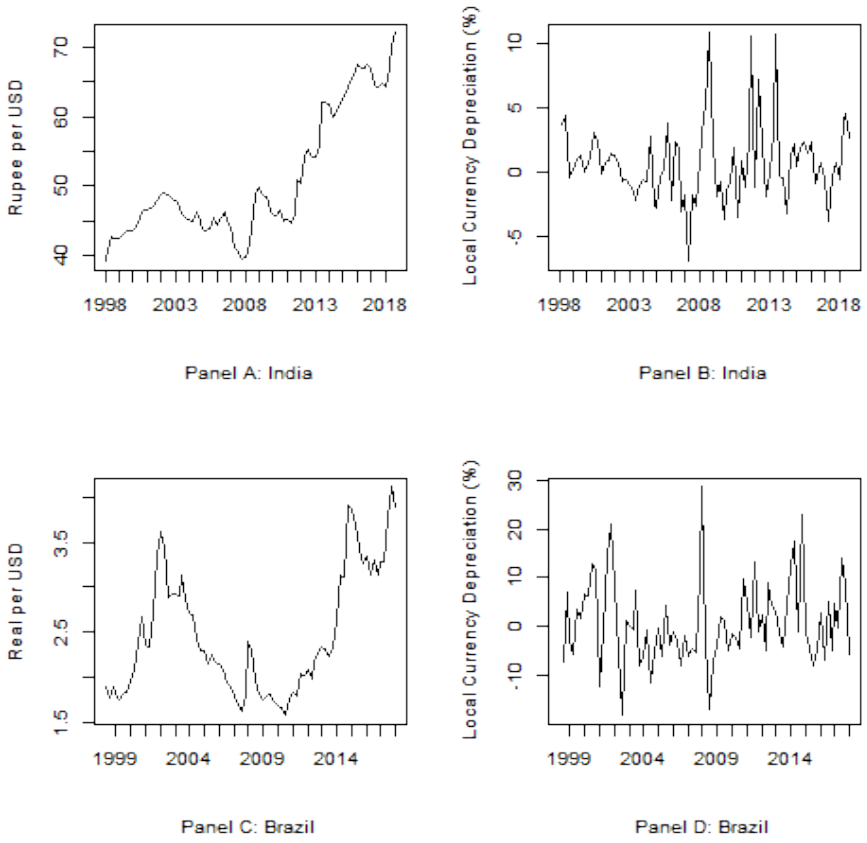


Figure 4: Exchange Rates

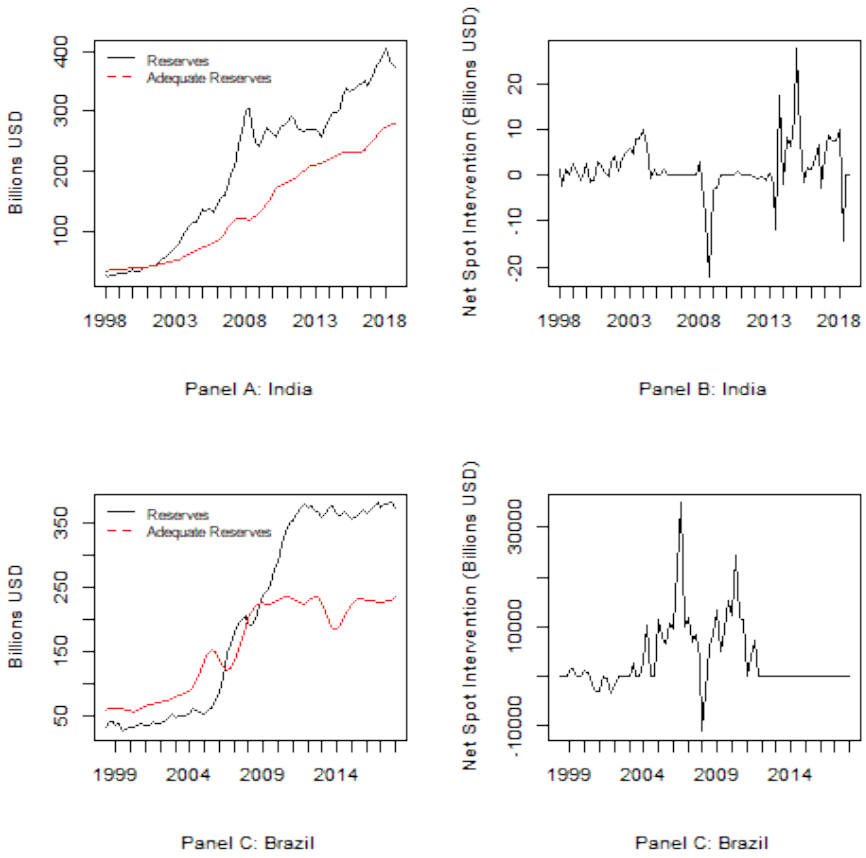
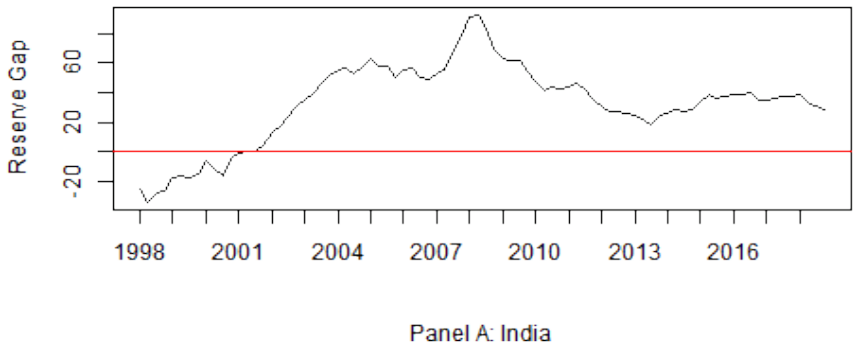
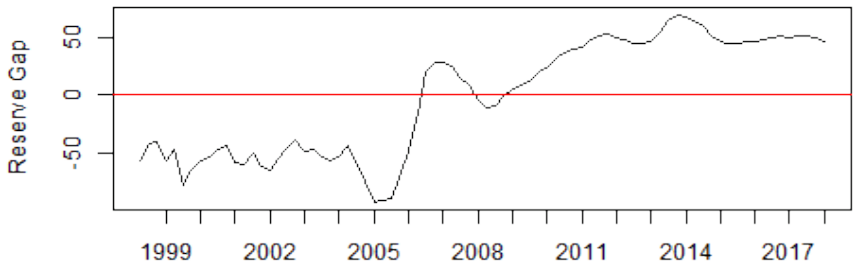


Figure 5: Reserves, Reserve Adequacy and Foreign Exchange Market Intervention

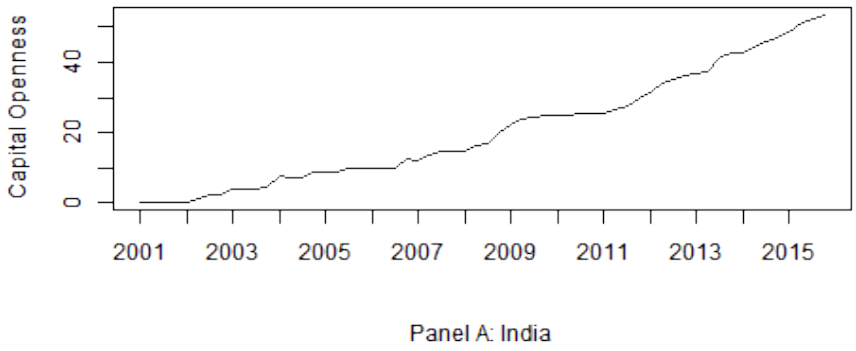


Panel A: India

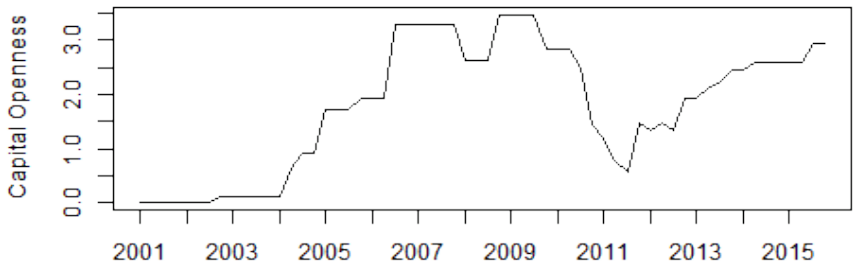


Panel B: Brazil

Figure 6: Reserve Gap



Panel A: India



Panel B: Brazil

Figure 7: Capital Openness

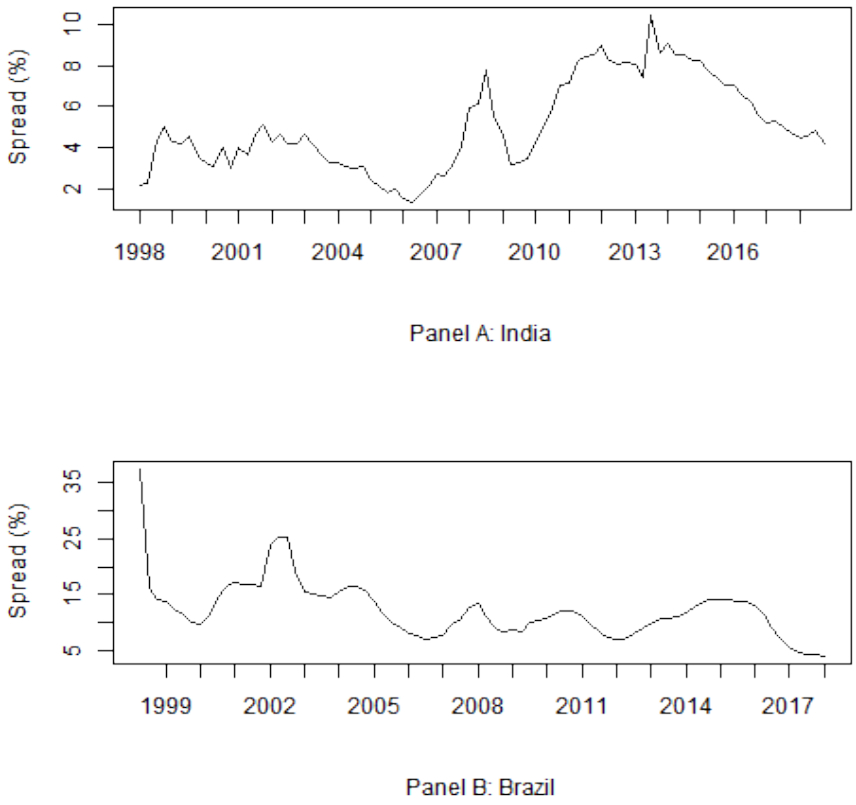


Figure 8: Domestic-US Interest Rate Spread

Appendix

A1. Variables description

• Δe: Percent change in nominal exchange rate, closing price reported by the Central Bank of Brazil and Reserve Bank of India. Quotations denominated in local currency per unit of US dollar. For quarterly data, exchange rate is for March 31st, June 30th, September 30th, and December 31st (or the closest date available). We applied the log changes and presented as percentage, $\Delta e = 100 \times (\ln(e_t) - \ln(e_t - 1)$.

• $\hat{Y}$: India output measured by Industrial Production. Brazil output is quarterly GDP series reported by the Central Bank of Brazil. Log of output series filtered by Hodrick-Prescott (HP) technique. Output gap is the cyclical component of the HP-filtered log(GDP) series.

• π: Inflation calculated as the anualized log change over local price index. India is the wholesale price index, Brazil is the IPCA (National Index of Consumer Prices, elaborated by the Brazilian Institute of Geography and Statistics). Percent Annualized change, $\pi = 100 \times (\ln(CPI_t) - \ln(CPI_{t-4}))$.

• π^*: India does not publish inflation target. We assume the implicit target constant through the whole period. For Brazil, IT is officially defined by the National Monetary Council and the Central Bank is required by law to pursue it, with some allowed deviations (tolerance bands). The IT changes through time. For 2019, it is defined as 4.25% with a tolerance band of 2% (meaning an accepted interval of [2.25%, 6.25%]).

• $(\pi - \pi^*)$: The inflation gap is measured as the deviation from the target, i.e. $[100 \times (\ln(CPI_t) - \ln(CPI_{t-4})) - \text{inflation target}] = [100 \times (\ln(CPI_t) - \ln(CPI_{t-4})) - \pi^*]$.

• i: Money market rate defined and controlled by the Central Bank of Brazil and Reserve Bank of India, respectively. For Brazil we have used the "SELIC" rate, and for India we've used 3 months money market defined by RBI & India: 1999Q1-2018Q4; Brazil: 2000Q1-2018Q4;

• i^*: The US interest rate is the 3-Month Treasury Bill Rate, published by the Federal Reserve Economic Data (FRED).

• openness: This variable is from Pasricha et al.(2015). The author provided a detailed dataset for the period 2001-2015 with quarterly frequency. Each data series counts the number of capital flow measures (for example, number of easings of inflow controls or tightenings of outflow controls) undertaken by each country. The variables used from the dataset weighted each policy action by the share of the country's international assets or liabilities that the measure was designed to influence. The policy actions in the dataset were counted by effective dates and included changes for which the announcement and effective dates are different. From the dataset we explored two specific series: "wgt_nettighteningin", and "wgt_neteasingout", that correspond to number of net inflow tightenings, weighted, and number of net outflow easenings, weighted, respectively.
As we are insterested to understand the degree of openness of the countries studied, we have transformed the first series "net inflow tightenings" to "net inflow easing" by inverting its sign (a positive tightening means a negative easing and a negative tightening means a positive easing). With the quarterly values of easing inflow and easing outflow we chose to work with the cumulative measures of both easing inflow and outflow combined. As this variable was intended to measure openness, we need to measure the easing policies, regardless of inflow or outflow.

• R: Level of Foreign Reserves in USD reported by the Central Bank, includes SDRs and excludes Gold holdings.

• R^*: The Reserve Target values are from IMF "Assessing Reserve Adequacy". The institution's

work compares the reserve holdings and alternative metrics of reserve adequacy. This reserves adequacy measure was initially developed in the IMF Board Paper "Assessing Reserve Adequacy" - RAM1 (February 15, 2011), and adjusted in the latest IMF Board Paper "Assessing Reserve Adequacy- Specific Proposals" (December 19, 2014), in order to reflect the outflows during the Global Financial Crisis which were not addressed in RAM1. The IMF Reserve Adequacy estimates adequate volume of reserves for a specific country taking into account exports, imports, broad money, and other liabilities.

- $(R - R^*)$:The Reserve Gap is calculated by the difference of the level of reserves and the adequate level proposed by the IMF (R^*). Log-transformation and percentage presentation is also applied: $100 \times (ln(R) - lnR^*)$

- Appreciation: Dummy variable that assumes value equals to 1 if the local currency appreciates versus US dollar, i.e., $\Delta e < 0$ and value equals 0 otherwise ($\Delta e \geq 0$).

- Spot Intervention: Amount of USD bought and sold in the spot market relative to the level of Reserves.

- Forward Intervention: Amount of USD bought and sold in the forward market relative to the level of Reserves.

A2. Tables

Table A1: Summary of Variables

Variable	Sources	Data Range
Δe	Central Bank of Brazil and Reserve Bank of India.	India: 1998Q2-2018Q4; Brazil: 1999Q1-2018Q4;
$\hat{Y}$	Central Bank of Brazil and Reserve Bank of India. For India it was used the Industrial Production.	India: 1998Q1-2018Q4 Brazil: 2000Q1-2018Q4;
$\pi - \pi^*$	Central Bank of Brazil and Reserve Bank of India. For Brazil we have used the "IPCA" index, and for India we've used Wholesale Price Index.	India: 1999Q1-2018Q4; Brazil: 2000Q1-2018Q4;
i	Central Bank of Brazil and Reserve Bank of India. For Brazil we have used the "SELIC" rate, and for India we've used 3 months money market defined by RBI	India: 1999Q1-2018Q4; Brazil: 2000Q1-2018Q4;
i^*	FRED - Federal Reserve Economic Data.	1998Q1-2018Q4
openness	Index developed by Pasricha (2015).	India: 2001Q1-2015Q4
$R - R^*$	Central Bank of Brazil, Reserve Bank of India, and IMF.	1998Q1-2018Q4; Brazil: 2000Q1-2018Q4;
Appreciation	Constructed by the Authors.	India: 1998Q2-2018Q4; Brazil: 2000Q1-2018Q4;
Spot Intervention	Central Bank of Brazil and Reserve Bank of India.	India: 1998Q1-2018Q4; Brazil: 2000Q1-2018Q4;
Forward Intervention	Central Bank of Brazil and Reserve Bank of India.	India: 1998Q1-2018Q4; Brazil: 2000Q1-2018Q4;

All variables were already available in USD unit.