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Facing the Quadrilemma: Taylor rules, intervention policy and capital controls in large emerging markets ☆

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ABSTRACT

This paper investigates extended Taylor rules and foreign exchange intervention functions in large Emerging Markets (EM), measuring the extent to which policies are designed to stabilize output, inflation, exchange rates and accumulate international reserves. We focus on two large emerging markets - India and Brazil. We also consider the impact of greater capital account openness and which rules dominate when policy conflicts arise. We find that 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. Large unpredicted intervention purchases (sales) accommodate low (high) interest rates, suggesting that external operations are subordinate to domestic policy objectives. We extend the work to Chile and China for purposes of comparison. Chile's policy functions are similar to Brazil, while China pursues policies that substantially diverge from other EMs.

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

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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. Changes in capital controls are also a powerful macroeconomic management tool in some emerging markets (Fernandez et al., 2016), but are generally used infrequently.

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), Cavallino (2019), Farhi and Werning (2012), Jeanne (2012)). 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, Cavallino (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 considerations by including an exchange rate stabilization objective, e.g. Aizenman et al. (2011). We extend previous work investigating modified Taylor rules by considering a second policy rule linking foreign exchange market intervention to exchange rate stability and an objective to accumulate reserves to a target level. Specifically, we explore how large emerging-market economies have in practice managed to accumulate substantial 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 foreign exchange market intervention, and four policy objectives—inflation, output, exchange rates and foreign reserve target. Against this background, we also investigate (1) the impact of changes in the intensity of capital controls, though this instrument is only infrequently cyclically applied in most EMs, and the impact of the transmission of U.S. interest rates; and (2) cases of very large discretionary (unpredicted) intervention operations and interest rate changes, evaluating whether the interest rate instrument (internal balance) or intervention operations (external balance) dominate when policy conflicts arise. Although not able to capture all aspects of the quadrilemma with our analysis, we are able to shed light on practical policy considerations for internal and external balance in the use of the two major tools - monetary policy and intervention policy.

Our primary interest is in two large emerging market economies, Brazil and India, with a comparative analysis of the largest EM, China, and one small open economy, Chile. 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 the 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).

Brazil and India use capital controls extensively as a macroeconomic management tool. Although 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; updated online June 2019) data set on capital control restrictiveness using the IMF Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) as the underlying data source, India and Brazil placed 0.93 and 0.65, respectively in 2017. (The range is from 0 with no restrictions to 1 as completely closed). The authors characterize India with "walls" to external financial flows and Brazil with a "gate." 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.[1] (The U.S. had a restrictiveness index of 0.16 in 2017 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.

These emerging markets have also 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. However, their stated macroeconomic policies and monetary regimes are very different. 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.[2]

[1] China is also characterized by Fernandez et al. (2016) as having "walls" with a capital account restrictiveness measure of 0.85 in 2017 and 1.0 in 2000. Chile is more much more open, with a restrictiveness measure of 0.45 in 2017 (and 0.88 in 2000).

[2] Chile also has an inflation targeting regime, while the People's Bank of China monetary policy demonstrates substantial discretion.

We empirically evaluate the significance of these regime differences on Taylor rules as well as intervention policy functions, and whether capital controls influence policy actions and the transmission of U.S. interest rate changes to policy rates. We also consider whether interest rate policy (internal balance) dominates or is subordinate to intervention policy (external balance) when policy conflicts arise. 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 (2017), into the interest rate rule (Taylor rule) and intervention rule equations.

We include China in our study as a counterpoint to the other large EMs. As China's institutions are quite different, it is an interesting comparison case. And, as a counterpart to our analysis of large emerging markets, we also consider a small commodity-based emerging market - Chile. Chile is a small open economy, largely commodity-based and with very open capital markets. We investigate whether the revealed policy choices for large emerging markets carry over to small emerging markets like Chile.

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. Section 4 presents data and methodology. Section 5 presents the empirical results for Brazil and India. Section 6 extends the analysis to China and Chile. Section 7 concludes.

2. Macroeconomic management in large emerging market economies

Our focus emerging markets - 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. Neither of these countries explicitly state that they follow a Taylor rule in setting interest rates, but in monetary policy statements note that inflation is a priority and usually point to the state of the economy as a consideration in setting policy. Our objective is to quantify the relative importance of these factors. Similarly, authorities rarely provide an explicit intervention policy guide, but ex post policy statements often refer to "disorderly" exchange market conditions, reserve and current account developments, and so forth in explaining their actions. Again, our objective is to quantity, if possible, the relative weight that these various considerations play in systematically influencing intervention operations. Previous research and policy statements help guide us in our empirical specifications.

In particular, the Reserve Bank of India formally states that its primary objective is to maintain price stability, while "...keeping in mind the objective of growth" and announced recently a "flexible inflation targeting" regime.[3] Empirical work has found that India alternates 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 (in 2013) of interest rate defense of the exchange rate. 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 has not been a "nominal anchor" for monetary policy in India, and as a consequence high inflation is 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 et al. (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).

[3] The Reserve Bank of India (July 2019) states that the goals of monetary policy are: "The primary objective of monetary policy is to maintain price stability while keeping in mind the objective of growth. Price stability is a necessary precondition to sustainable growth." Moreover, in May 2016, the Reserve Bank of India (RBI) Act, 1934 was amended to provide a statutory basis for the implementation of the flexible inflation targeting framework.

Similar, 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. However, it is evident from numerous policy statements that output stabilization is also an important element in setting interest rate policy in Brazil. Minutes from a recent monetary policy report from the Central Bank of Brazil (2019), for example, note that: "The Copom members assessed that economic conditions with anchored inflation expectations, underlying inflation measures at appropriate levels, 2020 inflation projected around or slightly below target, and high *level of slack in the economy prescribe stimulative monetary policy*, i.e., interest rates below the structural interest rate level. The structural interest rate is a reference for the conduct of monetary policy".[4] Hence, in this case it is also of interest to measure the weights the central bank places on the inflation target as opposed to output stabilization and other factors in setting interest rates. Other factors may include the exchange rate. For example, Aizenman et al. (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 also intervenes 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, waning in recent years, 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), and Oliveira and Novaesk (2007). Oliveira and Novaesk (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

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 identity.

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 et al., 2011). This formulation takes the form:

$$i_t = \alpha_1 + \alpha_2\left(y_t - y_t^*\right) + \alpha_3\left(\pi_t - \pi_t^*\right) + \alpha_4(e_t - e_{t-1}) + \alpha_5 i_{t-1} + \epsilon_t \tag{1}$$

where i_t is the central bank interest rate operating instrument, $\left(y_t - y_t^*\right)$ is (log) output less (log) output trend (i.e. percentage deviation from trend output), $\left(\pi_t - \pi_t^*\right)$ 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 manage 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:

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

where I_t is foreign exchange market intervention (USD purchases of foreign exchange are positive values and sales are negative values, as a percent of last quarter's stock of international reserves), $\left(R_t - R_t^*\right)$ 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 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:

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

[4] Minutes of the 223rd Meeting of the Monetary Policy Committee (Copom) Banco Central do Brasil, June 18–19, 2019. Italics in the quote are our own.

where i^*_{t-1} is the interest rate on foreign exchange reserves (represented by the 3-month U.S. Treasury Bill rate) and VAL_{t-1} is valuation changes on international reserve holdings. Hence, intervention is directly linked to the target for international reserves. Our assumptions are that i^*_{t-1} and VAL_{t-1} are exogenous variables.

As extensions of the basic models represented by Eqs. (1) and (2), we also include the terms-of-trade and the current account in both equations. A rise in either the terms-of-trade or the current account have wealth and liquidity effects on the economy and could elicit a monetary response. Similarly, a terms-of-trade change could impact the foreign exchange market (increasing foreign exchange receipts), as could a rise in the current account by increasing liquidity in the market. Both of these variables also have proved important in other studies of macroeconomic policy in EMs (e.g. Aizenman et al. 2011).

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.

4. Data and methodology

4.1. Data

We employ quarterly data over the period 1999q1-2018q4 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 A.[5]

Macroeconomic developments for both countries are detailed in the summary statistics of Table 1 and Figs. 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 "adequate" reserves).[6] Fig. 1 shows the output gap; Fig. 2 inflation (and, for Brazil, evolution of the inflation target); Fig. 3 money market interest rates; Fig. 4 exchange rates (left panel, level of the domestic currency per USD; right panel, percent change); Fig. 5, left column, is the level of international reserves and the "adequate reserves" level (estimated by the IMF) and the right column is the net spot foreign exchange market intervention; Fig. 6 is the reserve gap (difference between actual reserves and adequate reserves as a percent of adequate reserves; Fig. 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 Fig. 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 et al., 2003). It is evident from the figure that output gap volatility has been much larger in Brazil than India.

As noted, Brazil has had an inflation target since 1999. This target has changed several times over the sample period, shown in Fig. 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 therefore subsumed in the constant term of the estimated Taylor rule for India. We follow other studies (e.g. Gupta and Sengupta, 2014; Modenesi et al., 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 Fig. 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 Fig. 4, is the value of local currency against the USD. Brazil has

[5] Two appendices - sources of data and detailed variable definitions - are omitted from the text for brevity but are available from the authors upon request.

[6] It is an intriguing question as to why Brazil has had a much more volatile economy than India, with prime candidates more restrictive capital controls in India and, hence, less volatile capital movements; more volatile external shocks in Brazil associated with dependence on commodities and terms-of-trade fluctuations; and so on. Our focus is not in addressing this issue but to compare monetary and intervention policies in the two countries. Differences in policies, however, may play an important role in explaining relative volatility of these economies.

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	13.45	4.58	6.50	26.50
$y - y^*$	84	0.00	2.24	−6.46	6.61	76	−0.21	9.55	−18.71	16.25
π	80	4.56	3.19	−5.68	10.47	76	5.24	3.39	3.03	11.15
$\pi - \pi^*$	80	4.56	3.19	−5.68	10.47	76	0.42	1.02	−1.03	5.69
$e_t - e_{t-1}$	83	0.73	3.04	−6.91	10.86	76	1.02	8.50	−17.86	28.56
$R - R^*$	84	33.12	27.68	−34.01	93.13	76	1.24	49.98	−92.48	69.61
I_{spot}	84	1.56	3.89	−8.30	10.14	76	2.63	6.77	−8.82	32.00
I_{total}	84	0.01	11.64	−34.76	26.66	76	2.58	7.12	−11.29	32.00
openness	60	20.76	15.84	0.15	53.73	60	1.80	1.19	0.00	3.49
t.o.t.	76	107.27	11.33	90.02	142.56	80	95.15	14.37	62.85	143.17
currentaccount	83	−1.37	2.01	−6.99	4.61	88	−1.89	2.19	−5.48	3.43

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	16.93	3.78	11.25	26.50
$y - y^*$	44	0.25	2.61	−3.43	6.61	36	−0.62	10.05	−17.04	16.25
π	40	4.56	3.19	−5.68	10.47	36	6.27	3.87	3.03	11.15
$\pi - \pi^*$	40	4.56	3.19	−5.68	10.47	36	0.55	1.25	−1.03	5.69
$e_t - e_{t-1}$	43	0.5	2.87	−6.91	10.86	36	−0.15	8.11	−17.86	20.82
$R - R^*$	44	29.68	36.78	−34.01	93.13	36	−42.71	33.72	−92.48	28.55
I_{spot}	44	2.32	4.79	−8.3	10.14	36	4.26	9.36	−8.82	32.00
I_{total}	44	0.14	11.37	−25.35	23.4	36	3.99	9.80	−11.29	32.00
openness	32	8.07	5.67	0.15	20.36	32	1.41	1.35	0.00	3.49
t.o.t.	36	106.15	15.36	90.02	142.56	40	95.58	17.78	62.85	143.17
currentaccount	43	−0.78	1.92	−2.32	4.62	47	−1.43	2.61	−5.48	3.43

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	10.31	2.50	6.50	14.25
$y - y^*$	40	−0.27	1.74	−6.46	3.41	40	0.17	9.20	−18.71	14.71
π	40	3.97	4.05	−5.68	10.12	40	5.06	2.91	3.63	8.74
$\pi - \pi^*$	40	3.97	4.05	−5.68	10.12	40	0.31	0.76	−0.91	2.71
$e_t - e_{t-1}$	40	0.98	3.24	−3.86	10.72	40	2.07	8.80	−16.72	28.56
$R - R^*$	40	36.91	10.51	19.07	62.61	40	40.80	19.87	−11.28	69.61
I_{spot}	40	0.72	2.34	−4.56	9.12	40	1.16	2.20	−1.78	8.49
I_{total}	40	−0.16	12.08	−34.76	26.66	40	1.32	2.79	−2.74	8.96
openness	28	35.27	10.11	22.32	53.73	28	2.25	0.80	0.58	3.49
t.o.t.	40	103.77	2.97	97.49	108.01	40	97.82	9.34	77.08	120.36
currentaccount	40	−2.31	1.61	−6.99	−0.06	41	−2.42	1.43	−4.93	0.90

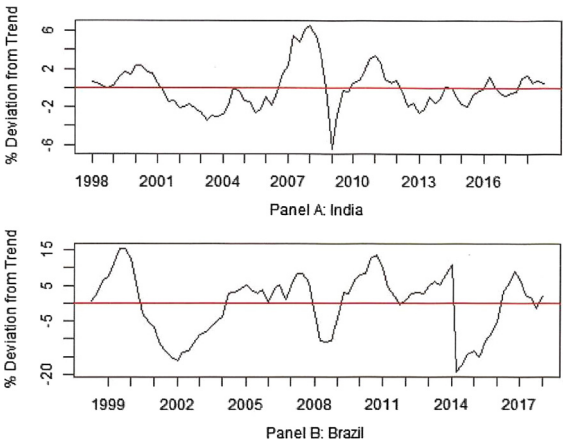

Fig. 1. Output gap.

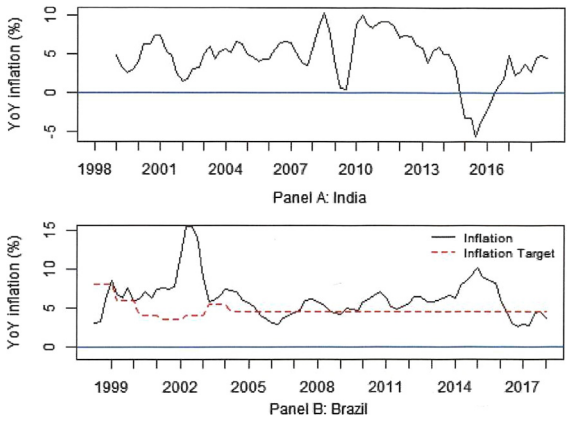

Fig. 2. Inflation.

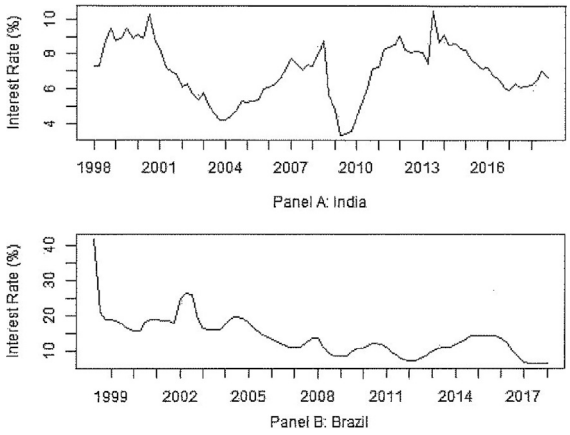

Fig. 3. Money market interest rates.

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 Fig. 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 Fig. 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 Fig. 5. It is apparent that both countries grew reserves very substantially since the early 2000 s, 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 Fig. 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.

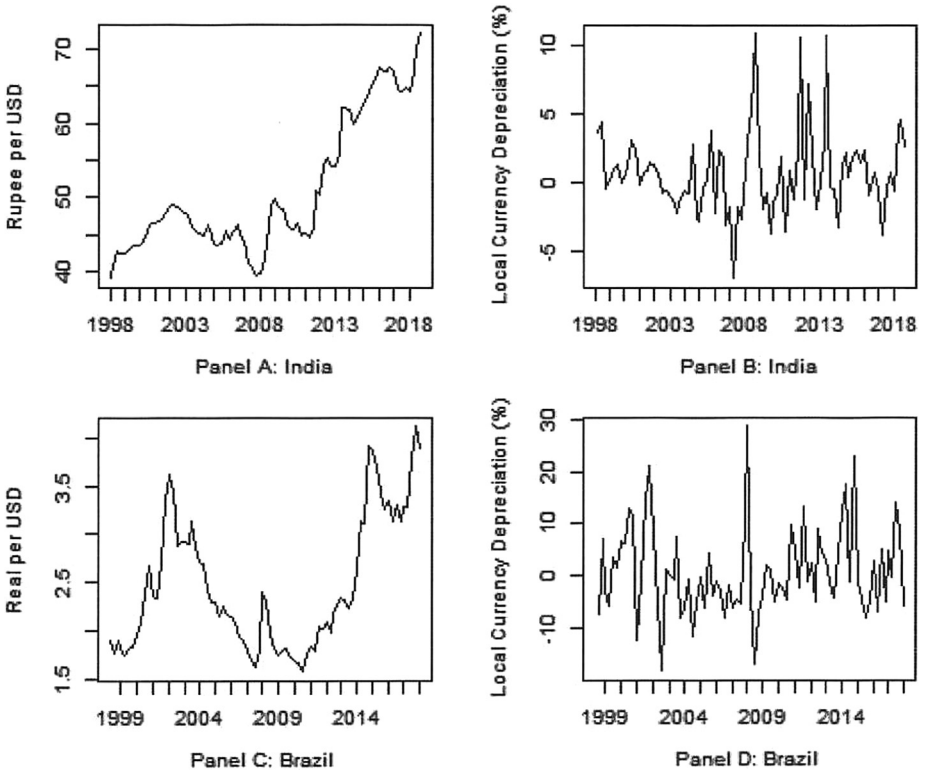

Fig. 4. Exchange rates.

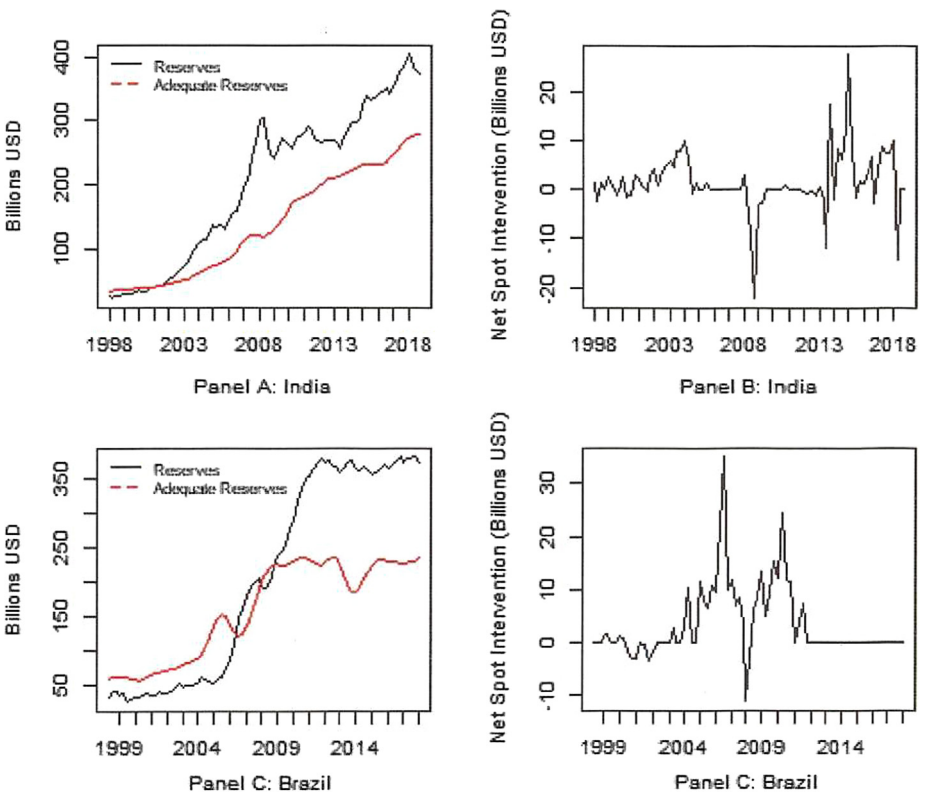

Fig. 5. Reserves, reserve adequacy and foreign exchange market intervention.

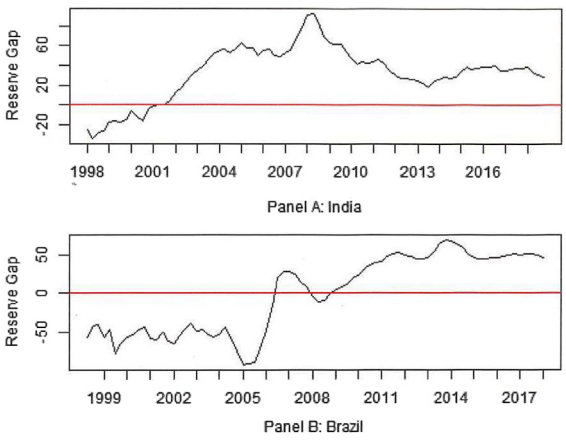

Fig. 6. Reserve gap.

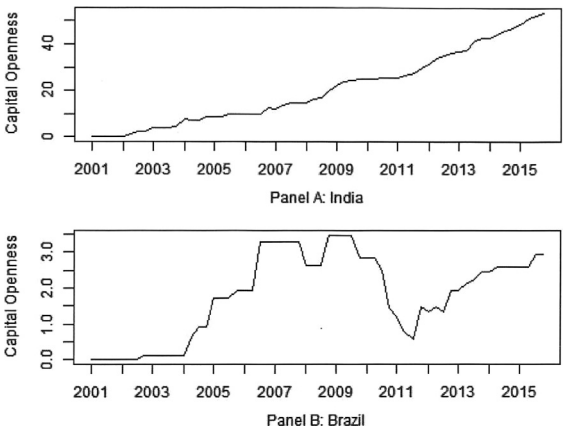

Fig. 7. Capital openness.

Capital Openness Index, shown in Fig. 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 Fig. 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.

4.2. 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 (1999q1-2008q4) and after the Global Financial Crisis (2009q1-2018q4), 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. Exchange rate fluctuations are likely to suffer from a two-way causality issue as well. However, we do not employ instrumental variables for the exchange rate. There are two reasons for this decision. First, exchange rates are notoriously difficult to predict 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 it isn't clear that instrumenting for the exchange rate leads to improved estimates. The

second reason is that the bias of the exchange rate coefficient works against our hypothesis. This is because lower interest rates and foreign currency purchases lead to exchange rate depreciation, whereas we expect depreciation to cause higher interest rates and purchases of domestic currency. Our results for the exchange rate can therefore be interpreted as a lower bound on the true effect of exchange rates 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 heteroscedasticity in the error term.

5. Results

5.1. Baseline and extended full sample results

Table 2 shows the full-sample baseline results for Brazil and India (column 1), together with the extended model including the terms-of-trade and the current account (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.[7]

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 60 basis points for every 1 percentage point above the inflation target. The extended results also suggest that the Central Bank of Brazil responds to exchange rate depreciation by raising interest rates. In sharp contrast with India, no output stabilization by Brazil's central bank is indicated over the full sample.

The additional variables (terms-of-trade and current account) of the extended model do not appear significant for India, but the terms-of-trade does enter significantly for Brazil. An improvement in the terms-of-trade in Brazil is associated with a (statistically significant) decline in interest rates. Interest rate policy is highly persistent in both countries, especially in India (lagged dependent variable coefficient equals 0.81–0.82 in India and 0.65–0.66 in Brazil).

Although following quite different Taylor rules, India and Brazil are similar in foreign exchange market intervention policy responses to exchange rate changes, shown in Panel B of Table 2. Both countries respond strongly to exchange rate movements in "leaning against the wind" intervention operations, selling (buying) about 0.17–0.22% in Brazil and 0.30–0.48% in India, of the stock of international reserves in response to a one percent depreciation (appreciation) of the domestic currency against the USD.

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).[8] Differences also emerge between the two countries in terms of responses to terms-of-trade fluctuations and the current account. A terms-of-trade improvement in Brazil reduces U.S. dollar intervention purchases - most likely attributable to higher foreign exchange earnings for Brazilian exports. No intervention response is noted to changes in the current account in Brazil. By contrast, the current account is estimated to be highly significant for intervention policy in India, with a rise in the surplus (as a percent of GDP) leading to a significant increase in U.S. Dollar purchases, perhaps absorbing excess liquidity generated by the surplus in the foreign exchange market in the face of fairly restrictive capital controls. Although the exchange rate response remains significant in Indian intervention policy, albeit weaker than in the basic equation, targeting of reserves is no longer statistically significant (although the coefficient estimate is very similar, it is measured with less precision).

It is noteworthy that both India and Brazil built very substantial foreign exchange reserve positions during the sample period. This is reflected in the empirical model by the significant positive constant terms in the intervention regressions, indicating substantial average foreign exchange purchases (as a percentage of existing reserves).

5.2. Policy shifts and the global financial crisis

We address whether policy shifts occurred at the time of the GFC in Table 3, comparing the pre-GFC 1999Q1-2008Q4 period with the post-GFC 2009Q1-2018Q4 period. We present both the baseline model and the extended model in Table 3, but focus our discussion on the extended model results.

The full sample results on output and inflation carry over to the sub-sample results—during both sub-samples India focused on output stabilization and Brazil focused on inflation targeting. Nonetheless, we find some evidence that India

[7] We also considered a measure of intervention aggregating spot and forward transactions. The results were unchanged, omitted for brevity, and are available from the authors upon request.

[8] This result is statistically significant in the baseline model at the 1% level, but not statistically significant in the extended model.

Table 2
Baseline Results.

Panel A: Interest Rate Policy	Dependent Variable:i_t			
	India		Brazil	
	(1)	(2)	(1)	(2)
c	1.13***	1.16***	3.51***	5.87***
	(0.39)	(0.56)	(1.31)	(1.38)
$y - y^*$	0.11***	0.11***	0.03	0.03
	(0.03)	(0.03)	(0.03)	(0.04)
$\pi - \pi^*$	0.02	0.02	0.60***	0.60***
	(0.02)	(0.02)	(0.22)	(0.16)
$e_t - e_{t-1}$	0.03	0.03	0.02	0.03*(0.015)
	(0.06)	(0.06)	(0.02)	
i_{t-1}	0.82***	0.81***	0.65***	0.66***
	(0.05)	(0.05)	(0.11)	(0.04)
t.o.t.		−0.00		−0.013**
		(0.00)		(0.012)
currentaccount		−0.04		0.11
		(0.03)		(0.17)
R^2	0.83	0.82	0.85	0.86
Num. Obs.	80	76	79	79
Panel B: Intervention Policy	Dependent Variable:I_t			
	India		Brazil	
	(1)	(2)	(1)	(2)
c	3.23***	3.12	3.12*	25.17***
	(0.71)	(6.21)	(1.70)	(9.36)
$e_t - e_{t-1}$	−0.48***	−0.30**	−0.22**	−0.17**
	(0.15)	(0.11)	(0.09)	(0.074)
$R - R^*$	−0.04***	−0.04	−0.04	−0.03
	(0.01)	(0.03)	(0.04)	(0.02)
t.o.t.		0.01		−0.23**
		(0.05)		(0.09)
currentaccount		0.91***		0.18
		(0.24)		(0.39)
R^2	0.13	0.45	0.11	0.32
Num. Obs.	83	76	75	75

*** p < 0.01.
** p < 0.05.
* p < 0.1.

began responding to inflation deviations in the post-crisis period[9] and also to terms-of-trade changes in both pre- and post-crisis samples. The current account is only statistically significant for India in the pre-crisis sample.

As stated, inflation targeting dominated the Central Bank of Brazil's interest rate policy in both sub-periods, as it did in the full sample period, but the estimated response is weaker in the post-GFC period.[10] This finding sheds some light on the concern that Brazil is adhering less to inflation targeting in recent years (Cortes and Paiva, 2017). However, no output response is estimated in Brazil in either sub-period, nor is there evidence of systematic responses to exchange rates, terms-of-trade or current account movements.

Exchange rate stabilization is a dominant feature of intervention policy for India in the pre and post-GFC, with quite similar responses, as for the full sample period. All the coefficient estimates are significant at the 5% level or better. By contrast, the estimates for the two sub-samples in Brazil are not statistically significant (unlike the full sample).

Stronger responses are suggested in the management of foreign exchange reserves in India from the pre to the post-GFC,[11] and the response in the latter period - selling foreign exchange when reserves are above target - is consistent with a stabilizing role. The response for the reserve gap is significantly negative in Brazil both periods, with policy targeting a desired reserve level, and the coefficient estimates are similar. The terms-of-trade played a role in intervention policy for both countries in the pre-GFC period, but not in post-GFC period. A rise in the current account surplus induced USD purchases in both periods for India, probably to absorb surplus liquidity in the foreign exchange market and limit pressure on the Rupee to appreciate in the face of capital controls. Surprisingly, the opposite result is obtained (negative and statistically significant) for Brazil in the post-GFC period.

[9] The coefficient is 0.04 (not statistically significant) for the early period and 0.03 (statistically significant) for the later period. The difference in coefficient values is not statistically significant.
[10] However, this difference in coefficient estimates is not statistically significant at conventional levels (z-statistic 0.96).
[11] The z-statistic measuring differences in coefficient estimates is 2.53 (significant at the 5% level).

Table 3
Pre and post global financial crisis.

Panel A: Interest Rate Policy	Dependent Variable:i_t							
	India				Brazil			
	Pre- Crisis		Post-Crisis		Pre- Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
c	1.48***	0.39	0.86	−6.32***	8.66***	5.13	1.90**	−0.15
	(0.50)	(0.85)	(0.53)	(2.68)	(1.55)	(3.30)	(0.76)	(1.27)
$y - y^*$	0.12*	0.18***	0.16***	0.15***	0.01	0.03	0.02	0.01
	(0.07)	(0.06)	(0.03)	(0.04)	(0.03)	(0.05)	(0.02)	(0.01)
$\pi - \pi^*$	−0.02	0.04	0.04**	0.03**	0.60***	0.61***	0.50***	0.43***
	(0.05)	(0.07)	(0.01)	(0.02)	(0.16)	(0.17)	(0.09)	(0.08)
$e_t - e_{t-1}$	−0.02	−0.03	0.08	0.10	0.01	−0.02	0.01	0.01
	(0.03)	(0.02)	(0.08)	(0.09)	(0.03)	(0.03)	(0.01)	(0.01)
i_{t-1}	0.79***	0.57***	0.86***	0.85***	0.41***	0.30***	0.74***	0.72***
	(0.05)	(0.13)	(0.08)	(0.09)	(0.08)	(0.07)	(0.07)	(0.10)
t.o.t.		0.02*		0.07**		0.06		0.02
		(0.01)		(0.03)		(0.04)		(0.02)
currentaccount		−0.07**		−0.07		0.13		−0.15
		(0.03)		(0.06)		(0.22)		(0.10)
R^2	0.85	0.84	0.86	0.87	0.78	0.80	0.93	0.94
Num. Obs.	40	36	40	40	39	39	40	40
Panel B: Intervention Policy	Dependent Variable:I_t							
	India				Brazil			
	Pre- Crisis		Post-Crisis		Pre- Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
c	3.57***	−23.78*	4.63**	7.92	3.64*	46.71***	5.06***	3.65**
	(1.15)	(13.46)	(1.82)	(8.26)	(2.05)	(8.65)	(1.08)	(1.42)
$e_t - e_{t-1}$	−0.66**	−0.37**	−0.35**	−0.35**	−0.37**	−0.11	0.04**	0.02
	(0.30)	(0.14)	(0.15)	(0.15)	(0.10)	(0.14)	(0.02)	(0.02)
$R - R^*$	−0.03*	0.07	−0.10**	−0.10**	−0.03	−0.13***	−0.09***	−0.09***
	(0.02)	(0.06)	(0.04)	(0.03)	(0.04)	(0.03)	(0.02)	(0.01)
t.o.t.		0.21**		−0.02		−0.53***		0.00
		(0.10)		(0.08)		(0.10)		(0.01)
currentaccount		1.13***		0.51**		−0.25		−0.38**
		(0.30)		(0.24)		(0.39)		(0.18)
R^2	0.15	0.63	0.14	0.26	0.11	0.37	0.29	0.36
Num. Obs.	43	36	40	40	35	35	40	40

Pre-Crisis corresponds to period before 2009Q1.
*** p < 0.01.
** p < 0.05.
* p < 0.1.

5.3. 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 by 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 Fig. 7, India—though much more financially closed generally than Brazil—set out on a gradual process of external

Table 4
Capital Account Liberalization (Openness).

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)
$y - y^*$	0.1277**	0.2475***	−0.0176	0.0041
	(0.0691)	(0.0578)	(0.0390)	(0.0416)
$\pi - \pi^*$	−0.0276	0.0909	0.5248	0.5183
	(0.0489)	(0.0849)	(0.3105)	(0.3798)
$e_t - e_{t-1}$	0.0323	0.0590	0.0089	0.0006
	(0.0336)	(0.0373)	(0.0294)	(0.279)
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)
$e_t - e_{t-1}$	−0.26**	−0.27*	−0.27	−0.00
	(0.11)	(0.16)	(0.20)	(0.12)
$R - R^*$	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)
R2	0.66	0.30	0.49	0.41
Num. Obs.	32	28	32	28

Pre-Crisis corresponds to period before 2009Q1.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

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.

5.4. Linkage across policies

Tradeoffs between interest rate and intervention policies are not explicitly addressed using our basic methodology. It is possible that "errors" in one policy function, i.e. deviations from predicted values, are discretionary policy actions connected to the second policy function. For example, unexpectedly low interest rates (intervention) may be linked to unexpectedly

low intervention (interest rates) as authorities are attempting to manage the exchange rate via the Taylor rule rather than direct intervention operations. In other words, there may be tradeoffs and substitutions between the internal and external policy functions that are manifested in the error terms.

We address this issue in two ways. Our first approach is to estimate the two equations using a Three Stage Least Squares (3SLS) systems estimator[12]. This method considers systemic linkages among the errors of the two policy equations while also accounting for the endogeneity of the reserve gap in the intervention equation. The estimates, not reported for brevity are virtually identical to the extended model results reported in Table 2, column 2 for both India and Brazil's interest rate (Panel A) and intervention (Panel B) policy equations[13]. This indicates that the error terms in the two equations are not significantly correlated in a simple way. This is confirmed by the simple error correlations across the two equations-- statistically insignificant correlation coefficients of −0.16 (standard error 0.11) for India and 0.02 (standard error 0.11) for Brazil.

We also explore possible linkages between large policy errors in the two equations since policy tradeoffs or conflicts may only be manifested during particular episodes. For example, a country may not respond to substantial pressure on the exchange rate in the Taylor rule if domestic conditions are clearly not warranting an interest rate change, placing greater emphasis on intervention policy. We identify the intervention policy errors (interest rate policy errors) that are equal to or larger than the 90th percentile in absolute value and regress these on the associated interest rate policy (intervention policy) function errors in Table 5. These results indicate that the equations are related in a highly non-linear way. In particular, large intervention policy errors in both India and Brazil are negatively and significantly correlated with corresponding interest rate policy errors. That is, unexpectedly large USD purchases (sales) by the foreign exchange fund are associated with lower (higher) than predicted interest rates. This suggests that episodes of especially large unexpected intervention purchases/sales may be designed to limit the need for interest rate changes in macro policy management. Interestingly, we do not find that large interest rate errors are correlated with associated intervention errors[14]. Discretionary intervention policy actions appear to serve as a "pressure valve" when policy conflicts arise, subordinate to interest rate policy.

6. Robustness: Extensions to China and Chile

In this section we contrast our results for Brazil and India with two other emerging markets, Chile and China. The contrasts between Chile and China are stark. Chile is a small open economy with inflation targeting, high dependence on commodity exports, flexible exchange rates and a very open capital account. China, on the other hand, is the largest emerging market—the second largest economy in the world after the United States—with discretionary monetary policy, dominance of manufacturing exports, rigid exchange rate and largely closed to (non-FDI) external capital flows. China is also characterized by heavy government involvement in the financial sector, government majority ownership in large banks, and regulated interest rates.

Chile is included to check the robustness of the results to a small open market-oriented EM with high dependence on commodity exports and a policy commitment to inflation targeting. China, of course, is the obvious choice to include in our study due simply to its importance to the world economy, rapid growth and buildup of international reserves. It is not a country of emphasis in this study, but rather an extension of our work, because China's macroeconomic institutions differ so markedly from other large EMs.

6.1. Chile

Chile was the second country in the world to adopt inflation targeting (IT), setting its first annual target in September 1990, and IT was used as a device to bring inflation gradually down to a stationary 3% level (Schmidt-Hebbel and Tapia, 2002). As noted in its 2019 monetary policy report:[15] "The main objective of the Central Bank of Chile's monetary policy is to keep inflation low, stable, and sustainable over time. Its explicit commitment is to keep annual CPI inflation at around 3% most of the time, within a range of plus or minus one percentage point".[16] Although the main objective of policy is focused on inflation, it does not preclude secondary objectives and several articles suggest that both internal and external factors may play a role in determining domestic interest rates (e.g. Edwards, 2015). Navdon and Vial (2016), for example, emphasize the impact of commodity prices and the exchange rate on inflation in Chile. Nonetheless, monetary policy statements from the central bank generally do not refer to output stabilization as a reason for policy changes.

Table 6 shows the empirical estimates results for Chile. Panel A indicates that over the full sample period interest rate policy responded significantly in the expected ways to both inflation and the output gap. But the estimates suggest that

[12] Greene (2012) shows that the seemingly unrelated regressions model, estimated equation by equation, is inefficient compared with an estimator that makes use of the cross-equation correlations of the disturbances. Following Greene (2012), we estimate both equations jointly with a three-stage least squares estimator (the IV estimator is simply equation-by-equation 2SLS). This procedure is asymptotically efficient.

[13] These results are available from the authors upon request.

[14] Not reported for brevity but available from the authors upon request.

[15] Monetary Policy Report, June 2019, Central Bank of Chile.

[16] This quote continues to state that output stabilization is a derivative of achieving stable inflation, but not an explicit objective of policy: "Low, stable inflation promotes economic activity and growth while preventing the erosion of personal income. Moreover, focusing monetary policy on achieving the inflation target helps to moderate fluctuations in national employment and output."

Table 5
Residual analysis.

Dependent Variable ϵ_{taylor}	India	Brazil
c	0.14	0.87***
	(0.12)	(0.10)
$\epsilon\_\{intern vention\}\|(\|\epsilon\_\{inter vention\}\|) > p90$	−0.21*	−0.09*
	(0.11)	(0.04)
R^2	0.17	0.05
Num. Obs.	16	16

**p < 0.05.
*** p < 0.01.
* p < 0.1.

Table 6
Chile policy rules.

Panel A: Interest Rate Policy			Dependent Variable:i_t			
	Fulll Sample		Pre-Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)
c	0.76***	1.60***	0.40	−2.98***	1.79***	2.11
	(0.25)	(0.54)	(0.35)	(0.95)	(0.52)	(1.43)
$y - y^*$	0.07***	0.10***	0.02	−0.03	0.21***	0.18
	(0.03)	(0.02)	(0.03)	(0.04)	(0.06)	(0.07)
$\pi - \pi^*$	0.20***	0.18***	0.22***	0.28***	0.05	0.07
	(0.06)	(0.05)	(0.04)	(0.05)	(0.12)	(0.11)
$e_t - e_{t-1}$	0.02	0.01	0.01	0.01	0.00	−0.01
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
i_{t-1}	0.64***	0.58***	0.74***	0.65***	0.44***	0.40***
	(0.08)	(0.09)	(0.08)	(0.09)	(0.05)	(0.04)
t.o.t.		−0.01		0.04***		−0.00
		(0.00)		(0.01)		(0.01)
currentaccount		−0.07		−0.11**		−0.06
		(0.04)		(0.05)		(0.05)
R^2	0.81	0.82	0.84	0.88	0.84	0.85
Num. Obs.	80	76	40	36	40	40
Panel B: Intervention Policy			Dependent Variable:I_t			
	Fulll Sample		Pre-Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)
c	1.63**	2.80	1.41**	3.67	13.62***	19.08***
	(0.64)	(3.83)	(0.60)	(8.25)	(4.94)	(5.62)
$e_t - e_{t-1}$	0.08	0.07	0.08	0.04	0.26	0.24
	(0.08)	(0.08)	(0.11)	(0.06)	(0.19)	(0.18)
$R - R^*$	−0.00	−0.00	0.01	0.02	−0.14***	−0.23***
	(0.01)	(0.01)	(0.03)	(0.03)	(0.05)	(0.05)
t.o.t.		−0.01		−0.02		0.01
		(0.04)		(0.08)		(0.03)
currentaccount		−0.04		−0.14		−0.80**
		(0.17)		(0.25)		(0.37)
R^2	0.00	0.01	0.03	0.05	0.05	0.05
Num. Obs.	75	75	35	35	40	40

*p < 0.1. Pre-Crisis corresponds to period before 2009Q1.
*** p < 0.01.
** p < 0.05.

greater focus in Chile was on inflation targeting in the pre-GFC period and on output targeting during the post-GFC period.[17] In the pre-GFC period, improvements in the terms-of-trade (and associated wealth gains and improving economy) were associated with interest rate hikes. Rising current account surpluses, in tandem with increased financial market liquidity, led to nominal interest rate declines. No statistically significant responses to either the terms-of-trade nor the current account were found in the post-GFC period, reflecting in part a low and largely unchanged policy interest rate during this period.[18]

[17] These differences are statistically significant. The z-statistic measuring the significance of the difference in the output gap (inflation target) is −2.60 (1.74), significant at the 1% (5%) level.

[18] These differences are statistically significant. The z-statistic for the difference in coefficients on the terms-of-trade (current account) between the two periods is 2.83 (-2.40), significant at the 1% (5%) level.

Panel B of Table 5 indicates that Chile's intervention policy targeted the reserve gap and was also impacted by the current account (with official purchases of USD declining with a rise in the surplus) during the post-GFC.[19,20] There is no systemic evidence of intervention policy directed towards exchange rate management in the full sample period or either sub-sample.

6.2. China

Analyzing monetary policy in China is not straightforward as the People's Bank of China (PBoC) uses more than one instrument for monetary policy and these instruments have evolved over time (Chen et al., 2017). The PBoC currently uses seven instruments of implementation of monetary policy, including the rediscount rate on loans to banks and other benchmark interest rates[21]. Moreover, stronger emphasis has been placed on targeting interest rates as the major monetary policy instrument in recent years (He and Jia, 2019). Given China's extensive use of capital controls and direct involvement in the banking sector and foreign exchange market, we modify the intervention equation in two ways beyond the models estimated for the other three countries investigated. First, we extend the intervention equation by including the broad money supply as an explanatory variable (M2, measured in USD as 100 * log(M2) divided by the log lag of nominal GDP).[22] In addition, we treat the current account as an endogenous variable.[23] This methodological adjustment is taken because tight capital controls on the financial account in China could lead to either current account surpluses or FDI inflows automatically increasing international reserves.[24]

Table 7 shows the empirical estimates for China. Panel A shows the Taylor rule estimates and panel B the intervention rule estimates. It is apparent that the central bank in China raises the policy rate in respond to an uptick in inflation, a very robust link that holds across sample periods and model specifications. Policy rates are also linked to the output gap, but with unexpected and significant negative sign, indicating that interest rates are reduced the larger is the output gap. Since GDP is only available for China on an annual basis, this result could be associated with the interpolation methodology. However, when employing industrial production rather than GDP as the output measure,[25] the significant positive coefficient is also obtained, and stands in contrast to estimates from the other EMs in the sample. There is also evidence that large current account surpluses in the pre-GFC period were associated with substantial liquidity in the Chinese financial system, leading the central bank to reduce interest rates. No estimated linkage with the terms-of-trade is statistically significant.

On the external side, we find no evidence that intervention policy systemically responds to (albeit small) variations in the nominal exchange rate or to the broad money supply (M2). However, we find a strong and robust intervention response to deviations in the reserve gap—the central bank systemically reduces its USD purchases when the reserve gap increases. This result holds across sub-samples and model specifications. This robust result is obtained despite the massive buildup of reserves by China, far exceeding "adequate" levels. Moreover, there is evidence that higher current account surpluses also led to more USD purchases prior to the GFC period, as the foreign exchange fund moved to absorb liquidity in the foreign exchange market, but not afterwards.[26]

In summary, applying our methodology to Chile, our small EM extension, is in line with our previous results. On the other hand, the results for China are at odds with the estimates for the other EMs. Estimation of the output gap in the Taylor rule is particularly problematic due to the lack of reliable quarterly output data in China. Nonetheless, we find a strong and robust inflation response in the Taylor rule and an intervention function consistent with targeting international reserve levels.

[19] We do not have central bank data on intervention for Chile and China (as we do for India and Brazil). We proxy for intervention by the change in international reserves, adjusted for interest earnings and valuation effects (as in equation (3)). We estimate interest earnings as the U.S. interest rate multiplied by lagged level of reserves. This adjusted series is divided by the lag level of reserves and regressed on the U.S. interest rate, as a proxy for valuation effects. The estimated coefficient on the U.S. interest rate is multiplied by the observed U.S. interest rate in each quarter to extract valuation effects from our intervention measure. As a robustness test of this approach, we made the same calculation of adjusted reserves for Brazil and India and correlated our estimated intervention with actual intervention data. The correlations are 0.71 and 0.62, respectively, for Brazil and India. This suggests that our "adjusted reserve change" proxy for intervention is a reasonable estimate of actual intervention.

[20] However, only the shift in the reserve gap coefficient between the two periods is statistically significant (z-statistic of 3.90, significant at the 1% level).

[21] Other instruments noted on the PBoC website in 2018 were open market operations, reserve requirement ratios, standing lending facility, medium-term lending facility, and pledged supplementary lending facility.

[22] This follows Schröder (2017) who finds both M2 and portfolio equity liabilities as significant determinants of reserve demand. The latter variable is not available past 2011 and not employed in our study. (It from the Lane and Milesi-Ferretti database, updated online through 2011 only).

[23] We instrument the contemporaneous current account in China with three lags of itself.

[24] This is related to the discussion of what constitutes intervention, "passive" increases in reserves that may be caused by interest earnings or valuation effects or "active" purchases and sales in the foreign exchange market. This is further complicated in the Chinese case by extensive capital controls.

[25] GDP data in China is only available at an annual level. Quarterly estimates of GDP are obtained by implementing a cubic spline interpolation. As a result, it is not possible to decompose the approximate quarterly series into the trend and cyclical components that would be needed to calculate the output gap. A simple quarter over quarter growth rate is calculated from the interpolated series and used as an alternative measure of the output gap in China. A potential concern with this methodology is that the variation in the interpolated series is being driven by statistical noise rather than actual output fluctuations in China. To alleviate this concern, the baseline Taylor rule in China is re-estimated using both the official annual measure of industrial production, interpolated to a quarterly series, and a quarterly measure of industrial production growth from the OECD. These two alternative measure of the output gap leaves the results qualitatively unchanged. Most noteworthy is that negative and statistically significant coefficients on the output gap are robust to using industrial production. Results omitted for brevity but are available from the authors upon request.

[26] This difference is statistically significant at the 1% level (z-statistic equals 2.65).

Table 7
China policy rules.

Panel A: Interest Rate Policy			Dependent Variable:i_t			
	Fulll Sample		Pre-Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)
c	2.17***	1.77*	1.57***	2.13***	2.86***	4.81
	(0.66)	(0.90)	(0.33)	(0.41)	(0.92)	(3.20)
$y - y^*$	−0.39**	−0.41*	−0.28*	−0.39***	−0.76**	−0.86**
	(0.18)	(0.24)	(0.15)	(0.07)	(0.35)	(0.40)
$\pi - \pi^*$	0.10***	0.16***	0.04*	0.12***	0.22***	0.17**
	(0.04)	(0.04)	(0.02)	(0.03)	(0.06)	(0.07)
$e_t - e_{t-1}$	0.00	−0.02	0.01	0.01	−0.07	−0.05
	(0.02)	(0.03)	(0.03)	(0.02)	(0.05)	(0.05)
i_{t-1}	0.28**	0.17	0.52***	0.36***	0.08	0.05
	(0.13)	(0.12)	(0.13)	(0.08)	(0.12)	(0.15)
t.o.t.		0.01		0.00		−0.00
		(0.01)		(0.00)		(0.02)
currentaccount		−0.07***		−0.07***		−0.04
		(0.02)		(0.01)		(0.12)
R^2	0.31	0.37	0.33	0.47	0.35	0.36
Num. Obs.	65	64	37	36	28	28
Panel B: Intervention Policy			Dependent Variable:I_t			
	Fulll Sample		Pre-Crisis		Post-Crisis	
	(1)	(2)	(1)	(2)	(1)	(2)
c	26.25***	37.79***	29.23***	−33.44	33.07***	66.64***
	(2.65)	(12.85)	(5.87)	(39.84)	(5.99)	(24.54)
$e_t - e_{t-1}$	−0.17	−0.19	−0.15	−0.08	−0.21	−0.24
	(0.10)	(0.17)	(0.14)	(0.24)	(0.14)	(0.26)
$R - R^*$	−0.06***	−0.06***	−0.07***	−0.08	−0.07***	−0.11*
	(0.01)	(0.01)	(0.02)	(0.05)	(0.01)	(0.06)
t.o.t.		−0.03		0.25		0.03
		(0.04)		(0.15)		(0.05)
currentaccount		−0.28		1.32*		−1.69
		(0.34)		(0.69)		(1.39)
M2		−0.02		0.15		−0.08
		(0.08)		(0.10)		(0.07)
R^2	0.63	0.62	0.27	0.51	0.40	0.33
Num. Obs.	59	59	19	19	40	40

Pre-Crisis corresponds to period before 2009Q1.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

7. Conclusion

Large emerging markets follow quite different policy configurations in attempting to achieve internal and external balance. India has quite stringent capital controls and follows a Taylor rule dominated by an output stabilization objective. Inflation has played a much smaller part in influencing interest rates in India, mostly evident in recent years, and the terms-of-trade occasionally plays a role. Brazil, by contrast, has a much more financially open economy and follows an inflation target regime that generally dominates other considerations. Though exchange rate and terms-of-trade fluctuations occasionally influence interest rates in Brazil, we find no evidence that the central bank attempts to stabilize output fluctuations directly.

External policies are more similar in Brazil and India despite differences in capital control regimes. Intervention policies in both countries focus on exchange rate stabilization, i.e. stabilizing 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 factors. Brazil, on the other hand, started targeting a specific level of reserves only after the Global Financial Crisis (GFC). Controlling for the exchange rate and the international reserves gap, both countries still made large net quarterly purchases of foreign exchange on average over the sample period.

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 particular sequence of administrative measures. This led to varying private capital movements and intervention policy responses. We also find that conflicts in internal and external policy occur occasionally and, for both countries, very large discretionary intervention operations appear negatively linked to discretionary interest rate changes. That is, large unpredicted intervention purchases (sales) accommodate low (high) interest rates, suggesting that external operations are subordinate to domestic policy objectives.

The results for Chile, the extension of our study to a small open economy, suggests the central bank follows a true Taylor rule in balancing output and inflation targets but with more emphasis on inflation prior to the GFC and on output after the GFC. The exchange rate does not appear as a factor either in setting interest rates or intervention operations, and targeting a particular level of reserves only appears after the GFC. China has a more complicated institutional framework for macroeconomic policy than the other three EMs, and quality of output data is also a concern. Nonetheless, we find that Chinese interest rate policy responds strongly to inflation and intervention responds to an international reserves target.

In conclusion, each country has its own idiosyncratic policies, varying over time, but commonalities emerge. Policy interest rates always respond to either inflation or output gaps, frequently both, with varying intensities, and intervention is directed toward managing targeted international reserve levels and usually to exchange rate stabilization. Terms-of-trade and current account fluctuations also occasionally influence intervention operations. In conflicts between interest rate and intervention policies, the former—focused on internal balance—appear to dominate policy.

Appendix A

Variables description

$e_t - e_{t-1}$: 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, $e_t - e_{t-1} = 100 \times (ln(E_t) - ln(E_{t-1}))$.

$y - y^*$: 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 in 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 an 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 inflation target, i.e. $[100 \times (ln(CPI_t) - ln(CPI_{t-4})) - inflation\ \ target] = [100 \times (ln(CPI_t) - ln(CPI_{t-4})) - \pi^*]$.

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 interested 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 considering 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: $100 \times (ln(R) - ln(R^*))$.

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 ($\Delta e \geq 0$).

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

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

Termsoftrade: Ratio of exports over imports. We have used the following monthly series elaborated by the IMF: Commodity Export Price Index, Individual Commodites Weighted by Ratio of Exports to Total Commodity Exports, Commodity Import Price Index, and Individual Commodities Weighted by Ratio of Imports to Total Commodity Imports. All for the 1999–2018 period.

Currentaccount: Quarterly data on the net current account balance is obtained from the IMF. The series is normalized by dividing the current account balance by the first lag of nominal GDP and multiplying by 100.

Summary of variables

Variable	Sources	Data Range
$e_t - e_{t-1}$	Central Bank of Brazil and Reserve Bank of India.	India: 1998Q2-2018Q4; Brazil: 1999Q1-2018Q4
$y - y^*$	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;
SpotIntervention	Central Bank of Brazil and Reserve Bank of India. Estimated from change in reserve holdings for China and Chile.	India: 1998Q1-2018Q4; Brazil: 2000Q1-2018Q4;
TermsofTrade	Data obtained by the IMF.	India: 2000Q1-2018Q4; Brazil: 2000Q1-2018Q4; China: 2000Q1-2018Q4; Chile: 2000Q1-2018Q4;
CurrentAccount	Data obtained from IMF. Quarterly nominal GDP data from the OECD is used to compute the current accountas a percent of GDP.	India: 1998Q1-2018Q4; Brazil: 1999Q1-2018Q4; China: 1999Q1-2018Q4; Chile: 1998Q1-2018Q4;

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jimonfin.2019.102122.

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