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Monetary Policy Rules in the BRICS: How Important is Nonlinearity?

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Abstract

Given limited research on monetary policy rules in emerging markets, this paper estimates monetary policy rules for five key emerging market economies: Brazil, Russia, India, China and South Africa (BRICS) analysing whether the monetary authority reacts to changes in financial markets, in monetary conditions, in the foreign exchange sector and in the commodity price. *To get a deeper understanding of the central bank's* behaviour, we assess the importance of nonlinearity using a smooth transition (STAR) model. Using quarterly data, we find strong evidence that the monetary policy followed by the Central Banks in the BRICS varies from one country to another and that it exhibits nonlinearity. In particular, considerations about economic growth (in the cases of Brazil and Russia), inflation (for India and China) and stability of financial markets (in South Africa) seem to be the major drivers of such nonlinear monetary policy behaviour. Moreover, the findings suggest that the monetary authorities pursue, with the exception of India, a target range for the threshold variable rather than a specific point target. In fact, the exponential smooth transition regression (ESTR) model seems to be the best description of the monetary policy rule in these countries.

Keywords: monetary policy, emerging markets, smooth transition.
JEL classification: E37, E52.

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1. Introduction

The Taylor rule defines a linear relationship linking a central bank's policy rate to the current inflation rate and the output gap– as a benchmark for analysing monetary policy in a closed economy. How important is this monetary policy rule in open emerging market economies? How does the monetary authority react to variation in inflation rate? Does it also follow considerations about economic growth? Does the monetary policy rule take into account a broader set of indicators such as stock prices, money growth or commodity prices? It is important to note that the effects of these indicators on monetary policy could be different depending on the pace of economic activity that a central bank could act more aggressively when inflation is high than when it is low, or responds more to a negative than a positive output gap, or to higher asset price movements than when it is low, or when there is more currency appreciation than when it depreciates, implying a discontinuous/ threshold effect on the relationship between key variables reflecting different economic conditions and monetary policy. This is the main question that we attempt to answer for which there is limited evidence in the monetary policy literature in the context of emerging markets, providing evidence of a threshold effect in relation to the factors driving endogeneity of monetary policy in key emerging market economies.

Double-digit or high single-digit inflation continues to be a major policy concern in many developing countries, but monetary policy appears to be highly pro-cyclical instead of being counter-cyclical as it is in developed countries. In fact, one typically finds that these developing economies have excess productive capacity and large negative output gap. Given that emerging market economies are growing below their potential level of output, monetary policy can also play an important role in output stabilisation, namely, by stimulating private investment via monetary easing.

As a result, understanding the role that monetary policy can play in the five key emerging countries - namely, Brazil, Russia, India, China and South Africa, the so called BRICS – is crucial, because monetary policy may not respond countercyclically to inflation as its sources in these economies may not be same as what we observe in advanced markets. In this context, the task requires a deep knowledge of the models that describe monetary transmission, where the monetary policy rule is a key ingredient. In fact, it provides the basis for forecasting future changes in its instruments and describes a systematic relationship among economic indicators and the central bank's response to them.

The extension of the conventional approach of estimating the monetary policy rule to emerging markets therefore poses important conceptual and methodological challenges. First, uncertainty about the access to international capital markets may lead to a large weight of balance-of-payments equilibrium in the central bank's reaction function, therefore, reflecting the role of adjustments in the exchange rate. Second, public finances may influence the behaviour of the monetary authority, in particular, in the context of unsustainable public debt, and lead to inflationary bias. Third, monetary policy may direct credit to strategic sectors when financial markets are underdeveloped. Consequently, monetary authority may react to other indicators that are typically neglected in the analysis for developed countries. Furthermore, due to the heterogeneity associated with emerging economies, we expect that monetary policy adopted by monetary authorities should vary according to country under consideration.

As a result, we assess the existence of nonlinearity in the monetary policy rule using a smooth transition regression (STR) model is appropriate to capture asymmetry and heterogeneity. The traditional models derive monetary policy rules from the minimization of a symmetric quadratic central bank's loss function and assume that the aggregate supply function is linear. However, in reality, this may not be the case and central banks can have asymmetrical preferences - i.e. they might assign different weights to negative and positive gaps in inflation, output or even in monetary variables included in their loss function. This gives rise to the existence of a nonlinear monetary policy reaction function (Surico, 2007a, 2007b). For these reasons, conventional constant parameter Taylor rules could distort the effect of (1) parameter uncertainty, (2) differing policy objectives, (3) shifting preferences, and (4) nonlinearities of policymakers' choices (Trecroci and Vassalli, 2010).

Using quarterly data for the period 1990:1-2008:4, we find strong evidence that the monetary policy followed by the Central Banks in the BRICS exhibits asymmetry and nonlinearity. In particular, considerations about economic growth (in the cases of Brazil and Russia), inflation (for India and China) and stability of financial markets (in South Africa) seem to be the major drivers of such nonlinear conduct of monetary policy. Moreover, the findings suggest that the monetary authorities pursue, with the exception of India, a target range for the threshold variable rather than a specific point target. In fact, the exponential smooth transition regression (ESTR) model seems to be the best description of the monetary policy rule in these countries. This heterogeneity in monetary policy determinants for the countries under consideration can be explained by the fact that the financial liberalization and financial and money market developments across these countries are not also similar.

Thus, in the case of Brazil, monetary policy is accomodative when there is an increase in the output growth. However, when the output growth exceeds the threshold of 0.4%, the monetary authority tightens the interest rate. For Russia, the Bank of Russia exhibits strong concerns about economic growth, but it also follows closely the developments in the money market. The evidence for India reveals that the monetary authority places more weight on the developments of the foreign exchange markets in addition to output growth: the Reserve Bank of India cuts the interest rate, when there is real exchange rate appreciation; and it raises the interest rate, when the output growth increases.

In the case of China, the dynamics of inflation seems to be the main driver of monetary policy changes. However, the magnitudes of the coefficients associated with inflation are quite similar for the linear and the nonlinear parts of the monetary policy rule. This feature may be explained by the fact that China uses instruments of both quantity and price in view of imperfect monetary policy transmission mechanism and uncontrolled monetary market. Finally, in the case of South Africa, the results corroborate the idea that the conduct of monetary policy is set in accordance with a diverse set of indicators, such as asset prices, balance of payments, credit growth, exchange rate, fiscal stance, output gap, and wage settlements. This is largely explained by the importance of the financial liberalisation process and the openness of capital accounts.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on the role of monetary policy in explaining macroeconomic fluctuations in emerging markets. Section 3 presents the econometric methodology and Section 4 describes the data. Section 5 discusses the empirical results. Finally, Section 6 concludes with the main findings of the paper and the policy implications.

2. A Brief Review of the Literature

The conduct of monetary policy in emerging market economies confronts important challenges. In fact, the past monetary policy experience has seen extreme episodes of monetary instability, swinging from very high inflation to financial instability (Mishkin, 2000).

Although monetary aggregates have been traditionally used as a framework for monetary policy, Nelson (2003) comments that models where the only effect of monetary policy is via the short-term interest rate can be consistent with the quantity theory of money. Laxton and Pesenti (2003) also find that inflation forecast based rules perform better than conventional Taylor rules in small open emerging economies.

Not surprisingly, monetary policy in emerging markets has increasingly moved towards inflation targeting and marked-based instruments (Fry et al., 1996).Given that other indicators may also be crucial in emerging markets, the Taylor rule has been extended to accomodate such features. One of such additional elements is the exchange rate (Filosa, 200; Mohanty and Klau, 2005; Devereux et al., 2006; Batini et al., 2009), which supports the "fear of floating" hypothesis. More recently, Mehrotra and Sánchez-Fung (2010) show that McCallum-Taylor specifications with an interest rate instrument and a nominal income gap target perform better than benchmark Taylor rules in describing monetary policy in inflation targeting emerging market economies.

Another variable typically considered refers to the role of financial markets and, in particular, the existence of financial frictions or vulnerabilities. Taylor (2002) argues that a rule-based monetary policy in emerging economies would increase expectation effects, an aspect that is particularly important if one accounts for their less developed financial markets. Calvo and Mishkin (2003) suggest that central banks should be subject to "constrained discretion" through inflation targeting, making it harder for them to follow an "overly expansionary monetary policy". The authors argue that financial crises are strongly determined by weak institutional credibility. Morón and Winkelried (2003) highlight that emerging market economies are incapable of smoothing out large external shocks, due to the large and abrupt swings in the real exchange rate generated by sudden capital outflows. In this context, Cúrdia (2009) suggests that a flexible targeting rule that stabilizes a basket composed of domestic price inflation, exchange rate, and output could minimize the domestic impact of reduced access to international capital markets. Batini et al. (2010) show that financial frictions, especially when coupled with liability dollarization, severely increase the costs of a fixed exchange rate regime.

As for the five largest emerging market economies such as BRICS (Brazil, Russia, India, China and South Africa), the empirical evidence on the estimation of monetary policy rules is roughly inexistent. In the case of Brazil, Lopes (2004) investigates why interest rates were so high and volatile from 1995 to 1998. The author identifies an overreaction to external shocks, where exogenous changes in international liquidity led to sharp movements on domestic interest rates. For Russia, Esanov et al. (2005) indicate that, during the period of 1993-2002, the Bank of Russia has used the monetary aggregates as the main policy instrument. More recently, Granville and Mallick (2010) emphasise the role of exchange rate shocks in Russia. In India, Singh and Kalirajan (2006) suggest that monetary policy addresses multiple objectives of achieving and managing sustained growth, while ensuring macroeconomic stability. As a result, commodity price driven inflationary shocks have not led Central Banks to tighten monetary policy.

For China, Wang and Handa (2007) find that, during the period 1993-2003, the People’s Bank followed a Taylor-type rule for the interest rate with the aim of inflation targeting and output smoothing. Goodfriend and Prasad (2007) suggest that anchoring monetary policy with an explicit inflation objective would be most relevant to tie down inflation expectations, and thereby enable monetary policy to make the best contribution to macroeconomic and financial stability, as well as economic growth. This requires empirical investigation with an eclectic set of indicators as pursued in our study. Burdekin and Siklos (2008) model post-1990 monetary policy with an augmented McCallum-type rule considering the country's emphasis on targeting the rate of money supply growth, and shows that the monetary authority appears responsive to the output gap as well as to external pressures. Zhang (2009) compares two monetary policy rules - the money supply (quantity) rule and interest rate (price) rule, and finds that the price rule is likely to be more effective in macroeconomic management, in line with the government's intention of liberalizing interest rates. According to Dai (2006), the People's Bank of China (PBC) is reported to have abandoned the quantity of money as its intermediate goal in 2004, and adopted some elements of the apparatus of inflation targeting, without giving up the managed exchange rate regime for the renminbi (RMB) – the Chinese currency. This basically suggests that there is a need to test an interest rate rule (and its possible non-linearity), instead of taking for granted a monetary aggregate based rule, which China has adopted since 1983. In the same line, Delatte and Fouquau (2010) argue that money supply targeting may not be effective when there is a nonlinear relation between the goal of policy (price stability) and the targeted monetary aggregate. In fact, the authors find evidence of a non-linear money demand for China during the period 1987-2008.

In the case of South Africa, Knedlik (2006) shows that interest rates and exchange rates have a relative influence on the output gap. Similarly, du Plessis (2006) finds evidence supporting the thesis that monetary policy has been used more consistently to dampen the cycle of economic activity since the early nineties. Despite the abovementioned literature and the fact that the central bank may respond differently to deviations of aggregates from their targets, the issue of nonlinearity in the estimation of monetary policy reaction functions has relied on the use of data for developed countries. Some studies have applied Markov-switching models (Kaufmann, 2002; Altavilla and Landolfo, 2005), namely, by considering that monetary authorities tend to have a different behaviour during recessions and expansions. Other studies have used smooth transition autoregressive specifications (Martin and Milas, 2004; Taylor and Davradakis, 2006; Qin and Enders, 2008; Castro, 2010), and suggested that monetary policy reacts more strongly to upward than to downward deviations of inflation away from the target range. In a more recent paper, Bunzel and Enders (2010) explore the possibility that the Taylor rule should be formulated as a threshold process, providing empirical support that the Federal Reserve acts more aggressively in the so-called "opportunistic" monetary policy, which we investigate here in the context of emerging market economies.

However, for emerging markets, a nonlinear Taylor rule may be a more realistic description of the systematic response of the monetary authority to economic developments as it enables to apprehend asymmetrical, discontinuous and time-varying monetary policy reaction. Indeed, Mohanty and Klau (2005) point in this direction by suggesting that, in some countries, the central bank's response to a negative inflation shock might be weaker than to a positive shock. Similarly, Marfán et al. (2008) show that misperceptions about future productivity may trigger boom-bust cycles in emerging market economies: if the central bank tries to stabilize output, there is a large real appreciation of the currency and a deep contraction in the tradable goods sector; if it follows a more strict inflation targeting regime, the boom-bust pattern is exacerbated. It is to this issue we turn now in the next section.

3. Econometric Methodology

Taylor (1993) characterized the monetary policy in the US over the period 1987-1992 by proposing the following rule:

$$i_t^* = \bar{r} + \pi^* + \beta(\pi_t - \pi^*) + \gamma(y_t - y_t^*). \quad (1)$$

This rule regards the nominal short-term interest rate (i^*) as the monetary policy instrument and assumes that it should rise if inflation (π) rises above its target (π^*) or if output (y) increases above its trend value (y^*). As a result, β denotes the sensitivity of interest rate policy to deviations from the target inflation, while γ indicates the sensitivity of interest rate to the output gap. In equilibrium, the deviation of inflation and output from their target values is zero and, therefore, the desired interest rate (i^*) is the sum of the equilibrium real rate ($\bar{r}$) plus the target value of inflation.[1]

The above-mentioned Taylor-rule represents an optimal policy-rule under the condition that the central bank is minimising a symmetric quadratic loss function and that the aggregate supply function is linear. However, the central bank may respond differently to deviations of aggregates from their targets. Therefore, a nonlinear Taylor rule can be more appropriate to explain the behaviour of monetary policy.[2] Moreover, inflation and output gap, generally, reveal an asymmetric adjustment to the business cycle: recessions tend to be short and sharp, while recoveries are long and smooth; inflation increases more rapidly than it decreases (Hamilton, 1989; Neftçi, 2001).

Moreover, given that, for emerging market economies, other indicators may play an important role in the conduct of monetary policy, the Taylor rule can be extended in several directions. For instance, one may account for changes in the equity price (Cecchetti et al., 2000; Sousa, 2010), changes in the housing price (Julliard et al., 2008;

[1] Following Clarida et al. (1998, 2000), the equilibrium real rate and the inflation target are assumed to be constant.
[2] See Nobay and Peel (2003), Ruge-Murcia (2003), Dolado et al. (2005) and Surico (2007a, 2007b).

Sousa, 2010), changes in the exchange rate (Lubik and Schorfheide, 2007), the growth rate of the monetary aggregate (Leeper and Zha, 2003; Sims and Zha, 1999, 2006a, 2006b; Favara and Giordani, 2009; Sousa, 2010), and changes in the oil price (Leeper and Zha, 2003; Sims and Zha, 1999, 2006a).

To explain this nonlinear behaviour, the main options are the Markov-switching (MS) model and the smooth transition regression (STR) model. The MS model assumes that the regime switches are exogenous and driven by an unobservable process. In contrast, the STR model allows the regression coefficients to change smoothly from one regime to another, and, therefore, provides a better structural framework. Consequently, we follow the second approach in the current paper, which has the advantage according to MS model to capture the persistence and smoothness inherent to monetary policy relationships.

A two-regime usual STR model for a nonlinear Taylor rule can be defined as follows:[3]

$$i_t = \psi' z_t + \omega' z_t G(\eta, c, s_t) + \varepsilon_t, \qquad t = 1,\ldots,T \tag{2}$$

where $z_t = (1, i_{t-1},\ldots,i_{t-n}; \pi_t, \tilde{y}_t; x_{1,t},\ldots,x_{m,t})'$ is the vector of the explanatory variables and h=n+2+m. The parameters $\psi = (\psi_0, \psi_1,\ldots,\psi_h)'$ and $\omega = (\omega_0, \omega_1,\ldots,\omega_h)'$ denote ((h+1)×1) parameter vectors in the linear and nonlinear parts of the model, respectively. The transition function $G(\eta, c, s_t)$ is continuous and bounded between zero and one and depends on the transition variable s_t, the threshold parameter c and the transition speed.

The transition function can be defined in several ways. For instance, one may consider a logistic STR model (noted LSTR1 model), where the transition-function is assumed to be a logistic function of order one:

[3] For further details on the STR model, see Granger and Teräsvirta (1993), Teräsvirta (1998) and van Dijk et al. (2002).

$$G(\eta, c, s_t) = [1 + \exp\{-\eta(s_t - c)\}]^{-1}, \qquad \eta > 0. \tag{3}$$

This function is a monotonically increasing function of s_t, the slope parameter η indicates the smoothness of the transition between regimes, and the location parameter c determines where the transition occurs.

The STR model is equivalent to a linear model with stochastically time-varying coefficients and can be rewritten as:

$$i_t = [\psi' + \omega' G(\eta, c, s_t)] z_t + \varepsilon_t \Leftrightarrow i_t = \zeta' z_t + \varepsilon_t, \qquad t = 1,\ldots,T. \tag{4}$$

As in practice a monotonic transition may not be a satisfactory alternative, one can also use the quadratic logistic STR model (or LSTR2 model):

$$G(\eta, c, s_t) = [1 + \exp\{-\eta(s_t - c_1)(s_t - c_2)\}]^{-1}, \tag{5}$$

where $\eta>0$, $c=\{c_1,c_2\}$ and $c_1 \geq c_2$. As Martin and Milas (2004) suggest, central banks may consider not a simple numeric and rigid target for inflation but a band or an inner inflation regime, where inflation is considered under control and, consequently, the reaction of the monetary authorities will be different from a situation where inflation is outside that regime. This transition function is symmetric about $(c_1+c_2)/2$ and asymmetric otherwise, and the model becomes linear when $\eta \to 0$.

Finally, we also consider the case of the exponential STR model (also known as ESTR model). This corresponds to the situation where the transition function is exponentional, that is

$$G(\eta, c, s_t) = [1 + \exp\{-\eta(s_t - c)^2\}]^{-1} \qquad \eta > 0, \tag{6}$$

which, corresponds to the particular case of the LSTR2 model where $c_1=c_2$. Therefore, the transition function is symmetric. This specification enables to capture the behaviour of monetary policy in the extreme regimes (when central bank define their policies according to economic, financial and commodities variables) as well in the central regime for which monetary authorities are more independent. In practice, even though several tests enable the choice between exponential and logistic models, the first specification is invariably used for financial data than logistic one.

4. Data and Summary Statistics

We use data for the BRICS (Brazil, Russia, India, China and South Africa). The sample covers the period 1990:1-2008:3 for which data are available at quarterly frequency and the main data source for most series is Haver Analytics, unless otherwise mentioned. The variables and data definitions are as follows:

- Raw materials: Real Commodity Price Index (cp_t). Used as a proxy for changes in the global demand and to control for the price puzzle.
- Real GDP: GDP (GDP_t). Used as a proxy for economic activity and business cycle. In particular, we consider the output gap (og_t) in the specification of the monetary policy rule.
- Inflation rate: Inflation Rate (π_t). Computed from the GDP deflator.
- Interest rate: Nominal Central Bank Rate (i_t). Used as the monetary policy instrument.
- M_2: Real Growth Rate of M_2 (m_t).
- Exchange Rate: Real bilateral exchange rate versus the U.S. Dollar (er_t).
- Equity Price: Real Stock Price Index (sp_t). Compiled from Haver Analytics (Brazil, China, India) and Global Financial Database (Russia and South Africa).

Data are also transformed in several ways for the econometric analysis. First, all variables are expressed in logs and deflated using the GDP deflator, with the obvious exception of the policy instrument. Second, data on real GDP and the corresponding deflator for China are annual, and, therefore, interpolated to quarterly frequency using a cubic conversion method.[4]

Table A.1 in the Appendix provides a detailed description of the variables and data sources used in the analysis, while Tables A.2 to A.5 also present a range of descriptive statistics.

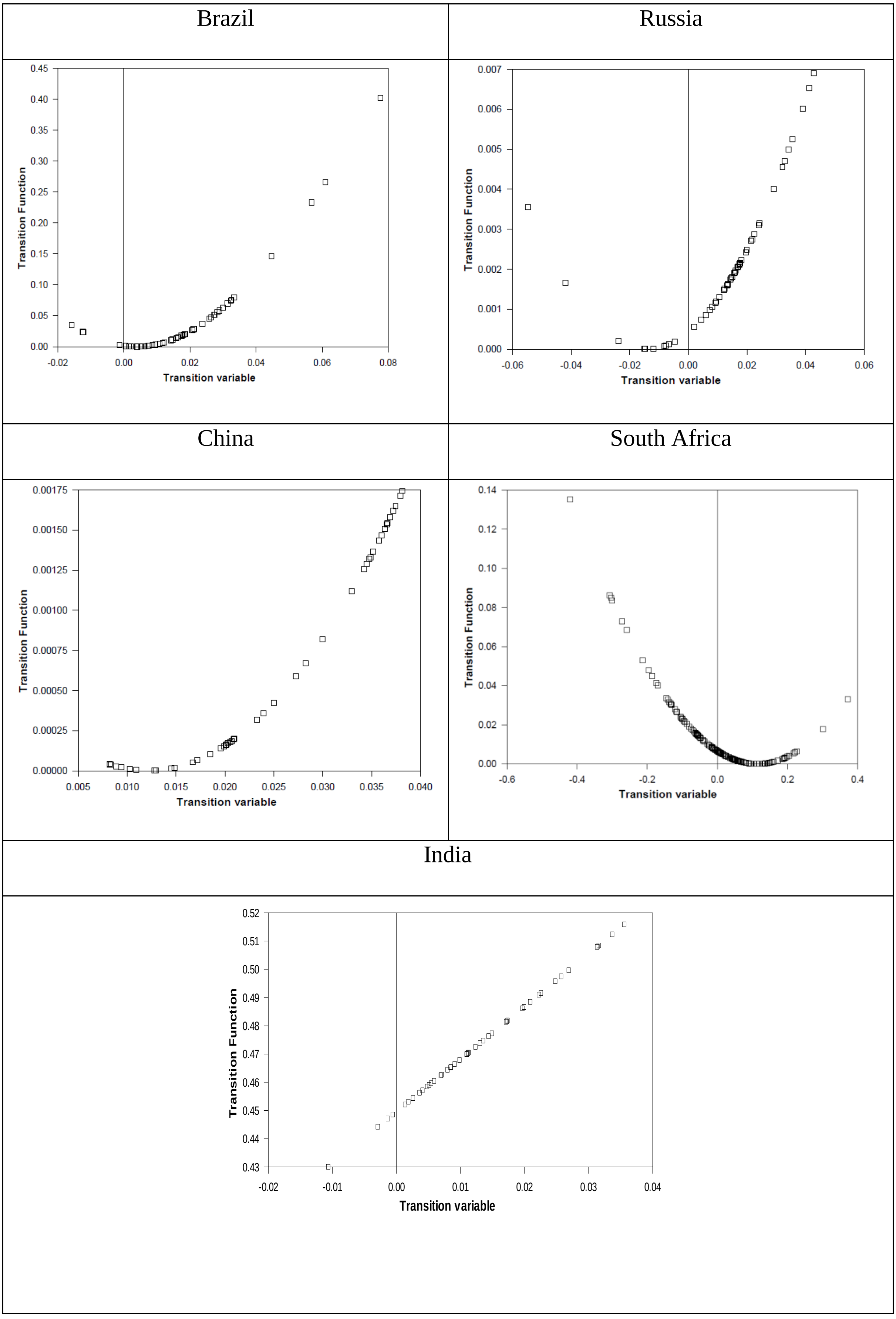
5. Empirical Results

The evidence from the estimation of the nonlinear monetary rules is presented in Table 1. The results for Brazil, Russia, China, India and South Africa are reported in Columns 1 to 5, respectively, while Figure 1 plots the estimated transition functions and shows the switching of monetary policy regimes.

In general, results are robust in supporting the idea that the monetary policy followed by the Central Banks in these countries exhibits nonlinearity. In practice, linearity was tested for several transition variables for each country under consideration. Our findings show that the output gap was selected to be the threshold variable ($s_t = og_t$) in the cases of Brazil and Russia, while for India and China the threshold variable is inflation ($s_t = \pi_t$). Finally, for South Africa, the threshold variable is the stock price ($s_t = sp_t$). In all cases, the choice optimal transition variable is determined by the lowest p-value for the rejection of the linear model. This helps explain the important weight that central banks put on these variables and indicates the orientation of monetary policy for each country of our sample. Our results confirm once again our suggestions regarding the heterogeneity associated with these emerging countries.

[4] The cubic spline interpolation method is well suited to the data characteristics (e.g. China's GDP) and is commonly used in the literature. Nevertheless, the estimation results are qualitatively similar to the ones based on a linear interpolation.

Figure 1: Transition Functions for Brazil, Russia, China and South Africa



The choice of the transition function is presented at the bottom of the Table and indicates that an ESTR model is appropriate for the analysis carried out in this study in the cases of Brazil, Russia, China and South Africa, while the LSTR model describes better the conduct of monetary policy for India. This means that, over the time period, for the first group of countries, central banks seem to be more concerned in pursuing a target range for the threshold variable, while for India, there seems to be a specific point target (c).

Also, as can be seen in Figure 1, the transition between regimes is quite strong: (i) when the output gap is positive, in the cases of Brazil and Russia; (ii) when the inflation rate is above the threshold level, for China; and (iii) when there is a large fall in the stock market index, in the case of South Africa. However, the transition functions take high values notably for India, Brazil and South Africa, implying that transition between monetary regimes is more significant for these countries rather than for China and Russia.

In general, we expect that central banks have a specific reaction to economic developments when the threshold variable is below the abovementioned target and a different (stronger or weaker) reaction when it increases beyond it. Results provide such evidence for some variables. In the next step, we analyze those results in detail.

In the case of Brazil, the empirical evidence strongly supports the existence of a nonlinear specification as both the transition speed (η) and the threshold parameter (c) are statistically significant. Moreover, it suggests that the monetary authority always plays a special attention to the developments in the output gap. This is in accordance with the work of Hoffmaister and Roldôs (2001) who show that domestic (demand) shocks are the main source of GDP fluctuations in Brazil. Similarly, they are consistent with the evidence that suggests that a monetary contraction (i.e., an increase in the interest rate) can have (negative) persistent effects in GDP (see Mallick and Sousa (2009)). Moreover, og_t is statistically significant in both the linear and the nonlinear parts, although there is a flip in the sign of the coefficient. This means that, in general, monetary policy is accomodative when there is an increase in the output growth. However, when the output growth exceeds the threshold of 0.4%, the monetary authority starts tightening the interest rate.

For Russia, the results also corroborate the idea of a nonlinear formulation of the monetary policy rule, even less significantly, as only the threshold parameter (c) is statistically significant. As in the case of Brazil, concerns about economic growth seem to be the major determinant of the change in the conduct of monetary policy across regimes. Moreover, the Bank of Russia follows closely the developments in the money market. This feature is also found by Esanov et al. (2005), who show that, during the period of 1993-2002, the Bank of Russia has used monetary aggregates as a main policy instrument in conducting monetary policy.[5] In fact, the growth of the monetary aggregate, m_t, is statistically significant in both the linear and the nonlinear parts. Interestingly, there is also a flip in the sign of the coefficient between the two parts. In fact, when the output growth is relatively small (a threshold of -1.4%), the interest rate is raised (as suggested by the coefficient of 3.259) if the dynamics of money markets question medium to long-term price stability. When the output gap lies above the threshold, the interest rate is cut in reaction to a monetary expansion (as reflected in the coefficient of -4.958), because in this case price stability is not a concern and the cut helps stimulate the economy. These features are in line with the main goal of the Bank of Russia that was established in 2000 and which was to achieve an annual growth rate of GDP of 1.5%, while reducing inflation to 18%.

[5] Granville and Mallick (2010) also discuss the recent monetary policy shifts in Russia.

The evidence for India reveals that the nonlinear monetary policy rule also describes well but more significantly the behaviour of the Central Bank, as both the transition speed (η) and the threshold parameter (c) are statistically significant. Additionally, it shows that the exchange rate, er_t, and the output gap, og_t, also enter significantly in the nonlinear part of the monetary policy specification. In particular, when the inflation rate is above the target level of 2.7%, these variables become key indicators: the Reserve Bank of India cuts the interest rate, when there is a real exchange rate appreciation (an associated coefficient of -3.043); and it raises the interest rate, when the output growth increases (an associated coefficient of 7.198). In what concerns the exchange rate, this reflects the regular intervention of the Central Bank in the FX market to limit currency appreciation. Interest rates are found to be raised to prevent the contractionary effect of currency appreciation. Ravenna and Natalucci (2008) show that the real exchange rate appreciation is due to Balassa-Samuelson effect in an emerging market economy where productivity growth differentials between tradable and non-tradable sectors contribute to real appreciation in equilibrium. Although the estimated policy rule suggests an increase in interest rate, active exchange rate management in India for a depreciated level of the currency limits the pace of increase in the policy rate. Regarding output growth, it allows the Central Bank to ensure macroeconomic stability. All in all, the findings for India are in accordance with the objectives of the Reserve Bank of India of maintaining a reasonable price stability and ensuring adequate expansion of credit to assist economic growth (Rangarajan, 1998), while contributing to macroeconomic stability (Singh and Kalirajan, 2006). In addition, they support the engagement of the Central Bank in guaranteeing orderly conditions in the foreign exchange market to curb destabilizing and self-fulfiling speculative activities (Reddy, 1999). Not surprisingly, in April 1998, the Reserve Bank of India formally adopted a multiple indicator approach whereby interest rates or rates of return in different financial markets along with data on capital flows, currency, credit, exchange rate, fiscal position, inflation, output, trade are used for policy purposes.

In the case of China, the empirical evidence provides less support of a nonlinear specification, as also in this case only the threshold parameter (c) seems to be statistically significant. The dynamics of inflation seems to be the main driver of monetary policy. In fact, π_t is the threshold variable and is also statistically significant in both the linear and the nonlinear parts. Interestingly, the magnitudes of the coefficients associated with inflation are quite similar for the linear (2.735) and the nonlinear (-2.763) parts of the monetary policy rule. This also suggests that the monetary authority strongly reacts to inflation when it is below the threshold of 1.2%. However, there seems to be an accomodative monetary policy when inflation lies above that threshold. This can not be detached from the fact that China usually applies instruments of both quantity and price in view of imperfect monetary policy transmission mechanism (He and Pauwels, 2008). Similarly, one should note that short-term interbank interest rates may not necessarily be a good measure because of the segmentation of credit markets (Liu and Zhang, 2007), despite some evidence suggesting its effectiveness as a policy instrument (Zhang, 2009).

Finally, in the case of South Africa, the results provide strong evidence of a nonlinear formulation of the monetary policy rule as the transition speed (η) and the threshold parameter (c) are statistically significant. Interestingly, the growth in the stock price is the target variable, with a threshold level of 11.4%. Our results also show that the monetary authority reacts to the dynamics of commodity prices (cp_t), the foreign currency markets (er_t) and the output gap (og_t). The South African Reserve Bank seems to aim at promoting growth, as the coefficient associated with the output gap is statistically signifcant in “normal” times. That is, interest rates are raised when output growth may represent a threat to price stability. As in the case of India, the Monetary authority also reacts to developments in the FX market, and when the increase in the stock price index is large. However, in contrast, the aim of the Central Bank does not seem to prevent currency appreciation (in fact, the coefficient associated with the real exchange rate in the nonlinear part is positive (0.138)), but to help prevent the potentially unstable consequences of a disruption in financial markets. Finally, the coefficient associated with the commodity price in the nonlinear part of the monetary policy rule is negative (-0.102) which suggests that the Reserve Bank of South Africa cuts the interest rate in the outcome of a rise in the price of commodities.[6] As a result, although there could be some inflationary pressure, the Central Bank seems to put more weight on the importance of commodity exports as determinants of economic growth in South Africa.

Summing up, the empirical findings suggest that the monetary policy followed by the Central Banks in the BRICS exhibits nonlinearity. In particular, while the dynamics of economic growth seem to be the major development driving the behavior of the monetary authority in Brazil and Russia, considerations about inflation are crucial for India and China and vigilance towards the stability of financial markets are key in South Africa.

In addition, the results show that Central Banks conduct monetary policy in accordance with a target range for the threshold variable. In fact, the exponential smooth transition regression (ESTR) model is the best description of the monetary policy rule in these countries. The only exception is India, where the monetary authority seems to follow a specific point target for the threshold variable. Consequently, the

[6] This is in line with Frankel (2008) who argued that low real interest rates lead to high real commodity prices in the sense that a negative effect of interest rates is channelled through the desire to carry commodity inventories.

logistic smooth transition regression (LSTR1) model provides the most accurate basis for forecasting the response of the Reserve Bank of India to economic developments.

Table 1: Nonlinear monetary policy rules: Evidence for the BRICS (Brazil, Russia, India, China and South Africa)

	Brazil	Russia	India	China	South Africa
Linear part (ψ)					
Constant	0.373**	-0.048	-0.002	-0.006***	-0.009***
	[0.180]	[0.171]	[0.002]	[0.001]	[0.003]
cp_t					0.029
					[0.031]
sp_t					
er_t			-0.018		-0.043*
			[0.026]		[0.025]
og_t	-18.719**		0.014		0.546***
	[9.141]		[0.073]		[0.194]
π_t				2.735***	
				[0.731]	
m_t		3.259**			
		[1.412]			
Nonlinear part (ω)					
Constant	-0.384**	0.151	-0.157*	0.006***	0.016***
	[0.180]	[0.183]	[0.083]	[0.002]	[0.006]
cp_t					-0.102*
					[0.056]
sp_t					
er_t			-3.043*		0.138***
			[1.591]		[0.045]
og_t	18.638**		7.198**		-0.498
	[9.124]		[3.537]		[0.354]
π_t				-2.763***	
				[0.858]	
m_t		-4.958***			
		[1.498]			
η	93.891**	2.144	7.469**	2.589	0.509*
	[44.033]	[1.326]	[3.000]	[1.655]	[0.293]
c	0.004***	-0.014***	0.027***	0.012***	0.114***
	[0.000]	[0.002]	[0.003]	[0.001]	[0.021]
Obs.	47	51	46	44	148
Adj. R^2	0.364	0.572	0.556	0.451	0.244
Model	ESTR	ESTR	LSTR1	ESTR	ESTR
s_t =	og_t	og_t	π_t	π_t	sp_t

Notes: * statistically significant at 10% level; ** at 5% level; *** at 1% level. All variables are in log differences. Standard errors are in square brackets. Adj. R^2 is the adjusted R^2.

In order to check the robustness of our findings, we have finally applied several misspecification tests (Table 2). Overall, these tests have validated our estimation and implied interesting results and the nonlinear model is wholly and significantly appropriate to characterize monetary policies. Indeed, while testing for omitted nonlinearity in the estimation results, we show that except for China, our modelling has captured the nonlinearity in the data. According to the ratio of residual variances ($\frac{\sigma_{STR}}{\sigma_{L}}$), the STR model has supplanted linear model and the ratio is significantly less than unity. This result is interesting as it indicates that the introduction of nonlinearity enables to improve the modelling of monetary policy for emerging countries. Furthermore, the estimation residuals of nonlinear model are stationary for all countries under consideration, are not characterized by ARCH effect (except for China and South Africa), are not auto-correlated (except for South Africa), indicating that residuals adequately confirm the statistical properties.

Table 2: Robustness Tests

	Brazil	**Russia**	**India**	**China**	**South Africa**
$\frac{\sigma_{STR}}{\sigma_{L}}$	0.64	0.50	0.52	0.61	0.78
ADF Test	-4.62	-5.32	-6.2	-8.1	-6.64
ARCH Test (P-Value)	0.55 (0.75)	0.02 (0.99)	1.16 (0.55)	8.3 (0.01)	14.8 (0.0)
DW	2.03	2.3	2.4	1.95	1.35
Fisher Test (P-value)	4.7 (0.0)	6.1 (0.0)	5.0 (0.0)	4.7 (0.01)	3.9 (0.0)
LM^{ONL} Test (P-value)	0.46	0.67	0.43	(0.09)	0.17

All in all, the findings reflect that the conduct of monetary policy during the 1990s was supplemented by a diverse set of indicators, such as asset prices, balance of payments, credit growth, exchange rate, fiscal stance, output gap, and wage settlements (see Aron and Muellbauer (2007) and the references cited therein). Aside from the adoption of inflation targeting since 2000, the previous (money and interest-rate based) targets may have had limited usefulness due to the financial liberalisation process and the openness of capital accounts.

6. Conclusion

In this paper, we use a smooth transition autoregressive (STAR) model to assess the importance of nonlinearity of monetary policy transmission for five key emerging market economies: Brazil, Russia, India, China, and South Africa (BRICS). In addition, we analyze whether the monetary authority reacts to changes in financial markets, in monetary conditions, in the foreign exchange sector and in the commodity price.

Using high-frequency (quarterly) data, we find strong evidence that the monetary policy followed by the Central Banks in the BRICS exhibits nonlinearity. In particular, considerations about economic growth (in the cases of Brazil and Russia), inflation (for India and China) and stability of financial markets (in South Africa) seem to be the major drivers of such nonlinear pattern of monetary policy.

Moreover, the findings suggest that the monetary authorities pursue, with the exception of India, a target range for the threshold variable rather than a specific point target. In fact, the exponential smooth transition regression (ESTR) model seems to be the best description of the monetary policy rule in these countries.

The current work provides the basis for forecasting future central bank’s policy behaviour in the major emerging market economies. As a result and from a policy perspective, it provides important insights about the major economic and financial developments to which the monetary authority reacts in a systematic manner.

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Appendices

A. Data and Summary Statistics

Table A.1: Data sources

Variable	Source	Definition	Remark
Commodity price	HA	Commodity price index	Deflated
GDP	HA	Gross Domestic Product	CP, SA
Inflation	HA	Change of GDP deflator	CP, SA
Central Bank rate	HA	Central Bank rate	Nominal
M_2 growth rate	HA	M_2 growth rate	Deflated
Exchange rate	HA	Exchange rate versus the U.S. dollar	Deflated
Equity price	HA / GFD*	Composite Index	Deflated

Notes: * for Russia and South Africa.
In the source section, HA stands for Haver Analytics, GFD for Global Financial Database, CP means constant price, SA means seasonally adjusted, and Deflated means deflated using the GDP deflator.

Table A.2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Commodity price	311	3.360	3.154	-2.774	7.746
GDP	327	8.240	3.297	4.404	14.060
Inflation	308	0.035	0.076	-0.359	1.110
Central Bank rate	298	16.792	21.571	2.700	180.000
M_2 growth rate	306	0.018	0.046	-0.479	0.208
Exchange rate	311	-0.068	3.965	-8.037	4.121
Equity price	284	5.674	3.298	0.715	9.818

Table A.3: Sample size

Country	Obs	Sample period
Brazil	43	1998:1-2008:3
China	43	1997:2-2007:4
India	42	1998:2-2008:3
Russia	47	1997:1-2008:3
South Africa	74	1990:2-2008:3

Table A.4: Annual average by country

	Commodity price	GDP	Inflation	Central Bank rate	M_2 Growth rate	Exchange rate	Equity price
All	3.360	8.240	0.035	16.792	0.018	-0.068	5.674
Brazil	-2.406	4.683	0.052	24.914	0.015	-7.399	1.616
China	2.311	6.145	0.032	5.813	0.017	-1.151	1.6408
India	5.443	8.576	0.013	7.288	0.028	3.673	8.509
Russia	5.941	8.041	0.058	38.148	0.026	3.298	6.304
South Africa	5.619	13.731	0.022	12.966	0.010	1.775	9.060

Note: All series are in logs.

Table A.5: Correlation Matrix

	Commodity price	GDP	Inflation	Central Bank rate	M_2 Growth rate	Exchange rate	Equity price
Commodity price	1.000						
GDP	0.711	1.000					
Inflation	-0.050	-0.125	1.000				
Central Bank rate	0.066	-0.097	0.599	1.000			
M_2 growth rate	0.028	-0.053	-0.317	-0.107	1.000		
Exchange rate	0.976	0.611	-0.077	0.001	0.063	1.000	
Equity price	0.850	0.858	-0.133	-0.067	0.035	0.806	1.000

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