TEXTO PARA DISCUSSÃO N° 1285a

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* The views expressed in this article are those of the authors and do not necessarily represent those of the IPEA or of the Brazilian Ministry of Planning, Budget, and Management.

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Governo Federal

Ministério do Planejamento, Orçamento e Gestão

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URL: http:/www.ipea.gov.br

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ISSN 1415-4765

JEL: C22, C51, C52, E52, E58

TEXTO PARA DISCUSSÃO

Uma publicação que tem o objetivo de divulgar resultados de estudos desenvolvidos, direta ou indiretamente, pelo Ipea e trabalhos que, por sua relevância, levam informações para profissionais especializados e estabelecem um espaço para sugestões.

SINOPSE

Neste artigo estimamos a regra da política monetária adotada no período pós-Plano Real pelo Banco Central do Brasil (Bacen) ao fixar o seu principal instrumento de política, a taxa Sistema Especial de Liquidação e Custódia (Selic).

Para lidar com a incerteza referente às datas nas quais ocorreram mudanças nos parâmetros, adotamos as hipóteses segundo as quais essas mudanças são regime-dependentes e as probabilidades de ocorrência dos regimes seguem uma cadeia de Markov. O modelo assim especificado possui uma estrutura flexível e permite detectar possíveis desvios em relação a uma função de reação linear simples.

Concluímos que, de julho de 1996 a janeiro de 2006, a política monetária brasileira pode ser caracterizada por quatro regimes. As mudanças de regime ocoridas nesse período são mais adequadamente descritas por mudanças de regime recorrentes do que por mudanças permanentes. No entanto, identificamos diferenças substanciais na forma como a política monetária foi conduzida nos períodos anterior e posterior a 1999, quando o câmbio passou de administrado para flutuante. Em cada um desses períodos existem dois regimes de política recorrentes, sendo que os dois regimes do período anterior a 1999 diferem dos dois regimes do período posterior.

ABSTRACT

This article estimates the monetary policy rule followed by the Brazilian Central Bank for setting its main policy instrument, the SELIC rate, for the period after the Real Plan. In order to overcome the uncertainty over the dates at which changes in parameters occurred, this paper uses regime-dependent-switching probabilities according to a hidden Markov chain to model possible deviations from a simple linear reaction function.

From July 1996 to January 2006 the Brazilian monetary policy can be fully characterized by four policy regimes. The changes in monetary policy in this period are best described by recurring regime changes, instead of once-and-for-all shifts. We have identified substantial differences in the way monetary policy was conducted in the subperiods before and after 1999, when the Brazilian exchange rate policy regime changed from crawling peg to free-floating. At each of these subperiods there are two recurring regimes and the two regimes of one subperiod differ from the two regimes of the other.

SUMMARY

1 INTRODUCTION

Successful management of monetary policy has been one of the cornerstones of inflation stabilization in Brazil, achieved after the introduction of the Real Plan in 1994. This management involved changes in the instruments the Central Bank uses in its daily conduct of policy, its choice of variables for which it establishes targets, and the conditions under which the instruments are adjusted in light of the state of the economy (the " policy rule" or " the Central Bank reaction function"). This paper focuses on the last type of changes. It represents a contribution to the incipient (but growing) literature about the reaction function of the Brazilian Central Bank.

This article estimates the monetary policy rule followed by the Brazilian Central Bank for setting its main policy instrument, the Special Settlement and Custody System–Sistema Especial de Liquidação e de Custódia (SELIC) rate, for the period after the Real Plan.[1] One of the biggest challenges facing those interested in estimating the reaction function of the Brazilian Central Bank is how to deal with the regime changes that characterize the Brazilian economy, even after the Real Plan. In order to overcome the uncertainty over the dates at which changes in parameters occurred, this paper uses regime-dependent-switching probabilities according to a hidden Markov chain to model possible deviations from a simple linear reaction function. In this Markov-Switching Model (MS) the probability of occurrence of each regime and the time of regime change are endogenous.

According to our findings, the Brazilian monetary policy can be fully characterized by four different policy regimes (or states) between July 1996 and January 2006. There are substantial differences in the way monetary police was conducted before and after July 1999. Monetary policy between July 1996 and July 1999, which is associated with the control of the exchange rate float and the transition to the floating exchange rate, is characterized by two recurring states. In the first regime (" regime 1"), monetary policy is concerned with the defense of the exchange rate peg and interest rate changes are fundamentally related to movements in international reserves. This state is associated with spillover effects of international financial crises, like the Asian and Russian crises. The second regime (" regime 2") is associated with periods of less stress in the foreign exchange market, allowing the Central Bank to look at inflation, output and the interest rate dynamics when choosing the SELIC rate. On the other hand, monetary policy between August 1999 and January 2006, which is associated with the adoption of the inflation targeting regime and the floating exchange rate, is characterized by two other recurring states. In " regime 3", the Central Bank cares basically about the inflation rate and marginally about the exchange rate when setting the SELIC rate. It happened, for instance, during the period near the Presidential election of 2002, when political uncertainty raised concerns about inflation stabilization. In " regime 4", the Central Bank is more flexible when pursuing the inflation target, and in addition to inflation it includes also output in the SELIC reaction function. This regime prevailed, for example, between August 2001 and March 2002, after the electrical energy shortage menaced to jeopardize the Gross Domestic Product (GDP) growth.

1. The SELIC rate is the adjusted average rate of daily financing guaranteed by federal government securities, calculated in the Special Settlement and Custody System (SELIC).

The article is organized as follows. Section 2 discusses some of the changes in the monetary policy operational procedures implemented by the Central Bank of Brazil after the Real Plan. Section 3 presents a brief review of the literature about the estimation of the Brazilian monetary policy rule. Section 4 describes the estimation procedure used in this study, whose results are presented on section 5. Finally, we offer some concluding remarks on section 6.

2 CHANGES IN MONETARY POLICY OPERATIONAL PROCEDURES SINCE THE REAL PLAN[2]

At the introduction it was mentioned that Brazil experienced several changes in monetary policy operational procedures since the Real Plan. In this section we present an overview of some of these changes, which played a key role on the selection of the beginning of our sample period, July 1996.

The Real Plan, in the beginning (July 1994), established quarterly limits for money expansion in the new currency, the real. Starting in the first quarter of 1995 the procedure of setting monetary limits was substituted by a monetary programming with quarterly projections for the expansion of monetary base, M1, and M4 (the broadest monetary aggregate), formulated by the Central Bank and submitted to the Congress for evaluation, after approval by the National Monetary Council–Conselho Monetário Nacional (CMN).

Although the new currency (the real) was introduced at a rate of one-to-one to the U.S. dollar, there was no official commitment to any exchange rate policy. At first the Central Bank did not intervened in the foreign currency market and the real appreciated vis-à-vis the dollar. The Central Bank reports that it began intervening in the exchange rate market in the second half of September 1994. On March 10th of 1995 the Central Bank introduced a formal 0.88-0.93 exchange rate band with the commitment to intervene only on its limits, after an unsuccessful attempt to introduce a narrower band a day before when it lost US$ 4 billion in international reserves. At the same time the SELIC interest rate was sharply increased in order to prevent any speculation against the real.

On June of 1995 a new 0.91-0.99 exchange rate band was announced together with the introduction of a new mechanism of intervention in the foreign exchange market, the "spread-auction", that in practice resulted in an exchange rate peg through what became know as "mini-bands". There was no official rule for the speed of the crawling but it was understood that it was being set so as to slowly devaluate the real.

On June 20th of 1996 the Monetary Policy Committee–Comitê de Política Monetária (COPOM)–was created with the objective of setting the stance of monetary policy and the short-term interest rate. The design of monetary policy operational procedure was modified with the introduction of two new interest rates: Taxa Básica do Banco Central (TBAN) and the Taxa de Assistência do Banco Central (TBC). According to Lopes (2003), in this setup inspired in the Deutsche

2. This section draws extensively on Céspedes, Lima and Maka (2005).

Bundesbank the TBC, the rate at which banks could have financial assistance through rediscount window of the Central Bank, played the role of an interest rate floor, and the TBAN the ceiling. In principle, the SELIC rate would be allowed to fluctuate freely inside this interest rate band, with the values of both TBC and TBAN rates being determined by the COPOM. However, in practice the Central Bank managed to put the SELIC rate close to the TBC rate most of the time.

The Asian crisis and the Russian default affected Brazil through the loss of international reserves, which caused sharp interest rate increases on October 1997 and September 1998. The monetary policy during these periods was dominated by the Brazilian government attempt to defend the real. On September 4th, 1998 the rediscount window at the TBC rate was closed, making the SELIC rate jump to the TBAN rate. Despite the government's efforts, the international reserves kept sliding. On November 13th, 1998 Brazil and the International Monetary Fund (IMF) announced the conclusion of negotiations on a financial program that provided support of US$ 41.5 billion over the next three years, making US$ 37 billion available, if needed, over the next 12 months. The Central Bank gave up defending the exchange rate on January 15th, 1999 and announced the free-floating as the new exchange rate regime on January 18th, 1999.

On March of 1999 both TBC and TBAN rates were extinguished and a new monetary policy operational procedure was introduced. In this new framework the COPOM sets a target for the SELIC rate that remains constant until the next regular COPOM meetings. However, the COPOM could establish a monetary policy bias at its regular meetings; a bias (to ease or tighten) authorizes the Central Bank's Governor to alter the SELIC interest rate target in the direction of the bias anytime between regular COPOM meetings. Brazil implemented a formal inflation targeting framework for monetary policy on June 21 of 1999. Under the inflation targeting regime, the COPOM's monetary policy decisions have as their main objective the achievement of the inflation targets set by the CMN. If inflation breaches the target set by the CMN, the Governor of the Central Bank is required to write an open letter to the Minister of Finance explaining the reasons why the target was missed, as well as the measures required to bring inflation back to the target, and the time period over which these measures are expected to take effect.

As seen above, Brazil experienced several changes in monetary policy operational procedures in the period after the Real Plan. Unfortunately, some of these changes are short-lived, making any type of econometric analysis unfeasible. Based on the exchange rate regime and monetary policy operational procedures, we decided to begin our sample period on July 1996.

3 A BRIEF REVIEW OF THE LITERATURE ABOUT THE ESTIMATION OF THE BRAZILIAN MONETARY POLICY RULE

In the case of Brazil, most studies estimate the reaction function of the Central Bank with the specification provided by the Taylor rule or some variant of it.[3] The main

3. According to the Taylor rule, the Central Bank responds to both inflation (π) and output gap (x) when setting interest rates.

differences among these studies are the econometric methodology employed in the estimation and whether the policy rule depends on current or expected inflation.[4] We present next a brief review of some of these studies.

Minella et al. (2002) estimate the reaction function of the Central Bank by Ordinary Least Squares (OLS) using data from July 1999 to June 2002. Their results suggest that the Central Bank reacted strongly to inflation expectations and that there has been a high degree of interest rate smoothing. They found that both the output gap and the exchange rate change were not statistically significant components of the Central Bank reaction function.

Salgado, Garcia and Medeiros (2005) use a Threshold Autoregressive (TAR) model to explain the movement in nominal interest that after Real Plan in July 1994. This model utilizes an indicator of currency crisis to analyze the behavior of the interest rate during and after the currency crises. The indicator variable selected is the accumulated three months change in international reserves. The authors concluded that after Real Plan the Brazilian monetary policy experienced two distinct regimes. The first one is associated to the moments of international turbulence like the Asian and Russian crises that affected Brazil through the loss of international reserves. In these occasions Central Bank was forced to undertake a sharp interest rate increase in order to defend the exchange rate peg. In the second regime the Central Bank is concerned with the movement of the usual internal variables. They show that the TAR model performs considerably better then a modified Taylor rule estimated using OLS.

Soares and Barbosa (2006) estimate the Taylor rule with inflation expectations by Two-Stage Least Square (2-SLS) for the period after the introduction of inflation targeting, June 1999, using interest rate change as the dependent variable. Considering both long-run equilibrium interest rate and inflation target as time-varying, they present evidence that suggest that the Brazilian monetary policy respond to the usual variables included in the Taylor rule plus the change on current and lagged real exchange rate.

Policano and Bueno (2006) estimate a policy rule for Brazil using Time Varying Parameter (TVP) method, allowing the coefficients to vary each period according to a random walk process. The results indicate that between January 1995 and October 2005 the Brazilian monetary policy can be divided up in two periods. In the first one, associated to the fixed exchange regime, the interest rate reacted strongly to output and international reserves. In the second period, associated with the inflation target regime, the results depend on whether the policy rule is estimated with observed or expected inflation. When observed inflation is used, its coefficients are small in the first period and became even smaller in the second period. When expected inflation is used instead, its coefficients are bigger than one after January 1999 and increase even further after 2003.

4. Specifications based on forward-looking components, if estimated by single equation methods, imply an equivalent backward-looking specification, obtained by substituting for expected future values a function of current information. However, a stable behavioral rule in terms of expected inflation and output gap might appear unstable in a backward-looking specification. For further discussion, see Sims (2001).

Bueno (2006) use a MS model to estimate the Taylor rule with observed inflation for the period between January 1991 and December 2005, using quarterly and monthly data. For quarterly data, both Akaike and Hanna-Quinn information criteria selected the four regimes model, while for monthly data the Hanna-Quinn selected thethree regimes model while the Akaike selected the four regimes model. The results concerning coefficient estimates depend on the model being analyzed (quarterly/monthly data and the number of regimes assumed), but he found that the inflation parameter is less than one for all regimes, suggesting that there is a puzzle in the inflation stabilization after the Real Plan from the Taylor principle point of view.[5]

The next section presents the methodology followed in this article to estimate the policy rule followed by the Brazilian Central Bank for setting its main policy instrument, the SELIC rate, for the period after the Real Plan. Further details are discussed in the appendix.

4 METHODOLOGY

The econometric analysis of the Central Bank's reaction function followed in this article is based on a MS regression model that can be described by the following equations:

$$y_t = a(S_t) + \sum_{m=1}^{P} b_m(S_t) y_{t-m} + \sum_{m=1}^{p} c_m(S_t) x_{t-m} + \varepsilon_t , \qquad (1)$$

$$\varepsilon_t \sim N(0, \sigma^2(S_t))$$

$$P = [p_{ij}], \qquad p_{ij} = \Pr[S_t = i \mid S_{t-1} = j],\ i, j = 1,\ldots,4 \qquad (2)$$

where y_t is the nominal interest rate; x_t represents the vector of variables which the Central Bank takes into account when setting the interest rate; S_t is a latent random variable that evolves according to a one-step transition probability matrix expressed by (2) and that takes on, at each period *t*, one of four different values.

The model is nonlinear and mixes discrete and continuous components of random variation. It falls in the class of what Chib (1996) calls hidden Markov chain models. The model in Hamilton (1989) is also in this class and a variety of this class of models is also discussed in Kim and Nelson (1999).

Let $\theta_t = \theta(S_t)$ and $\theta(S_t) = \{a(S_t), \{b_m(S_t), c_m(S_t)\}_{m=1}^{p}, \sigma^2(S_t)\}$. Different from previous studies, in our model the parameters θ_t change over time and is determined by a discrete and unobserved random state variable S_t, which follows a MS process assuming, at each period *t*, one of four different states (regimes). Given θ, $\theta = \{\theta(S = i)\}_{i=1}^{4}$, P and a prior distribution for the initial state it is straightforward, as mentioned and shown by Sims (2005), to evaluated the pdf of the data conditional on the initial observation. Next we show how to evaluated the pdf and obtain the filtered estimates of state probabilities.

5. According to the Taylor principle, the Central Bank should raise the interest rate more than one-to-one with increases in inflation (or expected inflation), in order to guarantee uniqueness and stability of equilibrium. For further details on the Taylor principle, see Woodford (2003).

Let Ψ_{t-1} be the informational set until t–1. Given θ, P and $\Pr[S_{t-1} = i \mid \Psi_{t-1}]$ it is easy to obtain $\Pr[S_t = j \mid \Psi_t]$ (i, j = 1,...,4), the filtered estimates of state probabilities at t, and the distribution of y_t given Ψ_{t-1}. The computations are conducted through the recursion described in equations (3), (4) and (6)[6] presented below.

The distribution of S_t conditional on Ψ_{t-1} is given by:

$$\Pr(S_t = j \mid \Psi_{t-1}) = \sum_{i=1}^{4} \Pr(S_t = j \mid S_{t-1} = i) \Pr(S_{t-1} = i \mid \Psi_{t-1}), \quad i, j=1,...,4 \qquad (3)$$

The distribution of y_t given Ψ_{t-1}, $h(y_t \mid \Psi_{t-1})$, is easily obtained integrating S_t out $F(y_t, S_t)$, the joint density of y_t and S_t:

$$h(y_t \mid \Psi_{t-1}) = \sum_{j=1}^{4} F(y_t, S_t = j \mid \Psi_{t-1}) = \sum_{j=1}^{4} f(y_t \mid \theta(S_t = j), \Psi_{t-1}) \Pr(S_t = j \mid \Psi_{t-1}) \quad (4)$$

Where, $f(y_t \mid \theta(S_t), \Psi_{t-1})$ is the conditional distribution of observation y_t, given by the model described in (1) and, therefore, $f(y_t \mid \theta(S_t), \Psi_{t-1}) =$

$$= \frac{1}{\sqrt{2\pi\sigma_t^2(S_t)}} \exp\left\{ - \frac{\left(y_t - a(S_t) - \sum_{m=1}^{P} b_m(S_t) y_{t-m} - \sum_{m=1}^{p} c_m(S_t) x_{t-m}(S_t) \right)^2}{2\sigma_t^2(S_t)} \right\} \qquad (5)$$

Finally, the filtered estimates of state probabilities at t is given by:

$$\Pr(S_t = j \mid \Psi_t) = \Pr(S_t = j \mid y_t, \Psi_{t-1}) = \frac{F(y_t, S_t = j \mid \Psi_{t-1})}{h(y_t \mid \Psi_{t-1})} \quad (j = 1,...,4) \qquad (6)$$

To start the recursion, at t = 1, we need to know the prior distribution for the initial state, $\Pr[S_0 = j \mid \psi_0]$, for j = 1,…,4. The observed value y_1 is in fact informative about $\Pr[S_1 = j \mid \psi_0]$, for j = 1,…,4. Evaluating the unconditional joint distribution for y_1 and S_1, given ψ_0, is difficult and if the model is non-stationary, the unconditional distribution might not even exist. Like Sims (2005), we treat y_1 as non-stochastic and assume that S_1 and S_0, given ψ_0, are drawn from their unconditional distribution alone, which is the steady-state probabilities π computed as the right eigenvector of P, the matrix of transition probabilities, associated with its unit eigenvalue. Therefore π satisfies $P\pi = \pi$ and is unique if the Markov process is ergodic.

$$\pi = \begin{bmatrix} \Pr(S_1 = 1/\psi_0) \\ \Pr(S_1 = 2/\psi_0) \\ \cdots \\ \Pr(S_1 = 4/\psi_0) \end{bmatrix} = \begin{bmatrix} \Pr(S_0 = 1/\psi_0) \\ \Pr(S_0 = 2/\psi_0) \\ \cdots \\ \Pr(S_0 = 4/\psi_0) \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \cdots \\ \pi_4 \end{bmatrix}$$

6. The recursion assumes that θ and P are given. There are no explicit references to them because they are considered fixed throughout the recursions.

We have shown how to compute $h(y_t \mid \Psi_{t-1})$, $t = 1, \ldots, T$ (T = sample size), given θ and P.[7] The likelihood function is given by:

$$L(\theta, P) = \prod_{t=1}^{T} h(y_t \mid \Psi_{t-1}) \quad (7)$$

Equation (7) gives the mapping from the parameters contained in θ and P to the value of the likelihood. Therefore, adopting the classical approach, these parameters can be estimated through a numerical optimization routine.[8]

The likelihood described in (7) does not have a global maximum (HAMILTON, 1994; KOOP, 2003). A singularity arises whenever, for one observation, the model has a perfect fit, that is, $y_t = a(S_t = j) + \sum_{m=1}^{P} b_m(S_t = j) y_{t-m} + \sum_{m=1}^{p} c_m(S_t = j) x_{t-m}$ for some t and j, with 0 variance ($\sigma^2(S_t = j) \to 0$). If this happens the log likelihood becomes infinite. As pointed out by Hamilton (1994), numerical procedures very frequently will lead to a reasonable local maximum rather than a singularity. He also proposes that the maximum likelihood estimation should be defined as the largest local maximum with $\sigma(S_t = j) > 0$, for all j, and considers reasonable to restart at a different starting value whenever a singularity shows up in the numerical optimization process. Kiefer (1978) showed that likelihoods, similar to (7), have a bounded local maximum and yields consistent, asymptotically Gaussian estimates. Restricting the value of $\sigma(S_t = j)$, for all j, to lie within a region bounded away from 0–as implemented by Redner (1981), Hathaway (1985) and Sims (2005)–provided that this region includes the true value of $\sigma(S_t = j)$, yields the existence of a global maximum within this restricted set and yields the desirable estimator of parameters.[9]

5 EMPIRICAL ANALYSIS OF THE CENTRAL BANK REACTION FUNCTION

5.1 DATA DESCRIPTION

The monthly value, from July 1996 to January 2006, of the following variables were employed in the estimation of the Brazilian Central Bank policy rule :[10]

r_t = log of one plus the SELIC interest rate observed at period t (annual rate). Source: Brazilian Central Bank;

π_t = log of one plus the annual inflation rate accumulated in month t and previously, as measured by the Índice Nacional de Preços ao Consumidor Amplo (IPCA). Source: Instituto Brasileiro de Geografia e Estatística (IBGE);

q_t = log of the nominal exchange rate, as measured by the end of the month buying rate. Source: Brazilian Central Bank;

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7. We should include π in this list but there is, given our hypotheses, a mapping from P to π.

8. As an alternative, it is also possible to estimate this model using the Gibbs sampling method.

9. Further details on how we proceeded to estimate the MS model are given in the appendix.

10. The dataset used in this article is available upon request to the authors.

y_t = log of the sum of the twelve industrial production indexes observed in period t and immediately before divided by the same sum calculated at period *t*–13. Source: IBGE; and

res_t = log of the monthly foreign reserves, measured by the international liquidity concept. Source: Brazilian Central Bank.

5.2 RESULTS

In this subsection we present the results of the estimation of the MS model for the period between July 1996 and January 2006, following the procedure described in section 4 and in the appendix. Given the small sample size and the large number of parameters to be estimated in the MS model, it is not possible to specify the policy rule equation with many lags. Therefore, we (arbitrarily) decided to use lag length two in our estimation.

We assumed that the unobserved random variable S_t– see equations (1) and (2)– takes one of four different regimes (or states) at each point in time and that in each regime the policy rule equation is restricted as follows:

Regime 1: in this regime the Central Bank may react to past values of the SELIC rate and to past values of the level of international reserves when setting the SELIC rate;[11]

Regime 2: in addition to the variables of state 1, in this regime the Central Bank may also react to output and inflation;

Regime 3: in this regime the Central Bank may react to past values of the SELIC rate, inflation rate, exchange rate and output but not to the level of international reserves.

Regime 4: in this regime the Central Bank may react to past values of the SELIC rate, inflation rate, exchange rate and output but not to the level of international reserves.

We also observed, in the initial estimations of the transition probability matrix, the following: very low probability of occurrence of state 4 at period *t* if, at period *t*–1, the state was equal to 1 or 2; very low probability of occurrence of state 3 at period *t* if, at period *t*–1, the state was equal to 1; a small (but not very low) probability of occurrence of state 3 at period *t* if, at period *t*–1, the state was equal to 2; and very low probability of occurrence of states 1 and 2 at period *t* if at period *t*–1 the state was equal to 3 or 4. We, therefore, imposed that all those very low probabilities were equal to 0 when estimating the transition probability matrix.

The maximum likelihood estimates of the parameters are displayed in table 1, together with their respective asymptotic t-statistic.[12] The sign and the magnitude of the net impact of a variable on the SELIC rate are given by the sum of coefficients of

11. It is important to have in mind that even when some variable is not included in the policy rule that the Central Bank follows when setting the SELIC rate, that doesn't mean that the Central Bank does not take that variable into account when it sets other policy instruments.

12. The parameter's standard error comes from the (numerically calculated) Hessian of the log likelihood at its maximum. However, these approximations are not guaranteed to be accurate.

all its lags. The variables assumed to enter in each regime were found to be statistically significant, but their net impacts on the SELIC rate are small when compared to the one of the SELIC rate. In fact, except for states 1 and 3, the Central Bank displays an interest rate smoothing behavior, suggesting that it tries to avoid fast changes in the interest rates.[13] Table 2 displays the estimated transition probability matrix subjected to the restrictions described above.

TABLE 1
Markov-Switching model
(July 1996–January 2006)

Max likelihood = 469.7625

Dependent variable = SELIC

SC (p-value) = 266,43 (0.000)

R-squared = 0.9655

Rbar-squared = 0.9621

State 1 sigma = 0.0311

State 2 sigma = 0.0047

State 3 sigma = 0.0030

State 4 sigma = 0.0007

Nobs, Nvars = 113, 11

(not counting hyperparameters)

Variables	State 1		State 2		State 3		State 3	
	Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic
SELIC (–1)	0.0633	0.36	0.8497	27.99	1.5333	21.28	1.0894	18.37
Rate inflation (–1)	0.0000	0.00	0.1855	1.27	0.3839	3.75	0.1353	3.92
Exchange rate (–1)	0.000	0.00	0.0000	0.00	0.0100	1.33	0.0089	2.26
Industrial production (–1)	0.0000	0.00	–1.7731	–9.54	0.0083	0.11	–0.0002	–0.01
International reserves (–1)	–0.2066	–1.97	–0.1943	–12.56	0.0000	0.00	0.0000	0.00
SELIC (–2)	–0.6571	–3.57	–0.0130	–0.35	–0.7050	–10.75	–0.1949	–3.30
Rate inflation (–2)	0.0000	0.00	0.3130	5.05	–0.3314	–4.04	0.0003	0.01
Exchange rate (–2)	0.0000	0.00	0.0000	0.00	–0.0022	–0.29	–0.0105	–2.50
Industrial production (–2)	0.0000	0.00	1.8966	10.68	–0.0215	–0.26	0.0511	1.97
International reserves (–2)	0.0189	0.20	0.2090	11.76	0.0000	0.00	0.0000	0.00

13. Some of the reasons pointed out in the literature for this behavior of the Central Bank are fear of disruption of financial markets (GOODFRIEND, 1991) and uncertainty about the effects of interest changes (SACK, 2000).

TABLE 2
Transition probability matrix

Probabilities	$\Pr(\mathbf{S_t}=\mathbf{j}\mid\mathbf{S_{t-1}}=1)$	$\Pr(\mathbf{S_t}=\mathbf{j}\mid\mathbf{S_{t-1}}=2)$	$\Pr(\mathbf{S_t}=\mathbf{j}\mid\mathbf{S_{t-1}}=3)$	$\Pr(\mathbf{S_t}=\mathbf{j}\mid\mathbf{S_{t-1}}=4)$
$\Pr(\mathbf{S_t}=1\mid\mathbf{S_{t-1}}=\mathbf{j})$	0.321	0.278	0.000	0.000
$\Pr(\mathbf{S_t}=2\mid\mathbf{S_{t-1}}=\mathbf{j})$	0.679	0.682	0.000	0.000
$\Pr(\mathbf{S_t}=3\mid\mathbf{S_{t-1}}=\mathbf{j})$	0.000	0.040	0.896	0.120
$\Pr(\mathbf{S_t}=4\mid\mathbf{S_{t-1}}=\mathbf{j})$	0.000	0.000	0.104	0.880

TABLE 3
OLS
(July 1996–January 2006)

Max likelihood = 256.68

Dependent variable = SELIC

R-squared = 0.7944

Rbar-squared = 0.7742

Sigma = 0.0242

Durbin-Watson = 2.1932

LM ARCH = 45.34 (0.000)

Breusch-Pagan test = 6.76 (0.000)

Nobs, Nvars = 113, 11

Variable	Parameter	t-statistic	t-probability
SELIC (–1)	0.8759	9.29	0.00
Rate inflation (–1)	0.9714	2.38	0.02
Exchange rate (–1)	0.0685	1.93	0.06
Industrial production (–1)	–0.4479	–1.15	0.25
International reserves (–1)	–0.0972	–3.01	0.00
SELIC (–2)	–0.1035	–1.06	0.29
Rate inflation (–2)	–0.8816	–2.28	0.02
Exchange rate (–2)	–0.0819	–2.31	0.02
Industrial production (–2)	0.4657	1.25	0.21
International reserves (–2)	0.1134	3.54	0.00
Constant	–0.1269	–1.05	0.30

Figures 1-4 display the probability of occurrence of each regime over time, together with the graphs of the SELIC rate and foreign reserves.[14] We observe that regimes 1 and 2 are more likely to occur between July 1996 and July 1999, while regimes 3 and 4 are more likely to occur after July 1999. One can see that there are substantial differences in the way monetary police was conducted before and after July 1999. Monetary policy between July 1996 and July 1999, which is associated

14. Smoothed probabilities are given by $\Pr[S_t = j \mid \Psi_T]$, where t = 1, 2,…, T and j = 1, 2, 3, 4. Since the SELIC rate and foreign reserves have different scales, we normalized them in order to represent them in the same chart.

mainly with the control of the exchange rate and the transition to the floating exchange rate, is characterized by two recurring regimes.

FIGURE 1

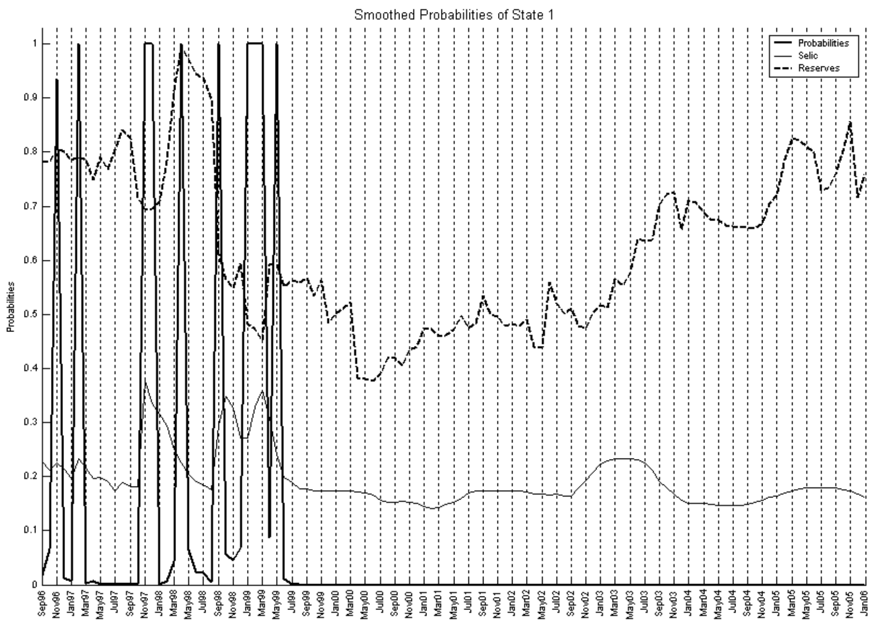


FIGURE 2

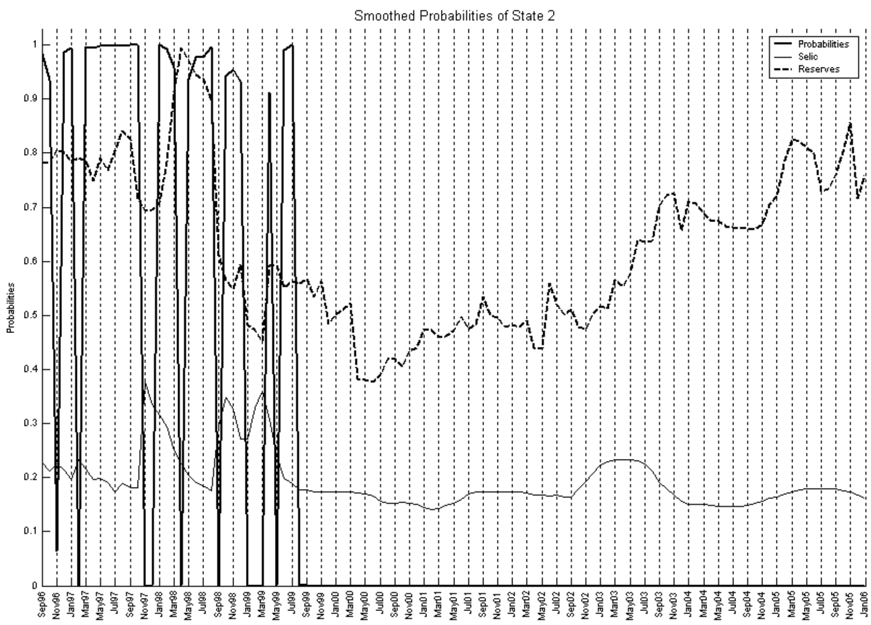


FIGURE 3

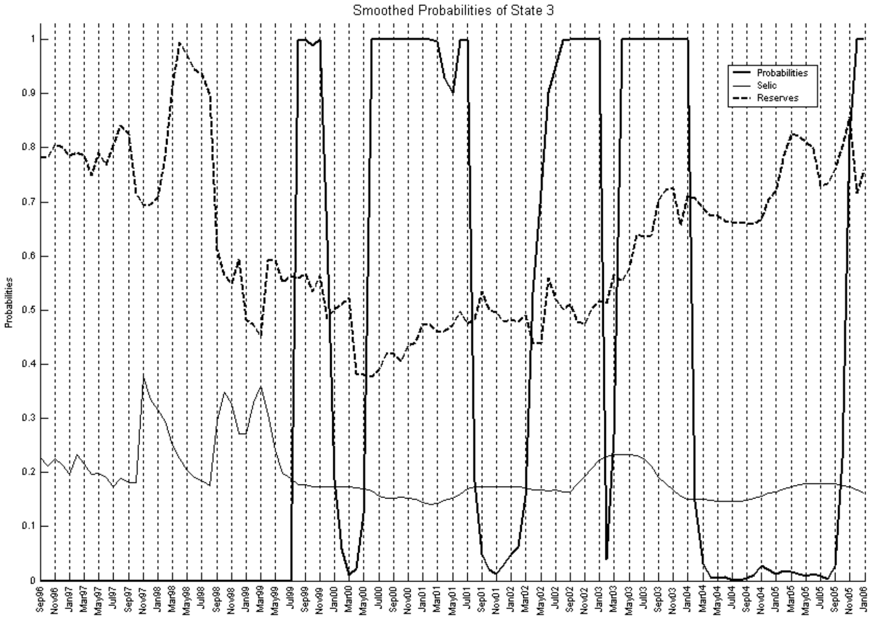
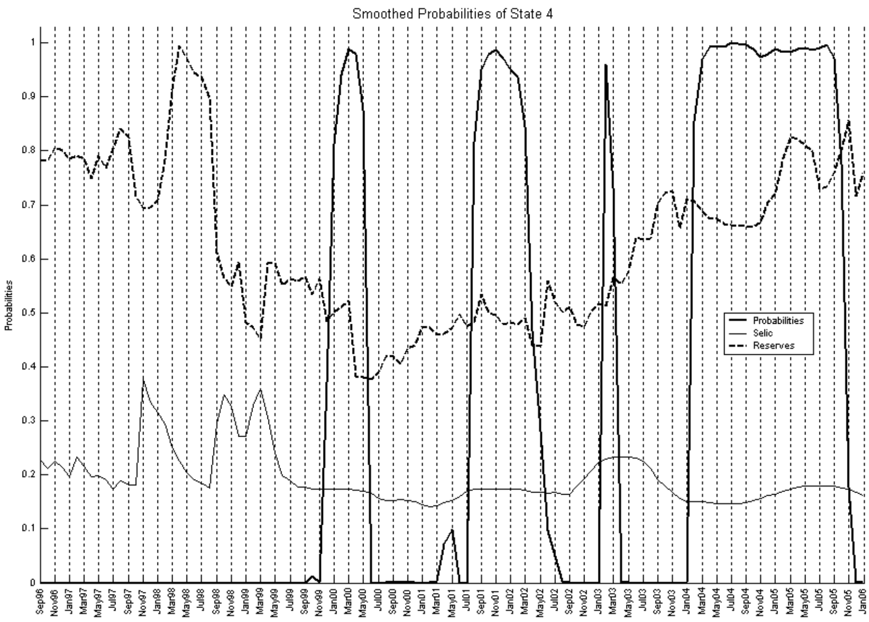


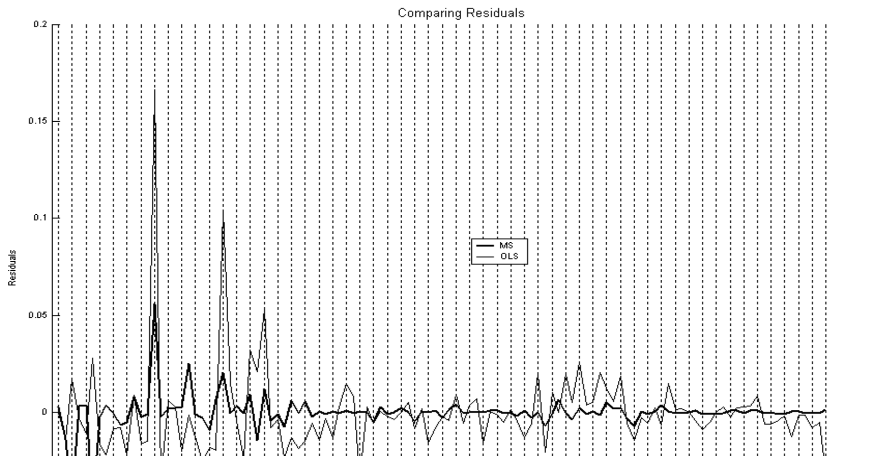
FIGURE 4



In the first regime (regime 1), monetary policy is concerned with the defense of the exchange rate peg and interest rate changes are fundamentally related to movements in international reserves. This state is associated with spillover effects of international financial crises, like the Asian and Russian crises. The second regime (regime 2) is associated with periods of less stress in the foreign exchange market, allowing the Central Bank to look at inflation, output and the interest rate dynamics when choosing the SELIC rate. On the other hand, monetary policy between August 1999 and January 2006, which is associated with the adoption of the inflation targeting regime and the floating exchange rate, is characterized by two other recurring states. In regime 3, the Central Bank cares basically about the inflation rate and marginally about the exchange rate when setting the SELIC rate. It happened, for instance, during the period near the Presidential election of 2002, when political uncertainty raised concerns about inflation stabilization. In regime 4, the Central Bank is more flexible when pursuing the inflation target, and in addition to inflation it includes also output in the SELIC reaction function. This regime prevailed, for example, between August 2001 and March 2002, after the electrical energy shortage menaced to jeopardize the GDP growth.

In order to check whether the MS model introduce some informational gain over the simple linear model, we display in table 3 the results of OLS estimation. Comparing the results between the MS and OLS estimations of the reaction functions, one can see that MS model performs considerably better than OLS. First of all, the value of the likelihood of MS is substantially higher than the one resulting from OLS estimation. The Schwartz criterion, which penalizes the less parsimonious model (the model with more parameters), also clearly favors the MS model. Although the Durbin-Watson statistic does not display any problem of autocorrelation for the OLS regression, the LM ARCH and Breusch-Pagan tests indicate the existence of heteroskedasticy in the OLS estimates. As Sims (1999; 2001) points out, heteroskedasticy can indicate the presence of structural breaks, making it necessary to use some method to mitigate the problem. Figure 5 displays the graph of both model's residuals. It shows that the MS model fits the data better than the OLS model. Another point in favor of the MS model is that its adjusted R^2 is larger then that of the OLS model.

Figure 5
Residuals
(July 1996–January 2006)



6 CONCLUDING REMARKS

This article studied the rule followed by the Brazilian Central Bank for setting its main policy instrument, the SELIC rate, for the period after the Real Plan. Using a

MS model, we found evidence that monetary policy between July 1996 and January 2006 can be fully characterized by four policy regimes and that changes in monetary policy in this period are best described as recurring regime changes, instead of once-and-for-all shifts that are the norm in theoretical models of monetary policy.

According to our findings, there are substantial differences in the way monetary policy was conducted before and after 1999, indicating that monetary policy was substantially affected (as should be expected) by the change in the exchange rate policy regime towards the free-floating of the Brazilian currency.

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APPENDIX

HOW THE MARKOV-SWITCHING MODEL WAS IMPLEMENTED

One of the difficulties of the MS methodology outlined on section 4 is that it does not possess a global maximum, which thus requires a certain amount of effort in order to establish a criterion that may ensure the well-defined existence of the best local optimum. Therefore, due to the complexity inherent to the stages of the estimation process, it is necessary to introduce a detailed description of the intermediate steps adopted during the process. At the end of section 4 there is a brief discussion of the strategies that may be used toward this objective. However, due to the complexity involved in each situation, such directives are difficult to use without the support of a specific complementary procedure.

Basically, the search for a local optimum followed an interactive process that may be illustrated as follows. Initially, the model was estimated for the entire period using four regimes. The first search revealed a pattern which was different from the one in which all regimes alter over time. The obtained regime change pattern showed that the four states of monetary policy were temporally distributed in pairs of states and the pairs where switched in a well-defined moment in time.[15] Before and after this moment monetary policy assumed two different pair of states. In other words, regimes 1 and 2 occurred before the moment of rupture, while regimes 3 and 4 only occurred after this.

The task was then to estimate two partial models based on the sample subperiods determined by the cut-off point. Once this was done, the model was estimated again for the entire period, using the results of the models estimated for the sub-samples as initial values in the optimization routine. Repeating this experiment a certain number of times, it was observed that the final result converged towards one quite similar to the one obtained initially, indicating that the four monetary policy

15. Defined here as a moment of cut-off or rupture.

regimes during the period were dispersed in such a way that regimes 1 and 2 occurred between July, 1996 and July, 1999, while regimes 3 and 4 occurred only after July, 1999.

An analysis of the models for the subsamples was also used as a base to test the robustness of the model regarding the number of regimes assumed during the entire period. Therefore, based on the sample for the second subperiod, a model was estimated which included three regimes. The result indicated that the third state was practically not visited, which allows us to deduce that the inclusion of a third state proved to be a statistically innocuous procedure. Also considering the reduced size of the sample for the first sub-period, it was not possible to test any additional state for this interval.[16] This leads us to suppose that assuming four states for the complete sample is quite reasonable.

We used *a priori* information to reduce the parameterization of the MS model. For most of the first period the exchange rate was controlled by the Central Bank. Therefore, for regimes 1 and 2–that occur in this subperiod–there is no need to include the nominal exchange rate in the regression. The second subperiod (August 1999 to January 2006) is related to a floating exchange rate regime, and therefore it makes sense to include the exchange rate as an explanatory variable for regimes 3 and 4. It was initially observed that the number of times that regime 1 was visited was practically equal to the number of the model's explanatory variables.[17] The option here was to impose a specification that imposes as explanatory variables only lagged international reserves as well as lagged interest rate. This way we assume that during regime 1 the monetary authority only oversees international reserves and the domestic interest rate. Finally, because there is no evidence that the Central Bank was concerned with international reserves during second subperiod it makes sense to exclude international reserves from the Central Bank reaction function in this last period.

16. Due to the limited size of the sample for the first sub-period (37 observations), the estimation of the three regime model could not be implemented due to the model' s insufficient degrees of freedom.

17. This leaves the variance of the residuals indeterminate.

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