Changes in central bank preferences: an empirical study for Brazil

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Abstract

This paper analyzes the behavior of the Central Bank of Brazil's (Banco Central do Brasil - BCB) preference parameters during the period between 2000: Q1 and 2017: Q4. To this end, we assume that Brazil's monetary policy is optimal and thus obtain the parameters of the policy function by estimating a macroeconomic model with backward-looking expectations and central bank preferences. The econometric approach used is based on Bayesian Markov Chain Monte Carlo (MCMC) estimation with the aid of the Kalman filter. Our results indicate that there was instability in the preferences over time, with fluctuations following the appointment of a new BCB president and during the 2008 international crisis.

Keywords: Central Bank Preferences; Monetary policy; Time-varying parameter; Extended Kalman filter.
JEL Code: E430; E520; E580.

Resumo

Este artigo analisa o comportamento dos parâmetros de preferências do banco central do Brasil (BCB), no período compreendido entre 2000.T1 e 2017.T4. Para isso, supomos que a política monetária do Brasil é definida de forma otimizada e, posteriormente, obtemos os parâmetros da função política a partir de estimação do modelo macroeconômico com expectativas backward-looking e das preferências do banco central. A abordagem econométrica utilizada é baseada em estimação bayesiana MCMC com auxílio do filtro de Kalman. Nossos resultados indicam que houve instabilidade nas preferências ao longo do tempo, com flutuações após posses de presidentes do BCB e durante a crise internacional de 2008.

Palavras-chave: Preferências do banco central. Política monetária. Parâmetro variante no tempo. Filtro de Kalman estendido.

Área 4: Macroeconomia, Economia Monetária e Finanças

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1 Introduction

Following the implementation of the inflation targeting regime in the late 1990s, the Central Bank of Brazil (*Banco Central do Brasil* - BCB) played a role in guiding monetary policy to achieve price stability in the economy. The interest rate plays a crucial role in monetary policy behavior, given fluctuations in output and inflation, as presented in Taylor (1993).[1] Monetary authorities thus face a trade-off between inflation stabilization or reduced unemployment. For Brazil, Minella et al. (2000), Silva and Portugal (2001) and Minella et al. (2003) evaluated the effect of the interest rate on macroeconomic variables and potential changes to the monetary policy regime.

The importance that the BCB places on inflation relative to outputs can be established as a fundamental preference measure for monetary policy decisions, as presented by Bogdanski, Tombini and Werlang (2000). The interest rate rule can be obtained by solving an intertemporal optimization problem with constraints as the monetary authority seeks to minimize the squared deviations of the objective variables from their respective targets. The coefficients of the central bank's reaction function are thus a fusion of the economy's preference and structural parameters.

In this study, the estimation of the preference parameter for inflation is variable, as it may exhibit different behavior over time. Monetary policy, together with time-varying preferences, establishes nonlinearities, which were estimated using the extended Kalman filter (EKF) incorporated into the Bayesian Markov Chain Monte Carlo (MCMC) Metropolis-Hastings algorithm. The objective of the study is thus to verify whether the BCB's preferences varied over time, considering that the study period included potential gradual changes in the economy and three different BCB presidents, namely, Henrique de Campos Meirelles (2004-2010), Alexandre Antonio Tombini (2011-2016) and Ilan Goldfajn (2016-present).

Most of the studies that address central bank preferences seek to combine a macroeconomic model with the first-order conditions of the policymakers. In studies focused on the United States' central bank (Federal Reserve System - Fed), gradual changes in the sample vary according to the interests of the central bank's president, as shown by Favero and Rovelli (2003), Ozlale (2003), Dennis (2006), Salemi (2006), Givens (2012) and Ilbas (2012). With a different focus, Söderström, Söderlind and Vredin (2002) and Castelnuovo and Surico (2004) estimate the Fed's preferences using calibration. The authors found that the Fed attributes an important weight to interest rate smoothing and places little importance on the output gap.

Dennis (2006) estimated the parameters of the Fed's reaction function together with the parameters in its optimization constraints. Positing that the economy can be represented by the model proposed in Rudebusch and Svensson (1999), the US inflation target was approximately 1.4%, and policymakers attributed greater weight to interest rate smoothing. In turn, Ilbas (2012) used Bayesian methods to estimate changes in US post-war monetary policy and concluded that output growth is explained by the combination of two factors: the decreased volatility of the structural shocks and the improved monetary policy behavior.

Givens (2012) sought to estimate the Fed's preferences under commitment and discretion. The author used an empirical New Keynesian model in which monetary policy minimizes the central bank's loss function. With estimates for different periods (Volcker-Greenspan-Bernanke), it was possible to observe that the estimates of the loss function weights suggest an excessive concern for interest rate smoothing in the proposed model. The author also found a relative balance with respect to inflation and output stability in the discretionary policy.

For Brazil, Aragón and Portugal (2009) investigated monetary policy under the inflation targeting regime by calibrating preferences and found that the BCB adopted a flexible inflation targeting regime and placed greater importance on inflation stabilization. Finally, these authors found that the monetary authority's concern with interest smoothing was deeper than with output stabiliza-

[1] One explanation for why applying estimated rules is important to describe the evolution of monetary policy stems from the fact that estimated rules capture the systematic relationship between interest rates and macroeconomic variables and, as such, can be used as approximations for the central bank's decision rules, as shown by Clarida, Gali and Gertler (2000).

tion. Similar results were found by Palma and Portugal (2011) and Palma and Portugal (2014). This study thus seeks to contribute to the national literature by analyzing the BCB's preferences with a time-varying approach in the period from 2000: Q1 to 2017: Q4.

The results indicate that there is some instability in the policymakers' preferences, particularly following the appointment of a new BCB president and during the 2008 international crisis. The Brazilian monetary authority seeks to smooth the Special System for Settlement and Custody (Sistema Especial de Liquidação e Custodia - Selic) interest rate, as well as control inflation and output gap fluctuations, via interest rates. We also found that the long-term responses to inflation and the output gap were larger during Henrique Meirelles's term compared to his successor, Alexandre Tombini.

In addition to this introduction, this article is divided into five sections. The second section shows an overview of Brazil's monetary policy. The third section presents the theoretical model used as a base for estimation. The fourth section is devoted to presenting the main methodological tools used to estimate the BCB's preferences. The fifth section presents the results. Finally, the sixth section is devoted to the study's conclusions.

2 An overview of Brazilian monetary policy

Based on BCB reports, this section presents a broad overview of Brazil's monetary policy and the interest rate as a policy instrument for achieving inflation targets.

According to Bogdanski, Tombini and Werlang (2000), Brazil's inflation stabilization occurred in mid-1994, resulting in single-digit inflation in less than three years. This process involved a series of economic reforms such as a reduction of the public sector through privatizations, greater trade liberalization with a reduction of tariffs and nontariff barriers, and a restructuring of the financial system. The main measure of inflationary inertia—automatic indexing of prices, wages and other contracts—was reduced considerably. As a consequence, annual output growth averaged 3.4% (in real terms) from 1994 to 1998.

Historically, countries that have adopted an inflation targeting regime—Australia, Canada, New Zealand—have obtained satisfactory results, although it is only natural for economic recessions to follow its adoption, and this was no different in Brazil. Although the stabilization of the Brazilian economy was successful, there were still some structural economic problems, namely:

- increased vulnerability of the country's confidence, exacerbated following the Russian moratorium in August 1998;
- capital flight from emerging markets, as a consequence of the crisis of confidence; and
- strong pressures on exchange reserves.

The inflation targeting regime was instituted in Brazil in July 1999. This regime took the following assumptions as its objectives: i) set inflation targets based on a predetermined price index; ii) assigned to the BCB the task of achieving the target; and iii) made the National Monetary Council (*Conselho Monetário Nacional* - CMN) responsible for determining the inflation targets, their relative ranges of variation and the price index to be followed.

Concomitant with the above measures, the Monetary Policy Committee (*Comitê de Política Monetária* - COPOM) determined the basic interest rate of the Brazilian economy (Selic) as a monetary policy measure for inflation control.[2] According to Carvalho et al. (2007), Selic is used to carry out transactions between financial institutions and functions as the government's main monetary instrument.

[2] According to the BCB, the Selic rate is the adjusted average rate of daily financing calculated in the Selic system for federal securities. The rate calculation considers the daily financing relative to transactions registered and settled in Selic and in systems operated by clearing and asset settlement services.

2.1 Interest rate as a monetary policy instrument

After implementing the inflation targeting regime and a floating exchange rate, in effect since 1999, the interest rate was used as the main monetary policy instrument for pursuing price stability. In this initial period, the inflation target was reduced in 2000 due to the turbulent international scenario. Some situations occurring around the world at the time included increased oil prices, political problems in the US and a critical scenario experienced by the Argentine economy. Figure 1 presents a series of the Selic interest rates accumulated monthly, annualized for the 2000-2017 period.

Following the recovery of the Brazilian economy in late 2000, reflecting the positive evolution of the macroeconomic fundamentals and low instability in the international environment, a target of 15.25% per annum (p.a.) was set for the Selic rate for January 2001. As of March 2001, there was an increase in the exchange rate (currency depreciation), and under these conditions, the COPOM raised the target for the economy's basic interest rate to the level of 19% p.a. in July, returning to the level observed in the early months of 2000.

According to the bulletin of the BCB (2004), in 2004, with Henrique de Campos Meirelles serving as the BCB's president, the COPOM interrupted the monetary policy easing process, which began in June 2003. This cautious measure was imposed with the objective of meeting the inflation target for 2004, given the increase in commodity prices caused by the high growth of the world economy. The target for the basic interest rate was set at 17.75% p.a. in late 2004.

In 2006, price stability was preferred in the monetary policy behavior.[3] In the first three months, the COPOM reduced the Selic rate target by 0.75% p.a., subsequently applying another cut of 0.5% p.a. in the ensuing months. This reduction in the basic interest rate represented two uncertainties to the economy: i) the degree of monetary policy easing that began in 2005; and ii) the external liquidity conditions resulting from changes in US monetary policy behavior, as presented in BCB (2006).[4]

In early 2008, the COPOM acted more cautiously in guiding monetary policy, given that the world and domestic economy showed signs of recovery, legitimizing a more restrictive monetary policy. During July of that same year, given the acceleration of wholesale prices and an increase in the inflation expectation, the decision was made to raise the economy's basic interest rate. Finally, at the end of the year, the committee decided to keep the interest rate high due to some negative aspects encouraged by the international crisis, namely, uncertainty in the positive evolution of economic activity and a decrease in consumer and entrepreneur confidence.

According to the BCB (2010), the economy's official price index, the Broad Consumer Price Index (*Índice de Preços ao Consumidor Amplo* - IPCA), remained between 2.5% and 6.5% in 2010, and the Selic rate target reached 8.75% p.a., which was the lowest level since the implementation of the inflation targeting regime in 1999. As the months passed, this rate was raised to 10.75% p.a., as shown in Figure 1. In this scenario, the CMN, together with authorities from the BCB and COPOM, adopted some important measures, including compulsory reserve and credit increases.

Following the deceleration of the Brazilian economy in the second half of 2011, the COPOM decided to reduce the Selic interest rate repeatedly throughout 2012. At the end of that year, the economic environment showed a favorable balance of risks for inflation, recovery of the domestic economy and the complexity surrounding the international economy, and these circumstances contributed to the COPOM keeping the economy's interest rate at a low level.

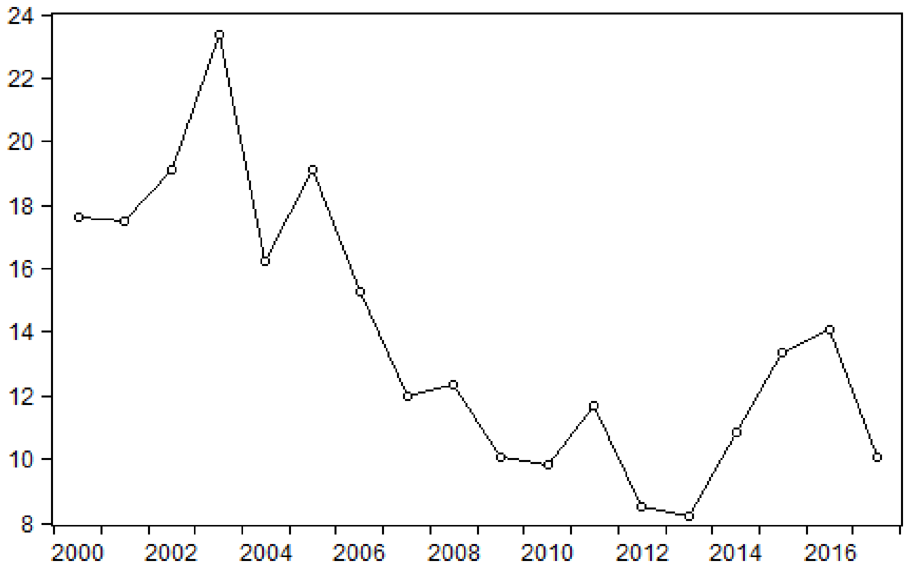
As stated in BCB (2014), over the next few years, the COPOM raised the Selic rate from 10% p.a. at the end of 2013 to approximately 11.75% p.a. at the end of 2014. This is justified by the fact that the relative price adjustments in the economy caused a deterioration in the balance of risks for inflation. The monetary authorities thus reached a consensus regarding the adjustment of monetary

[3] Based on the annual inflation target set at 4.5% by the CMN, the COPOM reduced the target for the basic interest rate to 13.25% p.a. in December 2006.

[4] The easing of the monetary policy in Brazil was enabled by the downward trend in the inflation expectations for 2006. That same year, an equivalent trend was confirmed, beginning in September 2007, in the price index expectations.

conditions to ensure—at a lower cost—hegemony of a less hostile environment for inflation in the next two years, 2015 and 2016.

Figure 1 – Trajectory of the accumulated/annualized Selic interest rate (2000-2017)



Source: Prepared by the authors using BCB data.

[1] Note: The value for each year was calculated from the 12-month mean of the cumulative monthly interest rate series.

As shown in appendix C, the inflation trajectory points to signs of changes in the preferences of the monetary authorities only at specific points in the economy; for example, after the 2003 presidential election, we observed a drop in the general price level, which rose once more in 2014. For the output gap, we found a clear deceleration during the 2008 international crisis. The trajectory of the variables thus indicates a slight change in the policymakers' preferences at specific periods in the Brazilian economy.

3 Theoretical Model

This section is devoted to presenting the theoretical model that will be used to estimate the BCB's preferences. This model is grounded in three elements: constraints, loss function and optimal policy.

3.1 Constraints

In this study, we consider a simple structural macroeconomic model with backward-looking expectations. The studies of Favero and Rovelli (2003), Ozlale (2003), Dennis (2006) and Lakdawala (2016) used this model to study central bank preferences. The model's equations are as follows:

$$\pi_t = b_0 + b_1\pi_{t-1} + b_2\pi_{t-2} + b_3\pi_{t-3} + b_{3_A}\pi_{t-4} + b_4 y_{t-1} + \mu_{\pi,t} \tag{1}$$

em que $\mathrm{b}_{3_A} = 1 - b_1 - b_2 - b_3$.

$$y_t = a_0 + a_1 y_{t-1} + a_2 y_{t-2} + a_3(i_{t-1} - \pi_{t-1}) + \mu_{y,t} \tag{2}$$

in which π_t is the annualized quarterly inflation rate and y_t is the output gap (obtained by the difference between the observed output and its potential value). The real interest rate, r_{t-1}, is defined as the difference between the nominal interest rate (i_{t-1}), considered as a monetary policy instrument, and the economy's inflation rate (π_{t-1}). The error terms $\mu_{\pi,t}$ and $\mu_{y,t}$ are independent and identically distributed (i.i.d.) and are interpreted as supply and demand shocks, respectively.

The Phillips or aggregate supply curve (1) shows that the current inflation depends on its past values and the fluctuation of the output gap in the previous period. Equation (2) is a conventional investment/saving (IS) curve where the output gap at time t depends on its lagged values and the real interest rate in the previous period. The coefficient a_3, which measures the output gap response at the real interest rate, should be negative.

3.2 Loss function

Following Rudebusch and Svensson (1999), we assume that the monetary authority seeks to choose a path for the policy instrument (the nominal interest rate) to minimize:[5]

$$L = \tilde{E}_t \sum_{j=0}^{\infty} \beta^j [\alpha_t(\pi^a_{t+j} - \pi^*_t)^2 + y^2_{t+j} + \nu(i_{t+j} - i_{t+j-1})^2] \tag{3}$$

where E_t is the expectation operator conditioned on the set of data available at t; β is the discount rate ($0 < \beta < 1$); $\alpha > 0$; the weight of the output gap relative to inflation is normalized to 1; and ν, which represents the interest rate smoothing coefficient, should be equal to or greater than 0.[6] With loss function L, the monetary authority is assumed to stabilize the annual inflation, $\pi^a_t = (1/4)\sum_{j=0}^{3} \pi_{t-j}$, around an inflation target (π^*) to keep the output gap closed at zero and smooth the nominal interest rate. Appendix A shows the detailed mathematical derivation of the model in a state-space representation and the optimal policy rule.

According to Lakdawala (2016), the theoretical motivation of the third term ($\nu(i_{t+j} - i_{t+j-1})^2$) is based on the desirable effects of private sector expectations.[7] This term may also be motivated by the central bank's desire to reduce asset price volatility to prevent high interest rate swings. Rudebusch (2002), Rudebusch (2006) and Castelnuovo and Surico (2004) argued that the central bank does not use the smoothing device directly but rather follows autocorrelated shocks that affect the economy or potential concern with the model's uncertainty. However, in recent empirical studies, Hamilton, Pruitt and Borger (2011) and Coibion and Gorodnichenko (2012) found that the central bank is truly concerned with interest rate smoothing.

Several points justify the use of the interest rate smoothing term: i) the data and coefficients of monetary policy transmission present uncertainties; ii) policymakers only take action when there is certainty about the results of these actions; iii) changes in interest rates may destabilize the financial and exchange markets; iv) reversions in monetary policy actions can be observed as errors or evidence of political consistency; and v) small and persistent changes in the short-term interest rate allow monetary policy to affect aggregate demand without the imposing volatility of the policy instrument. For further clarification on the interest rate smoothing term, see Clarida, Galı and Gertler (1998), Woodford (1999), Sack and Wieland (2000) and Woodford (2003).

In this study, the weight on inflation relative to the output gap (α_t) is variable over time. In literature, there are several studies treating this parameter as time-varying.[8] First, this weight may change depending on the BCB's personnel; new employees may be more concerned with stabilizing the economy's inflation or guiding the policy in an effort to decrease unemployment. Second, there is a distinct degree of political pressure on the central bank, as shown by Maggio (2010) and Meltzer

[5] According to Aragón and Portugal (2009), there are two reasons to use the quadratic loss function: i) this type of function, associated with linear restrictions, results in a linear policy rule; and, ii) it allows for the inclusion of the nominal interest rate smoothing term.

[6] As shown by Rudebusch and Svensson (1999), when $\beta \longrightarrow 1$, the policymaker's optimization problem and the intertemporal loss function can be interpreted as an unconditional mean of the loss function at time t, given by $E[L_t] = \alpha[\pi_t - \pi^*] + \lambda_y var[y_t] - \nu[i_t - i_(t-1)]$.

[7] See Woodford (2003).

[8] See Ireland (2007), Aragón and Medeiros (2015) e Lakdawala (2016).

(2011). Lakdawala (2016) argues that this change in political pressure can be captured over time in the weight the central bank puts on inflation relative to the output gap. The specified loss factor, with the weight of inflation on the output gap varying in time, is a simple and appropriate way to obtain central bank preferences.

3.3 Optimal policy

For each period t, the monetary authority determines the economy's interest rates. We want to observe the behavior of central bank preference parameters using a time-varying model.

The central bank minimizes the loss function (3) subject to the constraints given by the structural model (1)-(2). The derivation of the optimal policy rule is thus based on the state-space representation, denoted by (4):

$$Z_{t+1} = C + DZ_t + BX_t + \mu_{t+1} \tag{4}$$

where column vector Z_t represents the state variables, matrix D, column vector B and the column vector of disturbances, $\mu_t + 1$.

The interest rate rule is thus given by:

$$i_t = f_t + f_{1,t}\pi_t + f_{2,t}\pi_{t-1} + f_{3,t}\pi_{t-2} + f_{4,t}\pi_{t-3} + f_{5,t}y_t + f_{6,t}y_{t-1} + f_{7,t}i_{t-1} + \mu_{i,t} \tag{5}$$

where the nominal interest rate (control variable) at time t is a linear function of the state variable vector Z_t. The coefficients of line vector $f = \begin{bmatrix} f & f_1 & f_2 & f_3 & f_4 & f_5 & f_6 & f_7 \end{bmatrix}$ represent an interaction of the central bank preference parameters and the Phillips and IS curve parameters. Therefore, for each preference parameter value for inflation relative to output gap, there is an optimal rule. The coefficients of this rule, $f_{i,t}$, depend on the constant parameters of the constraints $(b_0, b_1, b_2, b_3, b_{3_A}, b_4, a_0, a_1, a_2, a_3)$, the interest rate smoothing parameter and the time-varying preference parameter. We estimate Equation (5) with a shock, $\mu_{i,t}$. This shock can be observed as a pure random component of monetary policy. Moreover, to capture the changes in monetary policy behavior, it is assumed that the parameters of the reaction function are time-varying and follow a random walk, as discussed by Cooley and Prescott (1976).

4 Estimation

Equation (5) was estimated with a shock, $\mu_{i,t}$, to eliminate the singularity problem in the estimation of the vector autoregression (VAR) parameters.[9] Equations (1), (2) e (5) podem escritas da seguinte forma:

$$A_{0,t}\hat{y}_t = A_{1,t} + A_{2,t}\hat{y}_{t-1} + A_{3,t}\hat{y}_{t-2} + A_{4,t}\hat{y}_{t-3} + A_{5,t}\hat{y}_{t-4} + L\Psi_t\mu_t \tag{6}$$

The $A_{i,t}$ matrices are functions of the time-varying preference parameter (α_t), modeled as a random walk:

$$\alpha_t = \alpha_{t-1} + z_t \tag{7}$$

where the shock, z_t $N(0, Q)$, is assumed to be independent of the shocks to the structural model. The random walk process, widely used in literature,[10] is an accessible and parsimonious way of modeling time-varying parameters, as it can detect permanent shifts in the preference parameter, simplifying the estimation relative to a general autoregressive process, as presented by Lakdawala (2016).

[9] See appendix B.

[10] Some studies used models following a random walk, including Cogley and Sargent (2001), Cogley and Sargent (2005), Boivin (2006) and Kim and Nelson (2006).

The error vector μ_t consists of three shocks: a supply shock ($\mu_{\pi,t}$), a demand shock ($\mu_{y,t}$) and a shock involving the interest rate ($\mu_{i,t}$). The model assumed the following covariance matrix:

$$Var\left(\begin{bmatrix}\mu_t \\ z_t\end{bmatrix}\right) = \begin{bmatrix} I & 0 \\ 0 & Q \end{bmatrix}$$

Some studies indicate that there is heteroskedasticity in the exogenous shocks included in macroeconomic models that involve inflation, output gap and interest rate.[11] The triangular decomposition of the variance matrix of the errors considers $\Omega_t = L\Psi_t\Psi_t L'$, where:

$$\Psi_t = \begin{bmatrix} \sigma_{\mu_{\pi,t}} & 0 & 0 \\ 0 & \sigma_{\mu_{y,t}} & 0 \\ 0 & 0 & \sigma_{\mu_{i,t}} \end{bmatrix}, L = \begin{bmatrix} 1 & 0 & 0 \\ l_{2,1} & 1 & 0 \\ l_{3,1} & l_{3,2} & 1 \end{bmatrix}$$

Since the model is characterized by the constraints, the optimal interest rate rule and the random walk process for the time-varying parameters, we can now write it in a state-space representation. We thus express the following nonlinear space system:

$$y_t = h(\alpha_t, X_t, \Gamma, \mu_t) \tag{8}$$

$$\alpha_t = \alpha_{t-1} + z_t \tag{9}$$

where $\Gamma = \left[\delta, \nu, L, \Psi_t\right]$. We estimate the following set of parameters: α_t: time-varying weight of inflation; δ: coefficients of the constraints (1), (2); ν: weight on interest rate smoothing; ψ_t: standard deviations; N: covariance terms; and Q: variance of the shock to the time-varying preference parameter.

4.1 Bayesian MCMC approach

To estimate the model's parameters as random variables, we follow Lakdawala (2016) and use Bayesian MCMC estimation. This method involves numerical sampling of the posterior distribution, which is done using the random walk Metropolis-Hastings (RWMH) algorithm.

For linear state-space models, the Kalman filter is suitable for evaluating the likelihood function. In this study, the preference parameter is nonlinear, and thus the EKF was used to linearize the observation equation at each point in time using a first-order Taylor expansion, and we then applied the techniques of the standard filter described. Based on nonlinear state-space representation of (8) and (9), the following equations show how to evaluate the likelihood using the EKF:

$$\alpha_{t|t-1} = \alpha_{t-1|t-1} \tag{10}$$

$$P_{t|t-1} = P_{t-1|t-1} + Q \tag{11}$$

$$\eta_{t|t-1} = \hat{y}_t - h(\alpha_{t|t-1}, X_t, \Gamma, 0) \tag{12}$$

$$f_{t|t-1} = H_t P_{t|t-1} H_t^{'} + M_t \Sigma_t M_t^{'} \tag{13}$$

$$\alpha_{t|t} = \alpha_{t|t-1} + K_t \eta_{t|t-1} \tag{14}$$

$$P_{t|t} = P_{t|t-1} - K_t H_t P_{t|t-1} \tag{15}$$

[11] For example, see Sims and Zha (2006).

where

$$H_t = \frac{\partial h()}{\partial \alpha}\bigg|_{\alpha_{t|t-1}} \tag{16}$$

$$M_t = \frac{\partial ()}{\partial \varepsilon}\bigg|_{\varepsilon_{t|t-1}} \tag{17}$$

$$K_t = P_{t|t-1} H_t' f_{t|t-1}^{-1} \tag{18}$$

With the filtered values available, the likelihood is evaluated using the error decomposition method.

$$llf = -\frac{Tn}{2}\log(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\log(|f_{t|t-1}|) - \frac{1}{2}\sum_{t=1}^{T}\eta_{t|t-1}' f_{t|t-1}^{-1}\eta_{t|t-1} \tag{19}$$

The likelihood is combined with the prior to obtain the posterior. We followed a two-step procedure. First, we numerically maximized the log of the posterior probability distribution to obtain a posterior estimate. Second, using the previously calculated posterior mode as a starting value, we used the Metropolis-Hastings algorithm to characterize the posterior distribution.

Let θ be the parameter vector to be estimated. The Metropolis-Hastings algorithm generates a draw from a candidate generating density, $q(.)$. Let this candidate draw be known as θ^{g+1}. This new draw is thus accepted with the following probability:

$$\alpha(\theta^{(g+1)}, \theta^{(g)}) = min\left(\frac{p(\theta^{(g+1)}|Y).q(\theta^{(g)})}{p(\theta^{(g)}|Y).q(\theta^{(g+1)})}, 1\right) \tag{20}$$

We used the inverse of the Hessian of the posterior method as a candidate-generating density that is centered around the current draw $\theta^{(g)}$, which is:

$$\theta^{(g+1)} = \theta^{(g)} + c\tilde{H}^{-1} \tag{21}$$

where c is a scale factor and $\hat{H}$ is the Hessian of the posterior mode. The RWMH algorithm was run for 400,000 draws, of which 200,000 were discarded, to ensure independence in the initial stages. The mean acceptance rate of the chain was 32%.[12] MATLAB R2015a software was used for estimation, and the code is available upon request.

4.2 Data

The estimation of the BCB's loss function with a time-varying preference parameter was based on quarterly data; the full sample covers 2000: Q1 to 2017: Q4. This period of analysis was chosen considering that, between 1994 and 1999, there were two important milestones in the Brazilian economy: the implementation of the Plano Real and the change to the exchange rate regime (from a fixed to a floating exchange rate). Furthermore, the period chosen covers only one monetary policy regime—the inflation targeting regime.[13]

We decided to use a quarterly frequency for two reasons: (i) quarterly data are less susceptible to noise and measurement errors; and (ii) to decrease monetary policy lag, in case the policy affects two or three periods after the policy is implemented. The dataset used includes the macroeconomic variables—inflation rate (π), Selic interest rate (i) and output gap (y) - obtained from the Brazilian Institute of Geography ans Statistics (*Instituto Brasileiro de Geografia e Estatística - IBGE*) and the BCB.

[12] This number of draws is sufficient to ensure convergence, as established by Raftery and Lewis (1992).

[13] This fact diminishes the importance of the critique by Lucas (1976).

Table 1 – Summary of the variables used

Variable	Unit	Symbol	Source
Inflation	Rate	π	IBGE
Interest	Rate	i	BCB
Output gap	Rate	y	BCB/HP Filter

Source: Prepared by the authors.

The variable π refers to the cumulative inflation for the last 12 months, measured by the IPCA and used as an inflation target (π^*) by the BCB. The output gap (y) is obtained from the percentage difference between the seasonally adjusted quarterly real GDP and its trend (proxy for the potential output), measured by the Hodrick-Prescott (HP) filter[14], and the Selic interest rate (i) is annualized (quarterly mean).[15]

5 Results

5.1 Estimation of parameters

We used data from 2000: Q1 to 2003: Q4 as a pre-sample to obtain the priors. For this initial sample, we estimated a seemingly unrelated regression (SUR). The priors for the coefficients of the constraints, δ, are assumed with normal distribution with a prior mean equal to the SUR estimate for the pre-sample and high variance to ensure that it has noninformative value. The prior for the interest rate smoothing weight, ν, has uniform distribution with a positive real value. The variances, $\sigma_{i,t}$, are assumed to be inverse gamma, with a shape and scale defined by 2 and 1, respectively. Finally, the variance of the time-varying parameter, Q, is defined by uniform distribution with a positive real number. Table 2 shows a summary of the priors.

Table 2 – Prior distribution of parameters

Parameter	Definition	Distribution
δ	Coefficients of the constraints	Normal ($\delta_{SUR}, 10.V_{\delta,SUR}$)
σ	Standard deviation of the parameters	Inverse gamma (2,1)
N	Covariance matrix	Normal (0,10)
Q	Variance of the time-varying parameter	Uniform (0,∞)
ν	Interest rate smoothing weight	Uniform (0,∞)

Source: Prepared by the authors.

To estimate the RWMH algorithm, it was first necessary to calibrate the discount factor (β) and inflation target (π^*) parameters. Following Castro et al. (2011), we established that β is equal to 0.989 and π^* is 4.5%, as Brazil's inflation target has been at that level since 2005.

The values of the estimated parameters are shown in Table 3. These values were obtained along with the 5th and 95th percentiles of the posterior distribution. The standard error for each parameter was also calculated. The results were compared with those in the literature.

As shown in Table 3, a_i and b_i are parameters of constraints; $\sigma_{i,t}$ and l_i refer to the standard deviations and the covariance terms of the variance matrix; ν is the interest rate smoothing weight of the loss function; and Q is the variance of the shocks in the equation governing the weight of the time-varying parameter.

In general, the parameter estimates have the expected signs. For the Phillips curve, the exception was b_2, which had a negative sign. The parameter that measures the impact of the output gap on the inflation rate presented a lower value compared to the result found by Aragón and Portugal

[14] To calculate the output gap, $\lambda = 1600$ was used, as suggested by Hodrick and Prescott (1997).
[15] The trajectory of the variables used is presented in appendix C.

(2009) and was also not statistically significant. These authors estimated a structural macroeconomic model for a small open economy, without considering a constant variable in the estimation of the IS and Phillips curves.

With regard to the IS curve, as expected, the coefficient for the real interest rate's effect on the output gap had a negative sign. In this case, a 1% increase in the real interest rate estimate suggests a decrease of 0.04% in the annualized inflation, but the parameter does not present a value statistically different from zero. Aragón and Portugal (2009) found that a 1% increase in the real interest rate caused a fall of 0.09% in the annualized inflation.

Table 3 – Estimation of the constant parameters

Parameter	**Posterior mean**	**95%IC**	**Standard error**
IS curve			
a_0	0.2979	[-1.5083;2.1780]	1.1554
a_1	0.9125	[0.4288;1.3662]	0.2836
a_2	-0.3866	[-0.6368;-0.1691]	0.0149
a_3	-0.0383	[-0.2019;0.1193]	0.0992
Phillips curve			
b_0	4.8536	[-2.3265;13.4183]	4.5276
b_1	0.5447	[0.0534;1.5512]	0.6321
b_2	-0.5573	[-1.8358;0.5056]	0.6981
b_3	0.3139	[0.1147;0.7823]	0.2671
b_4	0.5791	[-4.8990;4.5903]	2.8113
Standard deviation			
$\sigma_{\mu_{\pi,t}}$	0.6353	[0.2010;1.5380]	0.4414
$\sigma_{\mu_{y,t}}$	0.6400	[0.1997;1.5634]	0.4461
$\sigma_{\mu_{i,t}}$	0.6421	[0.2023;1.5138]	0.4126
Covariance			
$\mathrm{l}_{2,1}$	-0.1604	[-3.4047;3.5911]	2.1639
$\mathrm{l}_{3,1}$	-0.4333	[-5.8359;6.0909]	3.5211
$\mathrm{l}_{3,2}$	-0.5145	[-5.3067;3.5023]	2.5546
Interest rate smoothing			
ν	33.5525	[3.4985;67.9780]	21.3188
Variance of the state equation			
Q	20.4383	[1.5329;31.9229]	10.1345

Source: Prepared by the authors.

As shown in Table 3, the interest rate smoothing parameter has a high value statistically different from zero. For Brazil, the value of the interest rate smoothing found by Palma and Portugal (2011) was 20.005. In the international literature, this parameter has a value above 30.[16] There is still discussion about the true source of smoothing observed in the policy parameter.

The sign of the parameter a_0 is different from the studies in the international literature. The coefficient a_2 in this study has a negative value, unlike the results found in Rudebusch and Svensson (1999) and Dennis (2006). The signs of the other terms are similar. With regard to the IS curve, the parameters were similar, although the constant parameter (b_0) for this paper was negative (although not significant), relative to the studies in the general literature.

5.2 Optimal policy rule

To evaluate the optimal policy rule over time, the posterior mean of the IS and Phillips curve parameters, the interest rate smoothing term and the estimation of the varying parameter in each

[16] See Dennis (2006), Primiceri (2006) e Lakdawala (2016).

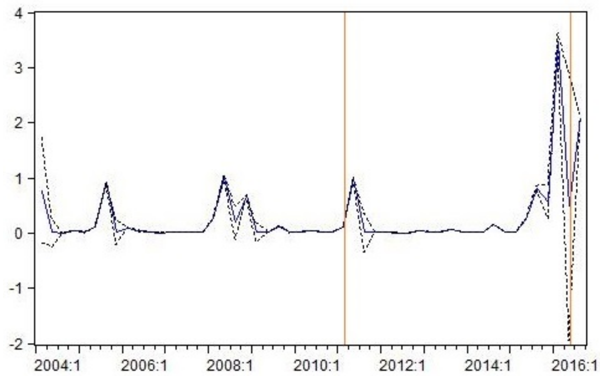
time period were considered.

The solid blue line in Figure 2 represents the estimate of the smoothed value of the variable preference parameter using the posterior mean of the constant parameters (described in Table 3). The dashed black line indicates the confidence interval for plus or minus one standard deviation. These confidence bands consider the uncertainty of the Kalman filter and the uncertainty of the parameter.

As Figure 2 suggests, during the term of Henrique de Campos Meirelles (2004-2011), there were small shifts in the weight given to inflation. With the appointment of Antonio Alexandre Tombini, there was a drop in the weight and some fluctuations during his term. At the beginning of Ilan Goldfajn's term, there seems to have been greater concern with controlling inflation, as we noticed a rising weight attributed to the parameter, flexible in time. We observed that after the 2008 international crisis, there was a downward trend in the weight of inflation.

Previous studies for Brazil estimated the central bank's loss function considering constant parameters. For the inflation preference parameter, Aragón and Portugal (2009) found a value of 0.73, Palma and Portugal (2011) arrived at 0.83 and Palma and Portugal (2014) obtained 0.42. The first two studies estimated the preferences using maximum likelihood, and the latter used Bayesian methods for a dynamic stochastic general equilibrium (DSGE) model.

Figure 2 – Time-varying preference parameter



Source: Prepared by the authors using BCB data.

[2] Note: The solid vertical line indicates the end of the BCB president's term.

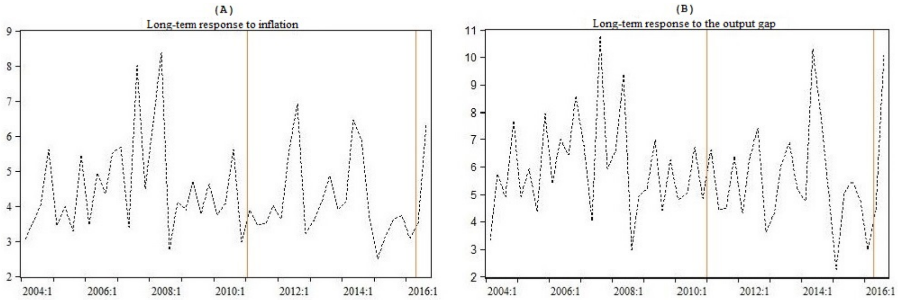
To evaluate the optimal policy rule, we consider the long-term responses to inflation and the output gap represented by equations (22) and (23):

$$\phi_{1,t} \equiv \frac{f_{1,t} + f_{2,t} + f_{3,t} + f_{4,t}}{1 - f_{7,t}} \tag{22}$$

$$\phi_{2,t} \equiv \frac{f_{5,t} + f_{6,t}}{1 - f_{7,t}} \tag{23}$$

Panel (A) in Figure 3 indicates that the long-term response to inflation has a mean value of 4.39 for the full sample and was greater during Henrique Meirelles's term when compared to the period when Alexandre Tombini was the BCB's president. We note a positive trend in the long-term response to inflation during the early years of Henrique Meirelles's term and a sharp drop following the 2008 international crisis.

Figure 3 – Optimal interest rate evaluated using the posterior mean of the estimated parameters



Source: Prepared by the authors using BCB data.

[3] Note: Panel (A) shows the long-term response to inflation given by (22) and panel (B) shows the long-term response to the output gap given by (23).
[4] Note: The solid vertical line indicates the end of the BCB president's term.

Panel (B) in Figure 3 shows the interest rate's response to changes in the output gap over time. We observed that after the international crisis and the start of Alexander Tombini's term, there was a downward trend in the interest rate's response to the output gap. The mean value of our estimates suggests that the BCB was more concerned with guiding the interest rate in response to the output gap during Henrique Meirelles's term when compared to the term of his successor. Aragón and Medeiros (2015) found that the Brazilian monetary authorities were more concerned with controlling the interest rate in response to the output gap following the 2008 international crisis compared to the pre-crisis period. These authors estimated the BCB's reaction function considering forward-looking expectations with time-varying parameters for the period 2002-2011.

Table 4 shows the optimal rules for different BCB presidents based on the mean of the time-varying parameter. We observed that, on average, the parameter that measures the weight of inflation preference relative to the output gap was greater during Alexandre Tombini's term. The estimated optimal rule for Henrique Meirelles shows that a 1% increase in inflation raises the interest rate by 1.25%, while a 1% increase in the output gap raises the interest rate by approximately 4.1295%. The coefficient that measures the inertia of the interest rate presented a value of 0.5065, i.e., a 1% increase in the interest rate of the previous period causes an increase of 0.51% in the interest rate of the current period.

Table 4 – Optimal monetary rule for different BCB presidents

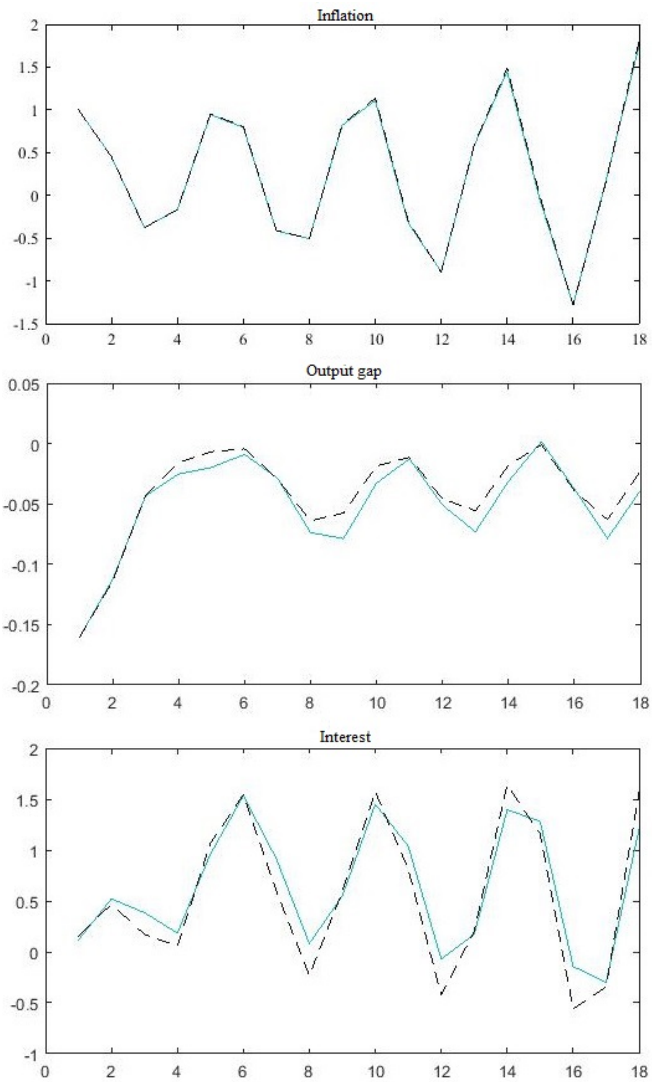
	Henrique Meirelles	Alexandre Tombini
α_t	0.1578	0.3207
ν	33.5525	33.5525
Short-term optimal monetary rule		
$\mathrm{i}_t = f_t + f_{1,t}\pi_t + f_{2,t}\pi_{t-1} + f_{3,t}\pi_{t-2} + f_{4,t}\pi_{t-3} + f_{5,t}y_t + f_{6,t}y_{t-1} + f_{7,t}i_{t-1}$		
f_t	4.7160	5.2252
$\mathrm{f}_{1,t}$	1.2500	1.1265
$\mathrm{f}_{2,t}$	0.0981	0.1526
$\mathrm{f}_{3,t}$	0.3968	0.4413
$\mathrm{f}_{4,t}$	0.0510	0.0343
$\mathrm{f}_{5,t}$	4.1295	3.5953
$\mathrm{f}_{6,t}$	-1.2408	-1.1982
$\mathrm{f}_{7,t}$	0.5065	0.6161
Long-term optimal monetary rule		
$\mathrm{i}_t = \phi_{1,t}\pi + \phi_{2,t}y$		
$\phi_{1,t}$	4.5701	3.6391
$\phi_{2,t}$	6.2434	5.8535

Source: Prepared by the authors.

The estimated coefficients of the optimal rule for Alexandre Tombini show that a 1% increase in inflation raises the interest rate by 1.13%; in turn, a 1% increase in the output gap raises the interest rate by 3.60%. Similar to the case of Henrique Meirelles, the coefficient that measures the autoregressive process of the interest rate presented a high value (1.25), indicating the Brazilian monetary authority's concern with smoothing the Selic rate. In both cases of optimal rule, the monetary authority responds to the lagged values of the inflation rate and the output gap, although this response is weaker when compared to period t.

In addition to the short-term coefficients f described in the optimal rule, the state variables also have secondary effects on the interest rate due to their lagged values and the inertial term of the interest rate i_{t-1}. We evaluated these effects in Table 4, and they are described by the coefficients $\phi_{1,t}$ and $\phi_{2,t}$. As established by the long-term rule, during Henrique Meirelles's term, a sustained 1% increase in inflation enables an increase in the Selic rate of 4.57%, while a 1% increase in the output gap raises the Selic rate by approximately 6.24%. For Alexandre Tombini, the coefficients that measure the long-term responses to inflation and the output gap were 3.63 and 5.85, respectively. The interest rate's response to inflation was thus more than proportional, corroborating the Taylor rule. Estimating the BCB's loss function with constant parameters, Aragón and Portugal (2009) found that during the period 1999-2007, there was also a more than proportional increase in the interest rate in response to inflation.

Figure 4 – Impulse responses to a unitary shock on inflation



Source: Prepared by the authors.

[5] Note: The solid line shows the responses using the estimated preferences in Henrique Meirelles's term, while the dashed line refers to Alexandre Tombini's term.

Figure 4 considers the mean varying preference parameter for each BCB president.[17] Our results indicate similarity in the responses for both presidents, although the mean of the preference parameter that measures the weight of inflation relative to the output gap was higher during Alexandre Tombini's term.

6 Conclusions

In recent years, numerous empirical studies have evaluated the central bank's actions using monetary policy estimation. This procedure is limited, given that optimal policy rules are restricted to equations whose coefficients are convolutions of policymakers' preferences and economic behavioral patterns.

We assume that the monetary authority solves an intertemporal optimization problem restricted to a simple macroeconomic model with backward-looking expectations. This study thus evaluated the behavior of the BCB's preferences by considering the time-varying inflation preference parameter relative to the output gap. Our results suggest the following: (i) there was some instability in the varying parameter, with fluctuations following the appointment of a new BCB president and during the 2008 international crisis; (ii) the Brazilian monetary authority was concerned with interest rate smoothing; (iii) the long-term responses to inflation and the output gap were greater during Henrique Meirelles's term compared to his successor; and (iv) the responses of both presidents to a unitary shock in inflation were similar.

There are countless studies in literature seeking to understand changes in central bank preferences. We can categorize the changes into two areas: changes that are policy errors and changes as a consequence of policy preferences. Although the literature focuses on the first line of thought, the primary motivation of this study is that insufficient attention is given to changes in central bank behavior. The results motivate future studies that consider time-varying preferences for a small open economy.

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[17] Given the brevity of Ilan Goldfajn's term, his respective responses to a unitary shock on inflation were not presented. This result is available upon request.

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APPENDIX A – Derivation of the theoretical model and the optimal rule

Putting constraints (1) and (2) in a state-space representation, where Z_t is the state vector and X_t is control variable, we have:

$$Z_{t+1} = C + DZ_t + BX_t + \mu_{t+1} \tag{24}$$

Let:
$Z_t \equiv \begin{bmatrix}\pi_t & \pi_{t-1} & \pi_{t-2} & \pi_{t-3} & y_t & y_{t-1} & i_{t-1}\end{bmatrix}'$, $X_t \equiv \begin{bmatrix}i_t\end{bmatrix}'$ e
$\mu_{t+1} \equiv \begin{bmatrix}\mu_{\pi,t+1} & \mu_{y,t+1}\end{bmatrix}'$.

We can, thus, write system (1)-(2) as follows:

$$Z_{t+1}=\begin{bmatrix}\pi_{t+1}\\ \pi_t\\ \pi_{t-1}\\ \pi_{t-2}\\ y_{t+1}\\ y_t\\ i_t\end{bmatrix}=\begin{bmatrix}b_0\\0\\0\\0\\a_0\\0\\0\end{bmatrix}+\begin{bmatrix}b_1 & b_2 & b_3 & b_{3_A} & b_4 & 0 & 0\\ 1 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0 & 0\\ -a_3 & 0 & 0 & 0 & a_1 & a_2 & 0\\ 0 & 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}\pi_t\\ \pi_{t-1}\\ \pi_{t-2}\\ \pi_{t-3}\\ y_t\\ y_{t-1}\\ i_{t-1}\end{bmatrix}+\begin{bmatrix}0\\0\\0\\0\\a_3\\0\\0\end{bmatrix}i_t+\begin{bmatrix}\mu_{\pi,t+1}\\0\\0\\0\\ \mu_{y,t+1}\\0\\0\end{bmatrix}$$

Let:
$P = \begin{bmatrix}0,25 & 0,25 & 0,25 & 0,25 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$ e $R_t = \begin{bmatrix}\alpha_t & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & \nu\end{bmatrix}$. We, thus, have:

$$W_t = P'RP = \begin{bmatrix}0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0 & 0 & 0\\ 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0 & 0 & 0\\ 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0 & 0 & 0\\ 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0 & 0 & 0\\ 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0,25^2\alpha_t & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & \nu\end{bmatrix}$$

Let:
$\bar{Z} = \begin{bmatrix}\bar{\pi} & \bar{\pi} & \bar{\pi} & \bar{\pi} & \bar{y} & \bar{y} & \bar{i}\end{bmatrix}'$. Thus,
$(Z_t - \bar{Z})' = \begin{bmatrix}\pi_t - \bar{\pi} & \pi_{t-1} - \bar{\pi} & \pi_{t-2} - \bar{\pi} & \pi_{t-3} - \bar{\pi} & y_t - \bar{y} & y_{t-1} - \bar{y} & i_{t-1} - \bar{i}\end{bmatrix}$
e $(Z_t - \bar{Z})'W(Z_t - \bar{Z})$.

Let $N = \nu$. Thus:

$$(X_t - \bar{X})'N(X_t - \bar{X}) = (i_t - \bar{i})\nu(i_t - \bar{i}) = \nu(i_t - \bar{i})^2 \tag{25}$$

Let $H' = G = \begin{bmatrix}0 & 0 & 0 & 0 & 0 & 0 & -\frac{\nu}{2}\end{bmatrix}$. Thus:

$$2(Z_t - \bar{Z})'H(X_t - \bar{X}) = -\nu(i_t - \bar{i})(i_{t-1} - \bar{i}) = 2(x_t - \bar{x})'G(Z_t - \bar{Z}) \tag{26}$$

Therefore, the central bank's loss function is defined as follows:

$$L_t = \alpha(\pi_a - \bar{\pi})^2 + (y_t - \bar{y})^2 + \nu(i_{t-1} - \bar{i})^2 + \nu(i_t - \bar{i})^2 - \nu(i_t - \bar{i})(i_{t-1} - \bar{i}) - \nu(i_t - \bar{i})(i_{t-1} - \bar{i}) \tag{27}$$

$$L_t = \alpha(\pi_a - \bar{\pi})^2 + (y_t - \bar{y})^2 + \nu(i_t - i_{t-1})^2 \tag{28}$$

With

$\pi_t = \pi_{t-1} = \pi_{t-2} = \pi_{t-3} = \bar{\pi}, y_t = y_{t-1} = \bar{y}, i_t = i_{t-1} = \bar{i}$ e $\mu_{\pi,t} = \mu_{y,t}$

We have:

$$\pi_t = b_0 + b_1\pi_{t-1} + b_2\pi_{t-2} + b_3\pi_{t-3} + b_{3_A}\pi_{t-4} + b_4 y_{t-1} + \mu_{\pi,t} \tag{29}$$

$$\bar{\pi} = b_0 + b_1\bar{\pi} + b_2\bar{\pi} + b_3\bar{\pi} + b_4\bar{y} => (1 - b_1 - b_2 - b_3)\bar{\pi} = b_0 + b_4\bar{y} \tag{30}$$

$$b_4\bar{y} = -b_0 + (1 - b_1 - b_2 - b_3)\bar{\pi} => \bar{y} = -\frac{b_0}{b_4} + \frac{b_{3_A}}{b_4}\bar{\pi}$$

$$y_t = a_0 + a_1 y_{t-1} \tag{31}$$

APPENDIX B – VAR derivation for Bayesian estimation

The system formatted by Equations (1), (2) and (5) can be represented in matrix form, as follows:

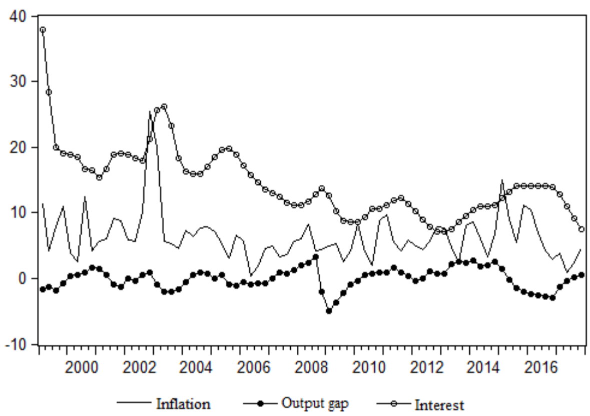
$$A_{0,t}\hat{y}_t = A_{1,t} + A_{2,t}\hat{y}_{t-1} + A_{3,t}\hat{y}_{t-2} + A_{4,t}\hat{y}_{t-3} + A_{5,t}\hat{y}_{t-4} + N\Psi_t\mu_t \tag{32}$$

where

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -f_{1,t} & -f_{5,t} & 1 \end{bmatrix} \begin{bmatrix} \pi_t \\ y_t \\ i_t \end{bmatrix} = \begin{bmatrix} b_0 \\ a_0 \\ f_t \end{bmatrix} + \begin{bmatrix} b_1 & b_4 & 0 \\ -a_3 & a_1 & a_3 \\ f_{2,t} & f_{6,t} & f_{7,t} \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ y_{t-1} \\ i_{t-1} \end{bmatrix} + \begin{bmatrix} b_2 & 0 & 0 \\ 0 & a_2 & 0 \\ f_{3,t} & 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} \pi_{t-2} \\ y_{t-2} \\ i_{t-2} \end{bmatrix} + \begin{bmatrix} b_3 & 0 & 0 \\ 0 & 0 & 0 \\ f_{4,t} & 0 & 0 \end{bmatrix} \begin{bmatrix} \pi_{t-3} \\ y_{t-3} \\ i_{t-3} \end{bmatrix} + \begin{bmatrix} b_{3_A} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \pi_{t-4} \\ y_{t-4} \\ i_{t-4} \end{bmatrix}$$

APPENDIX C – Trajetory of the variables used



Source: Prepared by the authors.