FUNDAÇÃO GETULIO VARGAS
ESCOLA DE ECONOMIA DE SÃO PAULO

FILIPE GROPELLI CARVALHO

THE CENTRAL BANK OF BRAZIL'S TIME-VARYING TAYLOR RULE

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Dissertação apresentada à Escola de Economia de São Paulo da Fundação Getulio Vargas, como requisito para obtenção do título de Mestre em Economia.

Campo de Conhecimento: Finanças

Orientador: Prof. Dr. Marcelo Kfoury Muinhos

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ABSTRACT

The monetary policy preferences of emerging market central banks have over the decades been subject of immense scrutiny, particularly allegations of dissociating from orthodox monetary policy, and lacking credibility given inadequate institutional frameworks and independence in decisionmaking. This study estimates the Central Bank of Brazil's (BCB) monetary policy preferences over time by estimating a forward-looking Taylor-type rule through a state-space model with time varying parameters. The study focuses on estimating two key parameters over time: first, the Taylor rule's inflation parameter's behavior over time; and second, the Taylor rule inflation target over time, the BCB's "implicit inflation target". The main findings of this study are, first, the BCB has over time taken a largely hawkish approach to inflation, over the 2003-2020 sample period, though since 2011 the BCB has taken a more dovish monetary policy preference. Second, since 2003, the BCB's implicit inflation target has largely stayed within the bands set by the National Monetary Council, though the implicit targets were until 2011 below the center of the official target but have since stayed between the center and the upper band.

Keywords: Taylor Rule, Monetary Policy, Inflation Targeting, Kalman Filter

RESUMO

As preferências de política monetária de bancos centrais em mercados emergentes têm sido, ao longo das décadas, objeto de grande escrutínio, particularmente por alegações de dissociação da política monetária ortodoxa e de falta de credibilidade devido a estruturas institucionais inadequadas e falta de independência na tomada de decisões. Este estudo estima as preferências de política monetária do Banco Central do Brasil ao longo do tempo, estimando uma regra do tipo Taylor *forwrd-looking* por meio de um modelo de espaço estado com parâmetros variando no tempo. O estudo busca estimar dois parâmetros e suas mudanças no período entre 2003 e 2020: primeiro, o comportamento do parâmetro de inflação da regra de Taylor; e segundo, a meta de inflação da regra de Taylor, a chamada "meta de inflação implícita" do banco central. As principais conclusões deste estudo são, em primeiro lugar, que o Banco Central do Brasil, adotou uma abordagem *hawkish* para a inflação, em grande parte do período da amostra, embora desde 2011 tenha assumido uma preferência de política monetária mais *dovish*. Em segundo lugar, desde 2003, a meta implícita de inflação do banco central permaneceu em grande parte dentro das bandas definidas pelo Conselho Monetário Nacional, embora as metas implícitas estivessem até 2011 abaixo do centro da meta oficial, mas desde então permaneceram entre o centro e a banda superior.

Palavras-chave: Regra de Taylor, Política Monetária, Metas de Inflação, Filtro de Kalman

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1. INTRODUCTION

Since 1999, the Central Bank of Brazil (BCB) has followed an explicit inflation-targeting (IT) mandate which, along with other economic reforms like the Real Plan in 1994, has contributed to a fall in inflation. Under this framework, the National Monetary Council (CMN) sets the annual inflation target. Since the start of the IT regime, the BCB has missed its target, and tolerance bands, five times: 2001, 2002, 2003, 2015, and 2017, requiring the respective BCB governors to draft an open letter, as mandated by presidential decree, to the finance minister.

This institutional characteristic of the BCB, among others, such as its newly-implemented *de jure* autonomy, have spared it from heavier criticism, namely that of political intervention, especially when compared with other emerging market central banks, but that is not to say the BCB has not been prone to scrutiny in its monetary policy preferences, especially given the abovementioned occurrences when it has missed its mandated inflation target.

This study estimates the BCB's monetary policy preferences over time by modeling a forward-looking Taylor-type rule through a state-space model with time varying parameters. The study focuses on estimating two key parameters: a) the Taylor rule's inflation parameter's behavior over time, and b) the Taylor rule inflation target over time, referred to as the "implicit inflation target". The purpose of the study is to assess the changes in the BCB's approach to inflation over the sample period and assess how the derived implicit inflation target has deviated from the official target. The latter point is critical, as though it is easy to compare annual inflation to the official target, the estimation of an implicit inflation target through a Taylor rule provides another tool to analyze a central bank's preference and performance vis-à-vis its target. Furthermore, the use of time-varying parameters has been an increasingly used method to address the Lucas critique of policy variation over time.

This study largely follows research by Aragon and Medeiros (2015) who estimate a forward-looking Taylor rule for the BCB with time-varying parameters, though unlike Aragon and Medeiros, our estimation keeps most parameters constant in time, with three different approaches to allowing the inflation parameter to vary. This study also updates the sample period studied by Aragon and Medeiros. Furthermore, a second paper this study follows is that of Leigh (2008) who estimated the implicit inflation target for the US Federal Reserve, and a subsequent study done by Klein (2012), who followed Leigh's approach to estimate the implicit inflation target for the South African Reserve Bank. Yet, different from Leigh and Klein, we

adjust for endogenous regressors, in line with Kim and Nelson (2004), as done by Aragon and Medeiros.

The main findings of this study are: 1) the BCB has over time taken a largely hawkish approach to inflation, following the Taylor principle over the 2003-2020 sample period, though with a fall in the inflation parameter starting in 2011 – during what became known as a policy "U-turn" by the BCB, then under the governorship of Alexandre Tombini, where the BCB's monetary policy preferences were below the Taylor principle coefficient, recovering somewhat since, but not to the levels seen pre-2011; and 2) since the IT framework was adopted, the BCB's implicit inflation target has largely stayed within the bands set by the CMN, though the implicit targets were, until 2011, below the center of the official target but have since stayed between the center and the upper-band. The two conclusions are complementary and show a much more stimulative attitude by the BCB since 2011.

Section 2 will provide a literature review, starting with works on central bank credibility, monetary policy preferences and the use of time-varying parameters in Taylor-type rules. Section 3 presents the underlying methodology used to estimate the time-varying parameters. Section 4 presents the data used and unit root tests. Section 5 provides the estimation results, and section 6 provides concluding remarks on the study.

2. LITERATURE REVIEW

The literature around monetary rules and monetary policy credibility and preferences is knowingly quite extensive, having largely followed the Taylor (1993) specification for a monetary rule, with a variety of econometric models and derivations around the original specification, applied to a variety of country-level idiosyncrasies.

There have been a variety of studies and methods to estimate central bank preferences. Dennis (2006) seeks to model and explain US macroeconomic outcomes subject to the assumption monetary policy is set optimally, estimating the parameters in the US Federal Reserve's (Fed) policy function, and finding its implicit inflation target under Paul Volcker to have been 1.4%. Ilbas (2010) also estimates the Fed's monetary policy preferences assuming optimal monetary policy, though using Bayesian methods, finding that there was a switch in the monetary policy regime since Volcker, with a focus on output growth instead of the output gap level as a target variable. Givens (2012) also estimates monetary preferences for the Fed under optimality in the Volcker-Greenspan-Bernanke period under commitment and discretion. Estimates of the

loss function weights point to an excessive concern for interest rate smoothing in the commitment model but a more balanced concern relative to inflation and output stability in the discretionary model. Arestis et. al. (2016) estimate the monetary policy preferences for the European Monetary Union and for the UK, extending a Markov Switching VAR framework first suggested by Cecchetti et. al. (2002), concluding the weight policymakers place on inflation gaps to target in Europe and the UK tends to be significant, and that volatility in economic disturbances is the main factor in changing policy preferences.

Studies on the credibility of central bank monetary policy dating back to the 1980s with Sargent (1981) researching money supply and disinflationary credibility under Raymond Poincaré in France and Margaret Thatcher in the UK. Blanchard (1984) studies the Fed’s change from an inflation target to a money supply target, looking at changes in the yield curve, whereas Perry (1984) does the same, but looking at inflationary expectations instead of the yield curve. Cukierman and Meltzer (1986) develop a theory of credibility, ambiguity, and inflation under discretion assuming asymmetric information, concluding that policymakers do not always choose the most effective available option for monetary policy, generating positive surprises when they care for economic stimulus, leaving “inevitable” economic surprises for periods when inflation prevention is necessary. Blinder (2000) surveyed economic actors and central bankers to understand what variables make a central bank more credible, concluding that independence, transparency, and a history of fighting inflation, are the most important factors. Finally, Faust and Svenson (1998) study central bank credibility in a model where it is an unobservable variable, defining high-credibility central banks as those that conduct a less-inflationary monetary policy than low-credibility central banks.

The literature around monetary policy preferences and credibility in Brazil is much more recent but has rapidly become more expansive since the adoption of the IT framework. Minella et. al. (2002) conducted the first review of Brazil’s IT framework once it had been in place for three years, concluding the BCB reacted strongly to anchor inflation expectations by estimating a variety of Taylor rule specifications. Figueredo and Ferreira (2002) estimated a Taylor rule for the BCB between 1999 and 2002 to study free and administered prices in Brazil. Muinhos (2004) expanded estimations of the BCB Taylor rule by adding an exchange rate term to consider the IT model’s response to external shocks, as well as study pass-through considerations on inflation. Mendonça (2004) creates a credibility index for Brazil based on Cecchetti and Krause, concluding that the IT framework for Brazil can be detrimental to the

BCB's credibility, not because of the framework itself, but because of the BCB's early attempts at rapidly decreasing inflation through its explicitly defined targets, which could have larger negative macroeconomic consequences.

The literature around time-varying parameter (TVP) estimations of monetary rules has also been growing over the past years. Yuksel et. al. (2012) attribute three key factors to the growth of TVP specifications of monetary policy rules: first, the fact monetary policy rules are based on policymakers' views towards the economy, as well as the presence of contradicting monetary policy objectives which lead parameters in interest rate rules to vary over time, as noted by Favero and Rovelli (2003), Ozlale (2003) and Valente (2003); second, the widening of the central bank's information set over time, meaning they no longer rely solely on a monetary policy rule, but instead on a variety of models in which the inflation and output gaps have different coefficients, and therefore point to different optimal interest rate decisions, translating to nonlinearities in the reaction function. And third, coefficients in a monetary policy rule can be unstable given changes in the monetary policy transmission mechanism over time, addressing Lucas (1976) critique.

Cogley and Sargent (2003) analyzed policy changes since World War II in the United States through a TVP Kalman filter, concluding there were in fact significant policy changes over time. Kuzin (2006) does the same for Germany, though in a backward-looking model, also concluding policy parameters were not consistent over time. Horwath (2006) estimated a Taylor rule with TVPs for the case of the Czech Republic.[1]

The literature surrounding TVP inflation targets is more limited, with Leigh (2005) estimating the Fed's inflation target in a forward-looking Taylor rule with time-varying natural interest rates derived using the Laubach and Williams (2003) method. Leigh's estimation shows significant drops in the Fed's implicit inflation target in the early 1980s and early 1990s. Similarly, Klein (2012) estimates the implicit inflation target for the South African Reserve Bank for the period of 2001 to 2011, concluding it tends to hover on the upper part of the bank's inflation target range, sometimes going above the upper band of the range.

The literature around monetary policy rules in Brazil is still somewhat limited though growing. Freitas et. al. (2017) estimate the credibility of the BCB's monetary policy from 2006 to 2017

[1] For a comprehensive literature review of the use of TVP in monetary policy rules, please see Yuksel et. al. (2012).

using a Kalman filter approach on breakeven inflation data and on the BCB's Focus survey of inflation expectations, finding a decline in credibility after the 2008 financial crisis and at the end of 2015. Policano (2006) was perhaps the first to estimate a monetary rule with TVP for Brazil, using data from 1995 to 2006. His study opted for a monetary rule which included terms for both foreign exchange and international reserves. Policano's conclusions are that the parameters in the reaction function do vary over time and that Brazil's monetary policy in the period studied could be divided into two periods: 1995-1999 when interest rates reacted more strongly to output gap and international reserve changes, during the fixed exchange rate period, and 1999-2006, when, under the inflation target regime, the interest rate reacted more strongly to inflation, despite this reaction not being entirely consistent during the period.

Aragon and Medeiros (2015), which this paper was largely based on, estimate a backward-, and forward-looking Taylor rules for the BCB from 2000 to 2011, showing significant changes in the BCB's monetary policy preferences over time, concluding that since 2010, the BCB's response to the inflation gap from its target is below the Taylor principle coefficient, and therefore too dovish. Salgado, Garcia, and Medeiros (2005) estimate the BCB's reaction function using a Threshold Auto-Regressive method allowing the interest rate to follow two distinct regimes, a regime with an external economic crisis, and a regime without such crisis, concluding that at times of crisis the BCB did not only respond to gaps to the inflation target, but also responded to changes in international reserves. Lastly, Rodrigues (2015) estimated the BCB's reaction function using a Markov switching estimation for a forward-looking Taylor rule, finding that most of the time the BCB acted within a regime where it assigned more weight to staying within the inflation target, though at times certain estimated regimes pointed to a more stimulative monetary policy, such as between 2011 and 2012.

3. THE EMPIRICAL MODEL

This section will outline the essence of the empirical model used to estimate the Taylor rule with TVPs. Section 3.1 discusses the origins of the Taylor-type rule in its most basic specification. Section 3.2 presents the forward-looking Taylor rule, and section 3.3 derives the smoothing parameter for the rule. Section 3.4 discusses the estimation of the initial parameters estimated for a Taylor rule for Brazil, to find the initial parameters used in the latter TVP estimation. Section 3.5 provides a brief introduction to state-space models and the Kalman filter used in the TVP estimation. Section 3.6 outlines the Taylor rule specification used for the

case of varying inflation and output gap parameters, whereas section 3.7 outlines the specification used to estimate the implicit inflation target. Lastly, section 3.8 outlines the derivation by Kim and Nelson (2006) which is used to deal with endogeneity in the regressors in the case of forward-looking monetary policy rules.

3.1 The Taylor Rule

The Taylor rule, based on John Taylor's study of the US Federal Reserve, sets out a theoretical optimal monetary policy rule as a function of inflation gap and output gap. The rule assumes central banks respond to the two factors when setting monetary policy: when inflation goes above its target, the Taylor rule sets out a central bank must raise nominal interest rates by a larger proportion than the inflationary increase to control the rise in prices, the so-called "Taylor principle". The rule also stipulates central banks can lower nominal interest rates when output falls below potential.

The rule Taylor proposed, which he deemed representative of an optimal rule based on the research of the time assumes a known structure with known parameters:

$$r = p + 0.5y + 0.5(p - 2) + 2 \quad (1)$$

where,

r = the federal funds rate

p = the rate of inflation over the previous four quarters

y = the percent deviation of real GDP from a target.

3.2 Forward-looking Taylor rules

Though Taylor's argued his rule applied to sample data from the Fed for 1987-1992, Clarida, Gali and Gertler (1997) expanded on Taylor's original rule by adding a forward-looking specification, following the linear equation:

$$r_t^* = \bar{r} + \beta\left(E\left[\pi_{t,n}\middle|\Omega_t\right] - \pi^*\right) + \gamma(E[y_t|\Omega_t] - y_t^*) \quad (2)$$

Where r_t^* is the optimal nominal interest rate, $\bar{r}$ is the equilibrium nominal rate in the long run, $\pi_{t,n}$ represents the inflation rate between period t and $t + n$, y_t is the output at period t and y_t^* is the potential output, which they define as the "level that would arise if wages and prices were perfectly flexible". Additionally, π^* is the inflation target, whether explicitly set or implicit.

Hence, β and γ are the coefficients for the inflation and output gap from their respective targets. Lastly, the expectation operator E is added and Ω_t is the information set available to the central bank at period t. Assuming a consideration for the implied *ex ante* real interest rate, rr_t, such that:

$$rr_t \equiv r_t - E\left[\pi_{t,n} \middle| \Omega_t\right] \tag{3}$$

Rearranging the terms above in (3) into (2), the optimal real interest rate, rr_t^*, follows:

$$rr_t^* = \overline{rr} + (\beta - 1)\left(E\left[\pi_{t,n} \middle| \Omega_t\right] - \pi^*\right) + \gamma(E[y_t|\Omega_t] - y_t^*) \tag{4}$$

Where the central bank aims for a real interest rate target which is a function of the neutral real interest rate $\overline{rr}$, as well as the deviations from the inflation target and potential output. Clarida, Gali and Gertler emphasize the importance of the magnitude of β and γ, noting that if $\beta > 1$, the real interest rate targeted by the central bank serves to stabilize both inflation as well as output (given $\gamma > 0$), whereas if $\beta < 1$, the central bank's approach is more accommodative to inflation given inflationary spikes will not be met with a sufficiently large interest rate response.

The addition of a forward-looking aspect to a Taylor rule reflects the fact policymakers react to forward-looking expectations for inflation, hence the expectations term is implemented.

3.3 Interest rate smoothing

Once again following the specification set by Clarida, Gertler and Gali (1997), an interest rate smoothing parameter is added to the Taylor rule. The justification of such a term is based on broad literature, namely Goodfriend (1991) which notes central banks smooth changes in interest rates to avoid large fluctuations which could in turn bring about turmoil in financial markets or hinder the central bank's credibility. Hence, a partial adjustment term is added to the Taylor rule specification:

$$rr_t = (1 - \rho)rr_t^* + \rho rr_{t-1} + \varepsilon_t \tag{5}$$

Where $\rho \in [0,1]$, which captures the rate of smoothing in a central bank's interest rate decision and ε_t is an exogenous random shock assumed to be i.i.d.[2]

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[2] Clarida, Gali and Gertler attribute a variety of interpretations which could cause such a shock, ranging from random components to policy, or potential for imperfect forecasts.

Simplifying the output gap terms, $(E[y_t|\Omega_t] - y_t^*) = \tilde{y}_t$, and rearranging (5) into (4):

$$rr_t = (1-\rho)\left(\overline{rr} + (\beta - 1)\left(E\left[\pi_{t,n}\middle|\Omega_t\right] - \pi^*\right) + \gamma\tilde{y}_t\right) + \rho rr_{t-1} + \varepsilon_t \quad (6)$$

Where the real interest rate set by the central bank is a function of the optimal real rate as denoted in (4) and the lagged real interest rate.

3.4 Estimating initial Taylor rule parameters

Following the method used by Leigh (2008), prior to estimating a Taylor rule through a Kalman filter in the state-space representation, initial parameters for the central bank's reaction function are estimated, serving as inputs for the Kalman filter estimation. According to Rummel (2015), the benefit of such approach is that the parameters estimated by Maximum Likelihood Estimation via the Kalman filter can be initialized using these estimations, and that not doing so may lead to software estimations using an inappropriate coefficient vector, meaning it is advisable to always specify appropriate starting values.

The Taylor rule parameters are estimated using Ordinary Least Squares (OLS). It should be noted there is still ongoing debate in literature around the estimation of a forward-looking Taylor rule using OLS. Given central banks react to inflation expectations and the output gap, which are endogenous to monetary shocks, implying the error term of a Taylor rule could be correlated with the regressors. Recently, some, like Carvalho, Nechio and Tristão (2019) have argued in favor of OLS estimation for monetary policy rules given potential questions around the validity of instrumental variables estimations and unobserved economic aspects, also arguing the endogeneity bias is small. To be sure, this study also estimated the initial Taylor rule parameters through Generalized Method of Moments (GMM) with lagged endogenous variables used as instruments but given there were no major differences in the final Kalman filter estimations, the OLS approach was opted for instead.

3.5 State-space representations and the Kalman filter

As noted in the Section 2, there is extensive and increasing literature focused on studying changes in monetary policy preferences and TVP specifications of central bank decisions. In this case a state-space model will be used to estimate the time-varying parameters of a Taylor rule for the BCB.

The state-space representation of multivariate models following Koopman and Commandeur (2007) is such:

$$y_t = Z_t\alpha_t + \varepsilon_t, \qquad \varepsilon_t \sim i.i.d.N(0, H_t) \tag{7.1}$$

$$\alpha_{t+1} = T_t\alpha_t + R_t\eta_t, \qquad \eta_t \sim i.i.d.N(0, Q_t) \tag{7.2}$$

for $t = 1, \dots, n$. Where (7.1) is the measurement equation for a $p \times 1$ vector y_t of observables values of p time series at time t. The component α_t is a $m \times 1$ state vector containing unobserved state variables. The matrix Z_t, follows a $p \times m$ order linking the unobservable factors in the state vector with the observation vector. Additionally, ε_t is a $p \times 1$ vector of disturbances for p observations which are assumed to have zero means and a variance-covariance structure represented by H_t of order $p \times p$ which is unknown. The transition equation (7.2) is composed of the transition $m \times m$ matrix T_t, the state disturbance vector η_t which is $r \times 1$ and has the state disturbances with zero mean and variances and covariances in the Q_t matrix or order $r \times r$ which are unknown. Matrix R_t is an $m \times r$ selection matrix where $r < m$.

The Kalman filter, invented by Rudolf Kalman (1960) is a recursive algorithm which sequentially updates and estimates of the state mean and variances one-step ahead as new information is added. According to Rummel, the usefulness of a Kalman filter in a state-space model is due to the fact a state-space model is a general formulation of linear models, in which TVP, measurement errors and missing observations can easily be addressed. Rummel notes that once Gaussian errors are assumed, the filter can estimate a log-likelihood function of the state-space representation, allowing the model to be estimated through Maximum Likelihood Estimation.

3.6 Estimating inflation and output as time-varying parameters

Joining the Taylor rule derived in (4) and the state-space representation shown in (7.1) and (7.2), the Taylor rule with a TVP for the inflation parameter β will be:

$$rr_t = (1-\rho)\left(\overline{rr} + (\beta - 1)\left(E\left[\pi_{t,n}\middle|\Omega_t\right] - \pi^*\right) + \gamma\tilde{y}_t\right) + \rho rr_{t-1} + \varepsilon_t, \tag{8}$$

$$\varepsilon_t \sim i.i.d.N(0, \sigma^2),$$

$$\beta = \beta_{t-1} + \upsilon_t, \qquad \upsilon_t \sim i.i.d\; N(0, \sigma_t^2) \tag{8.1}$$

Where β follows a random walk process without drift. The random walk assumption for unobserved time-varying parameters is the most used specification in state-space representations, having been used by Kuzin in his estimation of the Bundesbank's inflation

parameters, by Leigh and Klein in their implicit inflation target estimations for the Fed and SARB, respectively, and by Laubach and Williams when estimating the natural real interest rate of the US.

Similarly, a second specification of the model includes the output gap γ as a time-varying parameter, alongside the time-varying β, hence:

$$rr_t = (1-\rho)\left(\overline{rr} + (\beta - 1)\left(E\left[\pi_{t,n}\middle|\Omega_t\right] - \pi^*\right) + \gamma\tilde{y}_t\right) + \rho rr_{t-1} + \varepsilon_t, \quad (9)$$

$$\varepsilon_t \sim i.i.d.N(0,\sigma^2),$$

$$\beta = \beta_{t-1} + \upsilon_{1t}, \qquad \upsilon_{1t} \sim i.i.d.N(0,\sigma_{1t}^2), \quad (9.1)$$

$$\gamma = \gamma_{t-1} + \upsilon_{2t}, \qquad \upsilon_{2t} \sim i.i.d.N(0,\sigma_{2t}^2) \quad (9.2)$$

3.7 Estimating the implicit inflation target

Following Leigh and Klein, we allow the inflation target to vary in time and as done with the inflation parameter, using a random walk specification to estimate an implicit inflation target by the BCB, and comparing how monetary policy decisions have aligned with the explicitly defined target set by the CMN.

$$r_t = (1-\rho)\left(\overline{rr} + (\beta - 1)\left(E\left[\pi_{t,n}\middle|\Omega_t\right] - \pi_t^*\right) + y\tilde{y}_t\right) + \rho r_{t-1} + \varepsilon_t, \quad (10)$$

$$\varepsilon_t \sim i.i.d.N(0,\sigma^2),$$

$$\pi^* = \pi_{t-1}^* + \upsilon_t, \upsilon_t \sim i.i.d.N(0,\sigma_t^2) \quad (10.1)$$

3.8 Adjusting for endogenous variables

Estimation of a Taylor rule with TVP using a state-space representation and a Kalman filter relies on the assumption that there is no correlation between regressors and the error term, with endogenous regressors providing for invalid inferences as noted by Kim (2004). In the case of forward-looking specifications of the Taylor rule, the expected inflation, and the output gap regressors are correlated with the error term ε_t, as noted in section 3.4, and hence the Kalman filter estimation is empirically inconsistent.

Kim (2004) and later Kim and Nelson (2006) propose a two-step Heckman-type (1976) procedure to correct biases in TVP estimations of a forward-looking Taylor rule, when endogeneity is present.

The two-step method proposed by Kim and Nelson follows a general state-space representation of a Taylor rule like the ones presented in (8), (9) and (10):

$$r_t = (1-\theta)\big(\beta_{0,t} + \beta_{1,t}\pi_{t,J} + \beta_{2,t}g_{t,J}\big) + \theta_t r_{t-1} + e_t, \tag{11}$$

$$\theta_t = \frac{1}{1+\exp\big(-\beta_{3,t}\big)}, \tag{11.1}$$

$$\beta_{i,t} = \beta_{i,t-1} + \epsilon_{it}, \qquad \epsilon_{it} \sim i.i.d.N\big(0,\sigma^2_{\epsilon,i}\big), i = 0,1,2,3 \tag{11.2}$$

where $\beta_{0,t} = \beta^*_{0,t} - \beta_{2,t}\pi^*; e_t = (1-\theta_t)[\beta_{1,t}\left(\pi_{t,J} - E_t\big(pi_{t,J}\big)\right) + \beta_{2,t}\big(g_{t,J}\big))] + m_t$. In this specification, r_t is the target nominal interest rate, $\beta_{0,t}$ is the neutral interest rate, $\pi_{t,J}$ is the expected inflation gap between periods t and J, and $g_{t,J}$ is the output gap, also between periods t and J. Under Kim and Nelson's specification, the smoothing parameter θ_t is also assumed to lie between 0 and 1. Kim and Nelson approximate the distribution of the error term e_t by a GARCH (1,1) process:

$$e_t|\psi_{t-1} \sim N(0,\sigma^2_{e,t}) \tag{12}$$

$$\sigma^2_{e,t} = \alpha_0 + \alpha_1 e^2_{t-1} + \alpha_2\sigma^2_{e,t-1}, \tag{12.1}$$

Where $\psi_{t-1}$is the information set going up to $t-1$.

The first step to estimate a bias-corrected forward-looking Taylor rule with TVPs is to obtain standardized forecast errors for an estimation of the endogenous regressors: inflation gap and output gap ($\pi_{t,J}$ and $g_{t,J}$ respectively in the above Kim and Nelson notation). The specification for the respective instrumental variable estimation is the following:

$$\pi_{t,J} = z_t'\delta_{1t} + v_{1t}, \qquad v_{1t} \sim (i.i.d.N\big(0,\sigma^2_{v_{1t}}\big) \tag{13}$$

$$g_{t,J} = z_t'\delta_{2t} + v_{2t}, \qquad v_{2t} \sim (i.i.d.N\big(0,\sigma^2_{v_{2t}}\big) \tag{14}$$

with

$$\delta_{it} = \delta_{i,t-1} + u_{i,t}, \qquad u_{i,t} \sim N\big(0,\Sigma_{u,i}\big), i = 1,2, \tag{15}$$

$$\sigma^2_{vj,t} = a_{0j} + a_{1j}v^2_{j,t-1} + a_{2j}\sigma^2_{vj,t-1}, j = 1,2. \tag{16}$$

which suggest time-varying uncertainties in the parameters for inflation gap and output gap.

The Kim and Nelson two-step method sets $J = 1$, also decomposing the inflation gap and output gap into two sections: the first pertaining to predicted components and the second pertaining to prediction errors, in the following matrix structure:

$$\begin{bmatrix} \pi_{t,1} \\ g_{t,1} \end{bmatrix} = E\begin{bmatrix} \pi_{t,1} \\ g_{t,1} \end{bmatrix} |\psi_{t-1}] + \begin{bmatrix} \upsilon_{1,t|t-1} \\ \upsilon_{2,t|t-1} \end{bmatrix} \tag{17}$$

$$\begin{bmatrix} \upsilon_{1,t|t-1} \\ \upsilon_{2,t|t-1} \end{bmatrix} = \Omega_{t|t-1}^{\frac{1}{2}} \begin{bmatrix} \upsilon_{1,t}^{*} \\ \upsilon_{2,t}^{*} \end{bmatrix}, \sim i.i.d.N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}\right), \tag{18}$$

where ψ_{t-1} is the information set up to period $t-1$. Furthermore, $\Omega_{t|t-1}$ is the conditional variance covariance matrix, for a vector of prediction errors $\begin{bmatrix} \upsilon_{1,t|t-1} \\ \upsilon_{2,t|t-1} \end{bmatrix}$ which is time-varying and obtained from (13) and (14).

Continuing with Kim and Nelson's derivation for the model, a 2×1 vector of standardized prediction errors, $\upsilon_t^* = [\upsilon_{1,t}^* \quad \upsilon_{2,t}^*]'$, in which the covariance between the standardized predictions and the error term in the signal equation is:

$$\begin{bmatrix} \upsilon_t^* \\ e_t \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} I_2 & \rho\sigma_{e,t} \\ \rho'\sigma_{e,t} & \sigma_{e,t}^2 \end{bmatrix}\right), \tag{19}$$

where $\rho = [\rho_1 \quad \rho_2]'$ is a correlation vector. Kim and Nelson follow the Cholesky decomposition of the above covariance matrix:

$$\begin{bmatrix} \upsilon_t^* \\ e_t \end{bmatrix} = \begin{bmatrix} I_2 & 0_2 \\ \rho'\sigma_{e,t} & \sqrt{(1-\rho'\rho)}\sigma_{e,t} \end{bmatrix} \begin{bmatrix} \epsilon_t \\ \omega_t \end{bmatrix}, \begin{bmatrix} \epsilon_t \\ \omega_t \end{bmatrix} \sim i.i.d.N\left(\begin{bmatrix} 0_2 \\ 0 \end{bmatrix}, \begin{bmatrix} I_2 & 0_2 \\ 0_2' & 1 \end{bmatrix}\right), \tag{20}$$

Where 0_2 is a vector of zeroes. Hence, the above allows the error term in (11) to be rewritten as:

$$e_t = \rho_1\sigma_e\upsilon_{1t}^* + \rho_2\sigma_e\upsilon_{2t}^* + \omega_t, \qquad \omega_t \sim N(0, (1-\rho_1^2-\rho_2^2)\sigma_{e,t}^2) \tag{21}$$

whereby decomposing e_t into different components, υ_{1t}^* and υ_{2t}^*, which are correlated with inflation gap and output gap, but uncorrelated with the error term ω_t, the endogeneity bias is corrected. Substituting (21) into Kim and Nelson's generic Taylor rule specification, we have:

$$r_t = (1-\theta)(\beta_{0,t} + \beta_{1,t}\pi_{t,J} + \beta_{2,t}g_{t,J}) + \theta_t r_{t-1} + \rho_1\sigma_e\upsilon_{1t}^* + \rho_2\sigma_e\upsilon_{2t}^* + \omega_t,$$
$$\omega_t \sim N(0, (1-\rho_1^2-\rho_2^2)\sigma_{e,t}^2) \tag{22}$$

which is estimated using Maximum Likelihood Estimation via the Kalman filter.

Finally, applying the Kim and Nelson Heckman-type two-step bias correction method to our notation of the Taylor rule measurement equations (8), (9), and (10), which uses real interest rates, we have:

$$rr_t = (1-\rho)\big(\overline{rr} + (\beta - 1)\big(E\big[\pi_{t,n}\big|\Omega_t\big] - \pi^*\big) + y\widetilde{\gamma_t}\big) + \rho rr_{t-1} + v_1\sigma_e v_{1t}^* + v_2\sigma_e v_{2t}^* + \omega_t,$$
$$\omega_t \sim N\big(0, (1 - v_1^2 - v_2^2)\sigma_{e,t}^2\big) \tag{23}$$

where ν_1 and ν_2 in (23) are equal to ρ_1 and ρ_2, respectively in (22).

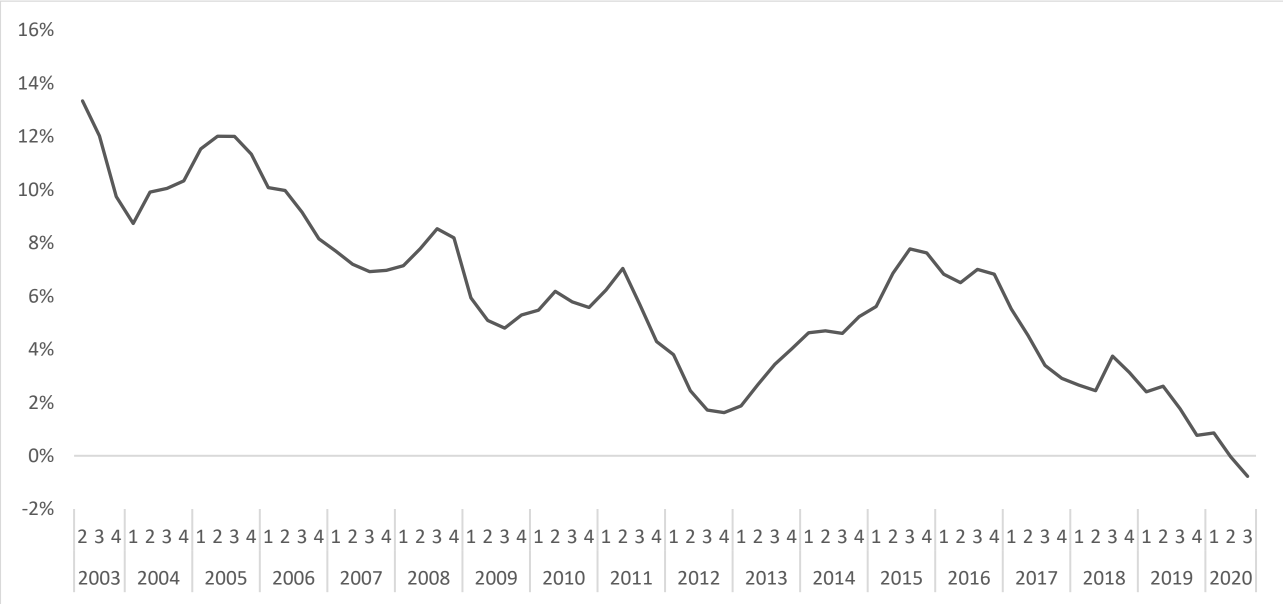
4. DATA

The study uses quarterly data from Q2 2003 to Q3 2020. The sample range was chosen because it contemplates a large portion of the time frame since the establishment of the BCB’s inflation-targeting regime in 1999. The study starts in the second quarter of 2003 to mitigate volatility in the Taylor rule estimation coming from sharp interest rate and inflationary movements in the early 2000s, as well as avoid volatility from the October 2002 general elections. The quarterly frequency is chosen as more appropriate for data such as output gap, calculated by most data sources on a quarterly basis. When a time series was not released in a quarterly frequency, the arithmetic average for all the data points in the respective quarter was used instead.

4.1 Interest Rate

The interest rate variable used in the Taylor rule estimation was the real swap rate: that is the natural log of the 360-day DI-fixed (*pré-fixado*) swap subtracted by the natural log of accumulated IPCA inflation expectations for the following 12-month period, collected by the BCB. The swap rate is opted in this case given a higher correlation with output than the Selic rate.

Figure 1: 360-day DI-Fixed Discounted by 12-Month Inflation Expectations



4.2 Output Gap

The output gap used is a weighted average of the utility capacity gap and the employment rate gap and the employment rate gap as defined in Alves and Muinhos (2003), where the output gap is the difference between actual and potential output, $\tilde{Y} = Y_t - \overline{Y}_t$, and therefore the log of the output gap is $y_{\tilde{t}} = \ln\left(\frac{Y_t}{\overline{Y}_t}\right)$, where output is derived from a Cobb-Douglas production function with capital and labor:

$$Y_t = A_t (K_t uci_t)^{\alpha_t} (L_t)^{1-\alpha_t} \tag{24}$$

and therefore:

$$h_t = \alpha_i * \left[\ln(uci_t) - \ln\left(uci_{fe}\right)\right] + (1 - \alpha_t) * [\ln(1 - u_t) - \ln(1 - \bar{u})] \tag{25}$$

where,

$L_t = LF_t(1 - u_t)$,

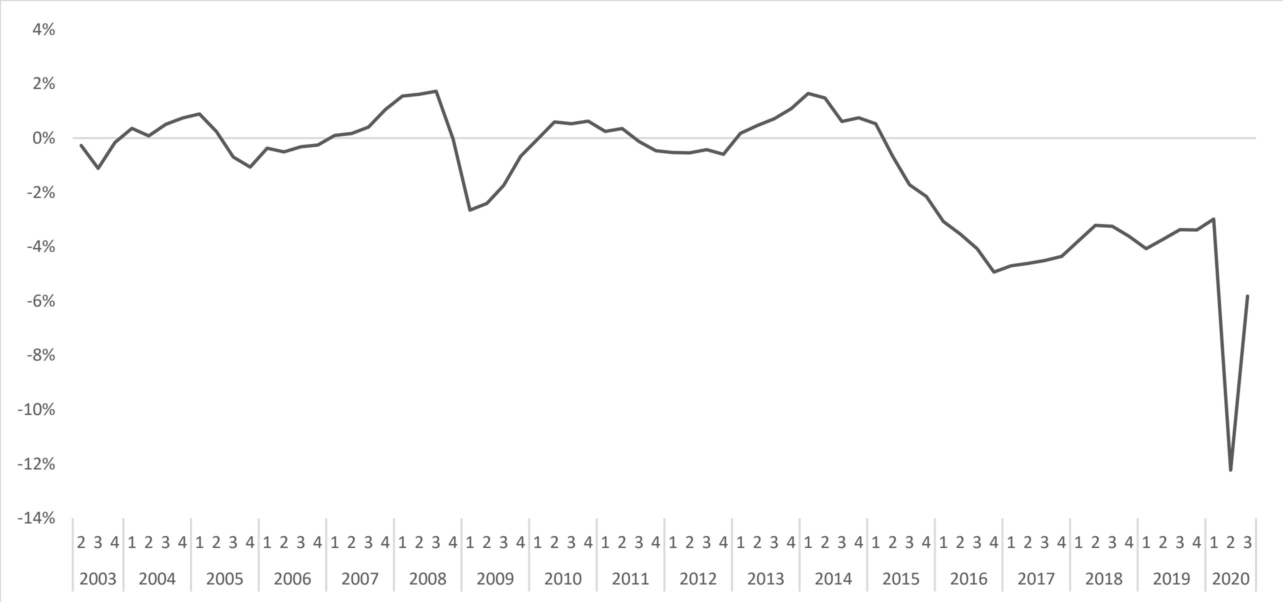
$K_t = (1 - \delta)K_{t-1} + \sum_{i=2}^{4} \beta_i * I_{t-i}$,

$\sum_{i=2}^{4} = 1$,

Being that LF_t is the labor force aged 14 and over, as released by Brazilian Institute of Geography and Statistics (IBGE) quarterly National Household Sample Survey (PNAD Continua), u_t is the unemployment rate, released on a monthly PNAD Continua. The variable

icu_t is the used installed industrial capacity released by the Brazilian Economics Institute of the Fundação Getúlio Vargas (IBRE/FGV) and δ is depreciation, assumed to not vary over time and derived from Alves and Muinhos, and α_t, the capital share yield, is derived through a Hodrick-Prescott filter as described in Alves (2001).[3]

Figure 2: Output Gap

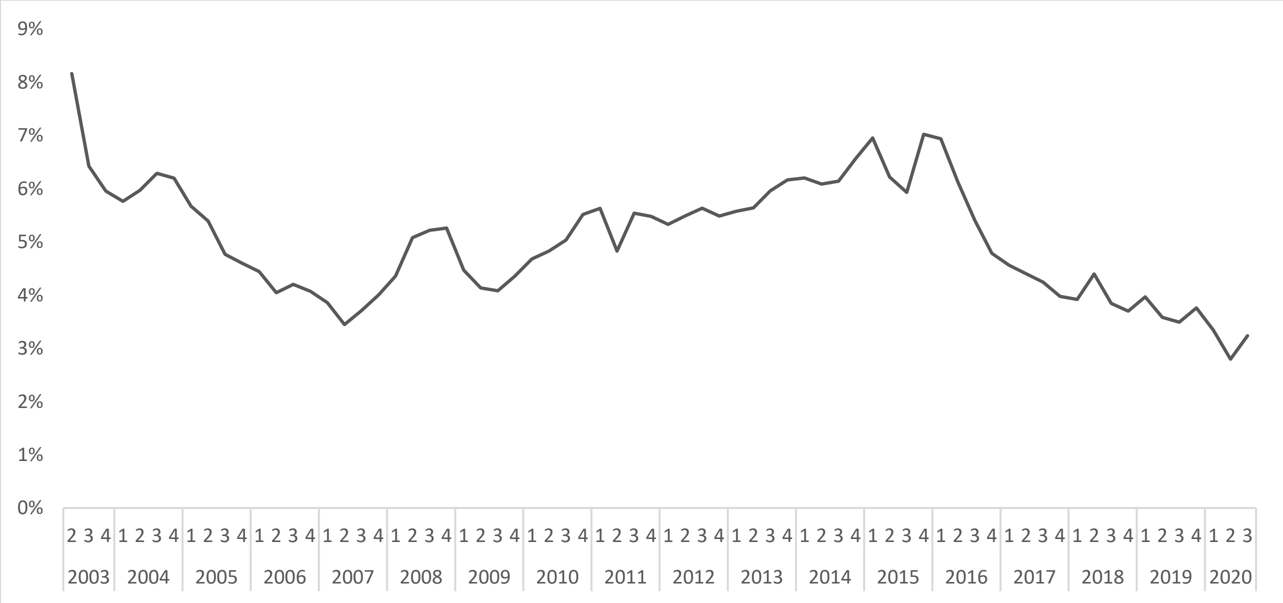


4.3 Inflation Expectations

The inflation expectation series is the natural log of the BCB's survey of economic agents for the accumulated 12-month forward IPCA (*Índice Nacional de Preços ao Consumidor Amplo*, Ample Consumer Price Index) inflation index. The series is calculated daily for all forecasting institutions who have projected all the twelve months ahead of inflation, and the median of all contributors is taken. As noted, the monthly frequency of the BCB data is converted into a quarterly frequency by calculating the arithmetic mean for the three months in each respective quarter.

[3] The author thanks Marcelo Kfoury Muinhos for sharing the output gap series as derived above.

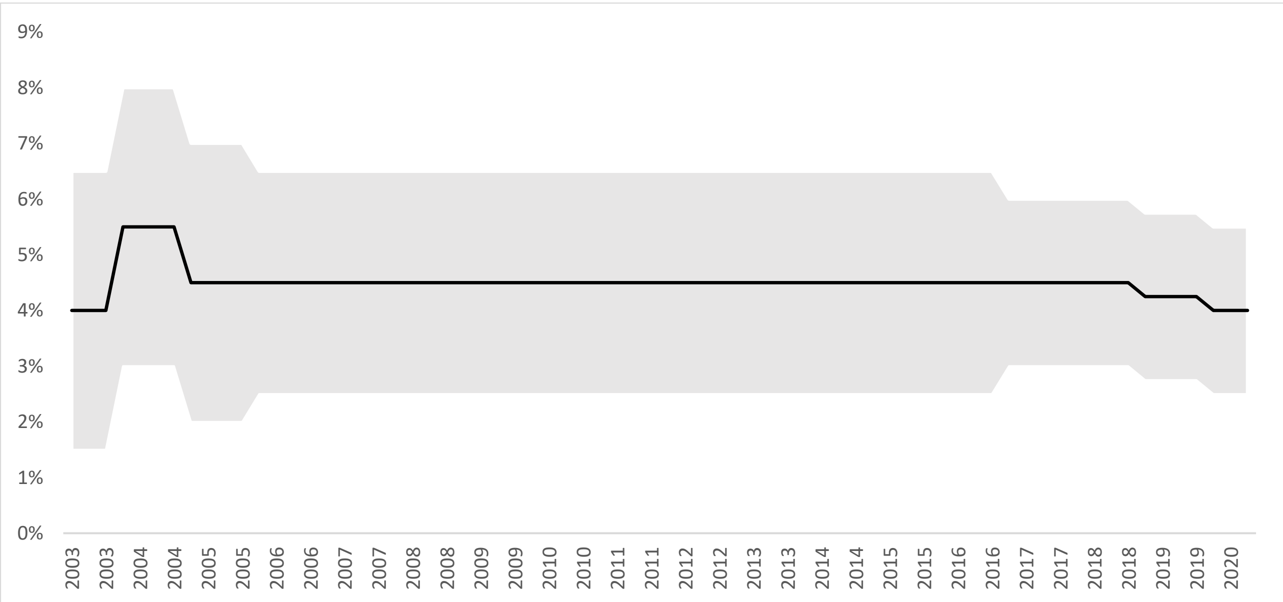
Figure 3: 12-Month IPCA inflation expectations



4.4 Inflation Target

The natural log of the respective annual IPCA inflation targets set by CMN resolutions was used. For 2003 and 2004, when the respective inflation targets were changed from the original CMN resolutions, the latter inflation targets, set by the respective new CMN resolutions, were used: 4% with a 2.5-percentage point band for 2003, and 5.5% with a 2.5-percentage point band for 2004.

Figure 4: Inflation Target and Tolerance Bands



4.5 Instrumental Variables

The instrumental variables used to estimate equations (13) and (14) include a constant term, one-to-four lags of the real interest rate (360-day DI-fixed swap discounted by 12-month forward IPCA inflation expectations), one-to-four lags of the 12-month forward IPCA inflation expectations, one-to-four lags of the output gap, one-to-four lags of the arithmetic mean for the quarter of industrial production as measured monthly by the IBGE.

Instrumental variables for the quarterly change in the exchange rate, the quarterly change in oil prices and the quarterly change in industrial production are also used. The first of the three, the $dlfx$ variable is the percentage change in the quarterly exchange rate, where the quarterly exchange rate is the arithmetic mean for the quarter of the daily median exchange rate of Brazilian reais to one U.S. Dollar, taken from the Federal Reserve Bank of St. Louis' FRED database. The oil price variable $dloil$ series follows the same method, but for the WTI crude daily oil price, taken from the U.S. Energy Information Administration database. The $dlpim$ variable has the same construction, but for monthly industrial production, as surveyed by the IBGE.

Lastly, dummy variables are added for Q3 2005, Q2 2008 and Q2 2011 in the case of the instrumental variable regression for expected inflation (equation 13), and a dummy for Q2 2020 for the instrumental variable regression for the output gap (equation 14).

Figure 5: Quarterly change in USD/BRL exchange rate

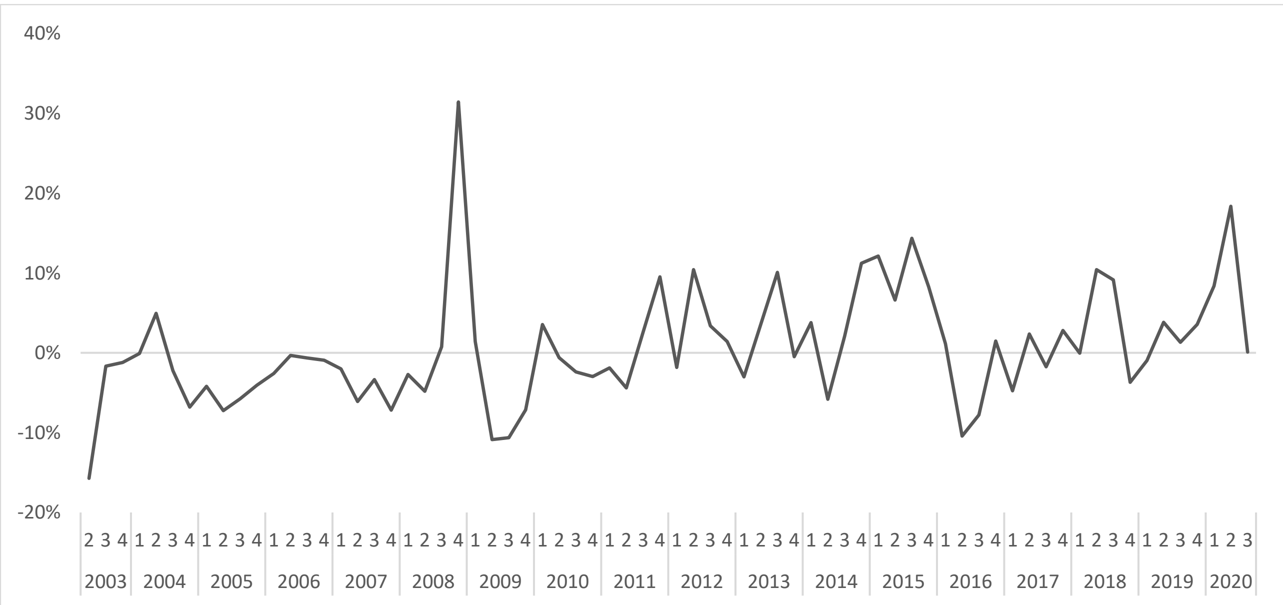


Figure 6: Quarterly change in WTI Crude Oil prices

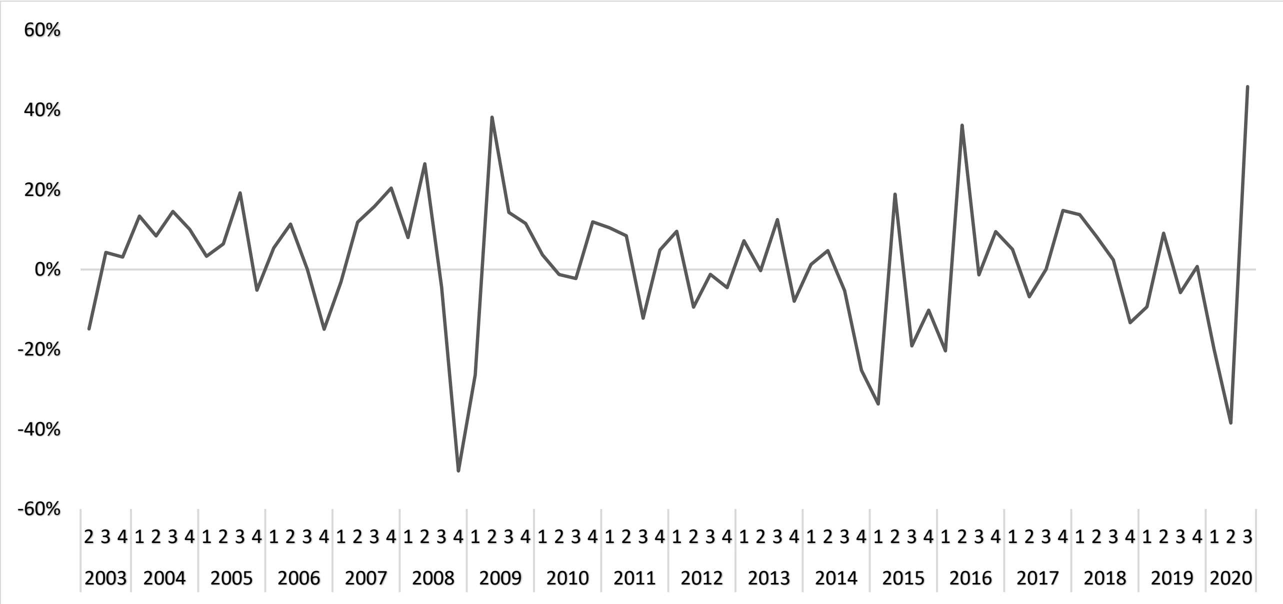
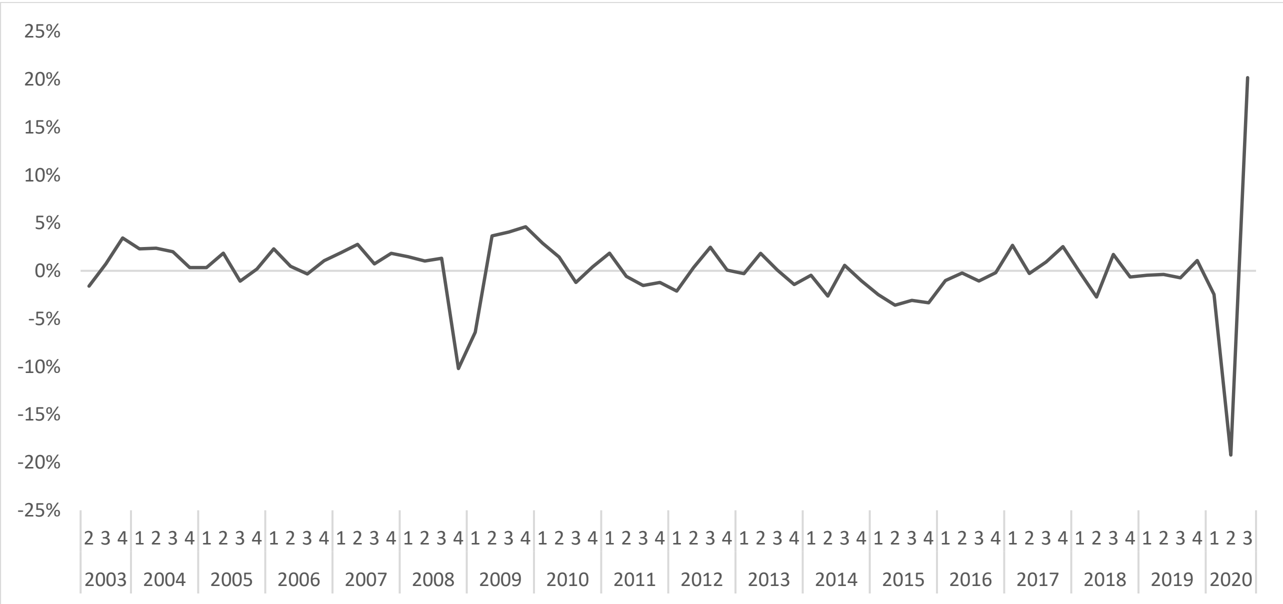


Figure 7: Quarterly change in monthly industrial production



4.6 Unit Root Tests

Unit root tests are run to assess the stationarity of the time series used in the Taylor rule (rr_t, $E[\pi]$, π^*, and γ), as well as the instrumental variables ($dlfx$, $dloil$, $dlpim$) used in the Kim and Nelson endogeneity adjustment. Three unit root tests are run for the level of the series, with trend and intercept terms included: the Augmented Dickey-Fuller (ADF) test, using a Schwartz Information Criterion, the Phillips-Perron (PP) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. The ADF and PP hold a null hypothesis the series has a unit root,

whereas the KPSS null hypothesis is that the series is stationary. Resulting statistics are shown in table 1.

Table 1: Unit root test statistics

Variable	**ADF**	**PP**	**KPSS**
Real interest rate (rr_t)	-0.3151	-2.6802	0.1206*
Inflation expectations ($E[\pi]$)	-4.6619***	-4.4178***	0.1473**
Inflation target (π^*)	-3.9597**	-4.0871**	0.0544
Output gap (γ)	-1.7250	-3.5214**	0.2153**
US Dollar to Brazilian Reais ($dlfx$)	-6.3676***	-6.1147***	0.0492
WTI oil prices ($dloil$)	-7.2571***	-7.3557***	0.0585
Monthly industrial production ($dlpim$)	-8.7574***	-8.6235***	0.0751

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$

Unsurprisingly, all instrumental variables $dlfx$, $dloil$, $dlpim$ are stationary given the series are already in first difference of the respective quarters. The inflation expectation series strongly rejects the null hypothesis of a unit root in the ADF and PP tests, but also rejects the null hypothesis of stationarity in the KPSS test, though given the first two, we will opt to assume it does not have a unit root. The inflation target series also rejects the null hypothesis in the ADF and PP tests to a 5% significance level and does not reject the null hypothesis of stationarity in the KPSS test, and we will thus treat it as stationary.

However, for the output gap variable, the null hypothesis of a unit root is not rejected in the ADF test but is rejected at a 5% level in the PP test, though the KPSS test also rejects the null hypothesis of stationarity. The conflicting outcomes is likely a result of the break in the series starting in 2015, as seen in Figure 2, with the output gap never recovering since, as well as the outlier quarters during the 2020 Covid-19 pandemic, which significantly hindered economic activity.

In addition, the ADF and PP tests do not reject the null hypothesis of a unit root for the real interest rate series, and the KPSS rejects the null hypothesis of stationarity at the 10% significance level. This is not surprising as Brazil’s real interest rates have been falling since the early 2000s, pointing to a structural change over time.

As noted by Perron (1989), regular, conventional, unit root tests can face biases towards false unit root conclusions when there are structural breaks in the series, hence the subsequent literature around unit root tests and structural breaks. For example, in their Taylor rule modelling, Aragon and Medeiros use the Perron and Yabu (2009) Exp-W_{FS} statistic to test the null hypothesis of no structural breaks in the nominal Selic interest rate trend function, against the alternative hypothesis of a break in the intercept and trend at an unknown date. Upon the rejection of the hypothesis of no structural break, they follow Carrion-i-Silvestre et al. (2009) and use the MZ_{α}^{GLS} and MZ_{t}^{GLS} statistics to test the null hypothesis of a unit root allowing for one structural break, rejecting the null hypothesis that the nominal Selic rate has a unit root.

Our approach is a simpler one-step approach, conducting a unit root with breakpoint test for both the output gap and real interest rate variables. The series are tested in level, assuming trending data and allowing for intercept and trend breaks. The structural break date is unknown and estimated by minimizing the Dickey-Fuller t-statistic. Ultimately the test is a modified ADF allowing for a structural break, and an innovative outlier break type is used, as it assumes a gradual break. The results of the breakpoint unit root tests are seen below:

Table 2: Unit root with breakpoint test statistics

Variable	**ADF**
Real interest rate (rr_t)	-5.7029**
Output gap (γ)	-5.8752***

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$

Both unit root tests with a breakpoint reject the null hypothesis of a unit root for the respective real interest rate and output gap series (p 0.01 and p = 0.0108, respectively). Hence, both the level data for the real interest rate and output gap will be used in the estimation.

5. RESULTS

In this section we present the results of the estimations of TVPs in the BCB's Taylor rule. The first subsection provides the results for the estimation of the Taylor rule used to gather the initial parameters for the state-space estimation of the rule. The second subsection shows the estimation that led to the standard errors υ_{1t}^{*} and υ_{2t}^{*} used to relate the endogenous regressors with the selected instrumental variables, allowing the adjustment of the state-space model in accordance with the method derived by Kim and Nelson. The third subsection shows the results of the Taylor-rule when the inflation parameter (β) varies over time. For this scenario, we

model three types of variations of the β parameter: the first when only β is allowed to vary over time, the second when the output gap parameter γ is allowed to vary alongside β, also assuming a random walk process, and finally, an estimation where only β varies over time in the space-state model, but when the neutral real interest rate $\overline{rr}$ is fixed, and not estimated, assuming it is the arithmetic average of the real interest rate over the sample period. The fourth subsection shows the results of the BCB's Taylor rule when the inflation target can vary with time, the so-called implicit inflation target, and how it compares to the target explicitly set by the CMN under Brazil's IT framework.

5.1 OLS Estimation of Taylor Rule Parameters

The OLS estimation is used to set the initial parameters for the Kalman filter estimation. We add time dummies are added to mitigate residuals and outliers at specific dates, ensuring a white-noise process. These include dummies for Q4 2003, during the first year of the Luiz Inacio Lula da Silva administration, Q1 2009, given the Great Financial Crisis, Q3 2011 and Q2 2012, given outlier data points and Q3 2018 due to the 2018 trucker strike.

Table 3: OLS estimation of initial Taylor rule parameters

Coefficient	Estimated Value	Standard Error	t-statistic	p-value
ρ	0.943704	0.025789	36.59342	0.0000
$\overline{rr}$	0.053340	0.018470	2.887984	0.0054
β	3.847894	2.035896	1.890025	0.0636
γ	2.374615	1.052556	2.256047	0.0277
D_{2003Q4}	-0.021782	0.006213	-3.505984	0.0009
$D_{GFC\ (2009Q1)}$	-0.017385	0.006004	-2.895674	0.0053
D_{2011Q3}	-0.013989	0.005958	-2.348115	0.0222
D_{2012Q2}	-0.015182	0.005987	-2.535733	0.0138
$D_{Trucker\ Strike\ (Q3\ 2018)}$	0.016710	0.006044	2.764695	0.0076
$R^2 = 0.968325$		Adjusted $R^2 = 0.964101$		

Most of the estimated parameters are significant at the five-percent level. The smoothing coefficient variable (ρ) of 0.94 reinforces a notion of significant interest rate inertia. The value is in line with other Taylor rule estimations, like Modenesi (2011), which found a 0.92 value

for the autoregressive term, rein, and Gonin de Campos (2015), which had a coefficient of 0.964. The neutral real interest rate ($\overline{rr}$) of 0.053, or 5.3% also appears to be a reasonable estimation, considering the period of higher real interest rates in Brazil in the early and mid-2000s, and appears to be within the median range of time-varying estimations for the period, like the Laubach and Williams approach by Fonseca and Muinhos (2018), and Perrelli and Roache (2014). The first main variable which will be time-varying in the state-space model, (β) is significantly higher than one, at 3.84, hence not only following the Taylor principle, but pointing to a hawkish BCB over the sample period. The coefficient weight for output gap (γ) is also above one, at 2.37, but lower than the coefficient for the inflation parameter. The dummy coefficients are all statistically significant.

5.2 Estimating standard errors for endogenous regressors

In line with the Kim and Nelson (2006) two-step bias-correction method, the residuals for equations (13) and (14) are estimated using the instrumental variables described in section 4.5, and shown in figures 8 and 9 below:

Figure 8: Residuals of instrumental variable estimation for $E[\pi_t]$

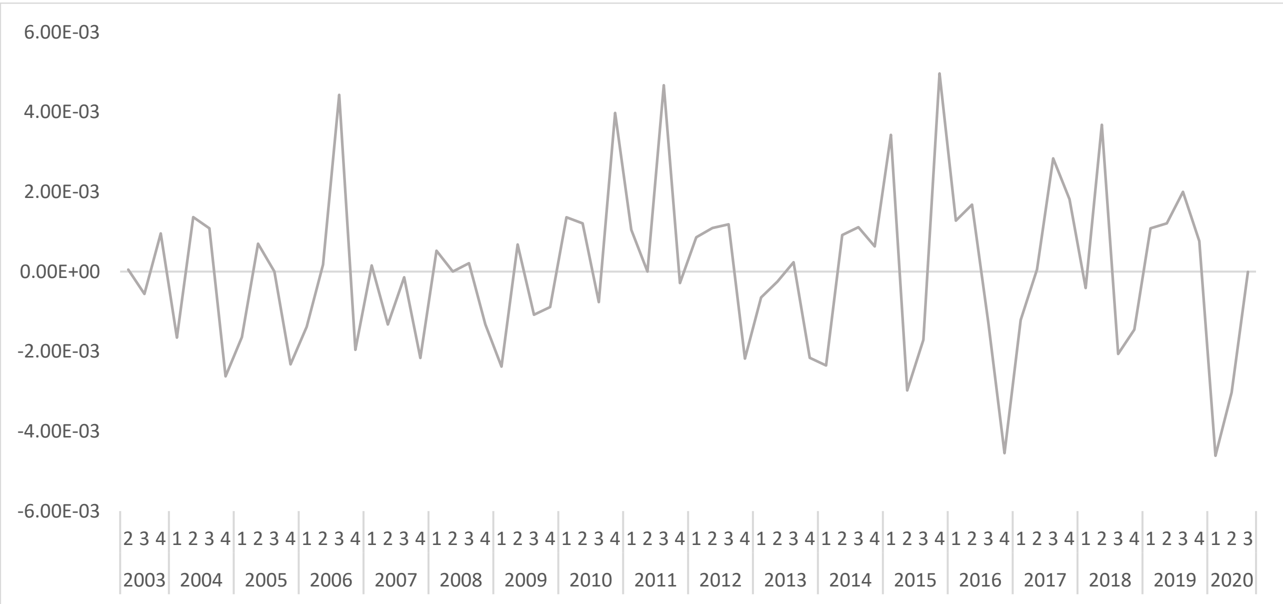
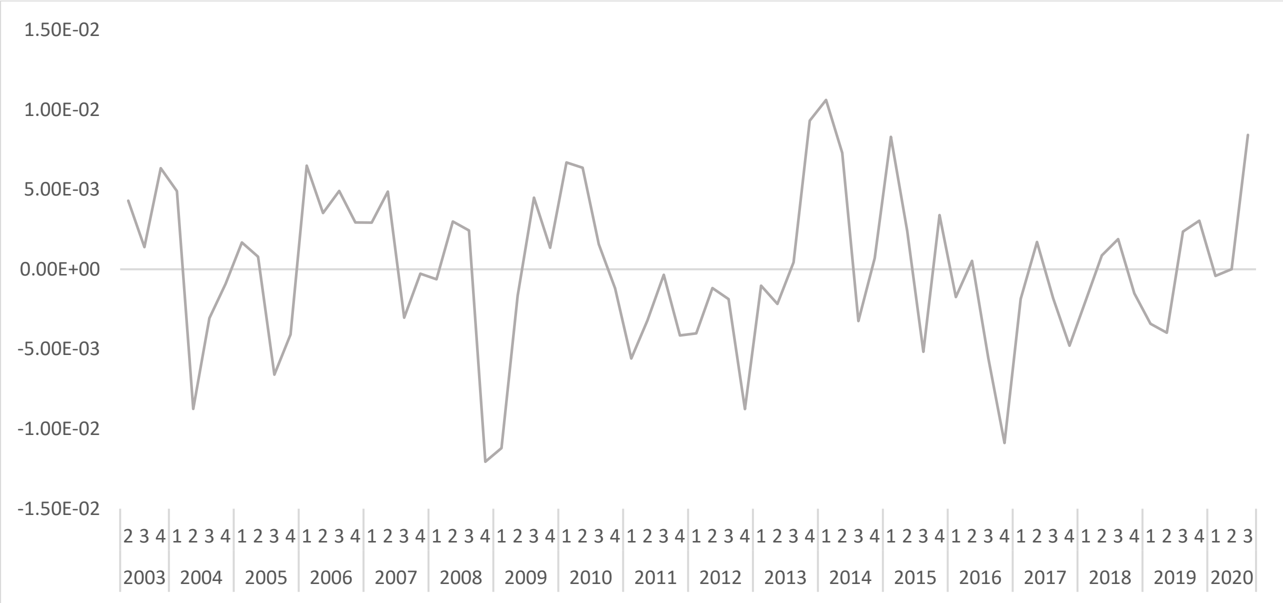


Figure 9: Residuals of instrumental variable estimation for γ_t

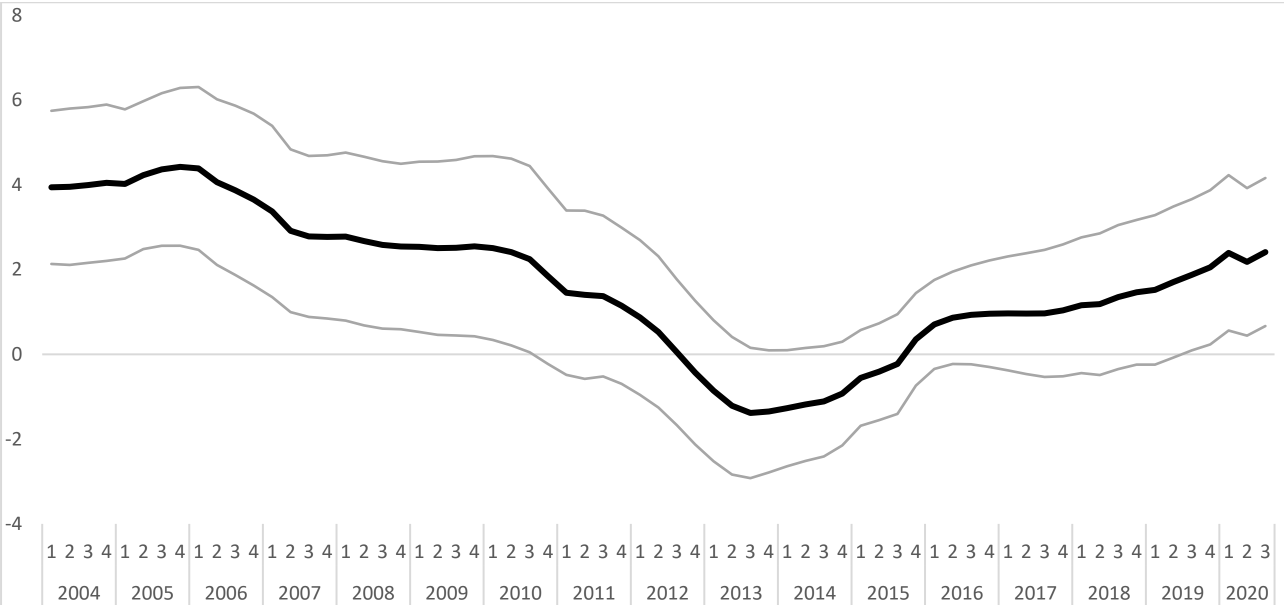


The residuals series of the two regressions above are used as variables ν_1 and ν_2, respectively, in the Taylor estimations below.

5.3 Estimating the time-varying inflation ($\boldsymbol{\beta}$) parameter

Using the parameters from the OLS estimation as initial values, and the ν_1 and ν_2 residual series estimated in 5.2. the Taylor rule equation (8) is estimated. The coefficient used for σ_e is the standard deviation of the residuals derived from the OLS estimation in subsection 5.1. Three different estimations are made for β in this section. The first is a Taylor rule where the only parameter varying over time is that of β. The second estimation allows both β and the output gap parameter γ vary over time, to see if the latter has any impact on the estimation of the former. Lastly, we estimate β, but in a Taylor rule where the real interest rate $\overline{rr}$ is fixed, instead of being estimated along with the other parameters.

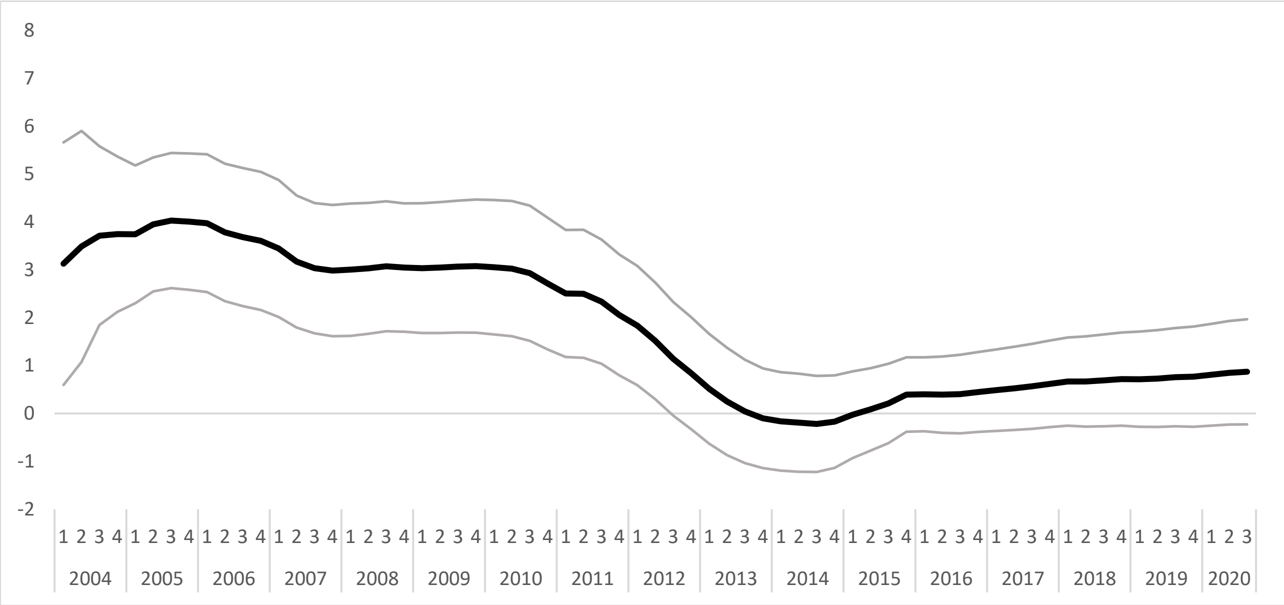
Figure 10: Model 1 – Estimating β as only time-varying parameter (plus/minus two standard errors)



The first estimation shows the coefficient for the inflation parameter β was above the Taylor principle for most of the sample period, in line with the OLS estimation in section 5.1, but dropped significantly starting in 2010, with the coefficient below one between Q1 2012 and Q4 2017, with the coefficient being negative between Q4 2012 and Q3 2015, indicating a dovish shift in the BCB's monetary policy preferences in the period. The coefficient recovers starting in 2016.

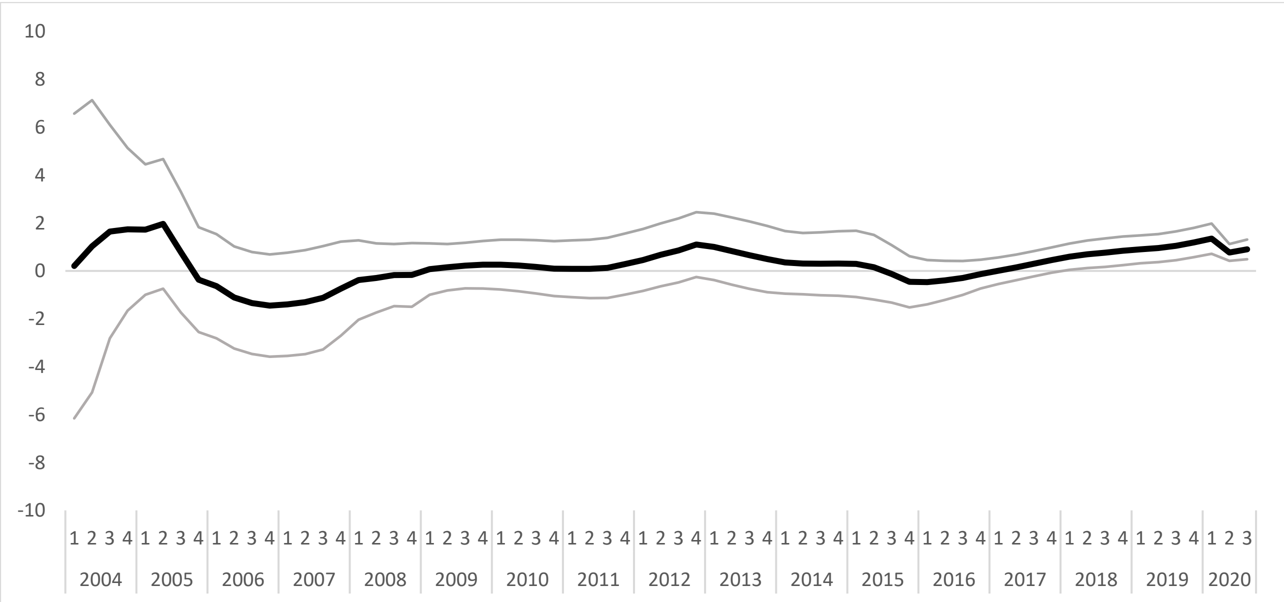
The second estimation, where the output gap parameter is also allowed to vary over time, shows similar results, indicating a hawkish response to inflation by the BCB in the first years of the sample, but a decline starting in Q2 2011. The coefficient falls below the Taylor principle of one in Q4 2012, like in the first estimation, but once the output gap is included, the coefficient never climbs back above one in the series.

Figure 11: Model 2 – Estimating β and γ as time-varying parameters: β plus/minus two standard errors.



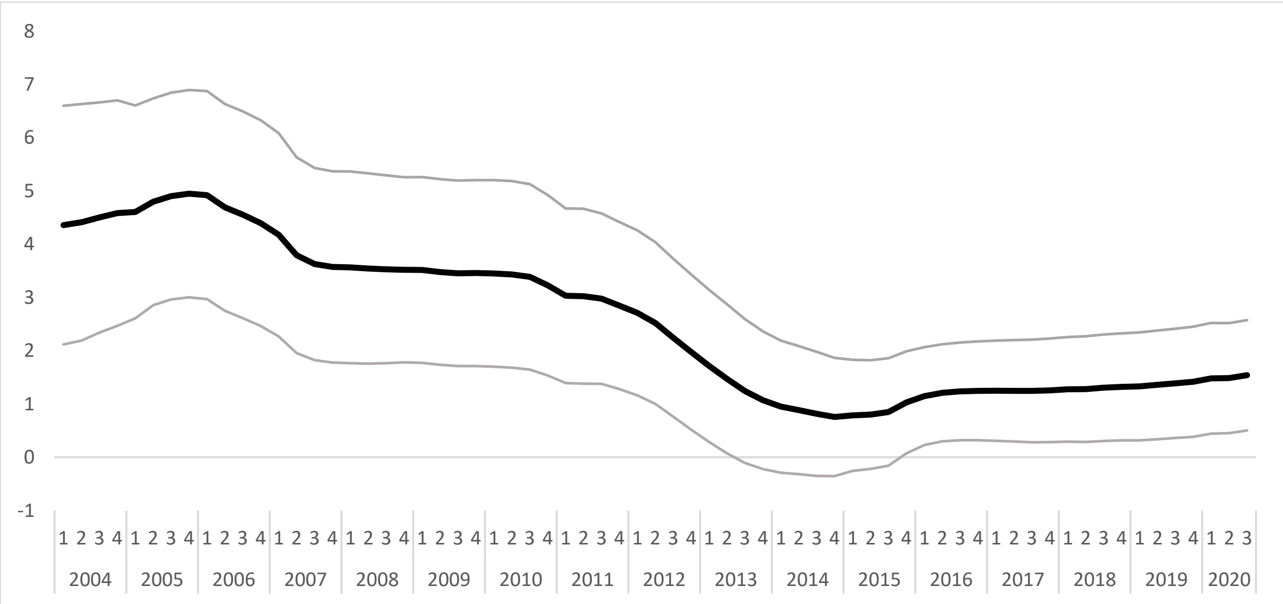
Meanwhile, while not the main point of analysis in this study, it is worth also looking at the behavior of the output gap coefficient over time. The coefficient is significantly lower than the one estimated through OLS in subsection 3.1, being negative for a part of the sample but increasing for part of the period where the BCB became more dovish between late 2011 and 2014. The estimation also points to an increase in the output gap coefficient starting in 2017, becoming slightly above the 2013 levels in Q1 2020.

Figure 12: Model 2 – Estimating β and γ as time-varying parameter: γ plus/minus two standard errors.



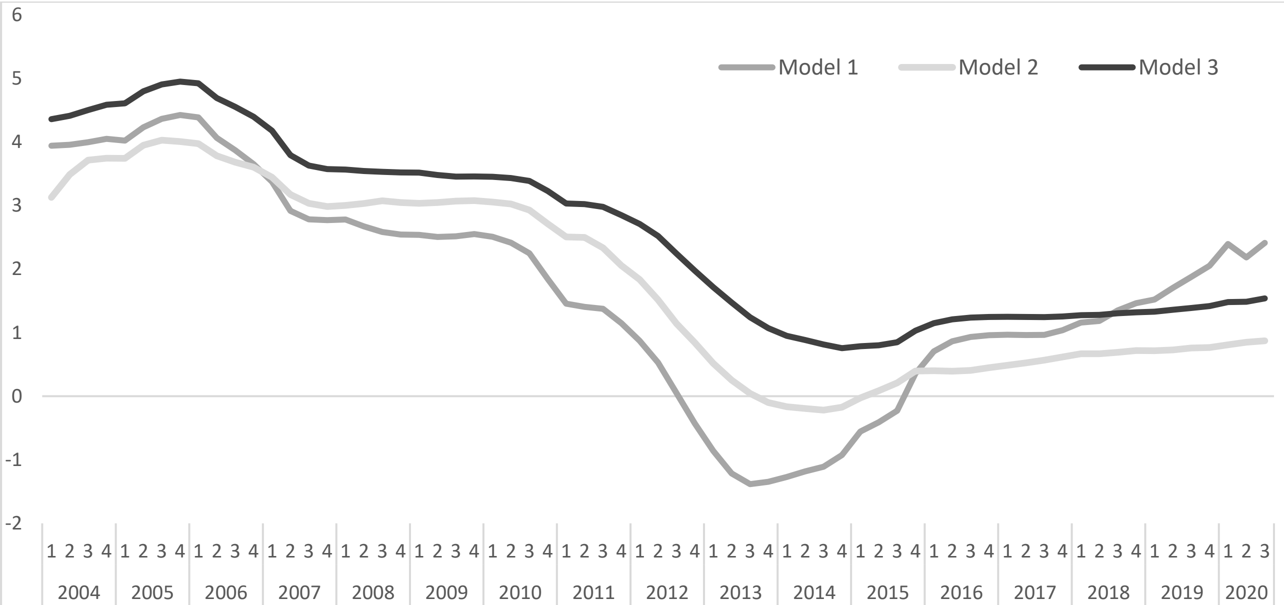
Finally, a third estimation is made, though this time, like in our first estimation, only β is allowed to vary over time, but we use a fixed value for the natural real rate coefficient $\overline{rr}$, instead of estimating it. For this estimation, the mean of the real interest rate over the sample period, 5.97%, is used. The use of the fixed coefficient for $\overline{rr}$ is used in Leigh and Klein. In this last specification, the inflation gap coefficient does not drop as much as the previous two, hovering around one at its lowest.

Figure 13: Model 3 – Estimating β as time-varying parameter with fixed $\overline{rr}$: β plus/minus two standard errors.



Overall, the three results of β point to similar trends over time. In all three cases there is a significant decline in the weight of inflation in the BCB's Taylor rule around 2011, consistent with criticism of an overly stimulative monetary policy by then-governor Alexandre Tombini, though with some recovery in the value of the parameter around 2016.

Figure 14: Comparison of models 1-3



5.4 Estimating the implicit inflation target of the BCB

The second aim of this paper is to estimate the implicit inflation target of the BCB through the TVP model. The results show significant variation of the implicit inflation target set by the BCB over time. Although most of the estimated values stay within the official inflation target bands, the implicit inflation target has, at times, left the established bands – despite staying within these bands if the two standard errors of the band are also accounted for.

Figure 15: Implicit inflation target and official inflation target (plus/minus two standard errors, %)

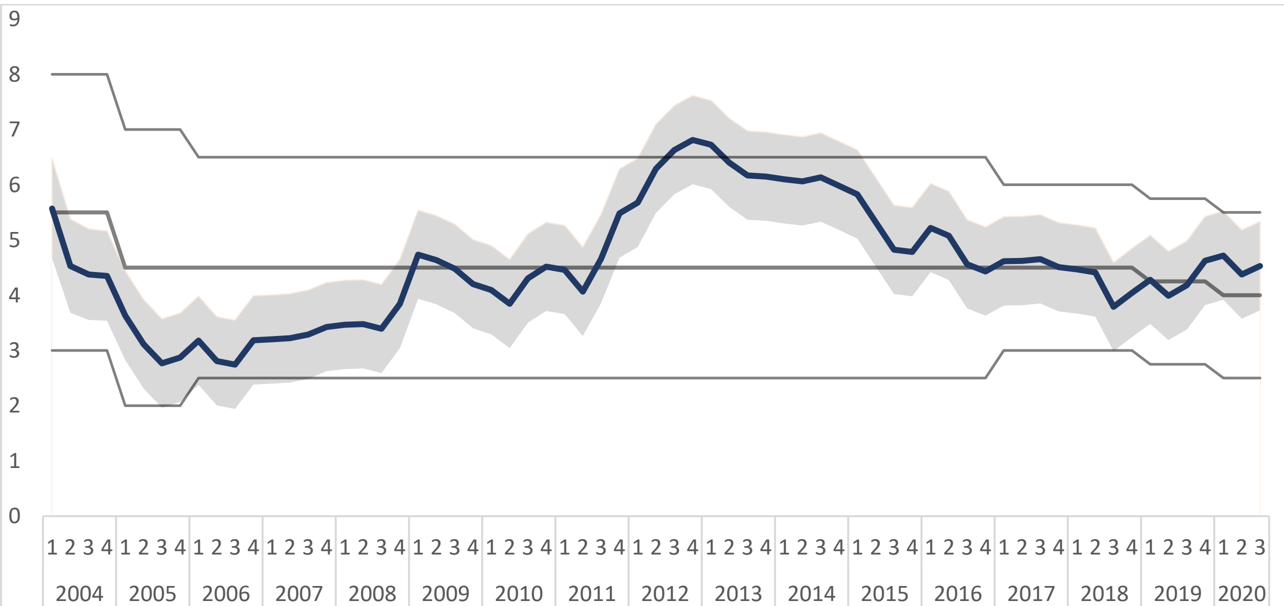


Figure 15 compares the estimated implicit inflation target to the official target set by the CMN and its bands. With the time series comparison, we can visually observe five distinct eras, or regimes, in the BCB's decisionmaking.

First, comes the 2004-2008 when the BCB's implicit target was below the center of the CMN target, though within the set band. The more hawkish approach in the estimation is in line with the inflation parameter coefficients estimated in section 5.3, which reach levels of three, or even above four in a few quarters. These years correlate with the first, and beginning of the second Lula terms, with the BCB still headed by Meirelles.

Second comes the period between Q3 2008 and Q2 2011, when the implicit inflation target estimated largely aligns with the center of the CMN inflation target. The data shows a rapid increase in the implicit inflation target around the Great Financial Crisis, with the BCB taking on a more accommodative tone, though still in line with the CMN target, ultimately being less hawkish than in the previous years. This estimation is also largely in line with what was seen in section 5.3, with the inflation coefficient falling from the three-to-four range, to a rather stable value around three between 2008 and 2011; still above the Taylor principle coefficient of one.

Third comes the period between Q3 2011 and Q2 2015, when the estimated implicit inflation target for the BCB was significantly above the center of the CMN inflation target. Between Q2 2012 and Q2 2013, the estimated implicit target values are not only above the center of the target, but also above the upper band set by the CMN. This result occurs during the Tombini years at the BCB where the bank followed a much more stimulative monetary policy. The implicit inflation target is also in line with the significant drop in the inflation parameters seen in section 5.3, when the coefficient for inflation hovered around zero.

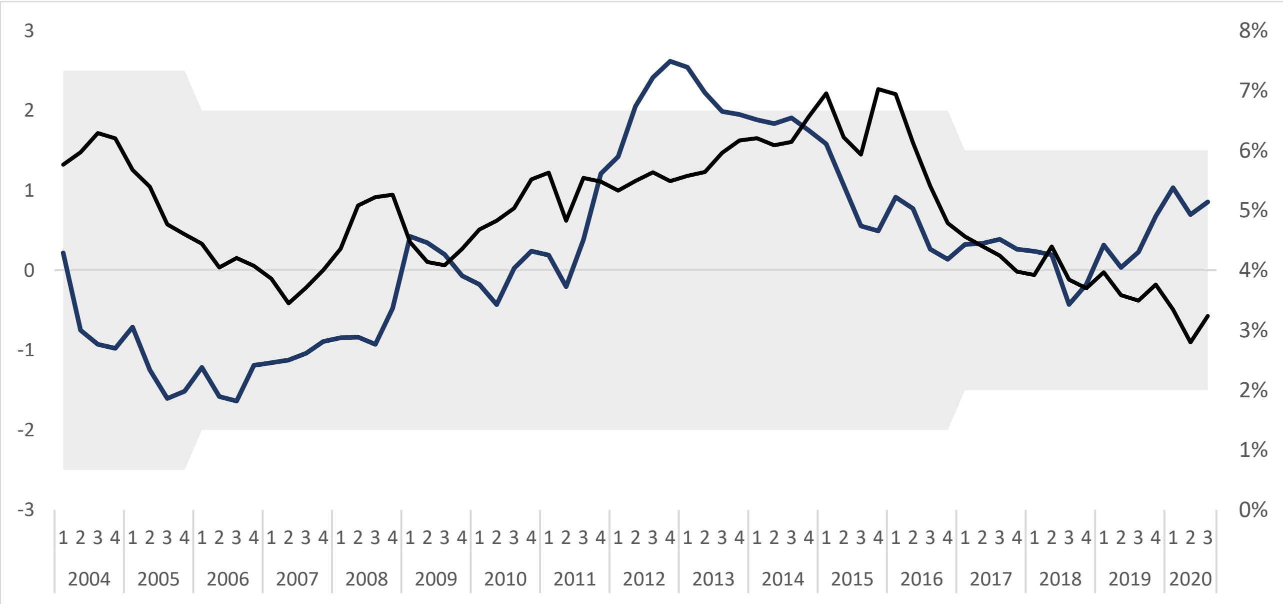
Fourth is the period between Q3 2015 and Q3 2019, when the BCB's implicit target follows the explicit target. The years followed the 2015-2016 economic downturn and the impeachment of President Dilma Rousseff, which also included a change at the BCB, with Ilan Goldfajn being appointed by President Michel Temer to replace Tombini in the new administration. The period saw a fall in inflationary pressures and interest rates as well. The inflation coefficients estimated in section 5.3 appear to have returned above the Taylor principle.

Lastly, starting in Q4 2019 and through to the end of the sample at Q3 2020, the BCB appears to have taken a more dovish approach to monetary policy. To be sure, it is difficult to conclude

that the BCB's policy choices during Q4 2019 were significantly different than those the previous quarters, but the more stimulative approach becomes clearer in the first two quarters of 2020 when the BCB responded to the shock in output caused by the Covid-19 pandemic.

We can also assess how the implicit target deviations from the official target varies over time, and how inflation expectations vary during the period.

Figure 16: Implicit inflation target deviation from official target (percentage points), and 12-month expected inflation rate (RHS, %)



Visually assessing Figure 16, it can be noted the time series of the implicit target deviation from the official target time series appears to "precede" changes to inflation expectations as surveyed by the BCB. As such, it is worth testing whether this relationship is Granger causal, Hence, a Granger causality test with four lags is run to see whether the implicit inflation target can help predict inflation expectations.

Table 4: Granger causality test between the implicit target deviation from the official target, and inflation expectations

	F-Statistic	p-value
Implicit target deviation from official target ***does not*** Granger cause inflation expectations	3.26156	0.0177

The F-Statistic in the Granger causality test is significant enough to reject the null hypothesis that the implicit target's deviation from the official target does not Granger cause inflation expectations, almost to the 1% level. Hence, there could be an argument to be made that larger

deviations between the implicit and official inflation targets in the BCB's Taylor rule can help predict dislocations in inflation expectations. To be sure, the above is a simple test, and further research should be done to deepen this understanding.

Lastly, the table below breaks down the implicit inflation target for the sample period under each governor's tenure, showing descriptive statistics for each. The mean squared deviation of each respective governor's estimated implicit inflation target, from the explicit center of the CMN target is also measured. With this metric, it can be noted that the Goldfajn tenure had the lowest mean squared deviation from the explicit target, using the implicit target estimated above.

Table 5: Descriptive statistics of implicit targets by BCB governor

	Meirelles	Tombini	Goldfajn	Campos Neto
Number of quarters in sample period (*n*)	30	22	10	7
Below bottom band	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Between center and bottom band	24 (80%)	2 (9%)	5 (50%)	2 (29%)
Between center and upper band	6 (20%)	17 (77%)	5 (50%)	5 (71%)
Above upper band	0 (0%)	3 (14%)	0 (0%)	0 (0%)
Mean squared deviation from official inflation target	1.168262	1.957557	0.078214	0.16439

6. CONCLUSION

Our main findings are that the BCB's approach to responding to inflation has, since 2003, become more dovish. Whereas early in the sample period, the bank took a much harsher response to inflationary pressures, since 2011 monetary policy has become much more stimulative, and though for a time the estimated time-varying coefficient for a forward-looking Taylor rule was below one, the response to inflationary pressures has strengthened since 2016, though not to the levels seen before the 2011 dovish turn in the bank's monetary preferences. The second conclusion of the study, which is inherently related to the first, is that the BCB's implicit inflation target has stayed largely within the bands set by the CMN, though the deviations between the estimated implicit target and the actual target vary over time, notably leading to implicit inflation targets that were outside the CMN's band.

The results are also largely in line with other research for the case of the BCB for the case of the inflation parameter varying across time: the latest observations used in Policano overlap with this study, and despite the different specifications, show the coefficient for the inflation gap from its target is around 3-3.5 in 2003-2004, but begins dropping in 2004, somewhat like our conclusions. Aragon and Medeiros, in their TVP estimation of a Taylor rule for Brazil, though with a different sample and slightly different specification, find the BCB’s response coefficient to inflation dropped below one after 2010. Additionally, Rodrigues estimated the BCB’s reaction function using a Markov switching estimation, finding that the majority of the time the BCB reacted in great part to the inflation gap to its target, though at times certain estimated regimes pointed to a more stimulative monetary policy, such as between 2011 and 2012.

The conclusion also shows the BCB has faced multiple changes in its implicit inflation target, which have varied across presidential and BCB terms. Visually, and unsurprisingly, the implicit inflation target’s deviation from the official target also shows some relation with inflation expectations over time, as seen on Figure 13. The results hence show much less commitment to the official inflation target in certain times, namely between 2011 and 2016, though most of the data sample still shows the BCB has been responsible when it comes to the inflation target, as the estimates for the implicit target remain largely within the bands allowed by the CMN.

A point to note is the Granger causality between the deviation of the implicit target from the official target and inflation expectations. While what was done in this paper is limited, further study into the relationship could yield relevant conclusions to understanding the impact of the BCB’s monetary policy preferences on economic agents’ expectations.

Ultimately, the main contribution of this study is to provide another framework to assess the BCB’s decisions over time, providing such in an updated TVP framework for, as well as present an implicit inflation target framework to easily provide a visual representation of the BCB’s decisions and the official target over time.

Lastly, it should be noted this study can still be advanced, with different specifications of monetary rules, such as the inclusion of an exchange rate variable to the Taylor rule, or further adjustments to the bias-correction method used. This research should be followed-up over time for a continuous assessing of changes on the TVPs in the Taylor rule.

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Appendix 1: Estimation Output for TVP models

Table 6: Model 1 – Estimating β as only time-varying parameter

Coefficient	Estimated Value	Standard Error	z-Statistic	p-value
ρ	-4.080052	0.250062	-16.31618	0.0000
$\overline{rr}$	0.069156	0.005964	11.59481	0.0000
γ	0.520082	0.217832	2.387535	0.0170
v_1	-670.1163	2026.426	-0.330689	0.7409
v_2	-702.9792	1045.290	-0.672521	0.5013
TVP	Final State	Root MSE	z-Statistic	p-value
β	2.412928	0.905056	2.666053	0.0077

Log-likelihood	38.36762	Akaine I.C.	-0.967177
Parameters	5	Schwarz I.C.	-0.805286
Diffuse priors	1	Hannan-Quinn I.C.	-0.902949

Table 7: Model 2 – Estimating β and γ as time-varying parameter

Coefficient	Estimated Value	Standard Error	z-Statistic	p-value
ρ	0.000528	0.000112	4.699920	0.0000
$\overline{rr}$	0.067951	0.003477	19.54500	0.0000
v_1	-262.2820	337.8877	-0.776240	0.4376
v_2	-33.63888	156.2058	-0.215350	0.8295
TVP	Final State	Root MSE	z-Statistic	p-value
β	0.870547	0.558089	1.559870	0.1188
γ	0.898746	0.256183	3.508214	0.0005

Log-likelihood	139.3330	Akaine I.C.	-3.922694
Parameters	4	Schwarz I.C.	-3.793181
Diffuse priors	2	Hannan-Quinn I.C.	-3.871312

Table 8: Model 3 – Estimating β as time-varying parameter with fixed $\overline{rr}$

Coefficient	Estimated Value	Standard Error	z-Statistic	p-value
ρ	-3.710086	0.212645	-17.44736	0.0000
γ	0.398050	0.305797	1.301681	0.1930
v_1	-954.5989	2589.041	-0.368708	0.7123
v_2	-657.2078	1216.875	-0.540078	0.5891
TVP	Final State	Root MSE	z-Statistic	p-value
β	1.538786	0.523789	2.937801	0.0033

Log-likelihood	32.34217	Akaine I.C.	-0.821512
Parameters	4	Schwarz I.C.	-0.691999
Diffuse priors	1	Hannan-Quinn I.C.	-0.770130

Table 9: Model 4 – Implicit inflation target

Coefficient	Estimated Value	Standard Error	z-Statistic	p-value
ρ	0.742983	0.053893	13.78630	0.0000
$\overline{rr}$	0.051069	54259861	9.41E-10	1.0000
β	3.622114	0.524541	6.905302	0.0000
γ	0.540605	0.278322	1.942370	0.0521
v_1	-239.9813	71.22085	-3.369537	0.0008
v_2	-35.39408	25.51706	-1.387075	0.1654
TVP	Final State	Root MSE	z-Statistic	p-value
π^*	0.045285	0.004865	9.309075	0.0000

Log-likelihood	228.8570	Akaine I.C.	-6.459622
Parameters	6	Schwarz I.C.	-6.265352
Diffuse priors	1	Hannan-Quinn I.C.	-6.382549

Appendix 2: Inflation Targets set by CMN

Year	Norm	Target (%)	Band (p.p.)	Upper and lower bounds (%)	Observed IPCA inflation (% p.a.)
1999	Resolução 2.615	8	2	6-10	8.94
2000		6	2	4-8	5.97
2001		4	2	2-6	7.67
2002	Resolução 2.744	3.5	2	1.5-5.5	12.53
2003*	Resolução 2.842	3.25	2	1.25-5.25	9.3
	Resolução 2.972	4	2.5	1.5-6.5	
2004*	Resolução 2.972	3.75	2.5	1.25-6.25	7.6
	Resolução 3.108	5.5	2.5	3-8	
2005	Resolução 3.108	4.5	2.5	2-7	5.69
2006	Resolução 3.210	4.5	2	2.5-6.5	3.14
2007	Resolução 3.291	4.5	2	2.5-6.5	4.46
2008	Resolução 3.378	4.5	2	2.5-6.5	5.9
2009	Resolução 3.463	4.5	2	2.5-6.5	4.31
2010	Resolução 3.584	4.5	2	2.5-6.5	5.91
2011	Resolução 3.748	4.5	2	2.5-6.5	6.5
2012	Resolução 3.880	4.5	2	2.5-6.5	5.84
2013	Resolução 3.991	4.5	2	2.5-6.5	5.91
2014	Resolução 4.095	4.5	2	2.5-6.5	6.41
2015	Resolução 4.237	4.5	2	2.5-6.5	10.67
2016	Resolução 4.345	4.5	2	2.5-6.5	6.29

2017	Resolução 4.419	4.5	1.5	3.0-6.0	2.95
2018	Resolução 4.499	4.5	1.5	3.0-6.0	3.75
2019	Resolução 4.582	4.25	1.5	2.75-5.75	4.31
2020	Resolução 4.582	4	1.5	2.5-5.5	4.52

Appendix 3: IV estimations of endogenous regressors

Table 10: IV estimation of standard error for $E[\pi]$

Variable	Coefficient	Std. Error	t-Statistic	p-value
$Constant$	0.008507	0.002337	3.640586	0.0007
$\overline{rr}_{t-1}$	0.013917	0.062808	0.22158	0.8257
$\overline{rr}_{t-2}$	-0.01474	0.11041	-0.13347	0.8945
$\overline{rr}_{t-3}$	-0.05265	0.111808	-0.47088	0.6402
$\overline{rr}_{t-4}$	-0.0112	0.063834	-0.17549	0.8615
$E[\pi]_{t-1}$	0.938528	0.128581	7.299118	0.0000
$E[\pi]_{t-2}$	-0.19395	0.140497	-1.38046	0.1747
$E[\pi]_{t-3}$	0.096797	0.114126	0.848153	0.4012
$E[\pi]_{t-4}$	0.075241	0.069898	1.076443	0.2879
γ_{t-1}	-0.17713	0.058963	-3.00414	0.0045
γ_{t-2}	0.12699	0.098314	1.291674	0.2035
γ_{t-3}	0.20795	0.124998	1.663631	0.1036
γ_{t-4}	-0.05005	0.105732	-0.4734	0.6384
Δoil_{t-1}	0.002097	0.003833	0.547156	0.5872
Δoil_{t-2}	0.009331	0.003279	2.845734	0.0068
Δoil_{t-3}	-0.00385	0.003527	-1.09221	0.281
Δoil_{t-4}	-0.00979	0.003599	-2.72075	0.0094
ΔPIM_{t-1}	0.06002	0.027928	2.149061	0.0374
ΔPIM_{t-2}	0.034542	0.026822	1.287859	0.2048
ΔPIM_{t-3}	0.000767	0.0295	0.026001	0.9794
ΔPIM_{t-4}	0.024144	0.02376	1.016173	0.3154
ΔFX_{t-1}	-0.00109	0.009563	-0.11374	0.91
ΔFX_{t-2}	0.018581	0.008366	2.221079	0.0318
ΔFX_{t-3}	-0.00549	0.007811	-0.70239	0.4863
ΔFX_{t-4}	-0.01187	0.006826	-1.73814	0.0895
D_{2005Q3}	-0.00674	0.002891	-2.33148	0.0246
D_{2008Q2}	0.005632	0.00278	2.025385	0.0492
D_{2011Q2}	-0.01087	0.00283	-3.84006	0.0004

Table 11: IV estimation of standard error for γ

Variable	Coefficient	Std. Error	t-Statistic	p-value
$Constant$	0.007177	0.005546	1.294156	0.2024
$\overline{rr}_{t-1}$	-0.254582	0.149543	-1.702401	0.0957
$\overline{rr}_{t-2}$	-0.055359	0.264069	-0.209639	0.8349
$\overline{rr}_{t-3}$	0.035849	0.262385	0.136627	0.8919
$\overline{rr}_{t-4}$	0.140576	0.150825	0.932048	0.3564
$E[\pi]_{t-1}$	0.005624	0.303546	0.018527	0.9853
$E[\pi]_{t-2}$	-0.041566	0.336719	-0.123444	0.9023
$E[\pi]_{t-3}$	-0.324956	0.276497	-1.175258	0.2462
$E[\pi]_{t-4}$	0.333611	0.168602	1.978689	0.0541
γ_{t-1}	0.103548	0.144299	0.717592	0.4768
γ_{t-2}	0.682389	0.233851	2.918046	0.0055
γ_{t-3}	-0.036705	0.302682	-0.121265	0.904
γ_{t-4}	0.310533	0.257959	1.203809	0.2351
Δoil_{t-1}	0.009625	0.009362	1.028074	0.3095
Δoil_{t-2}	0.009767	0.007719	1.265458	0.2124
Δoil_{t-3}	0.004704	0.008314	0.565823	0.5744
Δoil_{t-4}	-0.00486	0.008464	-0.574232	0.5687
ΔPIM_{t-1}	0.112262	0.068166	1.646889	0.1067
ΔPIM_{t-2}	0.116288	0.062866	1.849771	0.0711
ΔPIM_{t-3}	0.152679	0.068129	2.241032	0.0301
ΔPIM_{t-4}	0.113436	0.055393	2.04785	0.0466
ΔFX_{t-1}	-0.023488	0.022606	-1.038997	0.3045
ΔFX_{t-2}	0.015929	0.019685	0.809182	0.4228
ΔFX_{t-3}	0.019708	0.018045	1.092173	0.2807
ΔFX_{t-4}	0.022962	0.016051	1.430599	0.1596
D_{2020Q2}	-0.087754	0.007353	-11.93470	0.0000