Taylor Ruling Brazil – a System Dynamics Model for Monetary Policy Feedback

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Abstract

The paper introduces a system dynamics Taylor rule model for monetary policy feedback between the real interest rate, inflation and GDP growth for the 2004 to 2011 period in Brazil. The nonlinear Taylor rule for interest rate changes considers gaps and dynamics of GDP growth and inflation as well as monetary policy sluggishness. The results outline a high degree of endogenous feedback for monetary policy and inflation, while GDP growth remains strongly exposed to exogenous economic conditions. Furthermore, stocks of absolute monetary policy flows show that Brazilian monetary policy has been more driven by growth than by inflation considerations in the period under investigation. Moreover, simulation exercises under different future scenarios highlight potential outcomes of the new monetary policy strategy since August 2011. Regarding the new monetary policy strategy, an initial calibration until June 2012 suggests a new Taylor rule function structure with a recession avoidance preference. In total, the strong historical fit of the Taylor rule model calls for continued investigation for the Brazilian case and an application of the model to other inflation targeting economies.

Key words: Brazil, business cycle, monetary policy, system dynamics, Taylor rule

Introduction

Policymakers and academics have been intensively debating monetary policy and the extent to which a central bank should steer the economy. The debate about monetary policy has witnessed remarkable waves with booms and busts of theories including Keynesian theories [Keynes, 1936], Monetarism [Friedman, 1970] and Real Business Cycles [Kydland and Prescott, 1982]. One of the most established aspects of today's macroeconomic models is the interest rate rule of John Taylor [Taylor, 1993]. According to the Taylor rule, the central bank flexibly adjusts the interest rate in order to achieve a policy target combination of inflation and output.

With the introduction of an inflation targeting regime in 1999, the Taylor rule has also been considered by the Brazilian Central Bank in its macroeconomic models [Araújo et al., 2009].

Since then, Brazil has witnessed a remarkable stabilization process and an economic boom from 2004 on. Prudent monetary policy was a core element of making the country more resilient to shocks, including the 2008 financial crisis and the European debt crisis. This raises the question of how the Brazilian Central Bank (BCB) has approached the Taylor rule over the period from 2004 to 2011.

The goal of this paper is to introduce a small Taylor rule system dynamics feedback model for the Brazilian economy. The dynamic hypothesis is that the behavior of the real interest rate can be explained by its interaction with GDP growth and inflation, the elements of the Taylor rule. The research question is to what degree the Taylor rule hypothesis can explain the behavior of the 2004 to 2011 business cycle and to what extent growth and inflation are driven by monetary policy and vice versa. This analysis is supplemented by simulations of the business cycle, both for the past and including two future scenarios, showing the degree to which different Taylor rules lead to different outcomes of the business cycle. In addition, a calibration to more recent data will investigate which of the Taylor rules applied in the simulation is more likely to reflect the monetary policy easing since August 2011. In methodological terms, the paper makes a case for the applicability of system dynamics to macroeconomic modeling for monetary policy purposes.

Chapter 1 addresses the Taylor rule in general and its consideration by the BCB. Chapter 2 will introduce, calibrate, discuss and validate the Taylor rule feedback model. Chapter 3 will simulate the business cycle, including two future scenarios, under different monetary policies. These policies will also be validated before some final conclusions are drawn.

1. Taylor rule, macroeconomic modeling and monetary policy

John B. Taylor [1993] proposes an interest rule related to counter-cyclical Keynesian-type policies. The optimal policy is to adjust interest rates with regard to the changes in price level and real output, placing some weight on each component. The contribution of Taylor is to raise normative and positive implications [Clarida et al., 1999]. Taylor addresses the principles of gradual inflation targeting via the nominal interest rate. He proposes that the current nominal interest rate $\boldsymbol{i}_t$ should be a sum of the long run equilibrium interest rate $\boldsymbol{i}^*$, the inflation gap $\boldsymbol{\pi}_t - \boldsymbol{\pi}^*$ and the output gap $\boldsymbol{x}_t = \boldsymbol{y}_t - \boldsymbol{y}^*$ (formula 1). The positive implication is the description of U.S. monetary policy between 1987 and 1992, for which Taylor picks the following parameters:

$$\boldsymbol{i}_t = \gamma_\pi(\boldsymbol{\pi}_t - \boldsymbol{\pi}^*) + \gamma_x \boldsymbol{x}_t + \boldsymbol{i}^* \quad \gamma_\pi > 1, \gamma_x > 0$$
$$\boldsymbol{i}_t = 1.5(\boldsymbol{\pi}_t - 2) + 0.5\boldsymbol{x}_t + 2$$

(1) Taylor rule and U.S. specification 1987-1992 [Taylor, 1993]

One important implication of the rule is the role of the real interest rate. The nominal interest rate must rise more than in a one-tone fashion with inflation, which leads to the restriction $\gamma_\pi > 1$. According to the Fisher hypothesis [Fischer, 1930], the real interest rate is the difference between the nominal interest rate and the expected rate of inflation. Agents in the economy only respond to changes in the real interest rate since both higher inflation and higher nominal interest rates increase the opportunity costs of holding money balances

[Mundell, 1963]. Furthermore, Taylor assumes a countercyclical monetary policy with respect to the output gap, leading to the restriction $\gamma_x > 0$. The Taylor rule has also seen many extensions, including forward-looking expectations, monetary policy sluggishness, exchange rates and difference rules, which consider interest rate changes instead of levels [Carare and Tchaidze, 2005, Amato and Laubach, 2003]. Nevertheless, the Taylor rule has also been subject to criticism regarding its implementation and investigation. The information requirements for measuring the output gap may lead to significant difficulties in implementing a Taylor rule [Orphanides, 2000]. Furthermore, running Taylor rule regressions at the time of a study with ex-post available data does not represent the same information set a central bank had at the time it took a policy decision [Österholm, 2005].

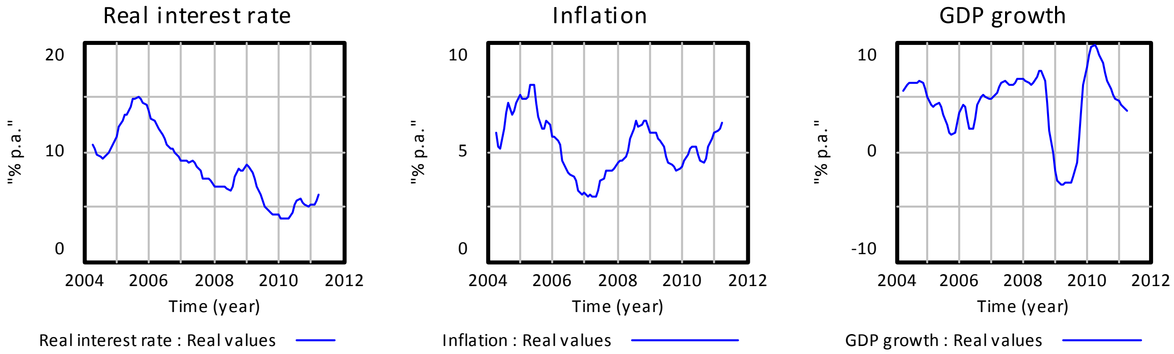
The introduction of inflation targeting in 1999 has fuelled the development of macroeconomic models and the consideration of certain Taylor rules at the BCB and the market nowadays agrees that the BCB follows a Taylor-type monetary policy rule [De Carvalho and Minella, 2009; Araújo et al., 2009]. The lack of an inflation targeting regime sample initially forced the BCB to focus on theoretical simulations within models [Araújo et al., 2009]. In its first working paper, the BCB already considered interest rate rules as central elements of future models [Bogdanski et al., 2000]. A Taylor rule should include an inflation target deviation, an output gap and an interest rate lag component. By 2002, the BCB conducted Taylor rule experiments with its own end-of-year inflation targets for 2000:Q1 until 2002:Q4 against the IMF program's quarterly inflation targets present at that time [Bogdanski et al., 2001]. Subsequently, the BCB simulated a rational expectations macro model for Brazil and tested several forward and backward looking monetary policy rules with data starting after the Plano Real implementation in 1994 [Bonomo and Brito, 2002]. The BCB proceeded to actually estimating model parameters in small to medium sized Keynesian models. It also shifted the focus to constructing dynamics stochastic general equilibrium (DSGE) models [De Almeida et al., 2003], which included certain variations of the Taylor rule [Muinhos and Alves, 2003, Minella and Souza-Sobrinho, 2009]. The BCB presumably based its monetary policy decision in October 2011 on a scenario stemming from their current DSGE model named SAMBA (Stochastic Analytical Model with a Bayesian Approach), which also includes a Taylor rule for monetary authority in the model [De Castro et al., 2011, Bristow and Soliani, 2011]: "[SAMBA] has in its DNA some of the idiosyncrasies of the Brazilian economy. We will use this model at least while this highly complex situation lasts [i.e. potential risks of the European debt crisis for Brazil].", declared Carlos Hamilton - Deputy Governor for Economic Policy and member of the COPOM.

2. Taylor rule model

2.1. Reference modes, dynamics hypothesis and causal-loop diagram

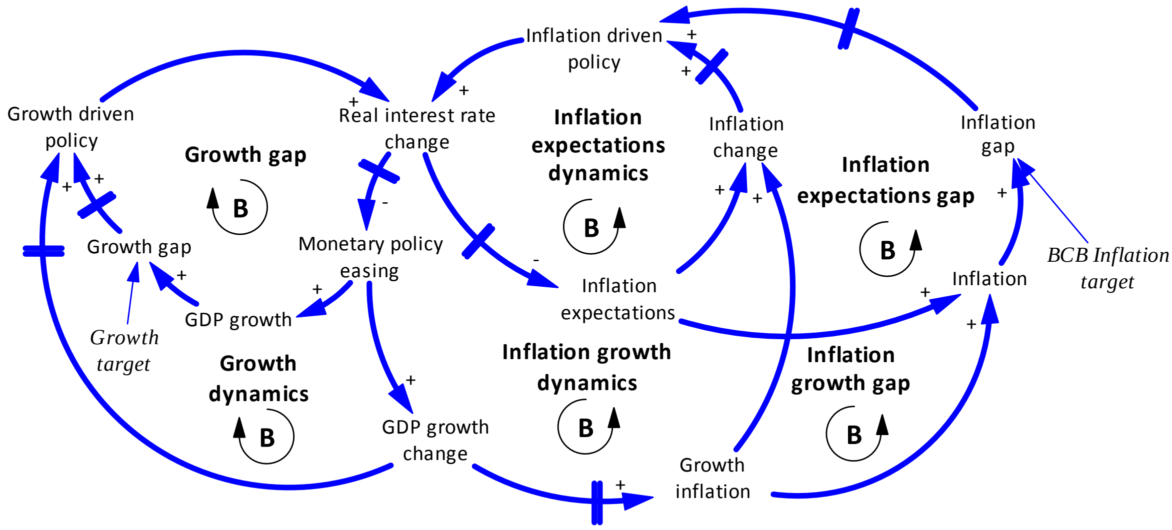
The goal is to exploit the interaction between the real interest rate, inflation and GDP growth as the reference modes with a Taylor rule hypothesis (figure 1).

Figure 1: reference modes of the Taylor rule hypothesis [BCB, 2012]



The Taylor rule causal loop diagram (CLD) considers five feedback loops, all of which feed back into real interest rate changes (figure 2). The dynamics loops describe how changes in inflation and growth interact with the real interest rate. The gap loops refer to how the levels of inflation and growth affect monetary policy as they deviate from their policy targets. The inflation expectation and inflation growth loops are the monetary policy feedback loops via which monetary policy interacts with inflation. The growth loops are the loops via which the monetary authority steers the growth in output in the economy.

Figure 2: causal loop diagram



In the inflation expectations gap, the central bank alters the real interest rate in order to prevent inflation from over- or undershooting the inflation target [Bryant et al., 1993]. It does so by moving the nominal interest rate in a more than one-to-one relation with inflation, which is the restriction of the Taylor rule [Taylor, 1993]. As monetary policy is adjusted, the change in the real interest rate alters inflation expectations of forward-looking firms with inflexible price setting [Rotemberg, 1987]. These firms realize that real interest rate changes will affect future growth and they know that they will be inflexible in setting prices at that future time. The rational firms therefore adjust prices already today, based on the monetary policy signal. Assuming a real interest rate increase, the firms adjust their inflation expectations downward and set lower prices than intended before. This leads to lower inflation and a negative inflation gap. Since the mandate of the central bank is to stick to the inflation target, it will lower the real interest rate in response [Orphanides, 2007]. The positive arrow of inflation change on inflation driven policy states that an increase in inflation triggers positive inflation driven policy, which leads to a rise in the real interest rate. Correspondingly, a decrease in inflation, a disinflation or even a deflation at the extreme, triggers negative inflation policy, which causes a real interest rate decrease.

Yet as current inflation changes, the central bank not only raises the real interest rate with respect to the current inflation gap, but also with respect to current inflation dynamics. Current inflation dynamics raise the probability of future inflation due to the autoregressive characteristics of inflation [Svensson, 1997]. Therefore, the central bank avoids future inflation gaps by taking care of current inflation dynamics. This results in a balancing inflation expectation dynamics loop in addition to a balancing inflation expectations gap loop.

The inflation expectations loops involve two delays. First, it is assumed that it takes some time until rational firms have factored real interest changes into their price expectations, representing an empirical expectation lag [Fuhrer and Moore, 1995a, Roberts, 2001]. The expectation delay is assumed to be caused by sticky information [Mankiw and Reis, 2002]. Furthermore, the adjustment of the real interest involves a monetary policy delay [Clarida et al., 1999, Woodford, 1999, Cobham, 2003]. The central bank is subject to imperfect information as inflation and output data take time to collect. The central bank may also be sluggish due to uncertainty with respect to its models and their parameters.

The growth loops are the feedback loops between monetary policy and GDP growth. A changing real interest alters demand in the economy and leads to a change in GDP growth as described by the IS-equation [Clarida et al., 1999]. For instance, a falling real interest rate triggers inter-temporal substitution of consumption. The consumers save less for tomorrow and consume more today. The reverse holds for an increase in the real interest rate, a monetary tightening.

The growth gap loop refers to the GDP growth level component. The increase in GDP growth leads to an overshoot of the growth target, causing a positive output gap. This triggers an increase of real interest rate by the monetary authority as it follows the mandate of minimizing the gap [Orphanides, 2007]. Furthermore, the central bank is also concerned about GDP growth dynamics, since currently upward trending growth indicates a future positive output gap [Svensson, 1997]. A rise in GDP growth therefore results in an increase of the real interest rate, both with respect to the gap and to the dynamics of growth.

The growth feedback loops involve two delays. The first delay is related to the lag between real interest rate changes and the impact on GDP growth. This is assumed to be a sticky information delay on behalf of the consumers [Mankiw and Reis, 2002]. The second delay is the smoothing of the real interest rate with respect to the output gap. Importantly, growth and inflation monetary policy delays are separate delays in order to distinguish between growth policy and inflation policy inertia. This may be related to different model and data uncertainty or the different extent to which moves with respect to inflation or growth cause financial market volatility [Woodford, 1999, Cobham, 2003].

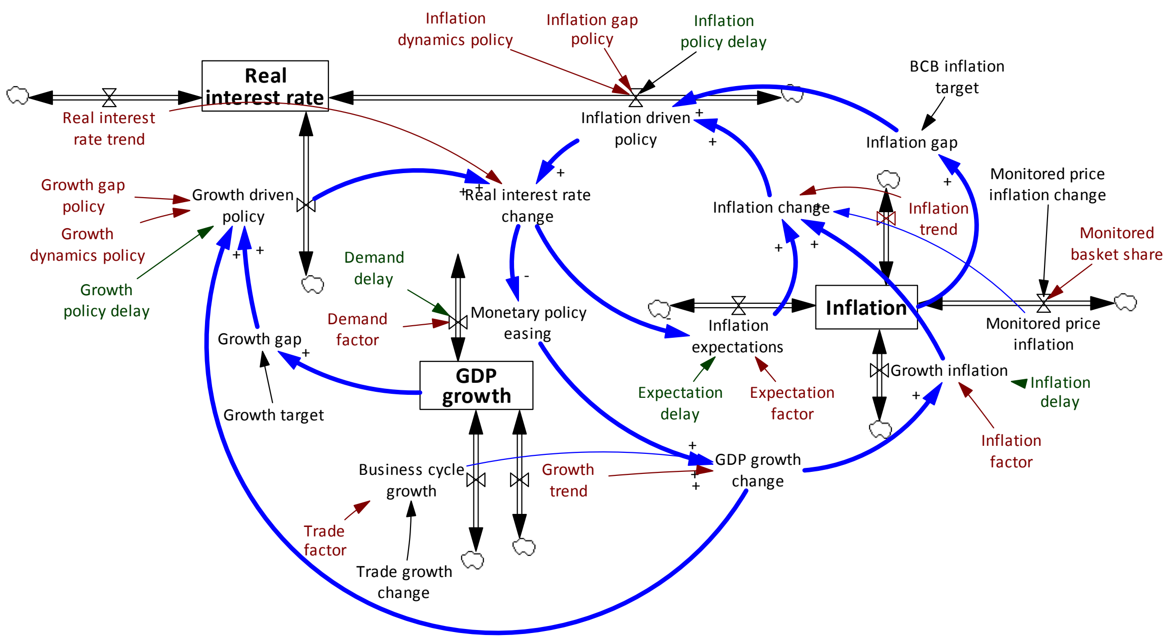
The inflation growth loops describe how inflation responds to past GDP growth dynamics and refer to price setters with adaptive expectations [Roberts, 1997]. This is because the rational firms have already considered the effects of changing GDP growth by considering the monetary policy signal in the expectation loops. A real interest rate decrease raises GDP growth in the economy again via inter-temporal substitution of consumption [Clarida et al., 1999]. Backward looking agents that look at the past state of the economy observe the higher growth and adjust their prices upwards [Roberts, 1997]. This increases the inflation gap and causes positive inflation dynamics, both leading to a monetary policy tightening.

The two inflation growth feedback loops are subject to three delays. The delay of the real interest rate on GDP growth is the same demand delay as for the growth loops. The delayed effect of GDP growth on inflation represents the backward looking delay of adaptive firms [Gali and Gertler, 1999]. The final delay related to monetary policy is the same inflation policy delay as in case of the inflation expectation loops with the rational firms.

2.2. Stock-and-flow diagram, calibration and description of behavior

The stock and flow diagram considers the actual structure of the model, including stocks, flows, estimated parameters and external inputs [Sterman, 2000]. The real interest rate stock is subject to three flows. Inflation driven monetary policy and growth driven monetary policy are the two flows related to inflation and GDP growth in the Taylor rule (figure 3). Both flows are subject to individual third order monetary policy delays. The monetary policy factors reflect the sensitivity of the real interest rate adjustment towards growth and inflation gaps and dynamics. Furthermore, the real interest rate trend is a flow that resembles the long-run equilibrium path of the Brazilian real interest rate. Notably, the real interest rate is not subject to any external input. The inflation driven and growth driven policy flows are part of the internal feedback structure while the real interest rate trend is a constant trend that will be estimated during calibration.

Figure 3: stock-and-flow model



The inflation stock has four flows. The inflation expectations flow is related to the rational firms in the economy while the growth inflation flow is related to the backward looking firms. Supervised basket inflation is the external inflation flow that stems from the inflation of government administered prices and contractual clauses, which together account for 30% of the IPCA's basket. This kind of administered inflation has also been considered as a separate part of inflation from free inflation in BCB models [Muinhos and Alves, 2003]. Supervised basket inflation is considered as a shock flow to inflation. Furthermore, the inflation trend reflects the long-run trend of inflation that will be estimated during calibration.

Given this structure as a stock, inflation becomes a hybrid Phillips curve [Gali and Gertler, 1999] subject to a lagged effect of GDP growth, current inflation expectations, monitored price inflation shocks and a long-run trend.

GDP growth is determined by three flows. The endogenous monetary policy growth flow is related to the effect of real interest rate changes on growth through intertemporal substitution. The growth trend is the constant steady-state growth term to be estimated through optimization. The general economic environment is proxied by the real trade volume flow. Trade volume is a favourable proxy for the business cycle. Net-exports are countercyclical in emerging economies while trade volume as a whole has a positive empirical relationship to growth [Harrison, 1996, Chang and Fernández, 2010]. Trade also leads to the synchronization business cycles since trade linkages cause demand spill-over effects across economies [Calderon et al., 2007].

To summarize, the principle structure and reasoning of the Taylor rule model largely corresponds to a small new Keynesian baseline model by Clarida et al. [1999]. The Taylor rule model covers an IS equation for GDP growth, a Phillips equation for inflation and addresses monetary policy. However, the Taylor rule model does not only include levels of inflation and growth, but also dynamics. Most importantly, it takes monetary policy as a Taylor rule of continuous interest rate changes, which is related to first difference Taylor rules [Fuhrer and Moore, 1995b, Orphanides, 2007]. The real interest rate level itself is not part of the internal feedback structure, but is considered as the central reference mode. A first difference Taylor rule has also been applied to the case of Brazil for the inflation targeting-period until 2005, with inflation, output gap and smoothing, but not considering growth and inflation dynamics [Holland, 2005]. Opposing the Taylor rule approach in here, the standard small new Keynesian models, with the exception of Woodford [2001], take monetary policy as an optimization problem of the central bank with respect to future outcomes of growth and inflation [Clarida et al., 1999]. Furthermore, the Taylor rule model drops income and inflation expectations but considers the Brazilian phenomenon of monitored prices and adds trade volume to GDP growth as opposed to standard small new Keynesian models.

2.3. Model calibration and description of behaviour

The real interest rate has a goodness of fit of 96% and a mean square error (MSE) of 0.42 percent per year. The goodness of fit of inflation is 88% with a MSE of 0.20 percent per year. GDP growth achieves a goodness of fit of 91% and a MSE of 0.88 percent per year. All simulated data have zero mean bias and almost or actually no unequal standard variation. Therefore, the MSEs stem from the unequal co-variation in the variables. This shows that the dominant trend and mean values are captured and that the deviation from the actual series relates to the point-by-point deviation [Schwaninger and Grösser, 2009]. Furthermore, the null hypothesis can be rejected for all parameters applying a sensitivity analysis with payoff percentage of 5 and corresponds to the 95% confidence bounds [Ventana Systems, 2011]. Yet the monthly residuals are first-order auto-correlated. In total, the model captures the systematic trends and its parameters are highly significant while the residuals exhibit autocorrelation (table 1).

Table 1: calibration parameter results

	Real interest rate	Inflation	GDP growth
Factors	Growth dynamics pol. = 0.61 Growth gap policy = 1.08 Inflation dynamics policy = 2.19 Inflation gap policy = 3.01	Expectation factor = -0.24 Inflation factor = 1.00 Monitored basket share = 2.86	Demand factor = -0.77 Trade factor = 1.46
Delays	Growth policy delay = 0.44 Inflation policy delay = 0.73	Expectation delay = 0.152 Inflation delay = 1.33	Demand delay = 0.05
Trends	Real interest rate trend = -1.66	Inflation trend = 0.25	Growth trend = -0.99
Initial value	Real interest rate = 11.22	Inflation = 6.61	GDP growth = 7.24

The BCB increases the real interest rate by 5.20% in response to a 1% increase in inflation. 2.19% of the increase is related to inflation dynamics while 3.01% is related to the inflation gap. With regard to GDP growth, the BCB raises the real interest rate by 1.69% in response to a 1% increase in GDP growth, with 1.08% being related to the growth gap and 0.61% related to growth dynamics. The growth gap is defined as the deviation of an assumed 4.50% GDP growth target, which closely corresponds to the average GDP growth rate of 4.43% of the sample period. Given the obtained parameters, the central bank is therefore almost three times more sensitive to inflation as opposed to GDP growth changes. However, it is less sluggish in adjusting monetary policy to growth dynamics as the growth policy delay amounts to only 0.44 years compared with 0.73 years for inflation policy. Finally, the real interest rate decreases by 1.66% per year according to its trend, reflecting the significant long-run decrease of the real interest rate over the sample period. Given these results, monetary policy is described by the following Taylor rule (formula 2):

$$\frac{dr}{dt} = 0.61\frac{dy_{t-0.44}}{dt} + 1.08\frac{y_{t-0.44} - 4.50}{dt} + 2.19\frac{d\pi_{t-0.73}}{dt} + 3.01\frac{\pi_{t-0.73} - \pi^*_{t-0.73}}{dt} - \frac{1.66}{dt}$$

(2) Brazilian Taylor rule

The sample period starts with the first regular monetary policy cycle in 2004, following the confidence crises of the economy, which was triggered by the consideration of a Brazilian debt moratorium by presidential candidate Lula da Silva in 2002 (figure 4) [Miller et al., 2003]. By mid-2003, the monetary tightening efforts of the BCB under the new BCB president Henrique Meirelles and the fiscal austerity of the Lula administration took effect and were able to stabilize the Real and to tame inflation expectations [Bevilaqua et al., 2008]. The subsequent cuts in the SELIC interest rate strongly supported economic growth, which stood at 5% in 2004. At the end of 2004, the BCB entered its first regular monetary policy tightening cycle that was not related to any internal or external shock but to overheating GDP growth and monetary policy tightening in the U.S. [Bevilaqua et al., 2008]. The BCB was relatively aggressive and lifted the nominal SELIC rate up to 19.75% in order to build up credibility. Inflation finally stood at 7.6% within the target band by the end of 2005, also driven by inflation of government monitored prices.

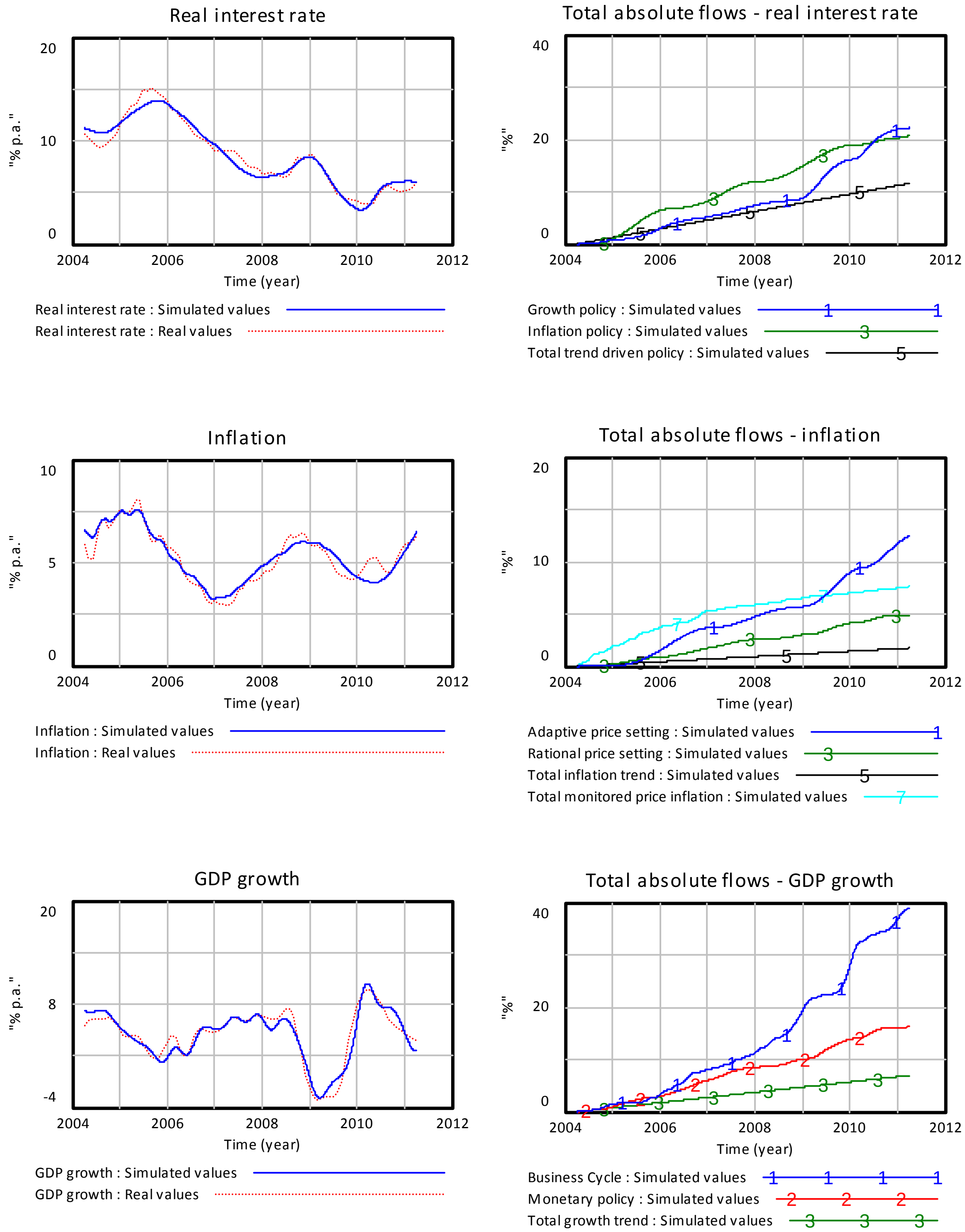
Meanwhile, external accounts improved significantly as Brazil saw increased demand for its commodities, especially from China. Furthermore, Brazil witnessed rising internal markets as anti-poverty programs provided for upward social mobility. Moreover, economic stability translated into booming financial markets. These favorable dynamics provided for historically positive developments into late 2008. The BCB decreased the SELIC rate to a low of 11.25%, the real interest rate fell correspondingly to 7%, and inflation stood below the target at 3.1% by the end of 2006. GDP growth marked at 6.7% by the end of 2007, also driven by decreasing interest rates. Meanwhile, President Lula entered a second administration after winning the 2006 election. Moreover, the exchange rate gradually appreciated and BCB started to accumulate foreign currency reserves. The reserves, in combination with the government's debt reduction and debt de-dollarization, led to an international net-creditor position of Brazil. Driven by these dynamics, Brazil gained investment grade BBB- rating from Standard & Poor's (S&P) in April 2008, which further boosted the economic outlook [Alves and Caminada, 2008].

By the end of 2008, Brazil's stabilization process was finally challenged. The country got hit by an investor flight and a plunge in exports as the Lehman default shocked financial markets and global trade fell abruptly. Yet Brazil proved to be well isolated from the financial turmoil and the BCB only had to lift the SELIC rate up to 13.75% in addition to certain other stabilization efforts, such as the provision of liquidity in the foreign exchange market [Mesquita and Torós, 2010, Stone et al., 2009]. GDP stagnated in 2009 due to the trade shock, and the BCB temporarily decreased the SELIC rate below 10% in order to support demand, yet exports and internal demand were already picking up by the end of 2009. Brazil witnessed a remarkable economic rebound with growth standing at 7.5% in 2010. The 2010 presidential election was won by Lula's succession candidate Dilma Rousseff, as Lula had to step down due to the constitutional restriction of two consecutive terms.

On January 1, 2011, Alexandre Tombini also took over the presidency from Henrique Meirelles at the BCB, while the institution faced opposing external and internal headwinds. On the external front, commodity demand fell amid OECD stagnation related to European debt crisis, low U.S. growth and a cool down of the Chinese economy [Tombini, 2011]. On the internal front, the overheating rebound led to inflation crossing the 6.5% upper bound of the target band for the first time since 2005.

In addition to the calibration, auxiliary stocks of the real interest flows have been constructed, which accumulate the total absolute monetary policy flows over time (figure 4). The result is that the total absolute moves with respect to growth have been more pronounced than with respect to inflation during the sample period while the exogenous constant trend has been accounting for about one-fifths of monetary policy moves. The observation of a dominant growth policy is principally caused by the 2009 recession and the 2010 rebound, when GDP growth gaps and changes highly exceed those of inflation. Therefore, monetary policy has been more growth than inflation driven over the horizon of the sample, despite the fact the BCB operates in an inflation targeting regime. The absolute inflation flows show that inflation has been dominated by adaptive price setting with respect to GDP growth. This observation principally stems from the 2008 to 2011 period, when it seemed to be more difficult to form correct rational expectations in a volatile environment caused by the external shock. Furthermore, monitored price inflation had a strong impact on inflation until 2007, but became less important in the following years. Expectations have been responsible for about one-fifths of all inflation changes, a somehow inferior role during the sample period. Finally, the inflation trend exhibited a rather small impact. Furthermore, the auxiliary stocks for the growth flows show that exogenous trade flows outperformed endogenous monetary policy flows, especially for the 2008 to 2011 period with the slump and rebound in trade growth as a proxy of demand. Monetary policy has only been responsible for about one-quarter of the changes in GDP growth, which outlines the somehow limited impact of monetary policy, especially following an external shock.

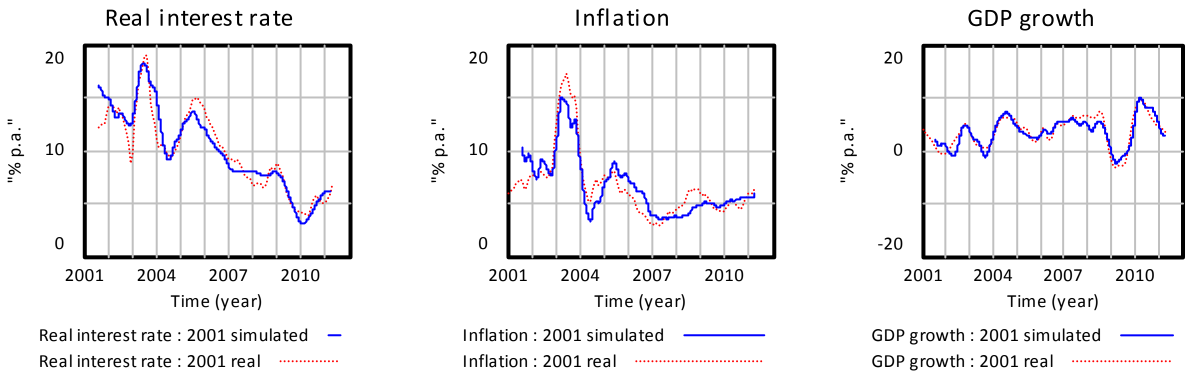
Figure 4: calibration results



2.4. Validation of model behaviour

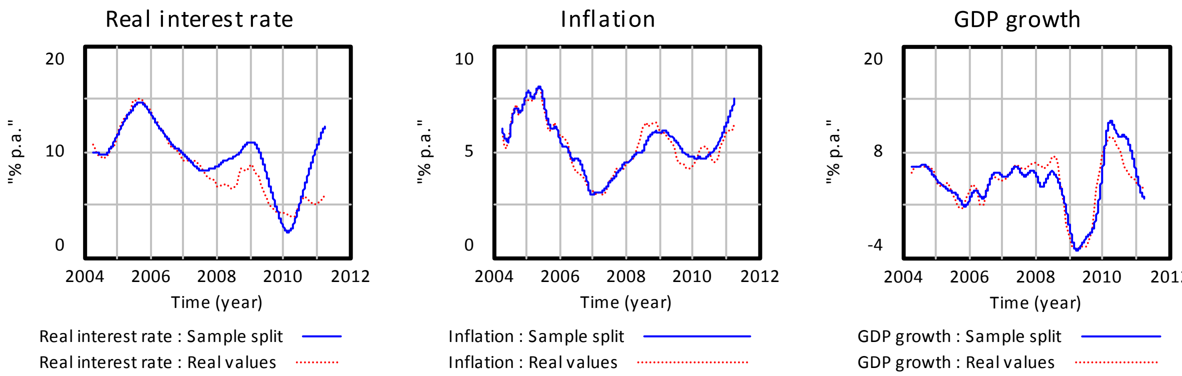
Behaviour tests refer to the ability of the model structure to match the behaviour observed in the real system [Forrester & Senge, 1980]. In order to get a broader picture of the model under different sample periods, the model is estimated for the 2001 to 2011 period, including the 2002 to 2003 confidence crisis. The starting point is motivated by the fact that the BCB's inflation expectations data series starts in July 2001 [BCB, 2012]. To recall, system dynamics behaviour prediction focuses on pattern instead of point prediction [Forrester and Senge, 1980]. The calibrated simulation closely matches the real interest rate and GDP growth variables (figure 5). However, inflation exhibits an upward trend starting in 2007 in the simulated results versus medium-run swings in the real values. This is because of the much lower inflation factor with respect to GDP growth in the 2001 to 2011 estimation.

Figure 5: 2001-2011 behaviour reproduction test



Furthermore, the model is optimized with regard to the 2004:Q2 to 2007:Q3 period and, given the estimated parameters, is run until 2011:Q1 (figure 6). The sample is therefore split into two artificial subsamples of equal length. The first subsample is employed for calibration and the second subsample for validation of the pattern prediction by the model [Schwaninger and Grösser, 2009, p. 9009]. The model takes the parameters of relatively low business cycle volatility until 2007 and is exposed to periods of high business cycle volatility starting in 2008 with the external trade shock. As expected, the reproduced behaviour gets very close to the actual behaviour until 2007:Q3. Afterwards, the simulated interest rate departs from actual levels. In the 2004-2007 calibration, a combination of a less decreasing real interest rate trend and a higher growth policy factor lead to a higher and more responsive real interest rate during the 2007:Q4 to 2011:Q1 period. Yet while the point prediction for the real interest rate is less accurate, the pattern of the model's dynamics does not suffer from the sample split. Furthermore, the model is able to still capture the essential dynamics of inflation and GDP growth, both with respect to levels and to the pattern of behaviour.

Figure 6: pattern reproduction test



3. Business cycle scenarios and monetary policies

3.1. Base Scenario: old and new BCB strategy

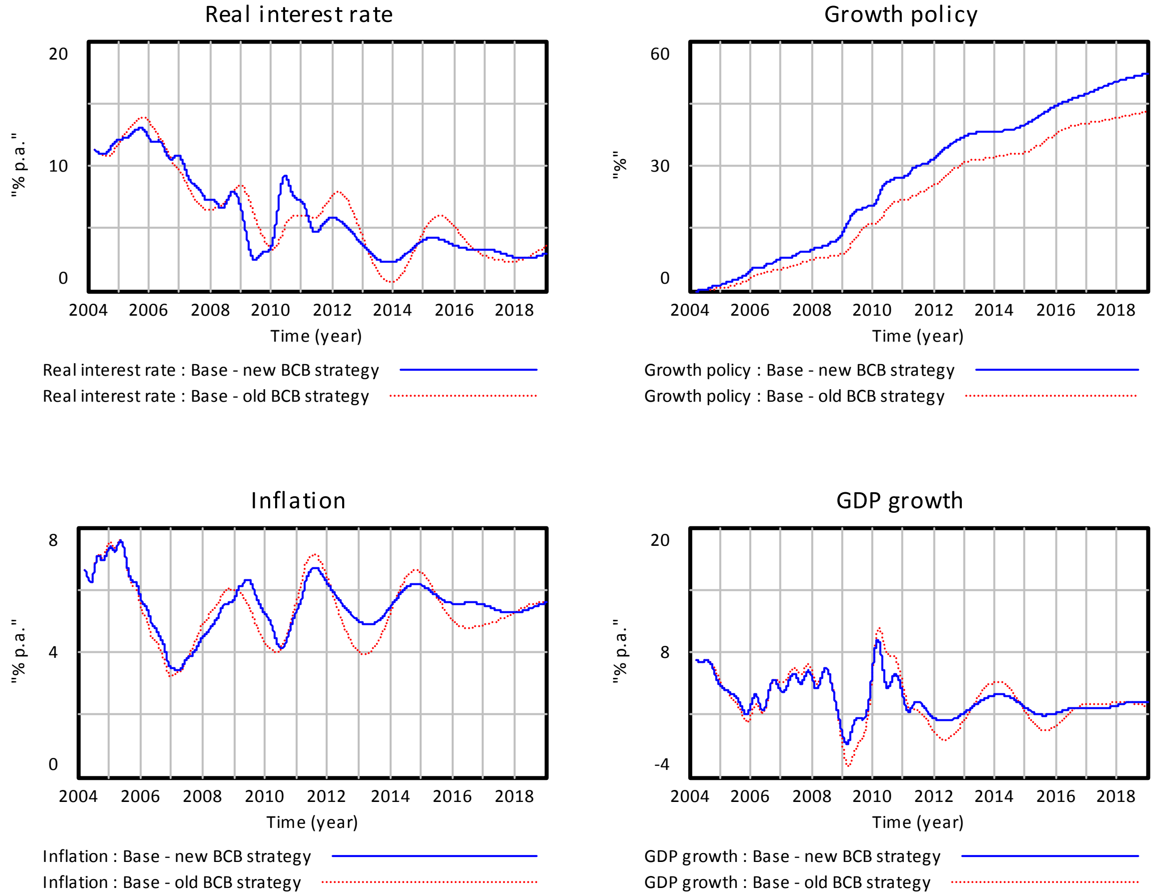
The base scenario is the most likely scenario, including slower growth but less inflation pressure [IMF, 2011, BCB 2011c]. For the real interest rate, it assumes a continued decreasing trend as the government sticks to primary surpluses. For the inflation inputs, long-run monitored price inflation temporarily increases during the 2014 World Cup and 2016 Olympic Games years due to infrastructure overheating [Guerrero, 2010]. Furthermore, the inflation trend is assumed to remain flat, meaning that the government neither increases nor decreases the pressure on inflation through its spending [Economist, 2011c, Barrionuevo, 2011]. With regard to growth, trade growth decreases temporarily in 2012, reflecting a continued negative external outlook [IMF, 2011, BCB, 2011b]. Afterwards, the 2014 World Cup, the 2016 Olympic Games and the 2014, 2018 presidential elections [Economist, 2011a], assuming an election year effect of government spending [Economist, 2010], both inject a temporary increase in GDP growth via the growth trend.

The old BCB strategy refers to simulating the future evolution of the model with the estimated parameters of the 2004:Q2 to 2011:Q1 calibration, as if the new COPOM under Alexandre Tombini would continue past monetary policy until 2019. The new COPOM under Alexandre Tombini however changed the strategy of the BCB in its August 31, 2011 meeting. The COPOM surprisingly lowered the SELIC target rate from 12.5% to 12.0% despite upward trending inflation dynamics and a positive inflation gap. It based its decision on a bearish global growth outlook with potential negative spill-over effects on Brazilian growth prospects and on lower import prices [BCB, 2011a]. This decision ultimately surprised market participants, who viewed the decision as a potential BCB strategy switch in the favour of GDP growth and at the expense of inflation control [Economist, 2011b]. The new BCB strategy becomes more sensitive to GDP dynamics more concerned about the growth gap, increasing growth policy factors by 50%, and also decreases its growth policy sluggishness by two months.

The new BCB strategy would have responded to the post-Lehman GDP growth shock by a faster reduction in interest rates through the growth dynamics loop. The real interest rate would have fallen to as low as 2.5%. Furthermore, the BCB would have quickly absorbed the overshooting rebound of growth in 2009 in the growth dynamics loop. For the future scenarios, the new policy provides for smoother interest rates in the absence of growth shocks while approaching the same long-run levels as under the old BCB policy. In total, the new BCB strategy yields more historical short-term fluctuations in the interest rate as the BCB become very nervous with regard to growth fluctuations in the growth dynamics loop. This also makes the convergence of inflation expectations more difficult.

In the historical business cycle, inflation is about the same as under the old BCB policy (figure 7). This is because the inflation loops are not subject to the growth policy parameters. For the future scenario, the 2011 inflation overshoot would be less pronounced due to lower growth triggered inflation from the 2010 rebound in the growth inflation loop. Also, inflation would suffer from smaller medium-term swings and tend towards the same long-run target as for the old BCB policy. Importantly, the new BCB strategy achieves its goal of smoothing GDP growth through fast and pronounced countercyclical monetary policy moves. It would have achieved a 1% higher average growth rate during the severe recession in 2009 and provide for slightly higher average growth rates in total.

Figure 7: new BCB policy in base scenario



3.2. Bust scenario: new BCB strategy and recession avoidance

The bust scenario considers a combination of external turmoil and internal inflation pressure with downside risks becoming fully pronounced. It assumes that an OECD double dip recession and lower Chinese growth lead to falling demand for Brazilian exports, which also spills over to a cool down of internal demand [IMF, 2011, BCB, 2011b]. Trade declines in 2012 and only partially rebounds afterwards. The event effects of 2014, 2016 and 2018 are the same as for the base scenario. Concerning interest rates, capital markets witness an investor flight into safe assets and out of emerging markets, for instance triggered by a worsening of the European debt crisis. In response, the BCB needs to raise the real interest rate in 2012 in order to prevent significant Real devaluation. Opposed to the base scenario, the rise in monitored price inflation in the World Cup and Olympic Games years will not remain temporary. Furthermore, the government puts continued upward pressure on inflation with inefficient spending and consumption feeding into an upward inflation trend.

Under the new BCB strategy, the 2012 investor flight does not show an effect on the real interest rate since the BCB is too much concerned about the GDP growth gap and enters a strong monetary tightening until late 2013. Afterwards, the real interest rate decreases again as growth rebounds and levels out around 1.5% in the long run. The business cycle swings are more pronounced than under the base scenario. In the long run, GDP growth reaches an equilibrium of only 1% while inflation stays above the upper target bound at 7%.

Importantly, the gap loops start to dominate over the dynamics loop in the model since the BCB is unable to achieve both growth and inflation targets.

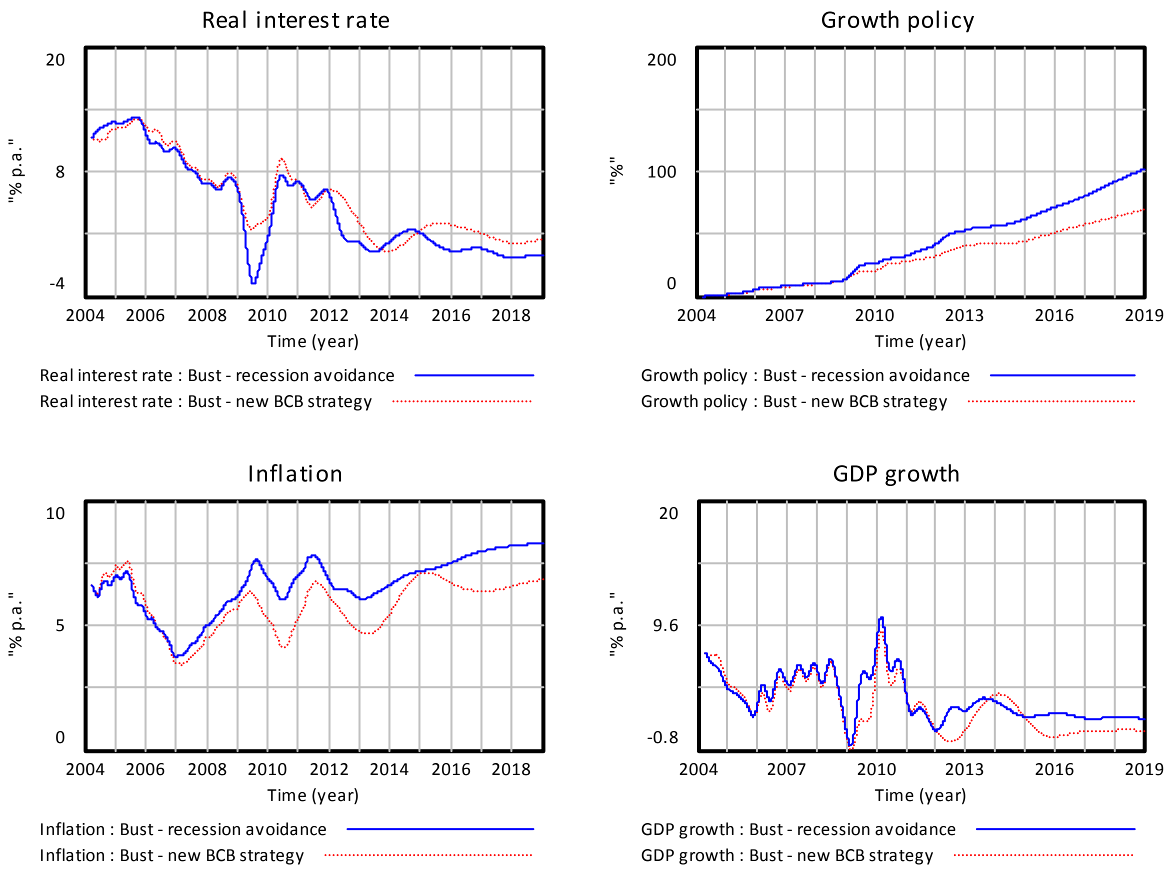
The recession avoidance policy considers a high ambition of the new BCB to avoid negative growth gaps. The BCB assumes a recession avoidance Taylor rule with a nonlinear growth gap [Cukierman and Muscatelli, 2008]. This type policy function is also motivated by the investigation of nonlinear reaction functions of the BCB by other authors including Aragón and De Medeiros [2011], Pagano and Rossi Jr. [2010] as well as De Mello et al. [2008]. If growth y_t is above the target y_t^*, the BCB does not care about the positive gap (formula 3). Yet, if growth falls short of the target, the monetary policy response becomes quadratic in relation to the gap:

$$if\ y_t < y_t^* : gap = -(y_t - y_t^*)^2, \quad else : gap = 0$$

(3) recession avoidance growth gap

The growth gap loop is switched off as growth exceeds the target while starting to dominate the system as it falls below the target. This recession avoidance policy yields an extreme monetary policy easing in 2009 and a stark overshoot in 2010 when the BCB switches off the growth gap loop (figure 8). The bearish future bust scenario leads to overall negative growth gaps, which lead to a zero real interest rate policy. This policy keeps growth within the 1.5% to 2% range at the cost of higher long-run inflation, which surpasses 8%.

Figure 8: recession avoidance in bust scenario



Concluding, the new BCB policy leads to smoother growth and inflation rates at the expense of a nervous monetary policy, which makes the convergence of rational expectations difficult. As expected, the new BCB strategy also trades off higher average growth against higher average inflation. In structural terms, the new BCB policy makes the growth loops more powerful and particularly raises the pressure from the growth gap loop, given the low average future GDP growth rate in the scenario. The recession avoidance policy leads to a much more growth prone monetary policy at the expense of higher inflation. Furthermore, in case of negative external shocks, the growth policy triggers an extreme monetary policy easing and becomes relaxed towards post-recession rebounds. These observations are related to the dominance of the growth gap loop as growth falls below the target and the silence of the growth gap loop when growth outperforms the target.

3.3. Validation of modified behaviour with respect to the August 2011 COPOM decision[1]

The new BCB strategy and the recession avoidance policies have shown different results in the bust scenario until 2019. At this point it is already possible to validate the model with regard to these two policies given the availability of BCB data for the real interest rate and inflation until 2012:Q2 [BCB, 2012]. For GDP growth, actual data are taken until 2012:Q1 and the July 18th 2012 market expectations collected by the BCB are taken for 2012:Q2. Since its August 2011 meeting, the COPOM has decreased the SELIC interest rate from 12.50% to 8.00% at its last meeting on July 11, 2012. Accordingly, the real interest rate has fallen from 7% in August 2011 to 3% in July 2012. This continuous easing was driven by a slowdown in GDP growth given a worsening of the external environment as well as by lower inflation pressures.

The question at stake is whether the monetary policy easing since August 2011 represents a change in the model structure, corresponding to recession avoidance, or simply in the parameter values, corresponding to the new BCB strategy. This question calls for a modified behaviour test [Schwaninger and Grösser, 2009, p. 9009]. Under the modified behavior test, the model is re-calibrated between 2004:Q2 and 2012:Q2 with the original structure of the Taylor rule and compared to a model with a switch to a recession avoidance Taylor rule in 2011. This switch is considered by a policy switch dummy from the linear growth gap to the recession avoidance growth gap. The best fit is achieved with a switch to a recession avoidance Taylor rule at the starting point of the Tombini presidency at the BCB in January 2011 (formula 2, figure 9). The effect of recession avoidance is that monetary policy easing becomes very pronounced as the GDP growth rate falls below 3.5% and is more than 1% off the target. The easing under recession avoidance policy is as pronounced as under the linear growth gap in the original Taylor rule structure during the 2009 recession when GDP growth rates were even negative. These observations indicate that the current BCB policy may indeed be reflected by a recession avoidance policy function in a bust scenario such as the current macroeconomic environment.

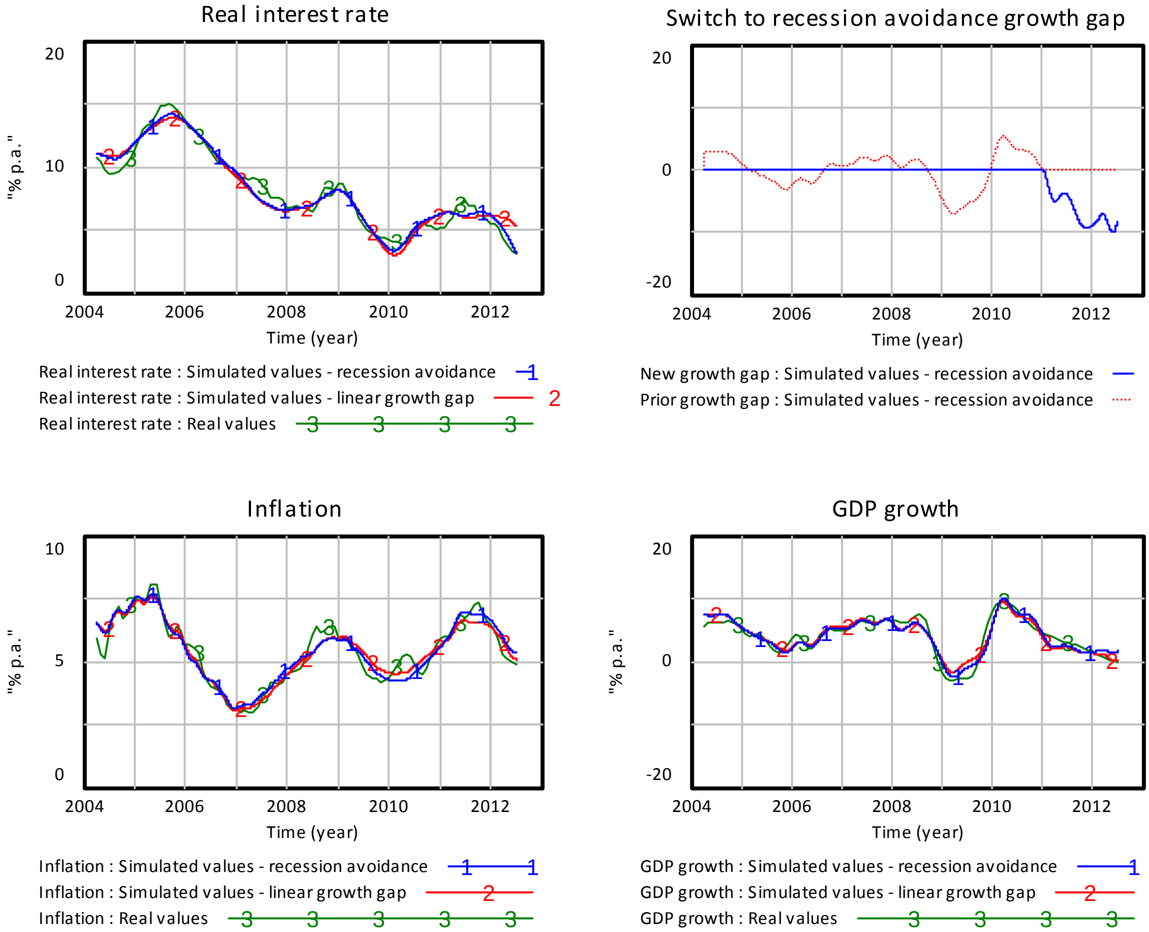
$$if\ y_t < 4.50: \quad \frac{dr}{dt} = 0.56\frac{dy_{t-0.43}}{dt} - 1.20\frac{(y_{t-0.43} - 4.50)^2}{dt} + 1.61\frac{d\pi_{t-0.47}}{dt} + 2.82\frac{\pi_{t-0.47} - \pi^*_{t-0.47}}{dt} - \frac{1.65}{dt}$$

$$else: \quad \frac{dr}{dt} = 0.56\frac{dy_{t-0.43}}{dt} + 1.61\frac{d\pi_{t-0.47}}{dt} + 2.82\frac{\pi_{t-0.47} - \pi^*_{t-0.47}}{dt} - \frac{1.65}{dt}$$

(2) Brazilian Taylor rule after switch to recession avoidance in 2011:Q1 in the 2004:Q2 to 2012:Q2 calibration

[1] Note of the author: The validation of modified behaviour has been conducted after submission of the file for review. Therefore, current supporting material in the conference proceedings does not include the results of the validation of modified behaviour test.

Figure 9: Calibration until 2012:Q2 with policy switch to recession avoidance growth gap by 2011:Q1



However, some additional initial observations from simulating the model beyond 2012:Q2 using a recession avoidance Taylor rule yield an important implication. The 4.5% GDP growth target should be readjusted if GDP growth remains as low as 2%. Otherwise, the recession avoidance Taylor rule triggers continuous excessive monetary policy easing with negative real interest rates in the future. In total, the model becomes much more sensitive to the growth target under a recession avoidance policy.

4. Conclusion

The goal of the paper was to estimate a Taylor rule model for Brazil and determine the degree to which growth and inflation are driven by monetary policy and vice versa. The model provides a strong historical fit for the 2004 to 2011 period and presents some important implications for monetary policy in Brazil. The majority of the policy moves during the sample period was related to growth driven policy, despite larger coefficients of inflation terms in the Taylor rule. This observation is inferred from stocks of absolute policy flows, a particular means by which the Taylor rule model can track monetary policy. Furthermore, the model identifies a strong and immediate impact of monetary policy on GDP growth, amounting to about one fourth of total absolute GDP growth changes. Moreover, inflation is explained by a high degree of endogenous feedback with a dominant impact of lagged GDP growth vis-à-vis the direct impact of monetary policy via expectations, representing a ratio of 2.5 backward-looking price setters per rational price setter in the economy. Overall, the model provides a strong historical fit which is achieved by covering both endogenous feedback structures and adding relevant additional exogenous inputs.

The policy and scenario exercises have shown the results of the BCB taking more aggressive growth policy parameters under a new BCB strategy, which trades off growth against inflation, also at the expense of a more nervous monetary policy. Furthermore, a nonlinear monetary policy growth gap offers a deal of avoiding large recessions. These exercises highlight the ability of system dynamics to easily cover different policy parameters and more complex policy functions. An initial calibration to available data beyond the August 2011 COPOM decision potentially indicates that the BCB has switched to a recession avoidance Taylor rule rather than simply taking more aggressive growth parameters.

Finally, the Taylor rule model represents an effort to apply system dynamics to macroeconomics upon the maxim of empirical testing. It stands in line with efforts to calibrate macroeconomic system dynamics models to particular economies as highlighted by Grcic's [2001] model for the balance of payments developed at the International Monetary Fund applied to the Croatian economy and by Arenas and Hamann's [2005] Mechanisms of Transmission Model for the Central Bank of Colombia. The Taylor rule model makes a case for the power of a small SD model to explain past monetary policy and reveal surprising insights. In total, the strong empirical fit calls for a continued investigation of Brazilian monetary policy and an application of the Taylor rule model to other inflation-targeting economies.

"[Brazil must keep] one eye on inflation, and the other on growth"

Dilma Rouseff, 13th of October, 2011, Curitiba [Folha, 2011]

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