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FELIX SEBASTIAN NEUGEBAUER

TAYLORING BRAZIL

—

A SYSTEM DYNAMICS MODEL FOR MONETARY POLICY FEEDBACK

SÃO PAULO

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Dissertação apresentada à Escola de
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obtenção de título de Mestre em Gestão Internacional

Campo de conhecimento: Política Monetária

Orientador: Prof. Dr. Antonio Carlos Manfredini da
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Abstract

The thesis introduces a system dynamics Taylor rule model of new Keynesian nature for monetary policy feedback in Brazil. The nonlinear Taylor rule for interest rate changes considers gaps and dynamics of GDP growth and inflation. The model closely tracks the 2004 to 2011 business cycle and outlines the endogenous feedback between the real interest rate, GDP growth and inflation. The model identifies a high degree of endogenous feedback for monetary policy and inflation, while GDP growth remains highly exposed to exogenous economic conditions. The results also show that the majority of the monetary policy moves during the sample period was related to GDP growth, despite higher coefficients of inflation parameters in the Taylor rule. This observation challenges the intuition that inflation targeting leads to a dominance of monetary policy moves with respect to inflation. Furthermore, the results suggest that backward looking price-setting with respect to GDP growth has been the dominant driver of inflation. Moreover, simulation exercises highlight the effects of the new BCB strategy initiated in August 2011 and also consider recession and inflation avoidance versions of the Taylor rule. In methodological terms, the Taylor rule model highlights the advantages of system dynamics with respect to nonlinear policies and to the stock-and-flow approach. In total, the strong historical fit and some counterintuitive observations of the Taylor rule model call for an application of the model to other economies.

Key words: Taylor rule, system dynamics, monetary policy, business cycle, new Keynesian economics

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Index of abbreviations

ARMA	Autoregressive-Moving-Average [model]
AS	Aggregate Supply [equation]
BANREP	Columbian Central Bank - Banco de la República de Colombia
BCB	Brazilian Central Bank - Banco Central do Brasil
CLD	Causal Loop Diagram
CMN	National Monetary Council
COPOM	Monetary Policy Committee – Comitê de Política Monetária
DSGE	Dynamic Stochastic General Equilibrium [model]
FX	Foreign Exchange [rate]
GDP	Gross Domestic Product
IBGE	Brazilian Institute of Geography and Statistics – Instituto Brasileiro de Geografia e Estatística
IMF	International Monetary Fund
IPCA	Broad Consumer Price Index – Índice de Preços ao Consumidor Ampliado
IS	Investment and Saving Equilibrium [equation]
M.I.T	Massachusetts Institute of Technology
MSE	Mean Squared Error
MTM	Mechanisms of Transmission Model
NK	New Keynesian [theory]
OECD	Organisation for Economic Co-operation and Development
p.a.	per annum
p.aa.	per annum squared
RBC	Real Business Cycle [theory]
S&P	Standard & Poor's
SAMBA	Stochastic Analytical Model with a Bayesian Approach
SD	System dynamics
SELIC	Special System of Clearance and Custody Sistema Especial de Liquidação e de Custódia
U.S.	United States
VAR	Vector Autoregressive
20xx:Qy	Year 20xx Quarter y

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 current 2011 European debt crisis. This raises the question of how the Brazilian Central Bank has approached the Taylor rule over the boom period from 2004 until 2011, given the resilience in face of the external environment.

However, established models at central banks most often treat the Taylor rule as the decision rule directly affecting one out of many sectors in the economy, i.e. the monetary sector. On the other hand, simply estimating the Taylor rule without feedback via growth and prices pays little respect to the complexities affecting monetary policy. Therefore, the goal of this thesis is to construct a Brazilian Taylor rule feedback model for the 2004 to 2011 period in order to replicate, understand and also affect the outcome of the Brazilian business cycle from a Taylor rule perspective.

1. Objectives

The goal of this thesis is to introduce a small structural Taylor rule system dynamics feedback model for the Brazilian economy. The model considers a Taylor rule for the real interest rate changes with GDP growth and inflation elements and sheds light on the endogenous feedback among these variables. The dynamic hypothesis is that the behaviour of the real interest rate can be explained by its interaction with GDP growth and inflation, as suggested by the Taylor rule. The model will be calibrated to Brazil for the 2004 to 2011 period and its results be validated. Finally, selected monetary policy simulations will be made for both the historical business cycle and three future scenarios.

The model is supposed to show the degree to which the Brazilian growth and inflation are monetary policy driven and vice versa. Furthermore, the model is going to address the degree to which the central bank is effectively targeting growth and inflation. The model will also assess to what degree the Brazilian business and monetary policy is subject to lags. Furthermore, some monetary policies will be applied to Brazil both under the historical business cycle and for three future scenarios. The discussion is supposed to address to what degree different Taylor rules determine different outcomes of the business cycle.

In methodological terms, the thesis makes a case for the applicability of system dynamics to macroeconomic modeling for monetary policy purposes. The model will also contribute to revealing the weaknesses of the methodology when applied to macroeconomic modeling. This is also supposed to provide an indication of future opportunities for system dynamics research in the monetary policy field.

Chapter 2 recalls the Brazilian business cycle since the introduction of inflation targeting in 1999. Chapter 3 addresses the evolution of macroeconomic modeling for monetary policy, both in general and at the BCB. This is followed by a discussion of system dynamics and its application to macroeconomics in chapter 4. Chapter 5 will introduce, estimate and discuss the Taylor rule feedback model. The model will subsequently be validated in chapter 6. Chapter 7 is going to apply policies to both the historical business cycle and a range of future scenarios before final conclusions will be drawn.

2. Brazil during inflation targeting

1994-1999: From crawling peg to inflation targeting

Following the introduction of the Real currency under the Plano Real in July 1994, inflation was rapidly brought down from monthly rates beyond 40% to a level of 2% under the new Real currency [Sachs and Zini Jr, 1996]. The Brazilian Central Bank (BCB) also used a nominal foreign exchange crawling peg against the USD. Under the crawling peg, the Real would continuously depreciate against the USD, which came at the cost of a continuous increase in sovereign USD denominated debt [Giambiagi et al., 2004]. When the Russian debt moratorium hit the markets in August 1998, a capital flight out of emerging markets heavily exposed Brazil to exchange rate pressure and its foreign debt [Garcia, 2008]. The BCB responded by lifting the domestic nominal short-term interest rate (SELIC rate) and by filing for USD 41.5bn financial support from IMF through a Stand-By Arrangement [Fraga, 2000].

Nevertheless, the Real witnessed further depreciation pressure and the BCB ultimately gave up its crawling peg regime and floated the Real on January 15, 1999, under its new BCB president Armínio Fraga [Figueiredo et al., 2002]. The nominal exchange rate saw an abrupt depreciation, resulting in upward pressure on inflation [Bogdanski et al., 2000]. The new BCB board further lifted the SELIC to a peak of 43.5%. On July 1, Decree No. 3088 of June 21st issued by the President of Brazil formally introduced the inflation targeting monetary policy regime. Based on the proposal of the finance minister, the national monetary council (CMN) set inflation targets until 2001 with a 2% tolerance band and selected the Broad Consumer Price Index (IPCA)¹ as the relevant price index of inflation. Figures 1 and 2 depict the evolution of the main macroeconomic variables under the new regime.

1999-2003: Wave of shocks hitting Brazil

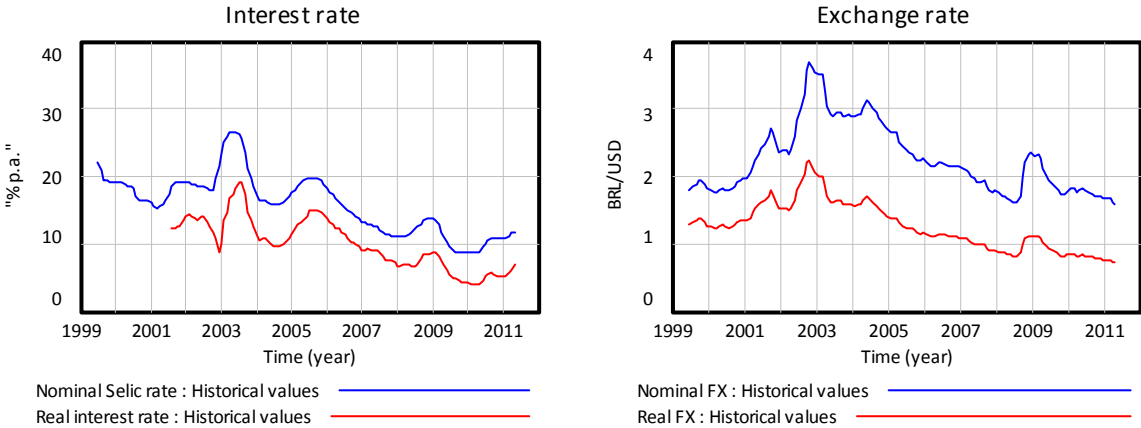
Inflation remained within the tolerance band in 1999 and 2000 as the exchange rate did not suffer from further depreciation, which provided for continued reductions of the SELIC rate [Figueiredo et al., 2002]. At the same time, GDP growth increased beyond 4% in 2000. The successful regime switch was also related to fiscal reforms as the government increased taxes, cut expenditures, privatized or restructured public enterprises and adjusted government-managed prices [Giambiagi et al., 2004].

Yet by 2001, the negative developments in OECD economies surrounding the bust of the dotcom bubble and the September 11 terrorist attacks, as well as the Argentinean debt

¹ The IPCA is composed of two broad components: free market prices and monitored prices administered by the government or defined by contractual clauses such as in the case of telephone and power supply that are indexed to past inflation (Tombini & Alves, 2006).

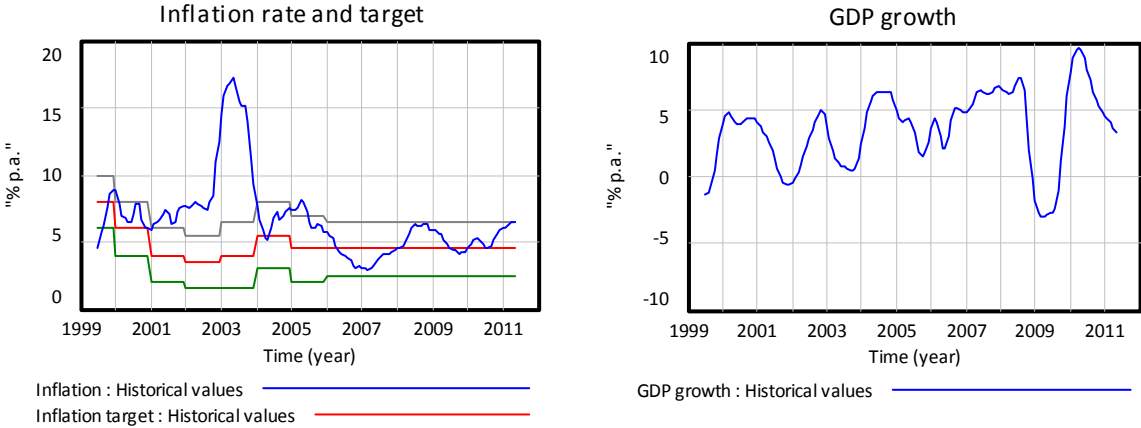
crisis triggered another investor flight out of Brazil [Figueiredo et al., 2002]. At the internal front, Brazil suffered from an energy crisis, leading to falling confidence and rising government-managed prices. Inflation ran out of the 6% upper target bound in 2001 and the public net-debt-to-GDP ratio also crossed the 50% mark. The government responded by raising primary surplus targets and by extending the IMF Stand-By Arrangement [Fraga, 2000].

Figure 1: interest rates and exchange rates during inflation targeting [BCB, 2011a]



However, markets remained in fear of worsening debt dynamics, which would potentially trigger further Real depreciation and inflation. The fears were also related to the high degree of dollarization as more than 50% of Brazilian government debt was either issued in USD or indexed to the USD [Garcia, 2008]. The situation was amplified by the consideration of a Brazilian debt moratorium by presidential candidate Lula da Silva, bringing a confidence crisis to Brazil in the end of 2002 [Miller et al., 2003]. Investors fled, the exchange rate depreciated and annualized inflation already stood above 10% at the time of Lula’s presidential inauguration on January 1, 2003. At the BCB, Henrique Meirelles replaced Arminio Fraga as the president of the institution and kept lifting the SELIC rate up to 26.5%. However, with the nominal exchange rate depreciation already passing through, Brazilian inflation peaked at 17% in April 2003.

Figure 2: inflation and growth during inflation targeting [BCB, 2011a]



2003-2008: Stabilization and economic boom

By mid-2003, the monetary tightening efforts of the BCB took effect and were able to stabilize the Real and tame inflation expectations [Bevilaqua et al., 2008]. The subsequent cuts in the SELIC rate strongly supported economic growth, which stood at 5% in 2004. On the fiscal side, the government kept, from the early days of Lula's administration, a fiscal primary surplus of more than 3% of GDP and announced a foreign debt buyback program [Bloomberg, 2004, Barden, 2006]. These measures reduced both the Brazilian stock of total debt outstanding as well as the dollarizing of debt.

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 SELIC 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. Meanwhile, external accounts improved significantly as Brazil saw increased demand for its commodities, especially from China. Also, the discoveries of offshore oil reserves tripled Brazilian oil reserves from 13bn barrels to 42bn barrels as of 2011 [BCB, 2011b], with the perspective of Brazil becoming an oil net-exporter in future. With stabilization taking hold, Brazil repaid its IMF obligations in advance [Dos Santos, 2005]. Furthermore, Brazil witnessed rising internal markets as anti-poverty programs provided for upward social mobility. Moreover, economic stability translated into booming financial markets, which saw a remarkable credit expansion.

These favorable dynamics provided for historically positive developments into late 2008. The BCB lowered the SELIC rate to a low of 11.25% while inflation stood below the target at 3.1% by the end of 2006. GDP growth marked at 6.7% by the end of 2007 and the real exchange rate saw a continued appreciation into 2008 and fell below the pre-floating January 1999 level. Meanwhile, President Lula entered a second administration after winning the 2006 election. Moreover, the BCB started to accumulate foreign currency reserves which, in combination with the government's debt reduction and 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].

2008-2011: External shock, overshooting rebound and new BCB strategy

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, 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 upper bound of the target band for the first time since 2005. In addition, Brazilian real interest rates of more than 5% attracted strong inflows of foreign portfolio investments amid historically low interest rates in OECD economies [BCB, 2011b]. These inflows, mostly pronounced by currency carry trades [Economist, 2011d], would impose threats of exchange rates destabilization, of rendering monetary policy ineffective and of making Brazilian exports uncompetitive due to exchange rate overvaluation [Plantin and Shin, 2011]. The BCB faced a trade-off between monetary policy easing at the expense of internal inflation or monetary tightening at the expense of financial risks and lower growth.

In its August 2011 meeting, the COPOM, the monetary policy committee of the BCB, decided in favour of a monetary policy easing [BCB, 2011c]. This marked the first such easing under the circumstances of rising inflation since the beginning of the Meirelles administration. 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]. In November 2011, the Brazilian Senate also saw a proposal to amplify the BCB competences to "stimulating economic growth and the creation of jobs" [Jubé, 2011]. While the proposal was ultimately withdrawn, the debate about the extent to which the BCB should stimulate growth took hold [Rosa, 2011]. On November 17, 2011, Brazil's sovereign debt rating was upgraded to BBB by S&P, with the rating agency stating that "cautious fiscal and monetary policies [...] should moderate the impact of potential external shocks and sustain long-term growth prospects" [Korby, 2011].

3. Monetary policy

3.1. Macroeconomic modelling

Structural Keynesian Models and the Lucas critique

Macroeconomic modelling is essentially linked to monetary policy. Macroeconomic modelling is supposed to provide short-run forecasts of the economy, an understanding of the economic system and a tool for evaluating policy options [Brayton et al., 1997, Diebold, 1998, Faust, 2005]. Macroeconomic models are separated into structural models and non-structural models. Structural models are linked to an explicit theory and mostly serve the purpose of analysis and policy evaluation. Non-structural models are purely statistical or econometric models, mostly applied for forecasting purposes.

With the 1950s and 1960s post-war economic boom, central banks developed models linked to Keynes' "The General Theory of Employment, Interest and Money" [Keynes, 1936] in order to identify structural economic relations. The Keynesian view is a demand driven business cycle. Falling demand causes recessions, during which firms produce below capacity, a temporary macroeconomic disequilibrium. The disequilibrium is supposed to be avoided by means of fiscal spending or monetary policy easing [Gordon, 1990]. In methodological terms, Keynesian models were estimated with statistical methods, which laid a basis for the development of econometric techniques [Diebold, 1998]. The models included many parameters and behavioural equations and did not allow for an easy identification, meaning a unique solution to the parameters of the model [Sims, 1980].

By the 1970s, the new Keynesian models were exposed to strong criticism as they did not provide a useful basis for evaluating the 1970s oil shocks [Diebold, 1998]. The shocks were related to the supply side and caused a rise of both unemployment and inflation, a combination not considered by the Keynesian theory. Moreover, the Lucas critique addressed the lack of forward looking agents using rational expectations in these models [Lucas, 1976]. Optimal decision rules of optimizing agents were to replace econometrically estimated policy parameters in the Keynesian models.

Monetarism

As inflation took hold after the oil price shocks, the monetarist view gained attention and the U.S. Federal Reserve switched from interest rate targeting to money supply targeting [De Long, 2000]. Monetarism states that the optimum of monetary policy is constant growth in money supply [Friedman, 1970]. Monetary authorities should only focus on price stability

and refrain from any stabilizing intervention, since the results of the intervention are difficult to engineer and fine tune and are ultimately unknown.

Non-structural, autoregressive Models

At the same time, macroeconomic modelling experienced a boom of the non-structural approach. Sims proposed multivariate vector-autoregressive (VAR) models, which consisted of a system of differential equations related to the phase relations across economic variables [Sims, 1980]. The non-structural approach also focused on the dynamics of single variables through univariate autoregressive integrated moving average (ARIMA) models [Diebold, 1998]. The non-structural models became very popular due to their high predictive power in the short-run. Yet policy evaluation was limited due to a lack of a structural approach.

Real business cycle theory

Following a boom of the non-structural approach and monetarist views, structural models regained attention as the real business cycle (RBC) theory emerged [Kydland and Prescott, 1982]. The RBC theory assumes rational expectations, addressing the Lucas critique, and perfect competition, but imperfect information [Diebold, 1998]. All markets would work fully efficiently in the absence of intervention and imperfections but real shocks related to technology or productivity trigger deviations from the long-run growth trend [Stadler, 1994]. Instead, a nominal fiscal or monetary policy shock would show no effect due to optimal decisions on behalf of the agents. Firms would raise prices and workers would negotiate wages that offset any intervention effect.

RBC models are micro-founded economies with utility maximizing consumers and workers and value maximizing firms [Stadler, 1994]. Postulated behavioural equations are replaced by first order inter-temporal maximization problems of the agents in the economy, responding to the Lucas critique. In perfect competition and markets without frictions, output gaps are optimal responses of the agents to real exogenous shocks.

Macroeconomic scenarios are approached by stochastic dynamic optimization, leading to their denotation as dynamics stochastic general equilibrium (DSGE) models [Diebold, 1998]. DSGE models were initially parameterized through maximum likelihood calibration. The introduction of Bayesian methods then allowed for an estimation of the likelihood distribution [Smets and Wouters, 2004]. Bayesian DSGE models became a favourable policy evaluation and, to a certain extent, forecasting tool applied by central banks around the world. Yet DSGE models are still in an early stage of development, especially in the case of emerging market economies [Tovar, 2008].

Mixed new Keynesian General Equilibrium and small structural models

While RBC theory assumes that monetary policy does not have a short-run effect, empirical evidence has supported the Keynesian view of short-run non-neutrality, meaning that monetary or fiscal policy has a short-run effect. This has supported the emergence of new Keynesian (NK) theory [Taylor, 1999, Nakamura and Steinsson, 2010]. The new Keynesian view states that demand and supply may be imbalanced even in the absence of market imperfections [Stadler, 1994]. Stabilizing monetary policy can avoid short-run output gaps as results of the imperfections in the economy.

Among the most established new Keynesian Models is the small structural baseline model by Clarida et al. [1999]. Small new Keynesian models only draw attention to part of the economy. The models neglect capital markets and firm investment, but consider rationality and imperfections. The two imperfections are monopolistic competition and costly price adjustments among firms, leading to inflexible price setting [Stadler, 1994]. The central bank as the public authority is supposed to restore balance. In the IS equation, output is determined by expectations about future income and by the current real interest rate, which determines inter-temporal substitution of consumers [Clarida et al., 1999]. In the NK Phillips equation, the general price level of the economy depends on expected future inflation and the current deviation of output from a natural output level, the output gap. Finally, the central bank minimizes a society loss function consisting of inflation and output gaps, which adds a micro-foundation to the model.

Small structural NK models are considered as convenient and simple tools with only a few equations explaining a complex reality while still being derived from optimization [Diebold, 1998]. The models are particularly applicable to inflation targeting regimes, given the central bank loss function with inflation and output terms. The NK models have also become a principle model for analysing fluctuations for teaching purposes.

Apart from small structural models, the new Keynesian theory has also been approached through DSGE models with fiscal stabilization [Del Negro et al., 2007, Iskrev, 2008].

Financial crisis and consideration of the behavioural approach

With the set of RBC new Keynesian models, economists had reached substantial agreement [Krugman, 2009, Blanchard, 2009]. Agents try to maximize their expected utility in an economy with imperfections, a general equilibrium approach solves the problem, and a numerical simulation provides model fit. Non structural models would in addition provide for powerful short-run forecasting.

However, the U.S. housing crisis, the Lehman-default, the subsequent financial market turmoil and the following global recession have triggered a reassessment of established models and theories [Krugman, 2009]: “What’s probably going to happen now [...] is that flaws-and-frictions economics will move from the periphery of economic analysis to its center.”

Behavioural economics is one peripheral approach related to cognitive sciences and prospect theory that has gained attention [Akerlof, 2002]. One important finding of behavioural macroeconomics is that wage and price setting of agents rather takes the form of rules of thumb instead of fully rational or fully adaptive calculations, implying a different employment-output relation in the Phillips curve. However, behavioural investigation is still under way [Krugman, 2009].

3.2. Monetary policy rules

Friedman’s monetarist k-percent rule

A monetary policy rule, for its own, does not require any forecasting or policy analysis [Orphanides, 2007]. It is a convenient tool for analysing monetary policy without entering into a detailed model. A monetary policy rule allows for an effective communication and explanation of monetary policy. It fuels the central bank’s accountability and credibility, reduces uncertainty and facilitates forecasting by market participants. Due to the transparency and the backward looking nature of a rule, firms and consumers can easily anticipate future monetary policy [Woodford, 1999].

Milton Friedman’s monetarism proposed a constant rate of growth of the monetary base approximately equal to the potential output growth of the economy, the k-percent rule [Friedman, 1960]. Changes in money growth rate would not have an effect but induce both nominal wage and price increases, which offset each other. Friedman’s monetarism doctrine stood against Keynesian views of a countercyclical component at the core of macroeconomic policy.

Keynesian Taylor rule

Taylor [1993] instead proposed an interest rule related to counter-cyclical Keynesian-type policies. Foundations were laid by Bryant et al. [1993], who compared nine different simple reactive interest rate rules for selected OECD economies. 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 was to raise normative and positive implications [Clarida et al., 1999]. Taylor addressed the principles of gradual inflation targeting via

the nominal interest rate. He proposed that the current nominal interest rate i_t should be a sum of target inflation rate π^* , the long run equilibrium interest rate i^* , the inflation gap $\pi_t - \pi^*$ and the output gap $x_t = y_t - y^*$. The initial positive implication was the description of U.S. monetary policy between 1987 and 1992 for which Taylor picked parameters:

$$\begin{aligned} i_t &= \gamma_\pi (\pi_t - \pi^*) + \gamma_x x_t + i^* & \gamma_\pi > 1, \gamma_x > 0 \\ i_t &= 1.5(\pi_t - 2) + 0.5x_t + 2 \end{aligned}$$

(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-to-one 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 been rapidly incorporated in new Keynesian and RBC models that considered some kind of inflexible price setting [McCallum, 1999]. It replaced the intertemporal loss minimization problem of the central bank with the postulated decision rule. Opposed to the forward looking loss minimization, a Taylor rule is by its nature backward looking. A Taylor rule, a Philips curve and an IS-curve together would already provide for equilibrium without optimization [Woodford, 2001]. The Taylor rule also saw 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].

3.3. Models and Taylor rules at the BCB

History of macroeconomic modelling

Before the implementation of the Plano Real in 1994, high inflation, price freezes, price indexation and many currency reforms had rendered macroeconomic forecasting close to impossible [Araújo et al., 2009]. During the USD crawling peg regime, the goal of the BCB was to supply or demand money in the foreign exchange market in order to keep the Brazilian Real within the FX target interval against the USD. The BCB developed some structural

models for money demand for this purpose. Yet a Taylor rule for inflation and output would not have been suitable for the FX crawling peg regime.

The introduction of inflation targeting in 1999 rapidly changed the relevance of macroeconomic forecasting and fuelled the development of macroeconomic models at the BCB [Araújo et al., 2009]. The inflation targeting also opened the way for a Taylor rule. The BCB suddenly had to build up knowledge about the interest rate channels, through which current monetary policy translates into future inflation. It created a research department with the study areas inflation targeting, financial risks and microeconomics of banking [Bogdanski et al., 2000]. The central bank also had to ensure transparency by publishing projections in order to enhance the credibility and effectiveness of monetary policy. Over time, the credibility of Brazilian monetary policy has increased as inflation targets were able to anchor inflation expectations [Araújo et al., 2009]. Importantly, the market agrees that the BCB follows a Taylor-type monetary policy rule [De Carvalho and Minella, 2009].

Taylor rule in macroeconomic models at the BCB

The lack of an inflation targeting regime sample initially forced BCB to focus on building models and doing theoretical simulations [Araújo et al., 2009]. In its first working paper, the BCB considered the IS-curve, the Phillips-curve, the uncovered interest parity condition and interest rate rules as central elements of future structural models [Bogdanski et al., 2000]. A Taylor rule should include inflation target deviation, an output gap and an interest rate lag component. The first effort was to simulate the impact of exchange rate shocks under a Taylor rule without drawing on a sample [Muinhos et al., 2001]. By 2002, the BCB conducted Taylor rule experiments against the IMF program's quarterly and the BCB's end-of-year inflation targets for 2000:Q1 until 2002:Q4 [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 [Bonomo and Brito, 2002].

The BCB proceeded to actually estimating model parameters in small to medium sized Keynesian models. It applied a small open and a closed economy Taylor rule for Brazil in a 1994:Q1 and 2001:Q4 sample [De Almeida et al., 2003]. This was followed by a more extensive medium size Keynesian model including a Taylor rule with sluggish interest rate adjustment, inflation gap, lagged output gap and equilibrium interest rate [Muinhos and Alves, 2003]. Later on, a Keynesian medium-sized semi-structural model with three monetary policy channels was the first to exclusively focus on an inflation targeting sample from 1999:Q3 to 2008:Q2 [Minella and Souza-Sobrinho, 2009]. The model considers a Taylor rule with interest rate smoothing, an expected inflation gap, an inflation gap and a shock term.

Motivated by the ongoing credit boom, the BCB later on evaluated the role of bank capital requirements in a large new Keynesian model with a range of agents [Agénor et al., 2011].

Meanwhile, the BCB had been aiming at the development of new Keynesian and RBC related DSGE models, extended by imperfections such as inflexible prices. The first step was to build a model economy for Brazil in an optimizing dynamic general equilibrium [Araújo et al., 2006]. The authors compared effects of adverse supply shocks under various Taylor rules in the model with real data for the sample between 1996:Q1 to 2003:Q4. The BCB moved on by presenting a two-country new Keynesian DSGE model, calibrating the model to Brazil and investigating fiscal and monetary policy interactions [Valli and Carvalho, 2010]. The model included a forward looking Taylor-rule with equilibrium interest rate, inflation gap, output gap and shocks. In 2011, the BCB introduced a stochastic analytical model with a Bayesian approach (SAMBA) [De Castro et al., 2011]. SAMBA was the first DSGE model parameterized to Brazil and also the first under the inflation targeting period. The small open economy is populated by several agents including households, domestic producers, importing firms, central bank and government. The model also considered Brazilian phenomena and restrictions such as monitored prices and primary fiscal surpluses. In SAMBA, the central bank follows a forward-looking Taylor rule. The nominal interest rate is adjusted in response to output and inflation gaps, is being smoothed and also exhibits a tendency towards an equilibrium rate. The estimations for the sample between 1999:Q3 and 2010:Q2 show that the BCB was dedicated to smoothing and sensitive to inflation, while paying little weight on the output gap. In a subsequent open economy DSGE model, the BCB further considered the role of fiscal policy and public investment [De Carvalho and Valli, 2011].

To conclude, the BCB has developed and applied a range of macroeconomic models [Araújo et al., 2009]. The BCB initially focused on new Keynesian small semi-structural and medium structural models and faced strong restrictions with regard to the availability of an inflation targeting sample. Over time, the BCB was able to draw on larger inflation targeting samples and also shifted the focus to the construction of DSGE models. With SAMBA, the BCB has developed a state-of-the-art DSGE model and presumably based its monetary policy decision in October 2011 on a scenario stemming from the model [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.

4. System dynamics

4.1. Methodological overview

Methodology

System dynamics (SD) is a computer simulation modelling methodology that is used to analyze complex feedback systems and to design policies that improve their performance [Forrester, 1991, Sterman, 2001]. System dynamics was developed by Jay W. Forrester in the 1950s at the M.I.T. in order to understand and deal with the dynamic behaviour of corporations as corporate systems [Forrester, 1958]. The origins of the methodology relate to management science, control engineering and digital computing.

System dynamics sets itself apart on the grounds of endogenous and nonlinear behaviour [Richardson, 1991, Sterman, 2002]. It draws on nonlinear endogenous feedback structures with delays [Sterman, 2000]. In a nonlinear system, the dominance of different feedback loops constantly alters the behaviour of the system over time [Radzicki, 2005]. System dynamics offers many advantages including the ease of calculation, the dynamic behaviour, the transparency of the model structure, the visibility of the model outputs and the applicability to almost any field of science.

System dynamics models

System dynamics (SD) modelling is about “constructing models as continuous feedback systems” [Schwaninger and Grösser, 2008]. It is an iterative process of structure identification, mapping, and simulation in order to explain and reproduce behaviour and to test policies. A SD model is supposed to grasp the functional relationship among the variables of a system, to formalize them and to make them transparent. Models are supposed to generate “the right output for the right reasons” [Barlas, 1996]. Formalizing SD models provides transparency and heavily contributes to falsifiability as each relation between variables can be evaluated on both logical and empirical grounds [Schwaninger and Grösser, 2008]. Individual variables in the model can be continuously traced and compared to real counterparts. This provides the instantaneous value of any variable in the system at each point in time.

The main structure of system dynamics models consists of stocks, flows and feedback loops [Radzicki, 2005]. Stocks are accumulating structures of material or information that flow into and out of their bath-tub type stock. Mathematically, flows are first derivatives of stocks with respect to time and stocks are integrals of flows over time. Feedback is the transmission and return of information about the material or information that accumulates in the stocks [Radzicki, 2011]. Positive feedback loops cause self-reinforcing behaviour that desta-

bilizes a system and leads to vicious or virtuous circles. Negative feedback loops are stabilizers of a system, generating goal-seeking behaviour that prevents the system from moving away from its current state. In addition, negative feedback loops also present oscillation structure in the presence of certain delays.

The major steps involved in system dynamics modelling are (a) problem identification, (b) construction of a conceptual CLD model, (c) construction of a formal stock-and-flow model, (d) model analysis and validation, (e) policy design, analysis and implementation [Barlas, 1996, p.185]. Starting with (a) the problem identification, a reference mode is a graph of variables the dynamics of which are not fully understood [Oliva, 2003]. The goal is to provide an endogenous explanation of the reference mode behaviour. In the initial form, this is done by (b) a causal loop diagram (CLD). The CLD interconnects the variables of a system that were found important with arrows that indicate causes between the variables and with the sign of an arrow indicating the polarity of the causal relation. Based on the CLD, the next step is (c) to construct a system dynamics stock-and-flow model. This is eventually followed by (d) model calibration, which links the structure of the model to the behaviour of the reference mode [Barlas, 1996]. Following the calibration, the model is exposed to validation tests. Once validation has established confidence to the model and its structure, the final step is (e) to exercise selected policies in the model in order to actively alter the behaviour of the reference mode.

Mathematical Considerations

System dynamics models are numerical models in which differential equations replace algebraic equations typically present in other fields of research [Barlas, 2007]. In practice, the differential equations are calculated as incremental difference equations in order to provide for the computation of numerical results. The big advantage of system dynamics models is that the differential equations do not require an analytical solution since model output is derived from computer simulations [Oliva, 2003]. SD models can be highly complex with potentially several hundred variables, while still providing for an immediate computer-based calculation.

System dynamics data are at the same time auto-correlated and cross correlated [Barlas, 1996]. These characteristics make the statistical significance levels of the parameters in the models very small, so that validation of system dynamics models goes beyond the significance level of its variables. System dynamics models are also very prone to violating the assumptions of ordinary least squares estimation. Therefore, system dynamics models are calibrated by maximum likelihood. This is done either through optimal filtering methods

from the engineering field [Peterson, 1980] or through model reference optimization linked to non-linear optimization algorithms [Lyneis and Pugh, 1996].

4.2. System dynamics and macroeconomics

System dynamics perspective on economics and econometrics

System dynamics can heavily enhance the understanding of economic dynamics [Wheat, 2007a]. Interactive computer simulation models replace static graphs in order to emphasize dynamics instead of static equilibrium. Feedback loops provide for a visualization of economic processes. Positive loops cause steady state long-run economic growth while negative loops generate the short-to-medium run business cycles oscillations.

System dynamics offers a non-linear modelling of the economic system and allows for the proper consideration of short-run and long-run behaviour at the same time [Forrester, 2003]. SD models identify time delays and evaluate the causes behind them instead of simply applying lagged variables. From a system dynamics perspective, many economic models, especially non-structural models, are black-box models that neglect feedback [Barlas, 1996]. Furthermore, economic models mostly take an equilibrium approach, while system dynamics models are disequilibrium models. The economy is either assumed to be temporarily off equilibrium, to never reach equilibrium, or to never switch into a new equilibrium [Radzicki and Sterman, 1994].

Furthermore, economic models are much more geared to mathematical solutions and parameter output. Consequently, economic models often treat evaluation as limited to algebraic self-consistency and econometric significance of variables [Barlas, 1996, Forrester, 2003]. From a system dynamics perspective, the econometric approach to economic models has to be considered as critical. Econometrics puts curve fitting by means of multiple regression analysis above the functional relationship of variables. Multiple regression analysis often does not correctly identify these functional relationships, assuming constant parameters and linear interrelations. Under these circumstances, multiple regression analysis is much more applicable to cross-sectional analysis at one point in time than to a non-linear closed-loop system of both cross-sectional and time-series nature. Most often, economic models apply linear and simultaneous algebraic equations to non-linear economic systems and treat the economic system as being balanced at each point in time [Forrester, 2003].

System dynamics can apply economic models in several ways [Radzicki, 2011a]. Models may be translated into a SD model, which provides for a well-known theoretical basis of the

model. Second, a system dynamics model can be drafted from the scratch, which typically yields counterintuitive results that challenge existing views. The third approach is a hybrid approach, in which an economic model is put into a system dynamics format and improved by adding system dynamics principles.

Economics perspective on system dynamics modelling

Economists have been sceptically approaching system dynamics [Radzicki, 2011a]. While system dynamists claim that economic theory suffers from black-box econometrics, economists have in return addressed the lack of analytical solutions and of estimation efforts in system dynamics.

System dynamics models do not correctly incorporate standard production or consumption functions, the underlying assumptions have little or no reference to established knowledge and the model reacts highly sensitive to them [Nordhaus, 1973]. Nordhaus [1973] also criticizes World Dynamics for not having any empirical reference in terms of data or empirical studies. A simulation model that was solely based on hypothetical relationships without empirical validation would not represent any whatsoever contribution. Such criticism has triggered the development of system dynamics calibration and has also split the system dynamics community into two schools [Radzicki, 2004]. The statistically inclined school applies calibration in order to achieve historical data fit and for accurate parameter estimation. The classical school consults the decision maker or observes individual interaction among variables in order to parameterize a model. The goal of a model is the ability to reproduce the shape of a system's reference modes over time and not the data fit: "the outcome of a [...] system dynamics modelling study is a robust feedback policy or rule that can be followed by policy makers to keep an actual system behaving in a desired manner, [...] without the need to forecast the future of any variable." [Radzicki, 2004, p.4].

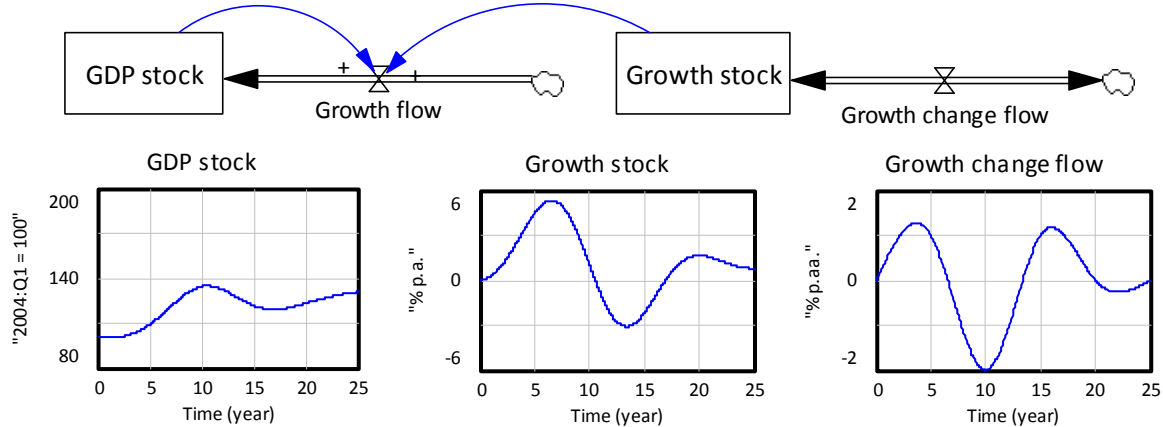
Moreover, in the past, most system dynamics researchers engaged in economic models did not have a background in economics [Radzicki, 2011a]. The value they added was to shed light on economics from a different perspective at the expense of not being taken as experts in the field. For instance, a search in the American Economic Association journal database, including the American Economic Review, yields no result for system dynamics [AEA, 2011]. A lack of professionalism has already been claimed as World Dynamics caught attention [Clement, 2002]:

"The one thing that really annoys me is amateurs making absurd statements about economics, and I though the Club of Rome was nonsense [...] was doing amateur dynamics without a license, without a proper qualification.", citing Robert Solow in 2002.

Richardson [1996] also addresses a lack of accumulating results for system dynamics models in order to build up an established body of structural mechanisms, for instance, regarding the business cycle. For instance, the efforts at the M.I.T., including the National Model, have never been replicated, and other, more particular applications of system dynamics, have never reached the stance of common knowledge in system dynamics. Without testing and replicating results, an established set of knowledge will not be accumulated and accepted.

Apart from the role of data fit, parameter estimation and potential lack of professionalism, much of the misunderstanding between economics and system dynamics is also related to the concept of stocks and flows [Sterman, 2000, p. 198]. In system dynamics models, technically everything can assume the format of either a stock or a flow, while economics views some variable as conventional stocks and others as conventional flows. For instance, GDP growth can be applied both as a stock and as a flow within the same stock and flow model.

Figure 3: concept of stocks versus flows in system dynamics



The GDP growth stock is an accumulation of GDP growth changes over time. The growth stock then enters a growth flow into GDP as the current GDP level in the GDP stock is multiplied by the current GDP growth level in the growth stock. Such an ambivalent understanding of stocks and flows contrasts the understanding of GDP as a natural stock and GDP growth as a natural flow [Wheat, 2007a, 2007b]. Yet economists have also debated the role of stocks and flows in monetary theory. This is highlighted by the controversial debate between Klein [1950] and Fellner and Somers [1949] as well as the remark by Michael Kalecki in the 1930s [Robinsons, 1982]: “I have found what economics is; it is the science of confusing stocks with flows.”

Applications of system dynamics to macroeconomic modelling

System dynamics has been applied to macroeconomics and monetary policy in a range of models. It has raised particular attention with the World Dynamics [Forrester, 1971] and Limits to Growth [Meadows, 1972] publications. The “pure macroeconomic” set of system

dynamics models is highlighted by the National Model of the United States, a project that has been going on at the M.I.T. since the 1970s [Forrester, 1989]. The National Model considers all sorts of economic behaviour including business cycles, inflation, stagflation, growth and the economic long wave.

System dynamics models often select unorthodox economic theories that are able to capture nonlinearities and information flows and yield counterintuitive results. Radzicki [2005, 2011b] is working on a project to merge institutional economics and Keynesian economics. He constructs a post-Keynesian institutional system dynamics model using a post Keynesian endogenous monetary policy formulation instead of a Taylor rule. Tauheed and Wray [2006] model the effects of interest rates on aggregate demand, also accounting for the possibility of co-movements of interest rates and demand.

The other set of macroeconomic models for monetary policy purposes considers a more orthodox approach and draws on established theories. Folk [1969] makes an early contribution on comparing monetarism versus neo-Keynesian approaches to monetary and fiscal policy. In the monetary policy sector of the MacroLab model, Wheat [2007b] considers a Taylor rule with inflation and unemployment and establishes a feedback via lending rates and aggregate demand. Grcic [2001] translates Polak's [1957] model for the balance of payments developed at the IMF into a system dynamics model and calibrates it to the Croatian economy. Arenas and Hamann [2005] construct a system dynamics Mechanisms of Transmission Model (MTM) for the Central Bank of Colombia (BANREP). The MTM evaluates the effectiveness of inflation target and monetary policy changes and considers policy options to external shocks. The choice of system dynamics was related to structural transparency, the stock and flow approach and the graphical representation of the output. In sum, the BANREP "considers that system dynamics models represent a potentially useful tool for policy design" [p. 15].

5. Taylor rule model

5.1. Reference modes

The starting point for a system dynamic hypothesis is a reference mode, the behaviour of a variable over time [Oliva, 2003]. The purpose is to explain the behaviour of the reference mode with a dynamic hypothesis and to intervene by altering decision policies. A dynamic hypothesis is a theory that explains the behaviour based on the endogenous structure of a model and related decision policies. There may be many dynamic hypotheses for addressing the same behaviour, yet they have to be realistically linked to the behaviour of the model so that the right structure replicates the right patterns of behaviour [Barlas, 1996].

Figure 4: reference modes of the Taylor rule hypothesis [BCB, 2011a]



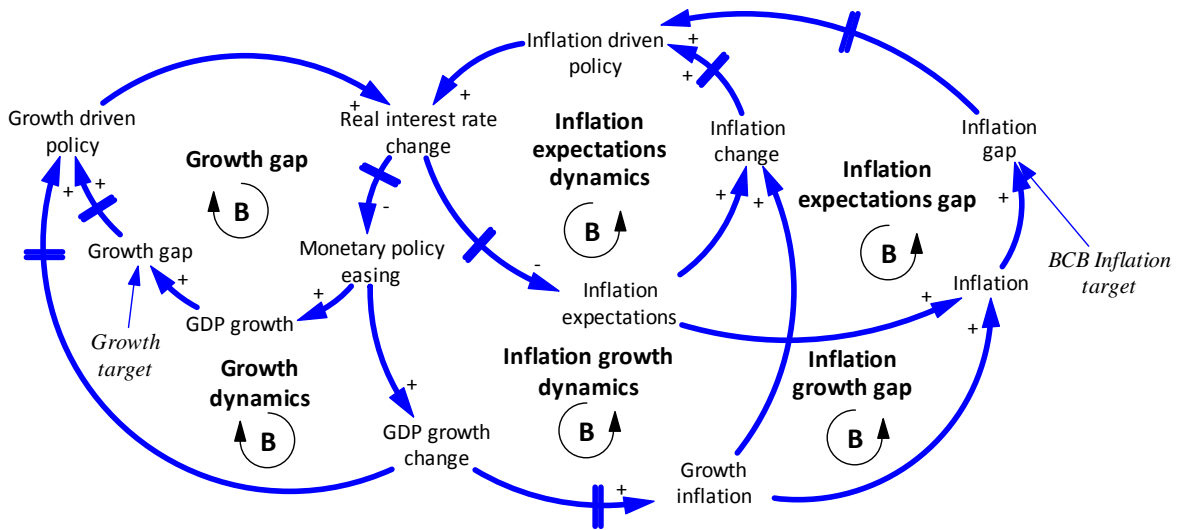
The goal is to exploit the interaction between the real interest rate, inflation and GDP growth as the reference modes. The purpose is to explain the behaviour of these variables with a Taylor rule hypothesis.

5.2. Causal loop diagram

Overview

The Taylor rule causal loop diagram (CLD) considers five feedback loops, all of which feed back into real interest rate changes. 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 5: causal loop diagram

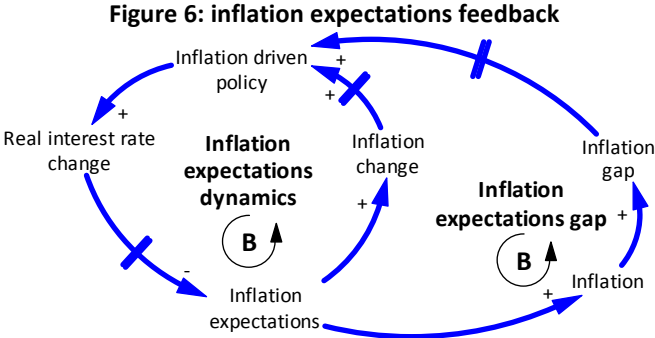


To summarize, the principle structure and reasoning of the Taylor rule model largely corresponds to the small new Keynesian baseline model by Clarida et al. [1999]. The Taylor rule model covers an IS equation for GDP growth, a Phillips equation for inflation and addresses monetary policy. However, the 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]. Opposing the Taylor rule approach in here, the standard NK models take monetary policy as an optimization problem of the central bank with respect to future outcomes of growth and inflation [Clarida et al., 1999]. Nevertheless, a small new Keynesian setup with a Taylor rule was already provided by Woodford [2001].

Inflation expectation dynamics and gap

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].

A point has to be raised with regard to the notion of changes and gaps and the sign of the arrows in the CLD. 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. Therefore, the notion of “change” is a neutral denomination that covers both increases and decreases in a variable. Similarly, a gap is a neutral denomination that covers both positive and negative gaps. In case of a positive gap, an inflation target overshoot, the central bank raises the real interest rate, a positive change. Positive gaps therefore trigger positive real interest rate changes, an increase, while negative gaps lead to negative real interest rate changes, a 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.

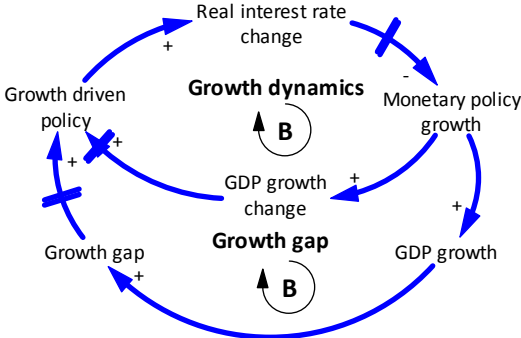
The inflation expectations loops involve two delays. First, it is assumed that it takes some time until rational firms have factored real interest changes into their prices expectations, representing an empirical expectation lag [Fuhrer and Moore, 1995a, Roberts, 2001]. The expectation delay is assumed 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.

Growth dynamics and growth gap

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.

Figure 7: GDP growth feedback



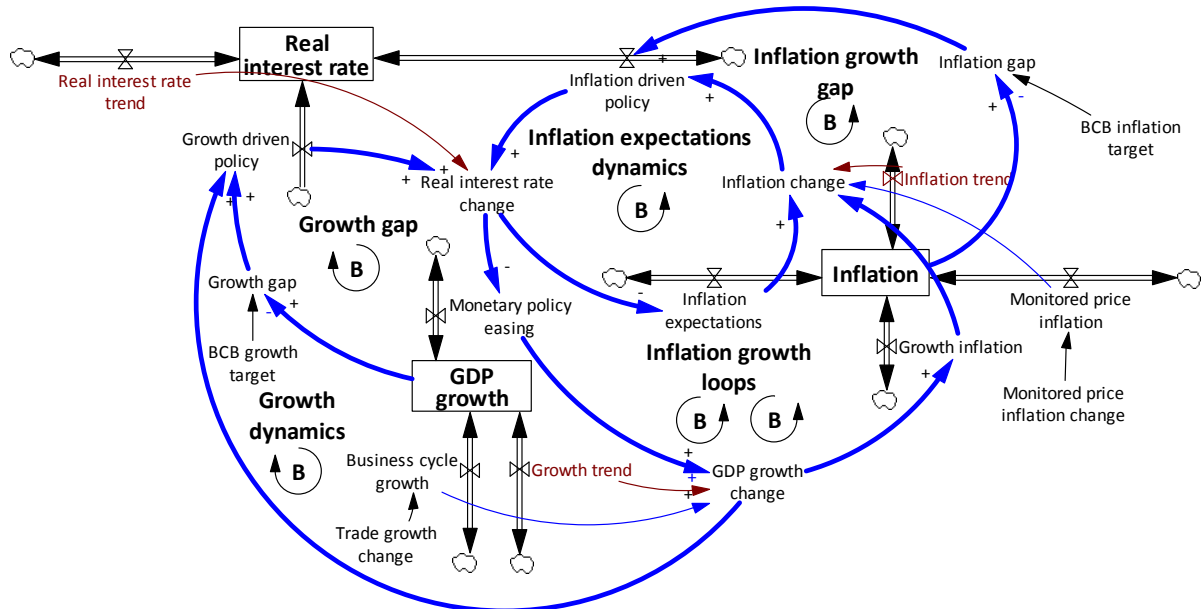
The growth feedback loops involve two delays. The first delay is related to the lag between real interest rate changes and the impact on GDP growth. This is assumed to be a sticky information delay on behalf of the consumers [Mankiw and Reis, 2002]. The second delay is the smoothing of the real interest 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].

Inflation growth dynamics and gap

The inflation growth loops describe how inflation responds to past GDP growth dynamics and refers to price setters with adaptive expectations [Roberts, 1997]. This is because the rational firms have already considered the effects of changing GDP growth by looking at

diagram in the model and for simplicity excludes the parameter variables. Figure 10-12 capture the stock-and-flow structure, while appendix B.1 contains the stock-and-flow model including factor and delay parameters.

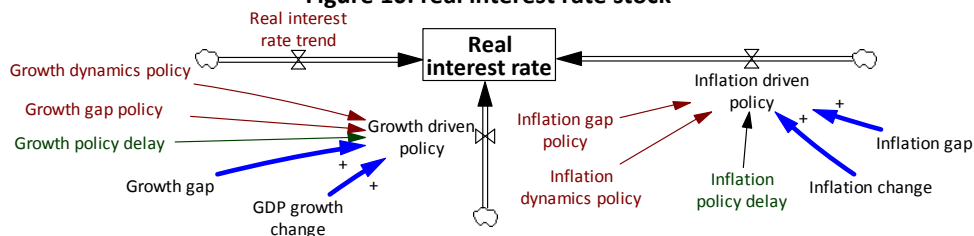
Figure 9: stock-and-flow structure



Real interest rate stock

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. 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 10: real interest rate stock

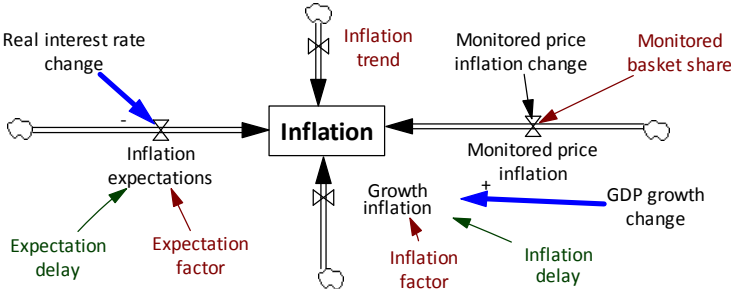


Inflation stock

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 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.

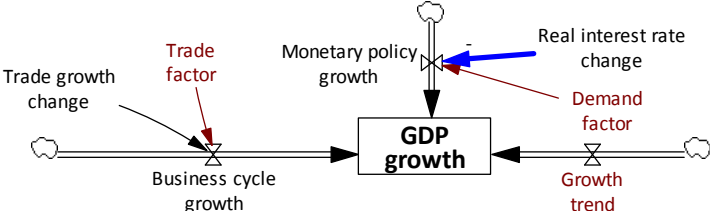
Figure 11: inflation stock



GDP growth stock

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].

Figure 12: GDP growth stock



Taylor rule and limitations of the model

According to the Taylor rule of the model, the real interest rate changes are determined by both current gaps of inflation and growth and current dynamics of inflation and growth. The

real interest rate level itself is not part of the internal feedback structure, but is considered as the central reference mode. The Taylor rule of the model is a nonlinear Taylor rule for interest rate changes with both gaps and levels of GDP growth and inflation. This is related to certain first difference Taylor rules [Fuhrer and Moore, 1995b, Orphanides, 2007]. 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].

The continuous Taylor rule in the model is that the real interest changes with regard to growth dynamics at factor a_1 and to the growth gap at factor β_1 after a growth policy delay of d_1 . In addition, the real interest rate is altered with respect to inflation dynamics at a factor a_2 and to inflation gaps at a factor β_2 , given an inflation policy delay of d_2 . Finally, the real interest rate is subject to a constant trend of size c :

$$\frac{dr}{dt} = a_1 \frac{dy_{t-d_1}}{dt} + \beta_1 \frac{y_{t-d_1} - \hat{y}_{t-d_1}}{dt} + a_2 \frac{d\pi_{t-d_2}}{dt} + \beta_2 \frac{\pi_{t-d_2} - \hat{\pi}_{t-d_2}}{dt} + \frac{c}{dt}$$

(2) Taylor rule for real interest rate changes

In total, the model is inspired by the small structural new Keynesian model [Clarida et al., 1999]. However, it substitutes the central bank minimization problem by a Taylor rule as in Woodford [2001] and considers modifications of the Phillips and the IS equation. The model also considers the Brazilian phenomenon of monitored prices and adds trade volume to GDP growth while dropping income expectations of the standard NK models. Screenshots of the core equations of the model are also listed in appendix B.1.

The model also bears some noteworthy limitations beyond the new Keynesian framework. There is no direct communication between the government and the central bank, for instance regarding fiscal policy. The central bank only looks at currently available numbers of trade volume, monitored price inflation and inflation expectations. It implicitly looks at inflation expectations since they are taken as an implicit external input for the calculation of the real interest rate. Furthermore, the model does not consider a foreign monetary sector, e.g. U.S. monetary policy, and also does not address the role of exchange rates. Moreover, the model pays no consideration of specific monetary policy channels.

5.4. Model calibration

Sample and data

The sample covers monthly data between the beginning of April 2004 and the end of March 2011, ranging from 2004:Q2 to 2011:Q1². The Real interest rate is the SELIC rate accumulated in the month in annualized denomination minus the 1-year expected inflation (IPCA) from the BCB's market expectations database. Inflation is based on the monthly 12-months IPCA inflation rate constructed from the IBGE's IPCA price index. GDP growth has been calculated based on the 12-months growth rate of the IBGE's GDP index in quarterly intervals. In order to turn the quarterly growth into monthly rates, a cubic spline interpolation has been applied³. A cubic spline turns quarterly GDP growth data into a piecewise continuous GDP growth curve [Reinsch, 1967]. This allows for picking monthly data from the continuous GDP growth curve.

The inflation target corresponds to the official BCB inflation targets. The historical targets were subject to a cubic spline in order to account for a smooth continuous target. Furthermore, a constant growth rate of 4.5% has been chosen as a GDP growth target, which is close to the actual average growth rate of 4.43% of the sample.

While the data for the stocks are applied as annualized rates, the data for the flows have to be put in as changes since they represent first differences of the stocks. For trade growth change, the growth rates of the quarterly IBGE export and import indices have been calculated and continuously transformed by means of a cubic spline. Afterwards, the growth rates have been added and monthly trade growth changes were taken by subtraction. For the monitored basket inflation changes, price changes in monthly intervals were collected from the BCB and a monitored price index has been constructed. Afterwards, monthly monitored price inflation is calculated as the difference in the index over 12 months to get to annual supervised inflation in monthly intervals. Finally, the differences in these monthly intervals were taken, resulting in the monthly change in annualized supervised basket inflation.

The time steps of the model are set as 0.0078 years, equivalent to 2.85 days between each step. The unit of time is years, which leads to annualized calibrated parameters. For the delays, the parameter values correspond to absolute years. For the trend flows, the esti-

² The second quarter 2004 is essentially the end-point of the confidence crisis monetary policy cycle when the SELIC reached its floor of 16% [BCB, 2011a]. At the same time, the second quarter 2004 marks the starting point of the first non-shock related monetary tightening cycle [Bevilaqua et al., 2008].

³ The cubic spline for Excel software is available on <http://www.srs1software.com/SRS1CubicSplineForExcel.aspx>

mates of the constants yield the value of a trend flow occurring over one year. With regard to the factor parameters, the interpretation of the optimization results may be tricky. Inputs into the model are annualized monthly changes while estimated parameters correspond to annualized parameters. This means that a constant change in trade growth over a year has an equivalent impact on a stock as a constant change over a month when multiplying the trade factor by twelve.

Appendix B.2 provides an overview of the data and the parameters. Calibration was done with version 5.11 of Vensim® [Venata Systems, 2011].

Summary statistics and estimated parameters

The calibration puts equal weights on the fit of the real interest rate, GDP growth and inflation. Nine auxiliary variables, five delays, three trend flows and three initial values of the stocks are considered as the twenty parameters for calibration.

The calibration statistics for the three stocks include the goodness of fit, the mean squared error and the Theil inequality statistics. The inequality statistics further decompose mean squared error into the components mean bias, unequal standard variation and unequal covariation [Sterman, 1984]. The mean bias refers to a systematic deviation of the model S from actual reality A, potentially related to parameter or specification errors. Unequal variance may indicate a different magnitude of business cycle fluctuations or different long-run trends. Finally, unequal covariation is the deviation from the actual series on a point-by-point-basis, indicating random noise or cyclical modes that are not well captured.

$$\frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2 = \underbrace{(\bar{S} - \bar{A})^2}_{U_m = \text{Mean bias}} + \underbrace{(\sigma_S - \sigma_A)^2}_{U_s = \text{Unequal variance}} + \underbrace{2(1 - \rho)\sigma_S\sigma_A}_{U_c = \text{Unequal covariation}}$$

\bar{S}, \bar{A} : Means
 σ : standard deviation
 ρ : coefficient of correlation

(3) Theil inequality statistics [Sterman, 1984]

All statistics are listed in appendix B.3.1. 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], which is eventually related to first-order autocorrelation. In total, the model captures the systematic trends while the residuals exhibit autocorrelation.

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 real interest rate is initially set at 11.22%. 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 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:

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

(4) Brazilian Taylor rule

Concerning inflation, the optimization yields a starting value of 6.61%. Inflation decreases by 0.24% in response to a 1% increase in the real interest rate after an expectation delay of 2 months. With regard to the growth component of the Phillips curve, the IPCA increases in exact one-to-one relation with GDP growth after a delay of 1.33 years, the longest delay in the model. Moreover, 1% of the monitored price inflation is estimated to increase the IPCA by 2.86%. This comes without delay since current monitored prices are part of the current IPCA. The monitored basket share factor of 2.86 seems intuitively extreme. However this percentage refers to the impact of a 1% monthly increase over the period of a year. The factor becomes 0.24% in monthly terms, which is close to the 30% share for administered prices in the IPCA basket. Moreover, the inflation trend is estimated at 0.25% per year, reflecting an overall increasing long-run inflation. However, the inflation trend becomes more

pronounced when considering that the -1.66% annual real interest rate trend translates into an additional indirect inflation trend of 0.40% via the inflation expectation factor of -0.24. As a result, the total inflation trend sums up to 0.65% per year.

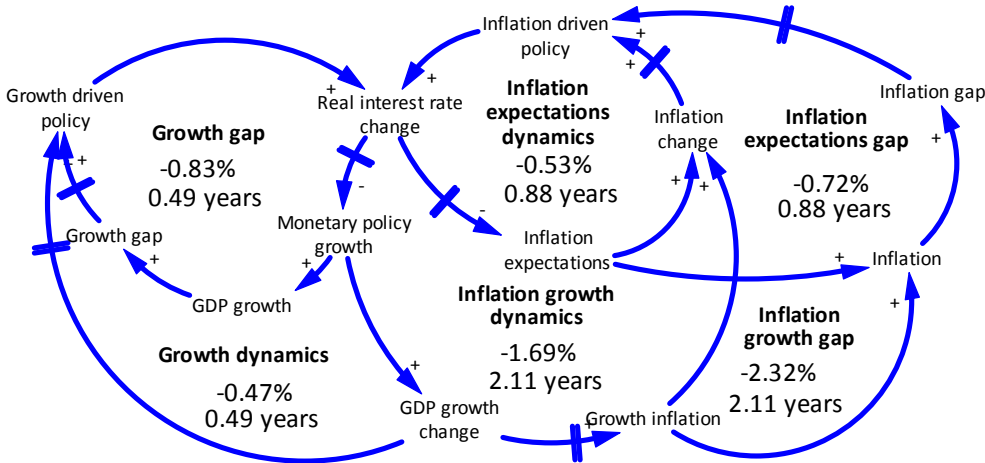
GDP growth is initially set at 7.24 %. With regard to the IS-curve, a 1% change in the real interest rate has an impact of -0.77% on growth with a delay of 0.05 years, the shortest delay in the model. Moreover, a 1% increase in trade growth indicates a 1.46% rise in GDP growth. Furthermore, the optimization yields an estimate of -0.99% of annual GDP growth trend. The strong decrease in the growth trend is mainly due to its role in offsetting the effect of the long run decrease in the real interest rate, which pushes growth by 1.28% per year. The net-growth trend is an idiosyncratic increase of 0.29% per year. Concluding, the estimated flows of GDP growth and inflation have to be split into an idiosyncratic component and the component related to setting off the strong decrease in the real interest rate.

Furthermore, appendix B.3.4 compares the Taylor rule model calibration results to the results from the SAMBA model and the semi-structural model at the BCB.

Analysis of loops

The results of the optimization also outline the timing and importance of the feedback loops. The amount of feedback is calculated by multiplying the auxiliary variables along a loop. The corresponding delay is calculated by summing up the delays along the loop.

Figure 13: monetary policy feedback – size and delays



The first feedback occurs through the growth related loops. It takes less than a month for a real interest change to affect growth and another five months for growth changes to trigger a change in real interest rates. With regard to the strength of the growth loops, a 1% real interest rate increase feeds back with a decrease of 1.30%. Of this decrease, 0.83% are related to the growth gap and 0.47% are related to growth dynamics. The feedback through the inflation expectation loops will occur after ten and a half months. This feedback sums up

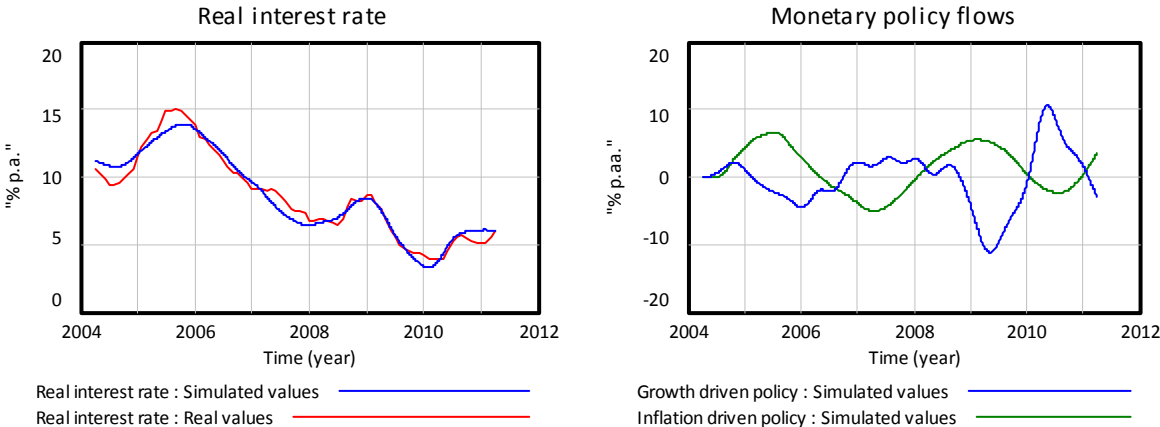
to a total value of 1.25%, with a higher impact of the expectation gap. The other inflation related feedbacks via GDP growth will only reach the real interest rates after 25 months, but amount to a total value of 4.01%. In comparison, the inflation growth loops exhibits more than three times the feedback compared to the growth and inflation expectations loops. Yet the growth loops will have already occurred four times by the time the inflation growth loops reach the real interest rate.

5.5. Brazilian business cycle

Reference modes

The simulated real interest starts above the historical real value and rises into 2005 following high growth. The difference to the real historical real value is likely related to the ambition of the BCB to build up credibility [Bevilaqua et al., 2008]. Following the initial monetary tightening, the real interest rate enters a long decrease until 2008 as inflation eases. In 2008, inflation above the target leads to a monetary tightening. At the end of 2008, the negative international shock feeds into growth and causes a stark monetary policy easing following. Monetary policy now becomes growth dominated, because the rebound in 2009 triggers a monetary tightening by 2010. In 2011, the real interest rate stands at 6% and sees upward pressure from inflation and downward pressure from falling growth.

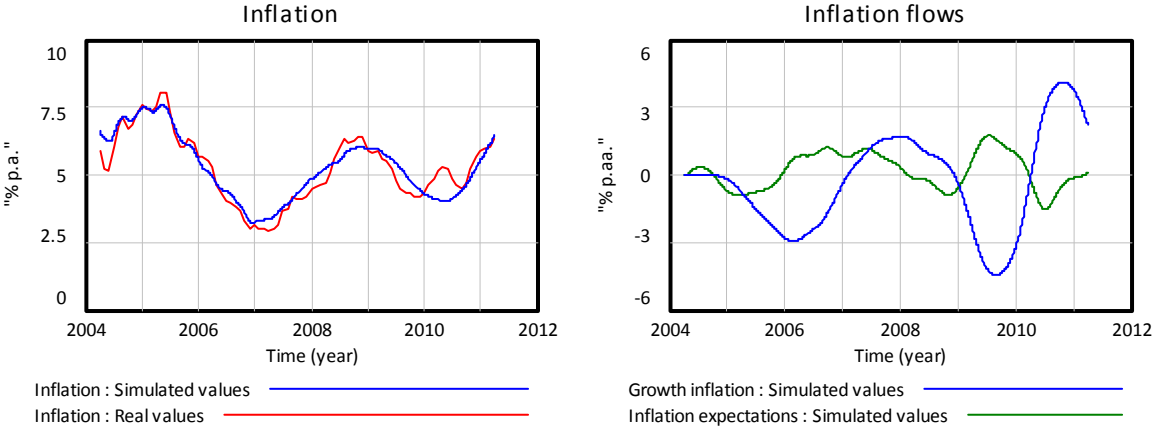
Figure 14: simulated real interest rate



Inflation increases into 2005 as a result of adjustments in monitored prices. Afterwards, it starts to fall in response to monetary policy easing, first via expectation and second through lagged growth effects. By the end of 2006, inflation has reached a historical minimum under the inflation targeting regime and starts to rise again amid rising inflation expectations and high GDP growth. In 2008, inflation peaks and starts to fall towards the 4.5% target rate in

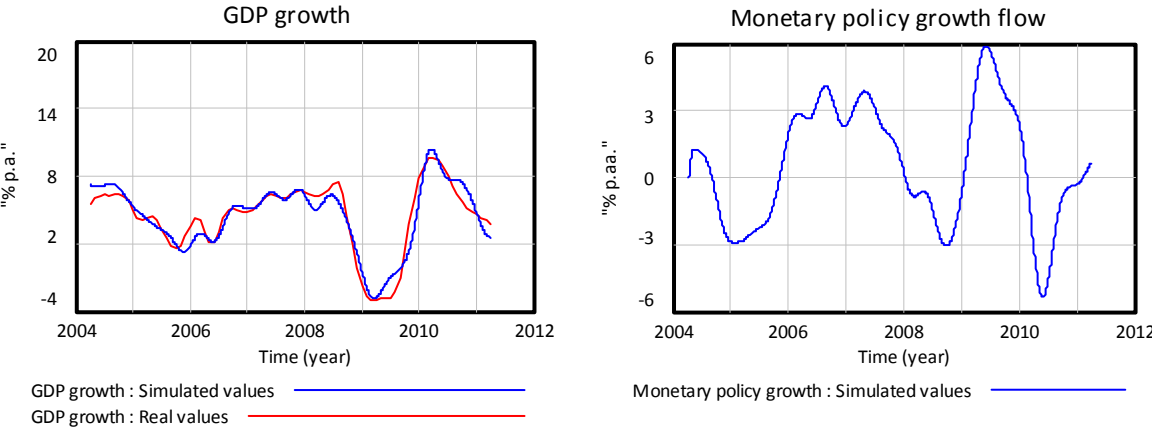
2009 as a result of falling GDP growth. The deviation from the historical series in the first half of 2010 is mainly related to non-tradable price inflation [BCB, 2011a]. Towards the end of 2010, the economic rebound finally triggers rising inflation dynamics, which persist until the end of the sample.

Figure 15: calibrated inflation



GDP growth starts at the high level of the post-confidence crisis rebound. With the first regular monetary tightening cycle starting in 2004, GDP growth falls to 2% by 2005. Afterwards, the long monetary easing allows for growth rates beyond 5%. By the second half of 2008, growth is hit by a slump, following the Lehman-default and its spill-over effects. Brazil enters a recession, with negative growth rates in the first half of 2009, and monetary policy easing not being able to set off the external shock. However, by the second half of 2009, growth rebounds significantly and reaches an average of more than 7%. Afterwards, growth rates start to fall again significantly into 2011, while increasing inflation prompts monetary policy to become tighter.

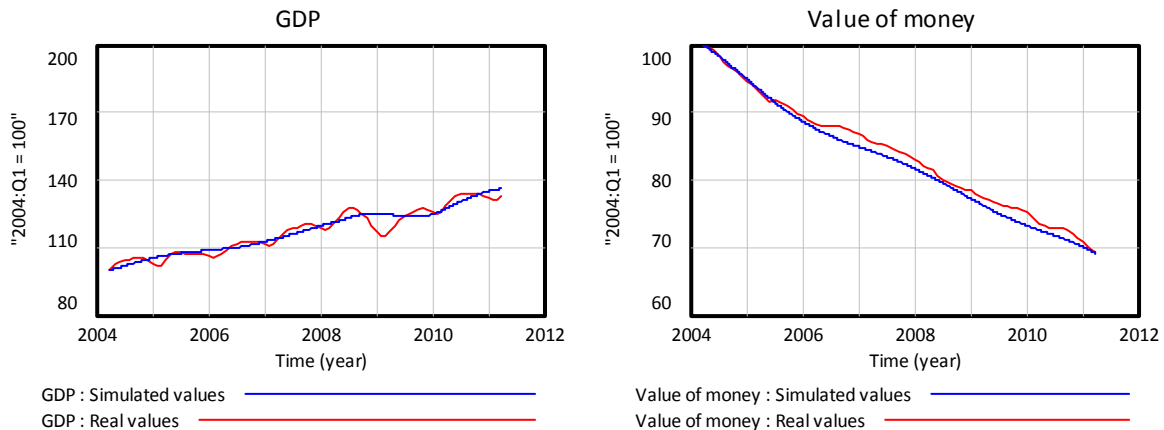
Figure 16: calibrated GDP growth



Welfare and impact of flows

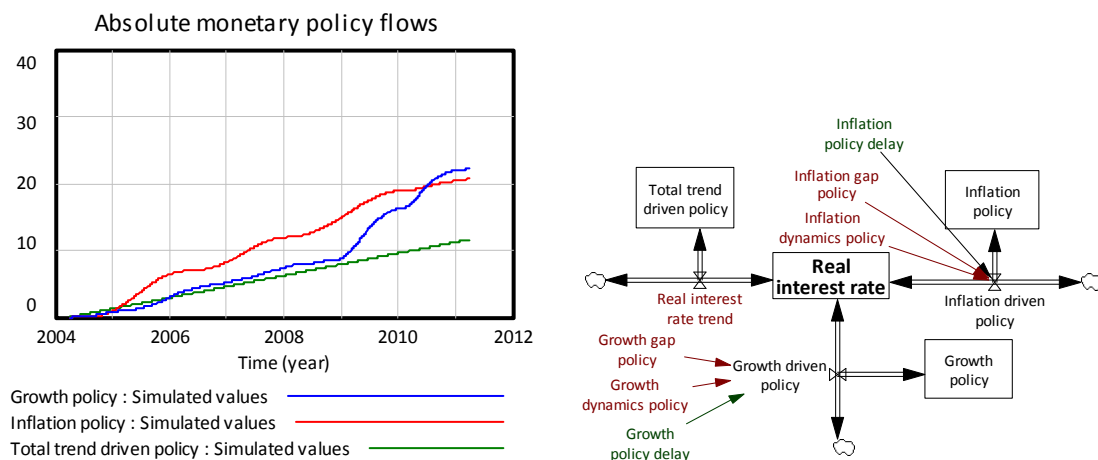
Furthermore, the accumulation of GDP growth and inflation in stocks of GDP and of the value of money yields implications about the evolution of welfare across the sample. In total, GDP has increased by more than one third to an index value of 136. As a negative welfare component, cumulative inflation has shrunk the value of 1.00 Real to 69 cents towards the end of the sample.

Figure 17: simulated GDP and value of money



Furthermore, auxiliary stocks of each real interest flow have been constructed which accumulate the total absolute monetary policy flows over time. This answers question of whether monetary policy is mostly inflation policy or growth policy driven. This absolute importance of the policy flows cannot be solely inferred from the Taylor rule parameters. 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 and that the exogenous constant trend has been accounting for about one-fifths of monetary policy moves.

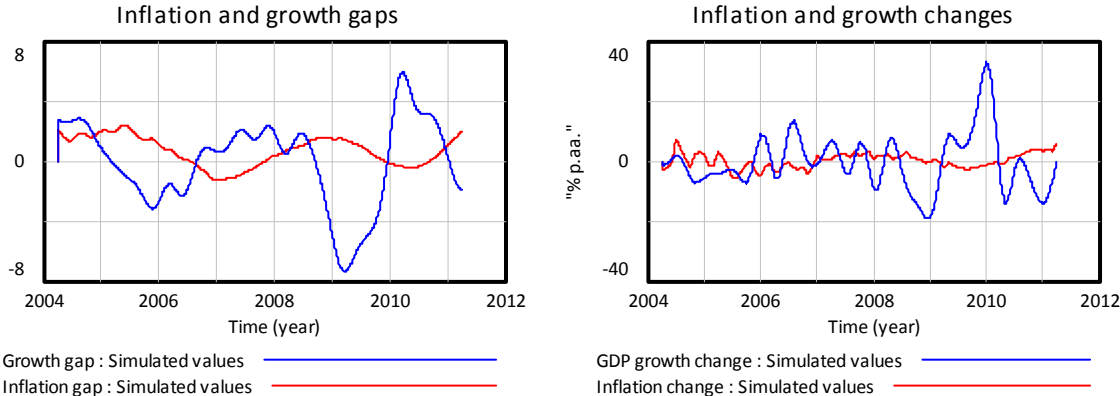
Figure 18: total monetary policy flows



The observation of a dominant growth policy is principally caused by the 2009 recession and the 2010 rebound. During these years, GDP growth highly exceeds inflation in terms of both

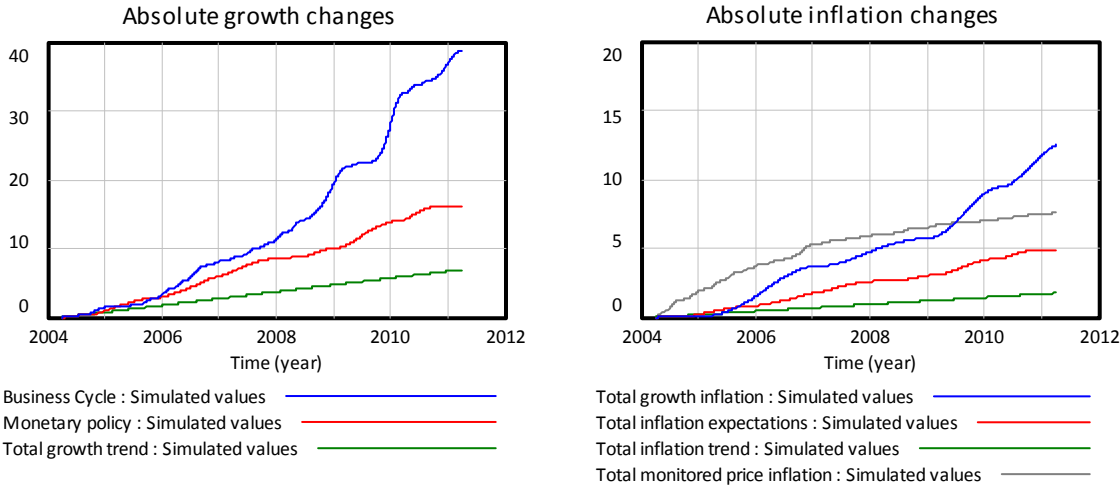
absolute gaps and absolute current changes. Furthermore, this happens over a pronounced horizon, such that the growth gaps and changes actually translate into growth related monetary policy instead of being smoothed out by the policy delay. Therefore, monetary policy has been more growth than inflation driven over the horizon of the sample, despite the fact the BCB operates in an inflation targeting regime. In general, inflation drives monetary policy in periods of low business cycle volatility through high inflation policy factors, while growth drives monetary policy in periods of pronounced external shocks, despite lower growth policy parameters.

Figure 19: inflation and growth gaps and changes



Furthermore, the auxiliary stocks for the growth flows show that exogenous trade flows outperform 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 20: total flows of growth and inflation



Moreover, 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 very small impact compared to the size of the GDP growth and real interest rate trends.

To conclude, the analysis of absolute flows in the model yields a surprising result. Monetary policy has been mostly driven by growth considerations as growth policy has accumulated more absolute monetary policy flows than inflation policy. Furthermore, monetary policy is highly endogenous in the model, while GDP growth is only partially explained by endogenous feedback, outlining the limited impact of monetary policy on overall economic activity. Finally, inflation is mostly explained by adaptive price-setting, especially following the external shock to GDP growth in 2008. Inflation has also become more endogenous over time as monitored price inflation has been little pronounced from 2007 on.

6. Model validation

6.1. Context: adequacy of methodology

System dynamics Validation

Validation is “the process of establishing confidence in the soundness and usefulness of a model” [Forrester and Senge, 1980]. Model validity is the degree at which a model adequately reflects a system [Barlas, 1996]. SD models must not only generate the “right output behaviour” but produce it “for the right reasons” in the internal structure of the model.

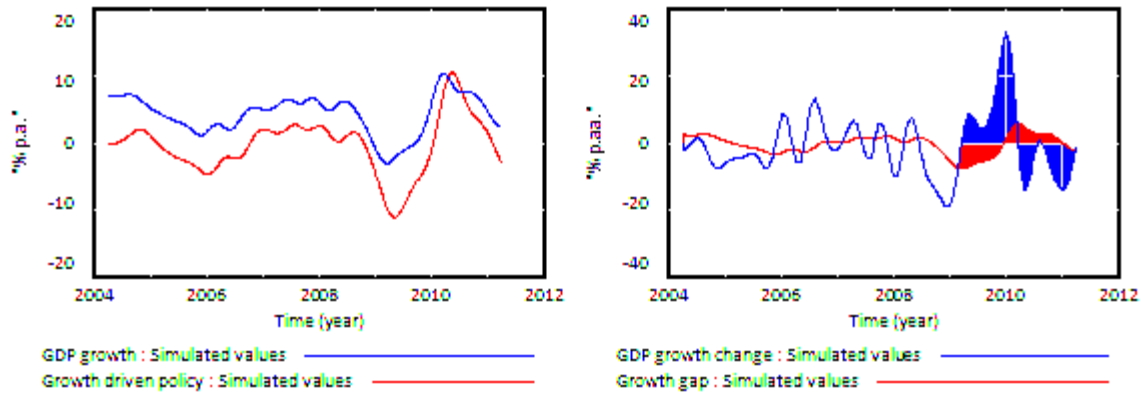
Context related tests as in chapter 6.1 address the situation to which the model is attached and evaluate the utility inferred from the modelling efforts [Schwaninger and Grösser, 2009]. This raises questions about the adequacy of the applied methodology and whether the issues have been adequately identified. Structure related tests as in chapter 6.2 evaluate the interrelationships and formal components of the model. Direct structure tests deal with the conformity of the model structure with established knowledge about the real system. Indirect structure tests deal with the plausibility of behaviour generated by the model. Model behaviour tests as in chapter 6.3 compare the model results with the real system, including behaviour reproduction and behaviour anticipation tests.

Degree of nonlinearities and delays

Validity essentially relates to the purpose of the model [Barlas, 1996]. The purpose of the Taylor rule model is to capture the feedback of monetary policy in Brazil. The adequacy of system dynamics for addressing a problem principally refers to the degree at which nonlinear feedbacks and stocks and flows determine the behaviour of the system [Sterman, 2001]. In this case, system dynamics can exploit its full potential in understanding and modelling the structural dynamics, also because it does not require a formal analytical solution to the whole system.

In the original specification, the Taylor rule referred to a linear combination of absolute deviations of output and inflation from a target [Taylor, 1993]. Instead, the Taylor rule model does not consider a linear rule but includes both gaps and changes of growth and inflation. The nonlinear Taylor rule leads to a growth policy flow of the real interest rate that does not follow GDP growth in a one-to-one fashion (Figure 21). This was heavily pronounced during the 2009 to 2010 fluctuations. During those abnormal times, gaps in red and dynamics in blue put opposing forces behind growth policy. GDP growth is below the target but trends upwards in 2009 and above the target but trends downwards in 2010.

Figure 21: effect of nonlinearities in the Taylor rule



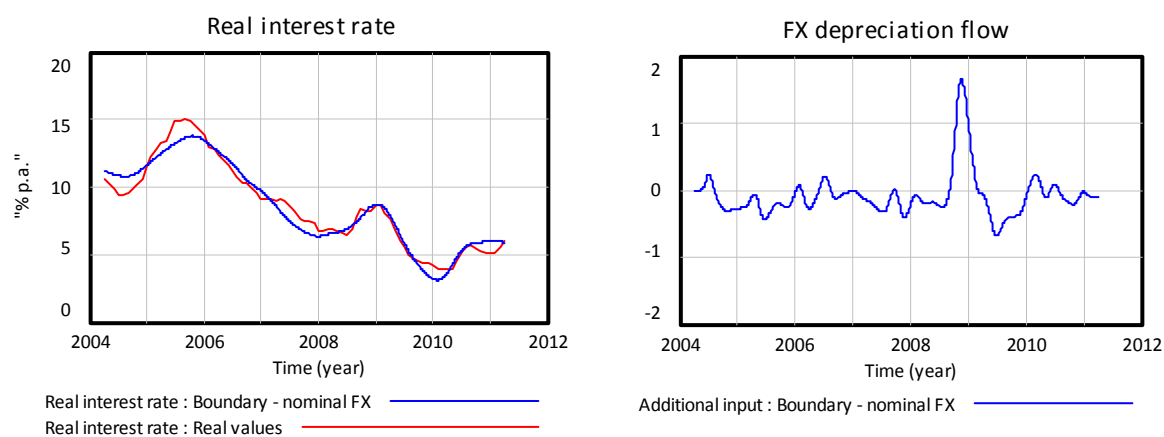
Furthermore, a new stance of highly nonlinear central bank preferences has been emerging [Ruge-Murcia, 2003, Bevilaqua et al., 2008, Cukierman and Muscatelli, 2008]. For instance, the central banker may place a larger loss on inflation target overshooting compared to undershooting, a positive inflation gap avoidance preference. This may be motivated by the ambition to build up credibility. Central banks may also be more averse towards negative output gaps during recession than to positive output gaps during boom periods, a recession avoidance preference. Yet while these models consider nonlinearities analytically, SD also makes nonlinearities visible in the historical business cycle. To illustrate this, the policy section will later on consider inflation and recession avoidance policies.

6.2. Structure: boundary, extreme conditions, sensitivities and impulse responses

Boundary adequacy test

The boundary structure test addresses whether the model includes all relevant aspects with regard to the model purpose [Forrester and Senge, 1980]. The model takes the real interest rate as an endogenous Taylor rule without external inflow. The question at stake is whether an additional external factor might improve the explanatory power of the Taylor rule. Initially, the BCB has considered the exchange rate as a central element of a Taylor rule [Muinhas et al., 2001] and nominal exchange rate depreciation has been identified as a significant factor in a first difference Taylor rule in a 1999:Q3 to 2005:Q1 sample [Holland, 2005]. The Taylor rule model will therefore be tested with the nominal USD exchange rate as an additional real interest rate inflow. The according calibration is done by estimating the factor and the delay of the inflow while leaving all other model parameters untouched.

Figure 22: boundary adequacy of real interest rate



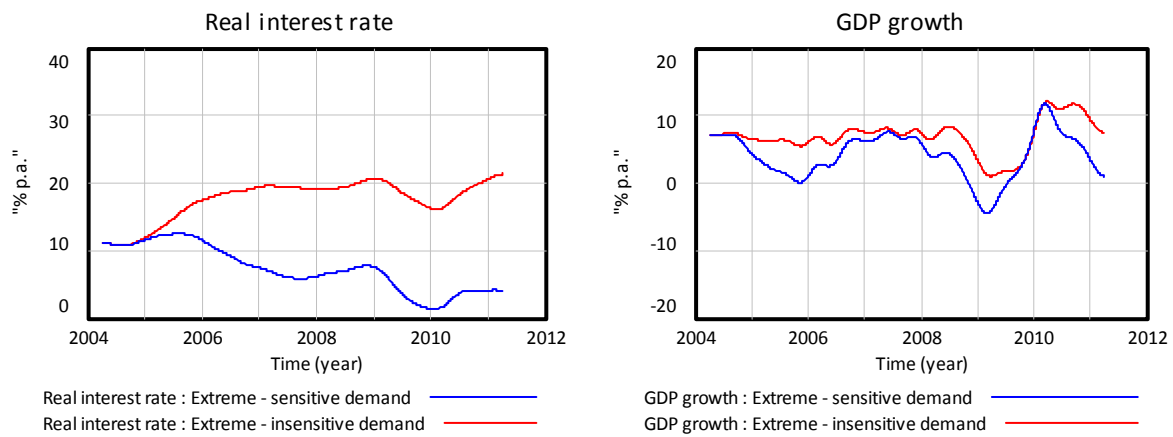
The extension only slightly improves the calibration payoff by 1.75%. The monetary policy delay of the nominal exchange rate is 0.12 years and the factor for the relative nominal exchange rate change is 0.13. This describes a 0.13% increase in the real interest rate per percentage of depreciation of the nominal increase exchange rate. The highest inflow rate is represented by the Lehman-default turmoil in 2008 with an investor flight out of emerging markets and a sudden depreciation of the Real [Stone et al., 2009]. This was followed by a reversed inflow as investors returned to emerging markets in the second quarter of 2009. Yet concluding, the inclusion of an additional factor does not significantly impact the behaviour of the stocks, nor alter the endogenous feedback.

Extreme condition tests

Extreme condition tests are particularly effective in revealing flaws in the model structure and discovering omitted variables [Forrester and Senge, 1980]. Furthermore, extreme condition tests may analyze policies that force the system out of historical behaviour patterns and regions. The focus is on the parameters of the economy, which have to be taken as exogenous by the central bank. The tests consider extreme conditions in expectations and demand.

The extreme demand conditions test considers the case of a changing demand factor. In case of a high demand factor, GDP growth becomes very sensitive to monetary policy, related to a steep IS curve. In this case, an increasing real interest rate translates into a steep reduction in GDP growth via a highly negative demand factor. Fully insensitive demand describes the case in which monetary policy has no effect on GDP growth, equivalent to a horizontal IS curve. An increase in the real interest rate does not effect growth in any way due to a zero demand factor in the model. Furthermore, the growth trend has to be adjusted under the two conditions in order to avoid a biased effect of the decreasing real interest rate trend.

Figure 23: extreme demand conditions

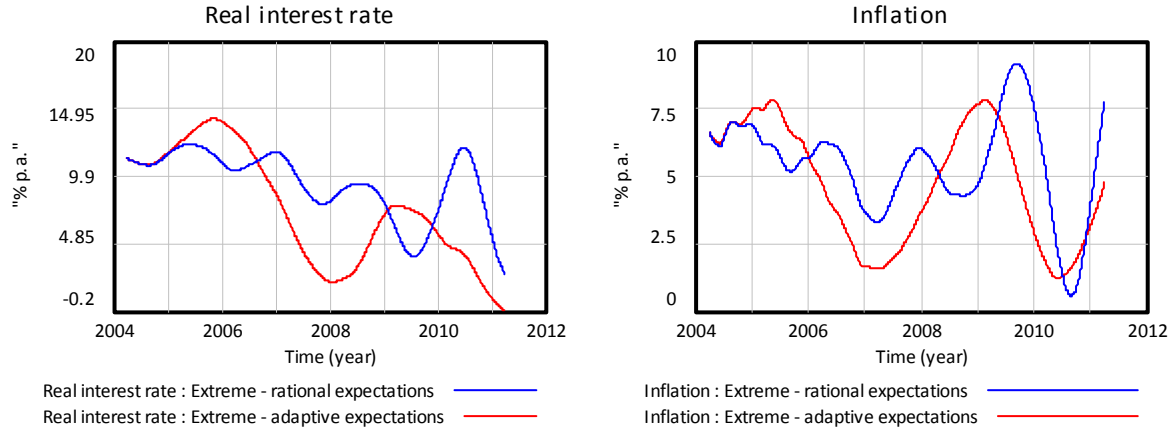


The case of sensitive demand considers a doubling demand factor with GDP growth responding to a 1% increase in the real interest rate with a 1.44% decrease. This leads to a higher impact of the feedback in the growth loops. It slightly increases the amplitudes of GDP growth and of the real interest rate compared to the real historical values due to a higher degree of oscillating feedback in the model. In case of fully insensitive demand, the relationship between the real interest rate and GDP growth is eliminated. Growth is entirely driven by trade dynamics and the residual growth upward trend of 0.29% per year. Since growth is initially above the target, the central bank starts to tighten monetary policy but does realize that the tightening has no effect on monetary policy. This observation of a nonsense monetary policy holds for the entire business cycle. As monetary policy becomes very tight due to the positive growth gap, inflation decreases. Therefore, the insensitivity of growth towards monetary policy is a free lunch for monetary policy tightening. The central bank cannot influence GDP growth any more, but can tame inflation expectations. However, this assumes that the rational agents, just as the central bank, do not realize that monetary policy does not have an impact on GDP growth any more. To conclude, a more sensitive GDP growth leads to slightly larger business cycle oscillations and insensitive demand eliminates the monetary policy trade-off between GDP growth and inflation. Yet the latter implication only holds under problematic assumptions.

The expectation tests consider fully rational expectations with a vertical Phillips curve and fully adaptive expectations, equivalent to a Phillips curve with unity steepness. This switches off either the inflation growth loops or the inflation expectation loops. For the fully rational scenario, the expectation factor is increased to 1.01 in order to consider that all adaptive agents have become rational. The reverse holds for the adaptive extreme condition scenario that all rational agents become adaptive, which increases the inflation factor to 1.31. Fur-

thermore, the inflation trend has to be adjusted for the case of adaptive expectations since the real interest rate trend exercises a higher impact on inflation in the adaptive case.

Figure 24: extreme expectations condition



In case of fully rational expectations, the real interest rate is subject to medium run fluctuations as the medium-run expectation channel takes over the long monetary policy feedback via GDP growth. The recession starting at the end of 2008 triggers a faster and relative to the level more pronounced monetary policy easing. Inflation expectations rise steeply, which leads to a sharp monetary policy tightening. In the case of fully adaptive expectations, the business cycle wave length becomes very large and monetary policy becomes very sluggish. As a result, the monetary policy easing triggered by the 2009 recession prevails beyond 2010. To conclude, inflation follows a stable long run wave in case of adaptive expectations while it is more exposed to shocks periods in the case of rational expectations. These observations are generally plausible and confirm the validity of the structure of the model.

Behaviour sensitivity test

The behaviour sensitivity test portrays the reaction of the model to a change in input parameters [Forrester and Senge, 1980]. The test is applied to the parameters related to the external inputs in order to outline their impact on the model behaviour. For trade sensitivity and monitored basket share the sensitivity test considers a random uniform distribution with 50% and 200% bounds of the estimated parameter value. A higher trade sensitivity corresponds to a more open Brazilian economy. A very open Brazilian economy exhibits more business cycle volatility resulting from external shocks and requires more aggressive monetary policy moves. Regarding the monitored price basket, a higher basket share leads to bigger volatility during normal times, while monitored prices play a relatively inferior role during times of external shocks.

The sensitivity test with respect to the inflation target is based on a uniform distribution with targets between the 2.5% and 6.5% current confidence bounds. The test shows that lower inflation targets correspond to higher real interest rates, lower inflation levels and lower GDP growth levels. An alteration of the growth target with the same +/-2% range leads to reverse conclusions. It translates into higher corresponding growth rates and lower inflation due to a more intense growth gap loop. However, the growth target policy is not as pronounced as the inflation target policy due to lower growth policy factors.

Figure 25: sensitivity to trade and monitored prices

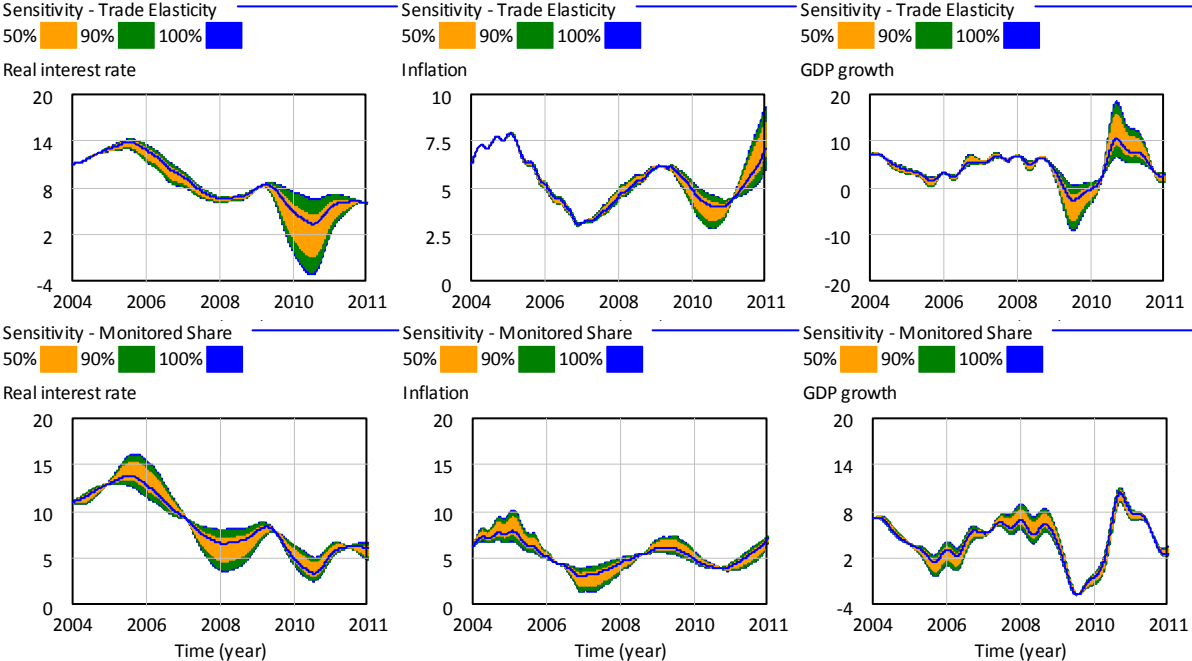
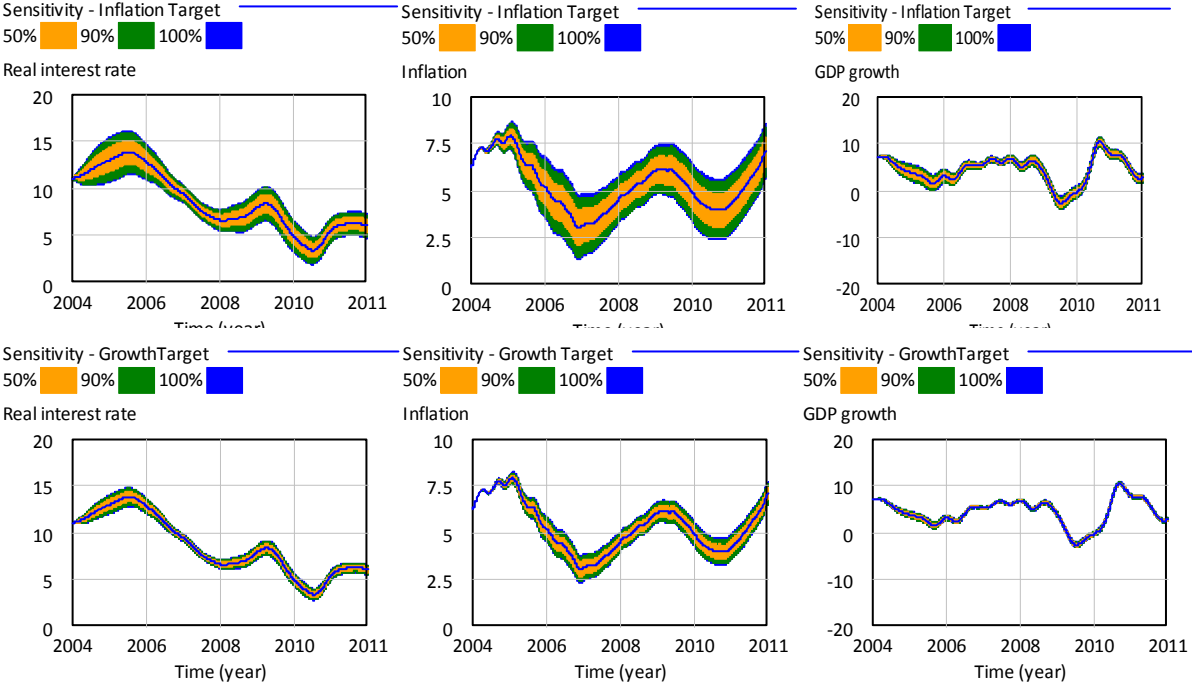


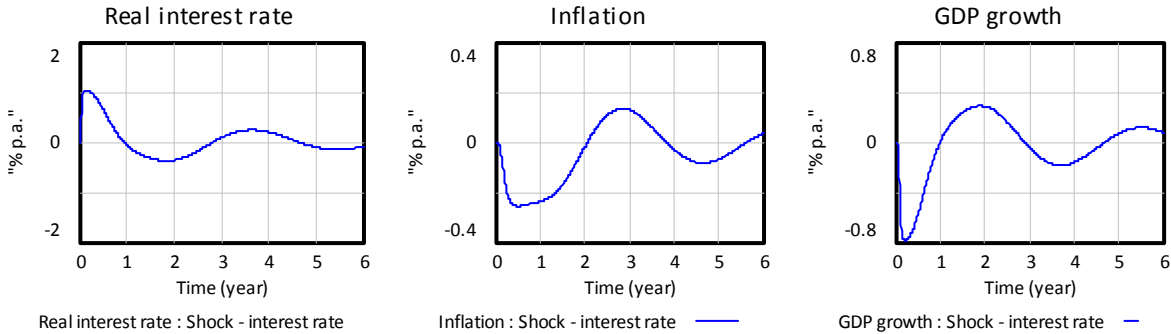
Figure 26: sensitivity to growth and inflation targets



Impulse responses

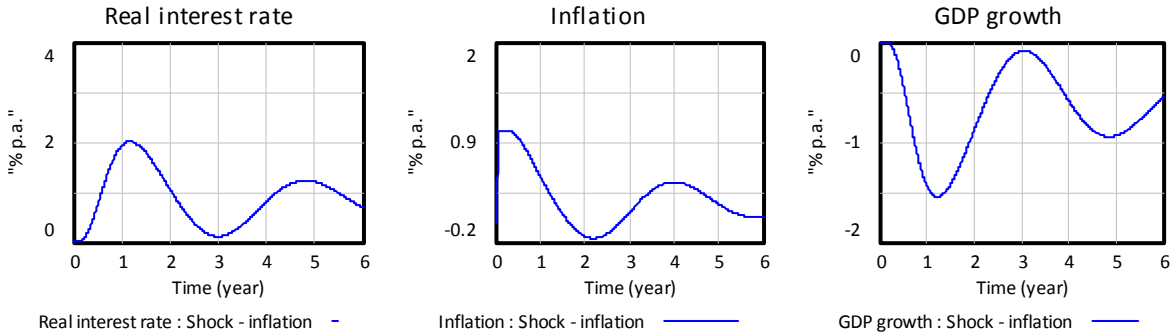
In the following, the model will be exposed to interest rate, inflation and GDP growth shocks, a common exercise for macroeconomic models [Koop et al., 1996]. The interest rate shock considers an increase of the interest rate by 1% over one month in both the real and the nominal rate. In the Taylor rule model, this triggers a sudden drop in GDP growth, forcing the BCB into monetary policy easing. Inflation falls due to lower expectations and subsequently due to lower growth. As growth and inflation bounce back, the BCB starts to tighten again in year two. In the long run, all variables will shift back to their pre-shock level.

Figure 27: impulse response – interest rate shock



A 1% shock to inflation triggers a strong monetary policy tightening with interest rates rising by 2% in year one. This triggers falling inflation expectations and a recession, which reinforces downward inflation dynamics. The monetary authority responds by letting interest rates fall again. Subsequently, growth rebounds, followed by inflation. In the long run, inflation shifts back close to the pre-shock level while the shock does not die out for GDP growth and the real interest rate.

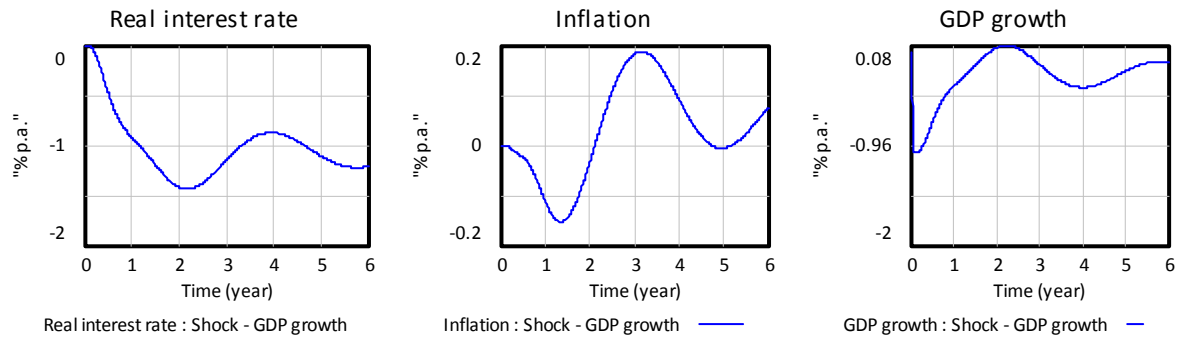
Figure 28: impulse response – inflation shock



The next exercise is to simulate a drop of GDP growth by 1%, which causes rapid monetary policy easing. However, inflation only slightly responds to the growth shock. Rational agents will only notice the growth shock when the central bank starts to raise the interest rate. This reveals the flaw of the model that rational agents only observe central bank behaviour while ignoring GDP growth. In the long run, growth approaches the pre-shock level while inflation

remains slightly above the initial rate. Most notably, the real interest rate tends towards an equilibrium far below the pre-shock level.

Figure 29: impulse response – GDP growth shock



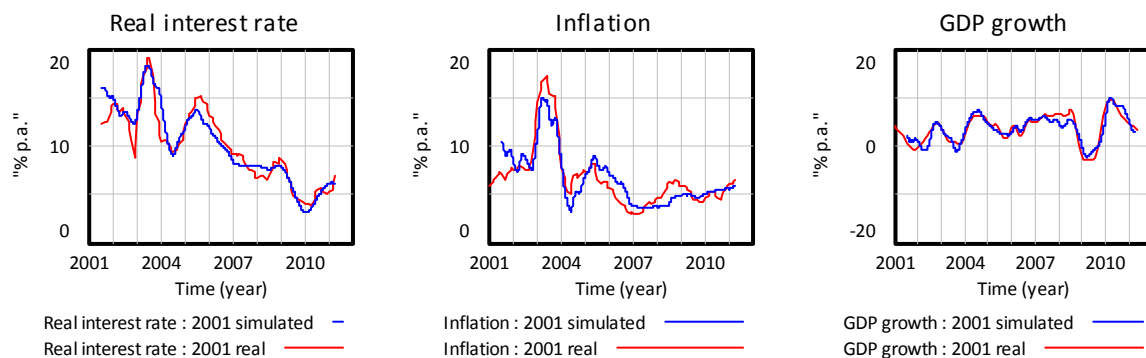
In total, the shocks trigger ample business cycle swings that only slowly flatten out. Furthermore, shocks do not die out in the long run as at least one stock does not shift back to the pre-shock level. Moreover, only the real interest rate shock is neutral in the long run, meaning that inflation and growth shift back to their pre-shock levels. Furthermore, appendix B.3.4 compares the Taylor rule model impulse responses to the SAMBA model impulse responses and draws conclusions regarding the different concepts of the two models.

6.3. Behaviour: reproduction and pattern anticipation tests

2001-2011 reproduction

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. The starting point is motivated by the fact that the BCB's inflation expectations data series starts in July 2001 [BCB, 2011a].

Figure 30: 2001-2011 behavior reproduction test

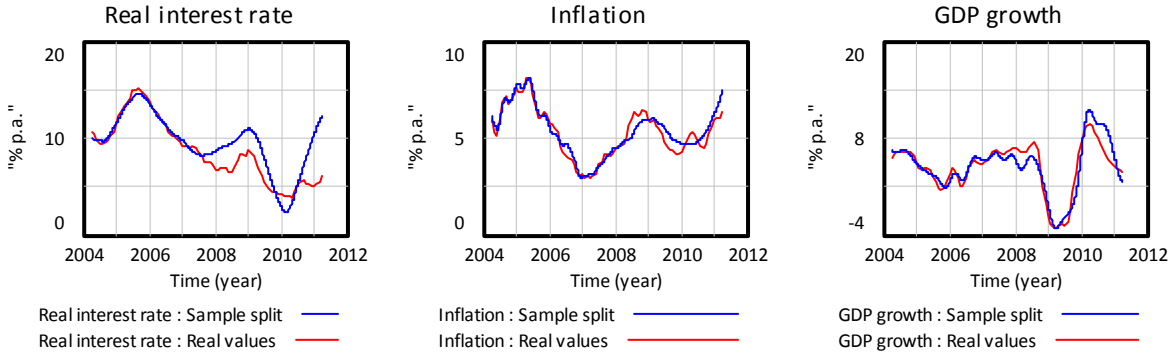


To recall, system dynamics behaviour prediction focuses on pattern instead of point prediction [Forrester and Senge, 1980]. The calibrated simulation closely matches the real interest rate and GDP growth variables. However, inflation exhibits a constant upward trend starting 2007 in the simulated results 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.

2004-2011 pattern anticipation

Furthermore, the model is then optimized with regard to the 2004:Q2 to 2007:Q3 period and, given the estimated parameters, runs until 2011:Q1. 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 therefore 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.

Figure 31: pattern reproduction test



As expected, the reproduced behaviour gets very close to the actual behaviour until 2007:Q3. Afterwards, the simulated interest rate strongly departs from real 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 trade and inflation, both with respect to levels and to the pattern of behaviour.

7. Business cycle scenarios and monetary policies

7.1. Scenario-policy setup

Base scenario configuration

Three scenarios are considered for the future time frame of the model beyond the first quarter of 2011 until the end of 2019. The base scenario considers the most likely economic developments for the Brazilian economy with regard to monetary policy, inflation, trade and internal growth. In addition, the boom scenario considers a bullish scenario while the bust scenario considers the bearish case of the future. The scenarios are injected into the model both via the external inputs of trade and monitored price inflation and future trends of the real interest rate, inflation and GDP growth. The trends are therefore treated as internal parameters over the time horizon of the sample until 2011:Q1 and as exogenous inputs for the future scenario until 2018:Q4. Furthermore, the scenarios do not consider volatility in external inputs of monitored price inflation and trade since the ambition is to only forecast the expected path of the business cycle. The scenario inputs into the model are indicated in appendix B.4.1.

However, some important aspects of the future economic outlook are neglected [BCB, 2011b]. The scenarios do not consider demographic dynamics, especially with respect to the continued increase in working population. Furthermore, the scenarios do not incorporate the potential effects of the offshore oil investments and explorations. Moreover, the Brazilian economy is becoming more sensitive to monetary policy as the credit channel of monetary policy is gaining importance and indexation in the economy is decreasing, which is also expressed by the increase in the share of fixed-rate government bonds. Concluding, the non-consideration of these aspects will potentially underestimate GDP growth in the model.

Policy configuration

Four policies are applied to the three scenarios. 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. Literally speaking, this policy considers the case that the COPOM would continue its past monetary policy until 2019, as if Alexandre Tombini had not replaced Henrique Meirelles. Opposing this, the new BCB strategy refers to the case that new COPOM strategy, introduced in August 2011, would have already been implemented in March 2004. This is as if the current COPOM under BCB president Alexandre Tombini had already been in office in January 2004 and would remain until January 2019. The new BCB strategy takes more aggressive growth policy parameters. This is reflected by the COPOM decision in its

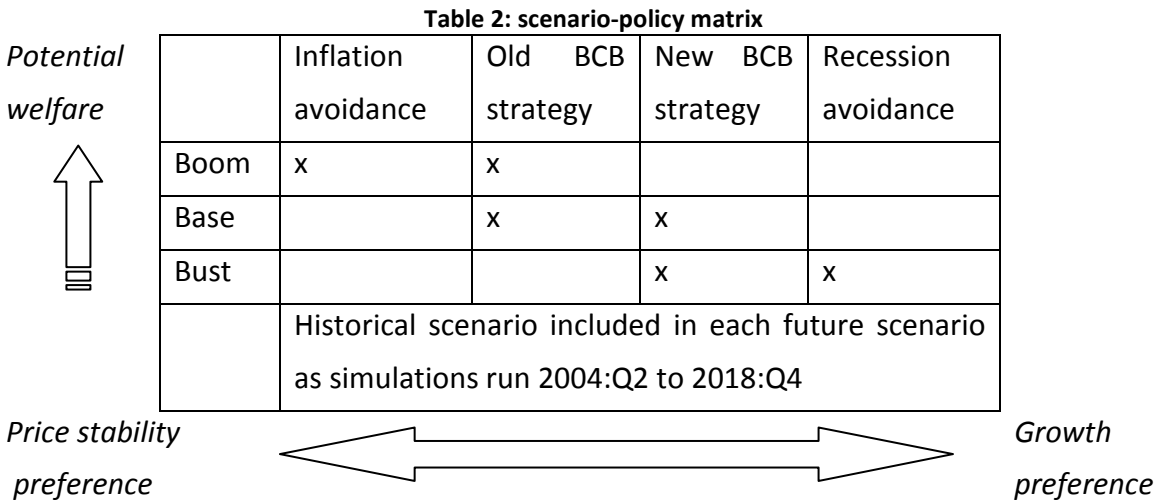
August 2011 meeting to lower the Selic rate in expectation of a slowdown of external demand and despite upward inflation dynamics [BCB, 2011c].

In addition, the inflation and recession avoidance policies consider nonlinear inflation policy gaps. The inflation avoidance policy refers to the case in which the old BCB strategy becomes very concerned about positive inflation gaps but remains fully relaxed with regard to negative inflation gaps [Cukierman and Muscatelli, 2008]. The recession avoidance policy considers a high ambition of the new BCB to avoid negative growth gaps.

Policy parameters and policy-scenario combinations

The policies are applied to both the historical business cycle and the future scenarios. This also allows for assessing what would have happened if the BCB had applied other policies in the past. The parameters of the policies are the growth and inflation policy factors and delay, the parameters via which the BCB conducts monetary policy in the model. The old BCB policy is the policy with the parameters estimated during optimization. The new BCB policy exhibits growth policy parameters with a higher responsiveness.

The three scenarios and the four policies provide for twelve future scenario-policy combinations. Out of these twelve possibilities, six combinations will be addressed that correspond to the likely policies under each scenario. The base scenario will cover the new and old BCB policies, which are in the middle between the inflation avoidance and recession avoidance policies. The bust scenario will consider the new BCB policy and recession avoidance, which represent the two growth oriented policies. The boom scenario will address the Meirelles policy and the inflation avoidance policy as the BCB is assumed to be more dedicated to inflation stabilization in a bullish economic environment.



7.2. Base Scenario: old and new BCB strategy

Base scenario description

The base scenario is the most likely scenario, including slower growth but less inflation pressure [IMF, 2011, BCB, 2011d]. For the real interest rate, it assumes a continued decreasing trend as the government sticks to primary surpluses. The total decrease amounts to 5% until 2019 but flattens out over time in a regressive manner. For the inflation inputs, long-run monitored price inflation is assumed to remain constant. However, during the 2014 World Cup and 2016 Olympic Games years it temporarily increases by 0.20% due to infrastructure overheating [Guerrero, 2010].

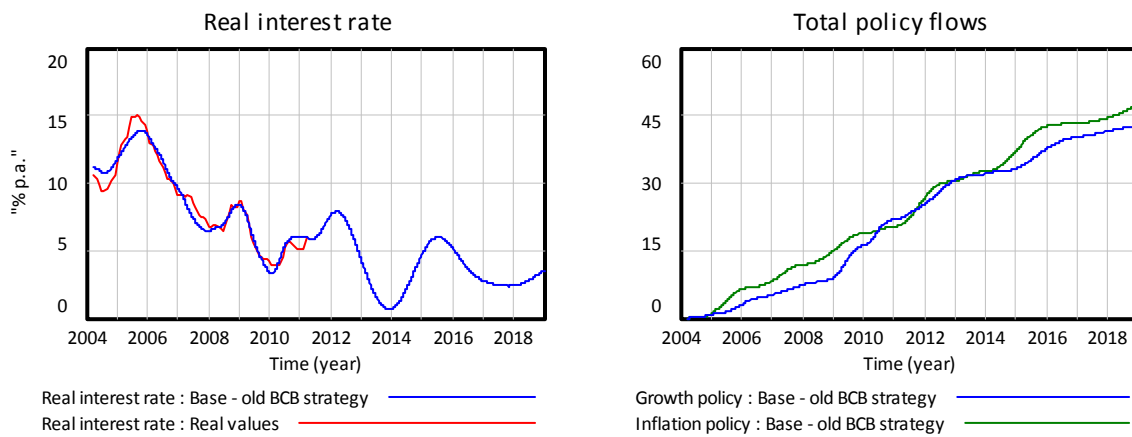
Furthermore, the inflation trend is assumed to remain flat, meaning that the government neither increases nor decreases the pressure on inflation through its spending [Economist, 2011c, Barrionuevo, 2011]. With regard to growth, trade growth decreases temporarily by 0.5% in 2012, reflecting a continued negative external outlook [IMF, 2011, BCB, 2011d]. Afterwards, the 2014 World Cup and presidential elections, assuming an election year effect of government spending [Economist, 2010], both inject a total temporary 0.5% growth increase via the growth trend. For the 2016 Olympic Games and the 2018 elections, GDP growth is also subject to temporary 0.5% increases [Economist, 2011a]. In all the other years, the idiosyncratic growth trend remains at 0.29% as for the historical sample.

Old BCB strategy in base scenario

The simulation results of the base scenario with old and new BCB strategy policies are included in appendix B.4.2.

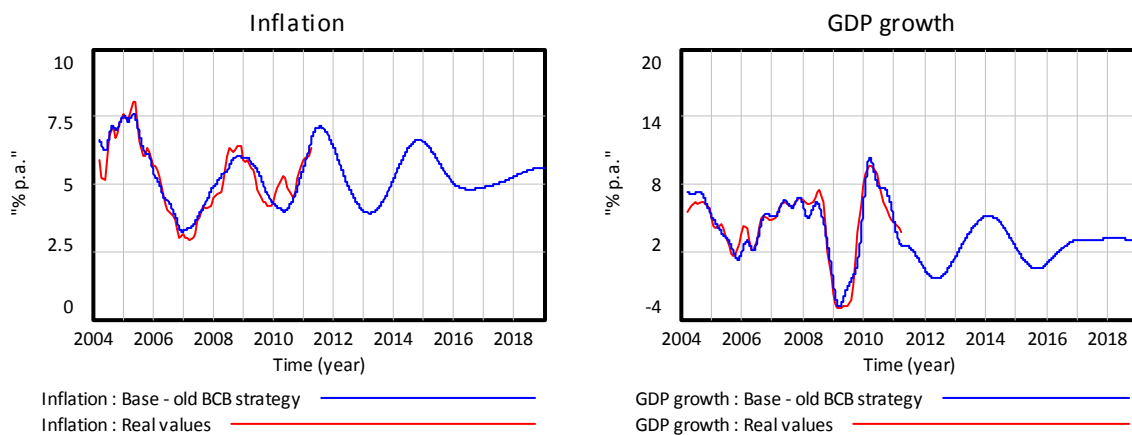
The historical 2004 to 2011 business cycle simulation corresponds to the results of the calibration. Afterwards, the real interest rate starkly increases into the first half of 2012 as the positive 2011 inflation gap feeds into monetary policy. This stabilizes the inflation dynamics loops and subsequently the inflation gaps loops. The interest rate enters a downward cycle until the fourth quarter of 2013. Having reached a historical real interest rate low of 1% by the end of 2013, inflation dynamic loops and subsequently inflation gap loops trigger another round of monetary tightening. This is followed by a decrease into late 2016, from when on interest rates will witness no more remarkable swings.

Figure 32: old BCB policy in base scenario – monetary policy



Inflation peaks by the middle of 2011 and starts to fall in the second half of the year as GDP growth has cooled down. It reaches a bottom of 4% in 2013 and starts to rise again as monetary policy easing enters inflation in the expectation dynamics loops. Meanwhile, growth has already picked up again and spills over to inflation in the growth inflation loop. Inflation peaks just below the upper target band in 2014 and finally tends towards 6% in 2018.

Figure 33: old BCB policy in base scenario – inflation and GDP growth



GDP growth falls to zero by mid 2012 due to unfavourable external dynamics and internal monetary policy tightening in the inflation growth gap loop. Afterwards, growth picks up driven by monetary policy easing, rebounding trade as well as World Cup and election effects and peaks at 5% in early 2014. Subsequently, monetary policy reverts growth dynamics, which leads to another low in 2015 before growth levels out around 3.5%.

Concluding, monetary policy is inflation dominated under the future scenario since it does not account for future trade volatility. Furthermore, future growth is surprisingly low, which may partly be attributed to the non-consideration of the certain dynamics of the Brazilian economy such as the growth of the working population. Most of the growth drivers during

the calibration period become less relevant in the future time frame, while new drivers become more significant.

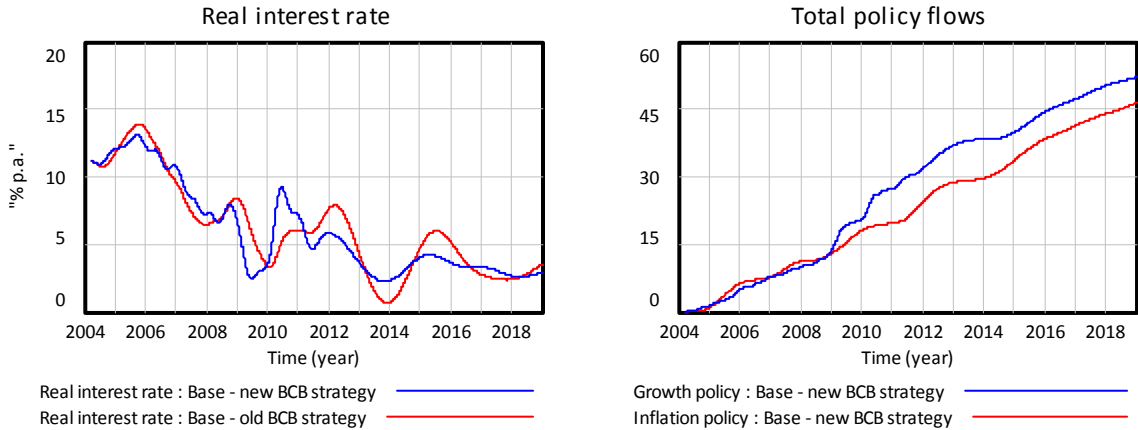
New BCB strategy in base scenario

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 spillover effects on Brazilian growth prospects and on lower import prices [BCB, 2011c]. The COPOM move can therefore, with caveats, be considered a new monetary policy strategy under the Tombini presidency with less emphasis on inflation.

In the model, this move is incorporated through a higher and faster dedication to growth. Under the new BCB strategy, the two growth policy factors are increased by 50% and the monetary policy delay is decreased by two months. The BCB becomes more sensitive to GDP dynamics, more concerned about the growth gap and also decreases its growth policy sluggishness.

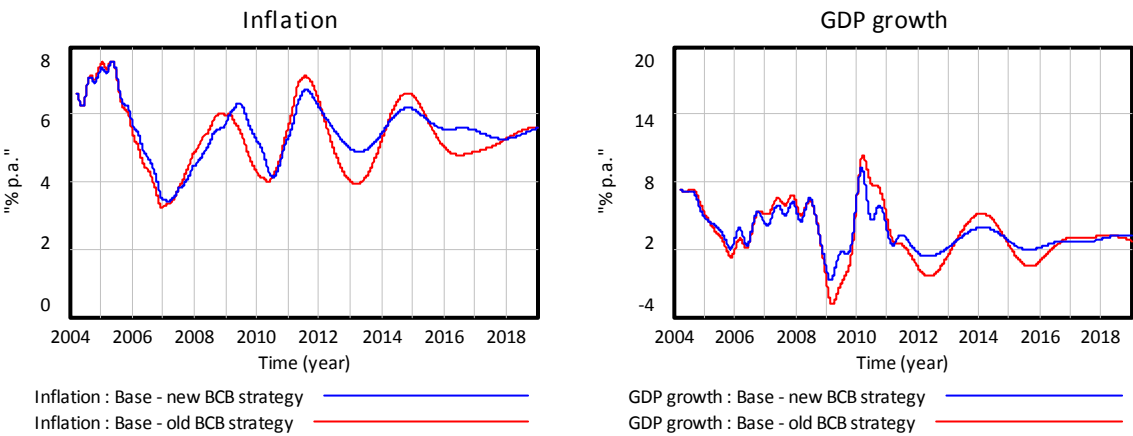
The new BCB strategy would have responded to the post-Lehman GDP growth shock by a faster reduction in interest rates through the growth dynamics loop. The real interest rate would have fallen to as low as 2.5%. Furthermore, the BCB would have quickly absorbed the overshooting rebound of growth in 2009 in the growth dynamics loop. For the future scenarios, the Tombini 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 makes the convergence of expectations more difficult.

Figure 34: new BCB policy in base scenario – monetary policy



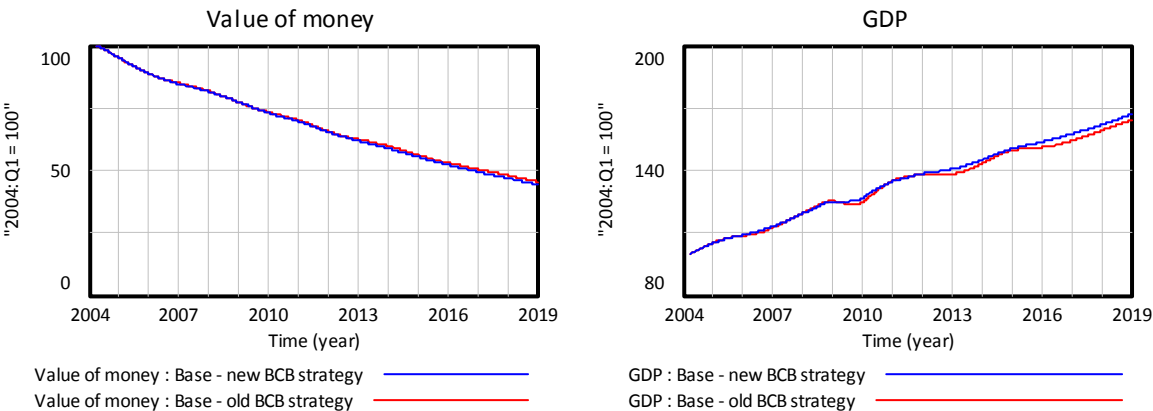
In the historical business cycle, inflation is about the same as under the old BCB policy. This is because the inflation loops are not subject to the growth policy parameters. For the future scenario, the 2011 inflation overshoot would be less pronounced due to lower growth triggered inflation from the 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 35: new BCB policy in base scenario – inflation and GDP growth



The observations about inflation and growth under the new BCB strategy also translate into the value of money and GDP. Due to higher inflation taxes, the value of money shrinks slightly more under the new BCB strategy. The upside is that GDP rises to a slightly higher level by 2018, which further underlines the inflation-growth trade-off in the model.

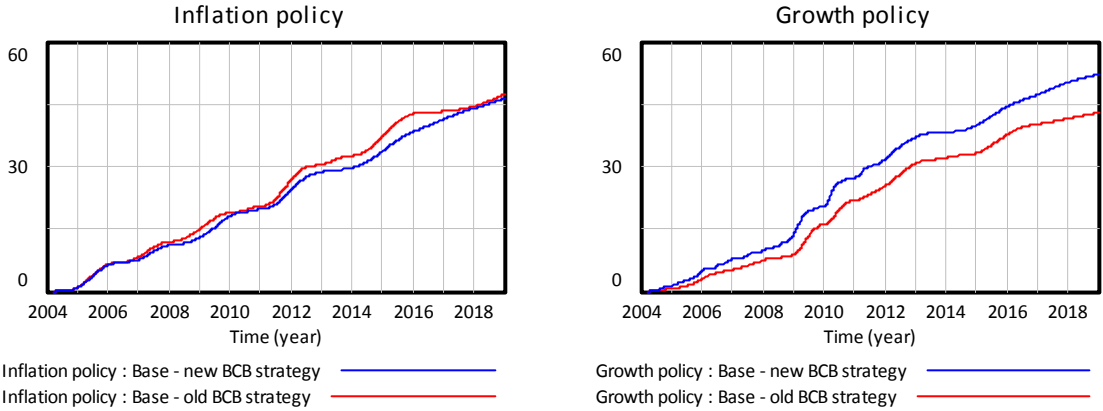
Figure 36: new BCB policy in base scenario – GDP and value of money



At the same time, monetary policy also becomes more growth than inflation driven compared to the old BCB strategy. Inflation policy moves are almost as pronounced as under the

old BCB strategy, while growth policy moves become more pronounced. This observation also implies that the amount of total monetary policy moves increases.

Figure 37: new BCB policy in base scenario – total monetary policy flows



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.

7.3. Bust scenario: new BCB strategy and recession avoidance

Bust scenario configuration

The bust scenario considers a combination of external turmoil and internal inflation pressure with current negative 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, 2011d]. Trade growth decreases by 2% in 2012 and only rebounds by 1% in the following year. 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, for instance triggered by a worsening of the European debt crisis. In response, the BCB needs to raise the real interest rate by 1.5% in 2012 in order to prevent significant Real devaluation. Afterwards, the real interest rate decreases again in a regressive manner as for the base scenario. With regard to inflation, internal overheating leads to increasing monitored price inflation in the World Cup and Olympic Games years. Opposed to the base scenario, the rise in monitored price inflation will not remain temporary. Furthermore, the government puts continued upward

pressure on inflation through inefficient spending and consumption and the inflation trend stays at 0.25% per year.

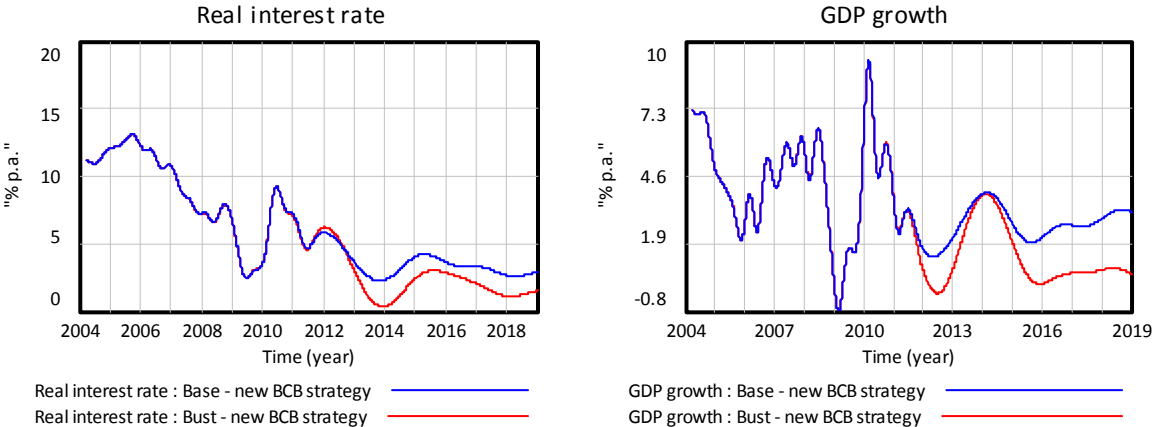
New BCB strategy in future bust scenario

The simulation results of the bust scenario with new BCB strategy and recession avoidance policy can be inferred from appendix B.4.3.

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 bust scenario causes both higher inflation and lower growth. 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.

Figure 38: new BCB policy in bust scenario



Recession avoidance in bust scenario

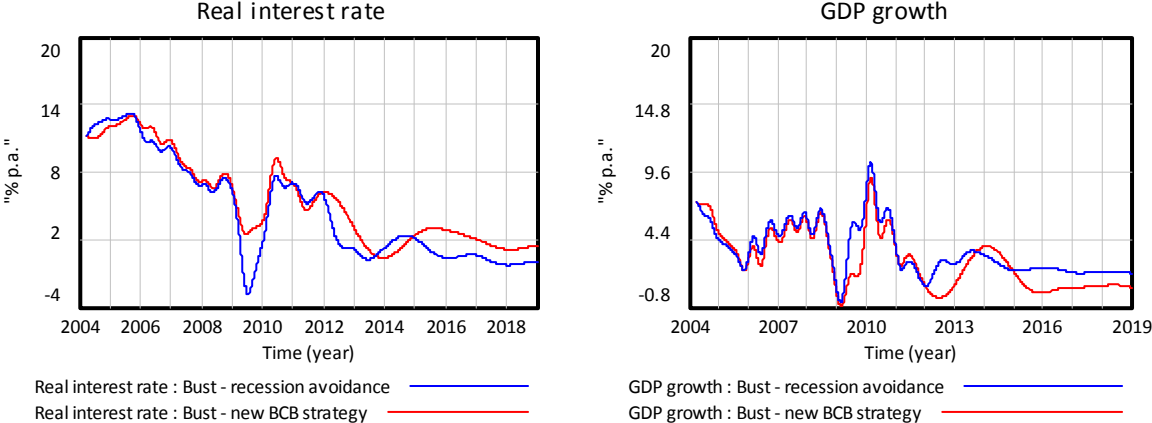
The new BCB assumes a recession avoidance Taylor rule with a nonlinear growth gap [Cukierman and Muscatelli, 2008]. If growth y_t is above the target y_t^* , the BCB does not care about the positive gap. Yet, if growth falls short of the target, the monetary policy response becomes quadratic in relation to the gap:

$$if\ y_t < y_t^* : gap = -(y_t - y_t^*)^2, \quad else : gap = 0 \quad (4)\ \text{recession avoidance growth gap}$$

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. 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 39: recession avoidance in bust scenario



In total, 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.

7.4. Boom scenario: old BCB strategy and inflation avoidance

Boom scenario configuration

The boom scenario consider that negative risks for inflation and growth disappear and that Brazil gets back on a strong growth path [IMF, 2011, BCB, 2011d]. Reinforced by primary government surpluses, the real interest rate trend decreases at a yearly regressive factor of 0.8, summing up to a decrease of 5.25% until 2019. Meanwhile, inflation witnesses a -0.5% decrease per year, considering both more efficient government spending and fewer monitored price inflation. Demand for Brazilian exports picks up in 2012 amid an OECD recovery and strong Chinese commodity demand. At the same time, GDP growth is still subject to the 2014, 2016 and 2018 event effects.

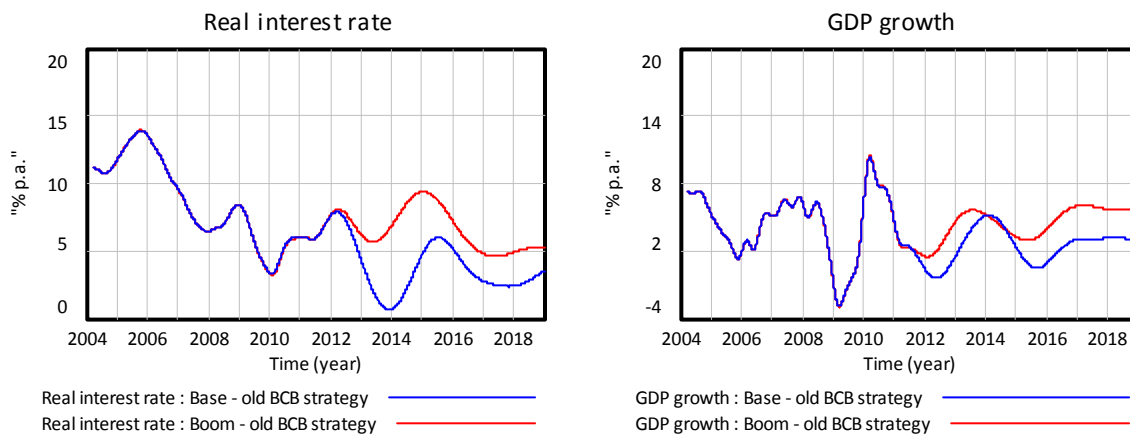
Importantly, monetary policy becomes more ambitious in the future scenario with an inflation target of 2% and a growth target of 6% starting in 2012. For the 2004 to 2011 period, the historical inflation and growth targets apply.

Old BCB strategy in boom scenario

Appendix B.4.4 includes the simulation results for the boom scenario with the old BCB strategy and the inflation avoidance policy.

In the boom scenario, the economy still suffers from inflation and a recession in 2011 to 2012. However, following a strong monetary policy easing until 2014, GDP growth rebounds to 4% and approaches a long-run equilibrium of 6%. At the same time, inflation will exhibit small swings and approach a long-run rate of 2%. Therefore, the BCB achieves its inflation and growth targets, but only in the long-run. Furthermore, the BCB leaves the long run real interest rate at the current 2011 level since both growth and inflation reach their targets.

Figure 40: old BCB strategy in boom scenario



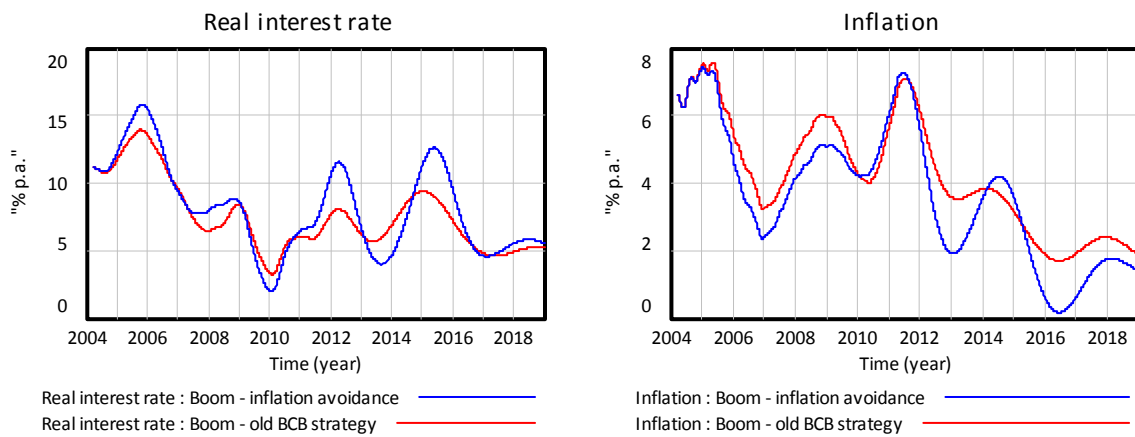
Inflation avoidance in boom scenario

The BCB now assumes an inflation avoidance Taylor rule with a nonlinear inflation gap [Cukierman and Muscatelli, 2008]. If inflation π_t is below the target π_t^* , leading to a negative inflation gap, the BCB does not care about the gap. If inflation is above the target, the BCB's gap policy becomes quadratic with respect to the positive inflation gap:

$$\text{if } \pi_t > \pi_t^* : \text{gap} = (\pi_t - \pi_t^*)^2, \quad \text{else} : \text{gap} = 0 \quad (5) \text{ inflation avoidance growth gap}$$

In the historical cycle, the inflation gap policy leads to a more pronounced monetary policy tightening in 2005 and in response to the 2011 inflation following the economic rebound. The historical inflation is already lower in comparison to the old BCB strategy policy and the difference becomes very pronounced for the future scenario. The 2011 inflation target overshoot leads to a strong monetary policy tightening that already pushes inflation below the new 2% target rate at the end of 2012. However, the subsequent rebound causes an inflation overshoot.

Figure 41: inflation avoidance in boom scenario



To conclude, the avoidance policies are better able to achieve ambitious growth or inflation targets. However, they also require extreme monetary policy moves, which cause larger business cycle swings. In structural terms, the nonlinear inflation targets switch their respective gap loops on and off along the business cycle. Once switched on, the quadratic approach causes very pronounced gaps, which trigger extreme monetary policy moves. The other possible implication of the avoidance policies is that non-linearity may imply more difficulties in actually managing policy implementation.

Conclusion and outlook

The small system dynamics Taylor rule model for monetary policy feedback reproduces the Brazilian business cycle in the 2004 to 2011 period. The structure of the model is related to the family of small new Keynesian models [Clarida et al., 1999, Woodford, 2001]. The nonlinear Taylor rule for interest rate changes consists of elements of policy sluggishness, inflation, GDP growth and a long run trend. The results show that monetary policy feedback with different phases via GDP growth and inflation is an important determinant of the Brazilian business cycle. However, GDP growth can only partly be influenced by monetary policy as it remains largely subject to exogenous demand conditions. Inflation is largely explained by endogenous feedback with a dominant impact of lagged GDP growth, representing backward-looking price setters, vis-à-vis the direct impact of monetary policy via expectations. In total, the model provides a strong historical fit which is achieved by covering both endogenous feedback structures and adding relevant additional exogenous inputs.

With regard to the Taylor rule, the calibration coefficients yield a higher parameter responsiveness of the BCB with respect to inflation as opposed to GDP growth. However, the majority of the policy moves during the sample period was related to growth driven policy, given the external shock in 2008 and the subsequent rebound. This observation is inferred from stocks of absolute policy flows, a particular mean by which the Taylor rule model can track monetary policy. Moreover, the validation of the model suggests that adding FX to a Brazilian Taylor rule provides for little additional explanatory power.

The Taylor rule model presents some important implications for monetary policy in Brazil. It identifies a strong and immediate impact of monetary policy on GDP growth, despite a high degree of exogenous GDP growth. Furthermore, the model observes a dominance of growth policy moves, which challenges the intuition that inflation targeting coincides with a dominance of inflation policy moves. Moreover, it shows that the majority of price setters takes a backward looking approach, which may be explained by the extent to which GDP growth is subject to the demand conditions beyond the influence of monetary policy.

The policy and scenario exercises have shown that the new BCB strategy, with more aggressive growth policy parameters, trades off growth against inflation, also at the expense of a more nervous monetary policy. Furthermore, nonlinear monetary policy gap functions offer a deal of avoiding recessions or excessive inflation and are particularly powerful under extreme scenarios. These exercises highlight the ability of system dynamics to easily cover different policy parameters and more complex policy functions, rather than intending to predict the future at the highest accuracy.

In methodological terms, system dynamics has been exposed to strong criticism from economists, despite offering unique opportunities. The methodology makes patterns of behaviour visible and is able to track policy effects in the system's variables over time as highlighted by the absolute policy flows in the Taylor rule model. The challenging proposition about the dominance of growth policy calls for further investigations on how results from System Dynamics model have to be critically assessed. At the same time, the Taylor rule model represents an effort to apply system dynamics to macroeconomics upon the maxim of empirical testing.

Finally, there are ample opportunities for future research. Recession avoidance has come to the centre of current monetary policy at many OECD central banks and system dynamics can easily consider such highly nonlinear policies and the related transition phase of monetary policy. SD models can also be useful in explaining past monetary policy and revealing surprising insights. The Taylor rule model has revealed that Brazilian monetary policy in recent years was in fact dominated by growth policy moves, which should motivate the investigation of empirical surprises in other samples. In addition, capturing Taylor rule feedback in other economies would further support the dynamic hypothesis of the model and might ultimately reintroduce system dynamics as a powerful yet underutilized tool in economics.

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

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



Image taken in Curitiba, 13th of October, 2011

Image Source: Dilma Rouseff Flickr Account

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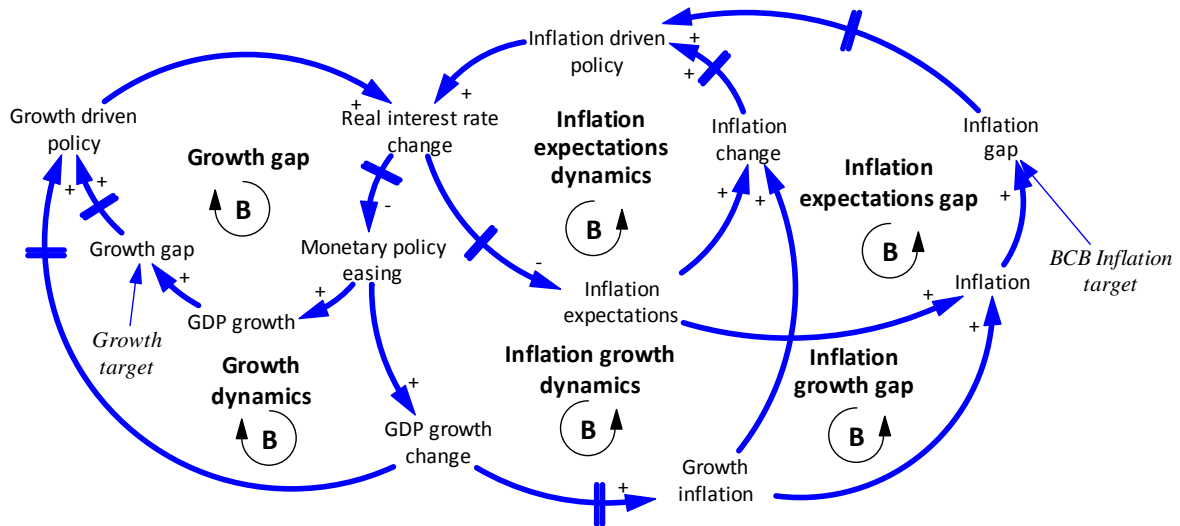
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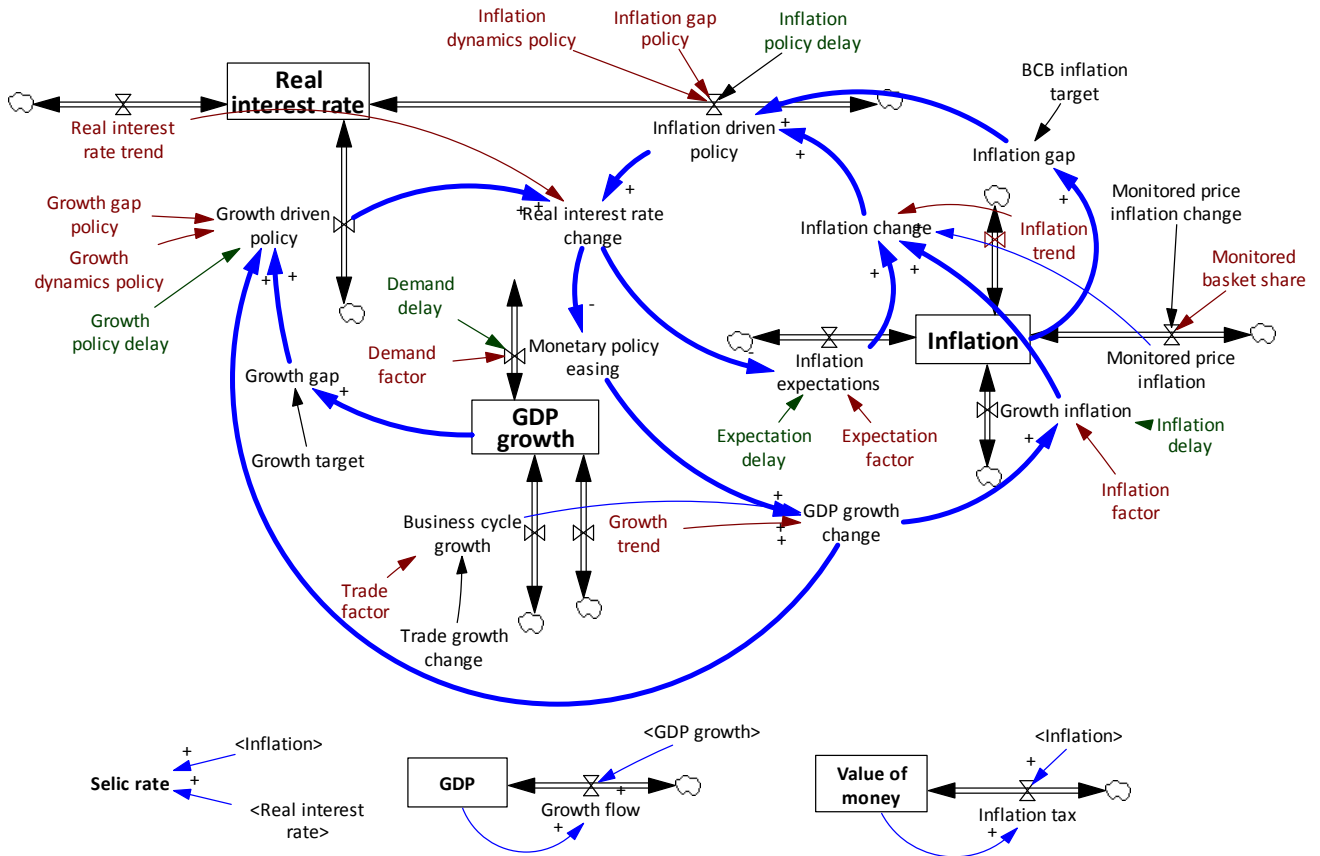
B. Appendix

B.1. Taylor rule CLD and stock-and-flow model

Causal loop diagram



Stock-and-flow model



Selected stock-and-flow model equations

Stocks

Editing equation for - Real interest rate

Real interest rate Add Eq

= INTEG (Growth driven policy+Inflation driven policy+Real interest rate trend

Initial Value Initial real interest rate

Editing equation for - GDP growth

GDP growth Add Eq

= INTEG (Growth trend+Monetary policy growth+Business cycle growth

Initial Value Initial GDP growth

Editing equation for - Inflation

Inflation Add Eq

= INTEG (Growth inflation+Inflation trend+Monitored price inflation+Inflation expectations

Initial Value Initial inflation

Endogenous interest rate flows and real interest rate change

Editing equation for - Inflation driven policy

Inflation driven policy Add Eq

= DELAY3(Inflation dynamics policy*Inflation change+Inflation gap*Inflation gap policy, Inflation policy delay)

Editing equation for - Growth driven policy

Growth driven policy Add Eq

= DELAY3(GDP growth change*Growth dynamics policy+Growth gap*Growth gap policy, Growth policy delay)

Editing equation for - Real interest rate change

Real interest rate change Add Eq

= DELAY FIXED (Real interest rate trend+Inflation driven policy+Growth driven policy, 0.001, 0

Endogenous Inflation and growth flows

Editing equation for - Monetary policy growth

Monetary policy growth Add Eq

= DELAY3(Demand factor*Real interest rate change, Demand delay)

Editing equation for - Inflation expectations

Inflation expectations Add Eq

= DELAY3((Real interest rate change)*Expectation factor, Expectation delay)

Editing equation for - Growth inflation

Growth inflation Add Eq

= DELAY3(Inflation factor*GDP growth change, Inflation delay)

B.2. Index of variables

Explained Stocks

	Calculation	Initial Value	Dimension	Source
Real interest rate	Monthly SELIC – 1 year expected IPCA	11.22	% p.a.	[BCB, 2011a] [IPEA, 2011]
Inflation	IPCA	6.61	% p.a.	[IPEA, 2011]
GDP growth	Monthly growth of 12-month GDP	7.24	% p.a.	[BCB, 2011a]

Exogenous Inputs

Trade growth change	Growth of Export + Import Volume Indices	0	% p.aa.	[BCB, 2011a]
Monitored price inflation change	Change in 12 months IPCA monitored price inflation	0	% p.aa.	[IPEA, 2011]
Inflation target	BCB end of the year inflation target rate	4.57*	% p.a.	[BCB, 2011a]
Growth target	Set at 4.50%, with sample average of 4.43%	4.50	% p.a.	-

*value resulting from cubic spline between the 4% inflation target for 2003 and the 5.5% target for 2004.

Delays

	Delay type	Calibration value	Dimension	
Demand	3 rd order	0.05	years	
Expectation	3 rd order	0.15	years	
Growth policy	3 rd order	0.27	years	
Inflation	3 rd order	1.33	years	
Inflation policy	3 rd order	0.73	years	

Auxiliary variables

	Calibration value	Dimension	
Demand factor	-0.77	-	
Expectation factor	-0.24	-	
Growth dynamics policy	0.92	-	
Growth gap policy	1.62	1/year	
Inflation dynamics policy	2.19	-	
Inflation factor	1	-	
Inflation gap policy	3.01	1/year	
Monitored basket share	2.86	-	
Trade factor	1.46	-	

Trends

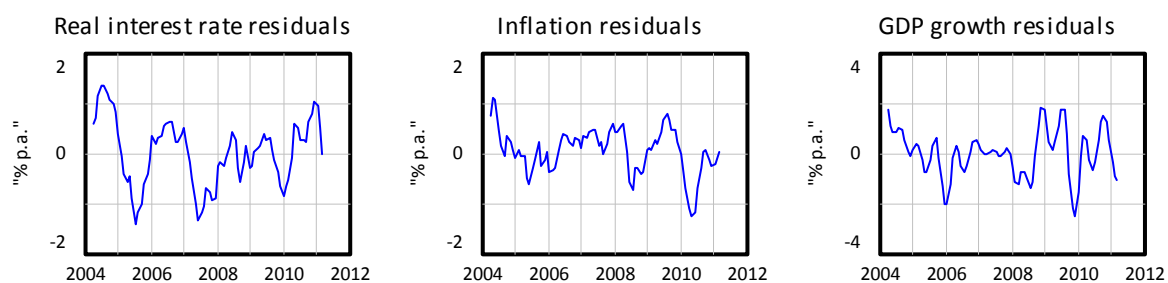
	Calibration value	Dimension	
Real interest rate	-1.66	% p.aa.	
Inflation	0.25	% p.aa.	
GDP growth	-1.66	% p.aa.	

B.3. Calibration results

B.3.1. Calibration statistics

Discrete statistics with monthly steps

	Real interest rate*	Inflation*	GDP growth*
Data fit n=82	$R^2 = 0.96$ $MSE = 0.42$	$R^2 = 0.88$ $MSE = 0.20$	$R^2 = 0.91$ $MSE = 0.88$
Theil Decomposition	$U_m = 0$ $U_s = 0$ $U_c = 0.43$	$U_m = 0$ $U_s = 0.01$ $U_c = 0.19$	$U_m = 0$ $U_s = 0.02$ $U_c = 0.87$



*subject to three interpolations in the time series and corresponding small rounding errors for the Theil decomposition. Vensim did not allow for exact time steps of 1/12 years.

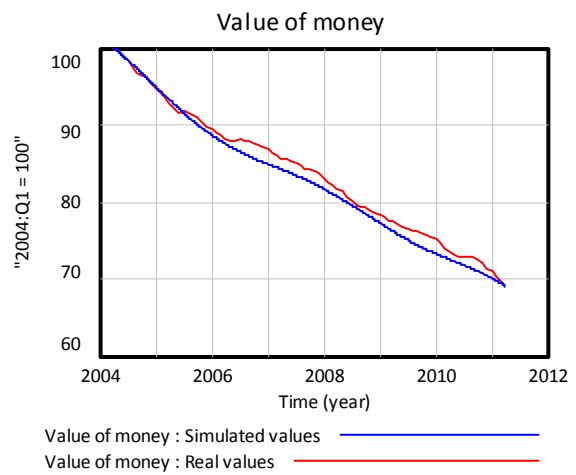
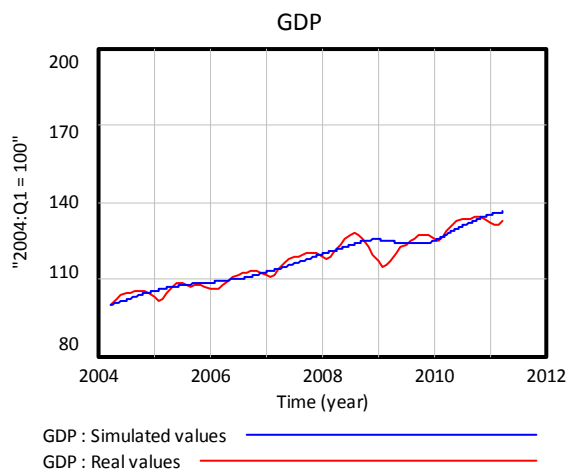
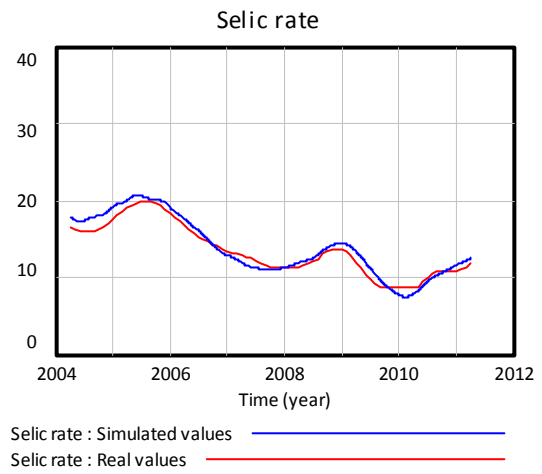
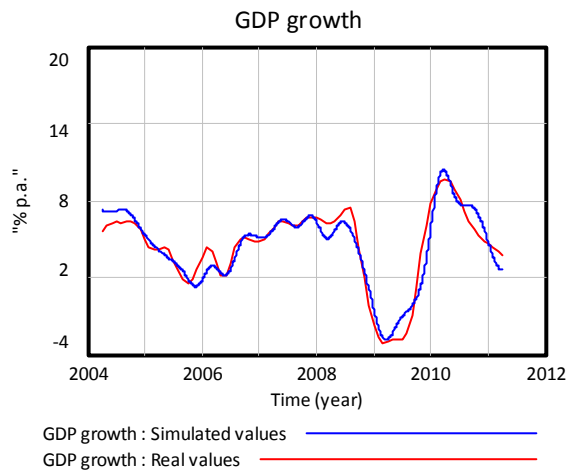
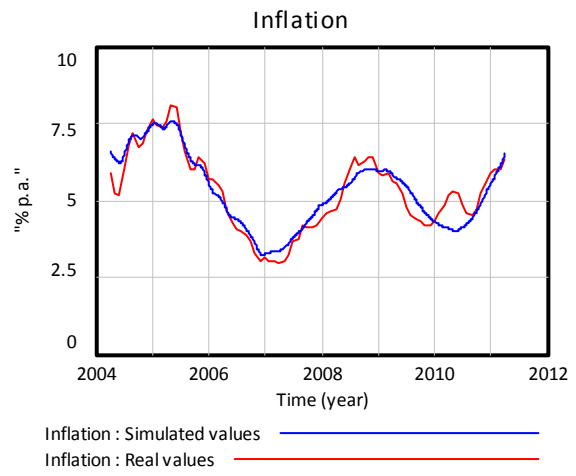
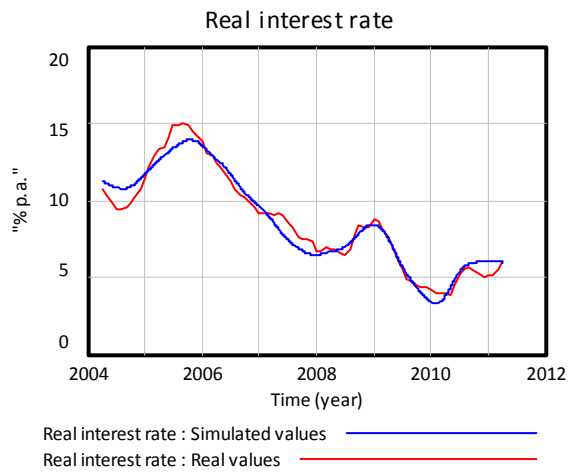
Continuous statistics with steps of 0.0078 years

Variable	Count	Min	Max	Mean	Median	StDev	(Norm)
Selected Variables for Time (year) from 2004.25 to 2011.25 Runs:				Simulated values		Real values	simu
GDP growth	897	-2.888	10.39	4.406	5.113	2.920	0.6629
: Real values	85	-3.082	9.664	4.429	5.031	3.034	0.6851
Inflation	897	3.217	7.578	5.285	5.254	1.198	0.2266
: Real values	85	2.957	8.071	5.258	5.218	1.274	0.2423
Real interest rate	897	3.300	13.92	8.615	8.015	3.088	0.3585
: Real values	85	3.86	15.05	8.631	8.380	3.157	0.3657

B.3.2. Calibration parameters

	Real interest rate	Inflation	GDP growth
Auxiliary variables	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

B.3.3. Calibration simulation



B.3.4. Comparison to estimation results in BCB models

Comparison of estimated parameters

In the SAMBA model [De Castro et al., 2011], the monetary authority applies a Taylor rule that puts 18 times the weight on inflation as opposed to output gaps [De Castro et al., 2011]. In the Taylor rule model, the inflation gap exhibits twice the factor of the growth gap. The interest rate smoothing is in line with the results from the Taylor rule model. The SAMBA model policy delay of nine months closely corresponds to the inflation policy delay of the Taylor rule model.

With regard to the Phillips curve, the semi-structural model [Minella and Souza-Sobrinho, 2009] estimates a higher importance of inflation expectations compared to the Taylor rule model and a smaller impact of GDP growth and labour costs on inflation. The total impact of a 1% GDP and unit labour costs increase feeds into a 0.4% higher inflation, compared to the Taylor rule model. Furthermore, Brazilian evidence has also addressed rational expectations lags. Inflation expectations are subject to sticky information, leading to a price rigidity lag of 2.7 to 3.8 months in Brazil [Gouvea, 2007]. This is in line with the 2 months lag in the Taylor rule model.

Furthermore, in the IS equation of the semi-structural model, a 1% real interest rate increase amounts to a total effect of -0.57% on GDP growth [Minella and Souza-Sobrinho, 2009]. This is quite close to the -0.77% effect estimated in the Taylor rule model. However the semi-structural model decomposes the monetary policy channels and uses nominal household interest rates for consumption demand and swap interest rates for investment demand on behalf of firms.

Comparison of parameters

Model	Taylor rule model	SAMBA model	Semi-structural model
Interest rate smoothing	0.44 growth policy 0.79 inflation policy	0.7375 years	1.13 for 1Q lag -0.51 for 2Q lag
Inflation policy	1.99 gap 2.19 dynamics	2.43 gap	0.51 expected gap 0.38 current inflation
Growth policy	0.86 gap 0.64 dynamics	0.16 gap	-
IS-curve	-0.77 demand factor	- (no IS equation)	-0.34 consumption coefficient -0.23 investment coefficient
Phillips curve	-0.24 expectation factor 1.00 growth inflation	- (no Phillips equation)	0.20 1Q lagged GDP growth 0.20 1Q lagged unit-labour costs

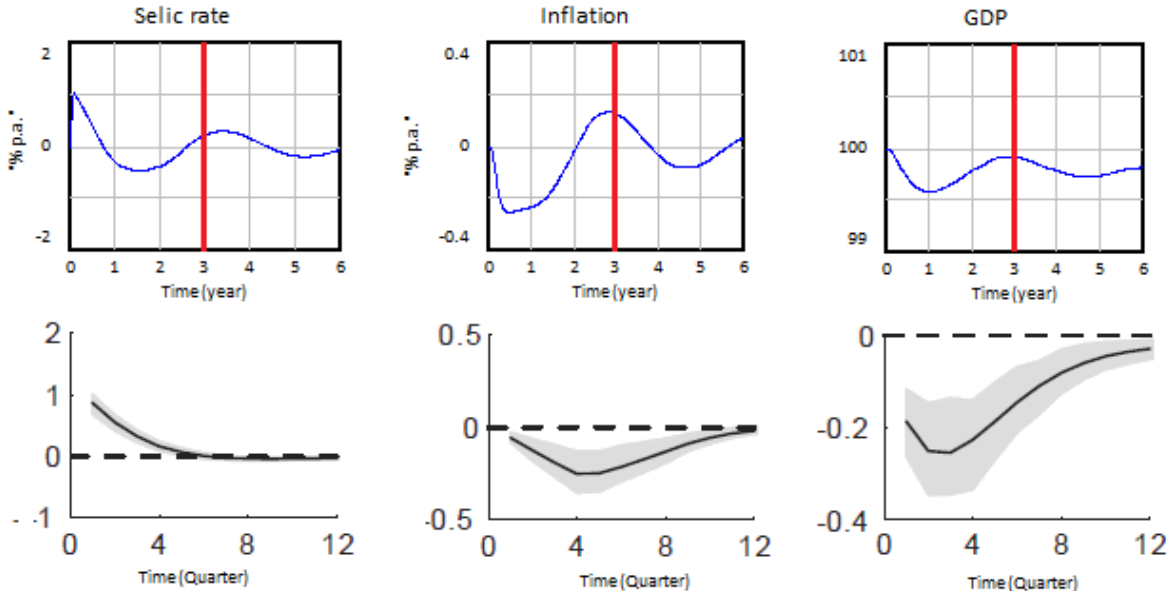
Comparing the Taylor rule model to the BCB’s SAMBA and semi-structural models is however critical with respect to the sample. The BCB models draw on sample starting with the inflation targeting regime including the shocks up to the confidence crisis, while the Taylor rule model sample starts in 2004 and explicitly excludes the pre-2004 years.

Comparison of Taylor rule model shocks to impulse responses in the SAMBA model

The SAMBA model paper exposes the model to some shocks including interest rate and output shocks [De Castro et al., 2011, p. 54-60]. The SAMBA economy is denominated in quarterly periods and impulse responses stretch over twelve quarters or three years. In the Taylor rule model plot, shocks are displayed over six years with the three years threshold indicated in red. The SAMBA shock outputs relate to the nominal instead of the real interest rate and GDP instead of GDP growth. The same outputs are taken for the Taylor rule model.

The interest rate shock considers an increase of the interest rate by 1% in both the real and the nominal rate. In the Taylor rule model, this triggers a sudden drop in GDP growth, forcing the BCB into monetary policy easing. Inflation has also fallen due to lower expectations and subsequently due to lower growth. As growth and inflation have reached their lows, the BCB starts to tighten again in year two. In the long run, all macroeconomic variables shift back close to their pre-shock levels. The interest rate shock also has long-run welfare effects with GDP decreasing by about 0.15 units.

Comparison of interest rate shock

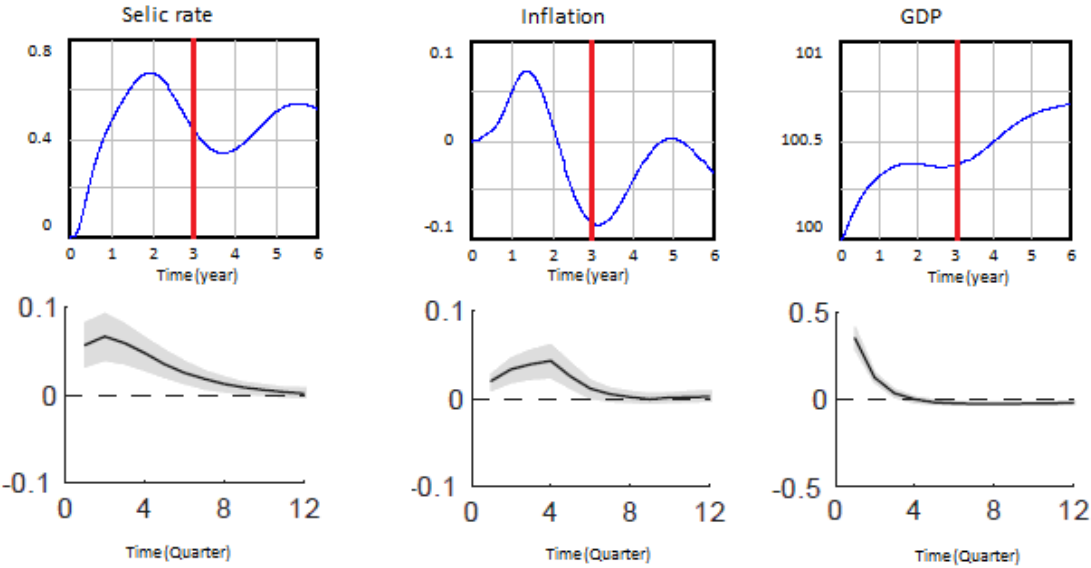


In the SAMBA economy, the central bank also decreases the interest rate after the initial interest rate shock as a response in the SAMBA Taylor rule. The nominal interest rate is back at its pre-shock level only one year after the shock and is not subject to any oscillations. Furthermore, inflation decreases into the first year after the shock and is back in equilibrium

after the third without any overshooting of the initial level. GDP decreases into the second quarter and also approaches its initial level afterwards. In a baseline, the SAMBA model considers that the monetary authority reacts to the shock by decreasing the nominal interest rate in an exponential manner without oscillations.

The next exercise is to simulate a positive 0.3% GDP output shock as a fiscal shock. In the SAMBA model, this is considered by a 1% increase in fiscal spending. Due to its stock-and flow nature, the Taylor rule model cannot account for an instantaneous fiscal shock to output, but only to GDP growth. Therefore, the government pushes GDP growth in order to increase GDP by 0.3 points until the end of the first year.

Comparison of output shock



In the SAMBA economy, the GDP shock leads to a rising nominal interest rate via the Taylor rule, which is linear in output. This brings real GDP back to its pre-shock level just one year after the shock. Furthermore, GDP does not witness from any oscillations. Inflation increases in the first years in a humped manner, suddenly switches from a concave increase to a convex decrease and falls back to its base level just two years after the shock.

To conclude, the Taylor rule model and the SAMBA model are very different, both conceptually and in terms of the resulting behaviour. The SAMBA economy considers a GDP shock as an instant jump in output. The Taylor rule model cannot consider a GDP shock, but only a shock to GDP growth. Furthermore, the SAMBA model brings back all variables into their initial values just two years after the shock. In the Taylor rule model, the effects of the shock have not even fully died out six years after the shock. These differences mainly relate to the oscillation character of the Taylor model versus the equilibrium approach of the SAMBA model.

B.4. Policy simulation results

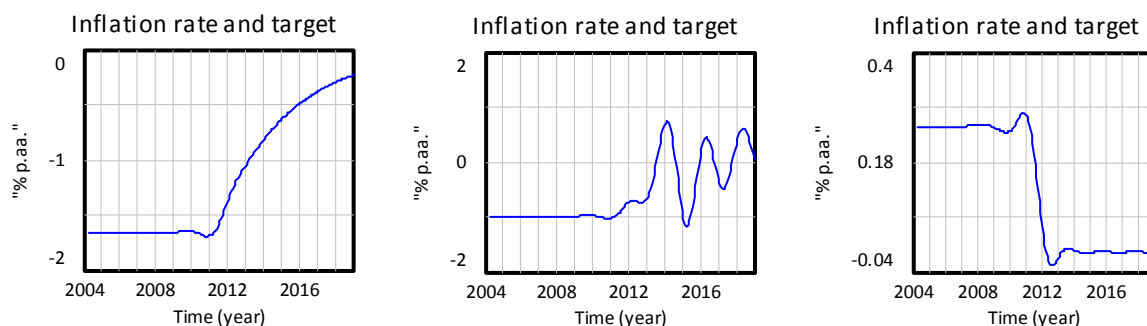
B.4.1. Scenario setup

Base	Real interest rate trend	Inflation trend	Growth trend	Trade growth	Supervised Inflation
2010,25	-1,66	0,25	-0,99	-0,13	0,01
2011,25	-1,66	0,25	-0,99	-0,13	0,01
2012,25	-1,29	0,00	-0,70	-0,50	0,00
2013,25	-1,00	0,00	-0,48	0,50	0,00
2014,25	-0,78	0,00	0,69	0,00	0,20
2015,25	-0,60	0,00	-1,17	0,00	-0,20
2016,25	-0,47	0,00	0,43	0,00	0,20
2017,25	-0,36	0,00	-0,49	0,00	-0,20
2018,25	-0,28	0,00	0,57	0,00	0,00
2019,25	-0,22	0,00	-0,38	0,00	0,00

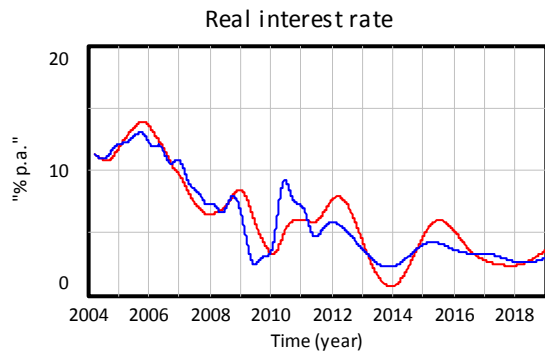
Bust	Real interest rate trend	Inflation trend	Growth trend	Trade growth	Supervised Inflation
2010,25	-1,66	0,25	-0,99	-0,13	0,01
2011,25	-1,66	0,25	-0,99	-0,13	0,01
2012,25	1,50	0,25	0,00	-2,00	0,00
2013,25	-1,29	0,25	-1,00	1,00	0,00
2014,25	-1,01	0,25	0,22	0,00	0,20
2015,25	-0,79	0,25	-1,61	0,00	0,00
2016,25	-0,61	0,25	0,03	0,00	0,20
2017,25	-0,48	0,25	-0,87	0,00	0,00
2018,25	-0,37	0,25	0,21	0,00	0,00
2019,25	-0,29	0,25	-0,72	0,00	0,00

Boom	Real interest rate trend	Inflation trend	Growth trend	Trade growth	Supervised Inflation
2010,25	-1,66	0,25	-0,99	-0,13	0,01
2011,25	-1,66	0,25	-0,99	-0,13	0,01
2012,25	-1,33	-0,10	1,77	0,50	-0,25
2013,25	-1,06	-0,10	0,97	0,00	-0,25
2014,25	-0,85	-0,10	0,64	0,00	-0,25
2015,25	-0,68	-0,10	-1,23	0,00	-0,25
2016,25	-0,54	-0,10	0,37	0,00	-0,25
2017,25	-0,44	-0,10	-0,55	0,00	-0,25
2018,25	-0,35	-0,10	0,52	0,00	-0,25
2019,25	-0,28	-0,10	-0,42	0,00	-0,25

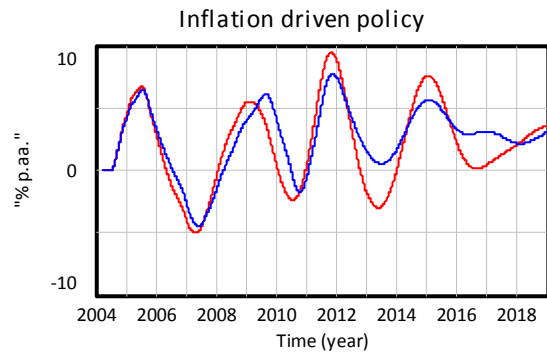
Remark: All trend inputs are subject to cubic spline. Example for base scenario inputs:



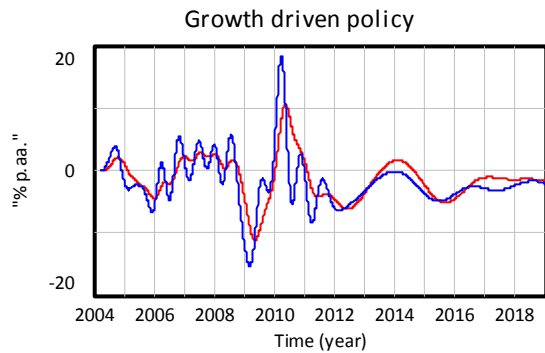
B.4.2. Base scenario – old and new BCB strategy



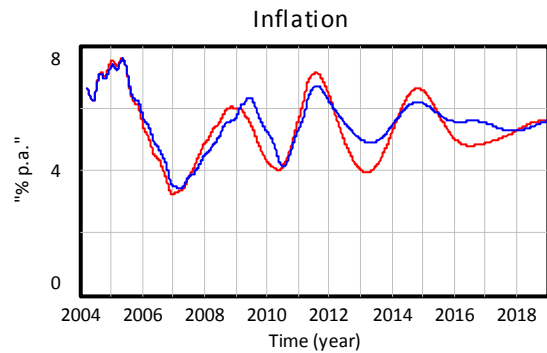
Real interest rate : Base - new BCB strategy — (blue line)
 Real interest rate : Base - old BCB strategy — (red line)



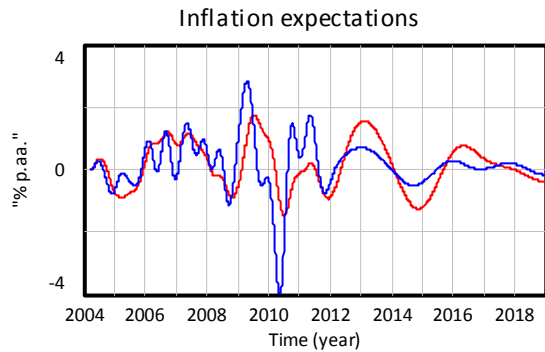
Inflation driven policy : Base - new BCB strategy — (blue line)
 Inflation driven policy : Base - old BCB strategy — (red line)



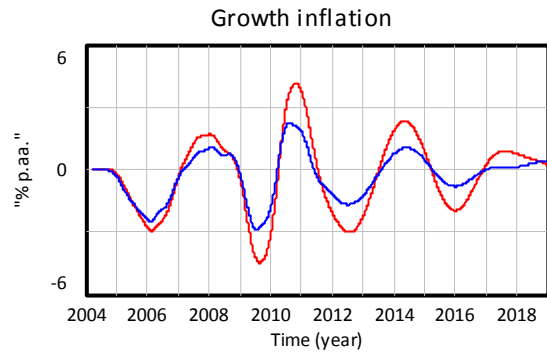
Growth driven policy : Base - new BCB strategy — (blue line)
 Growth driven policy : Base - old BCB strategy — (red line)



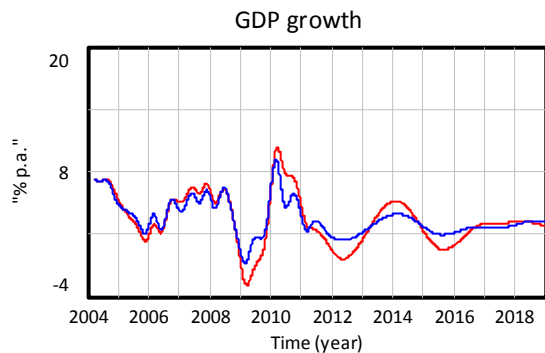
Inflation : Base - new BCB strategy — (blue line)
 Inflation : Base - old BCB strategy — (red line)



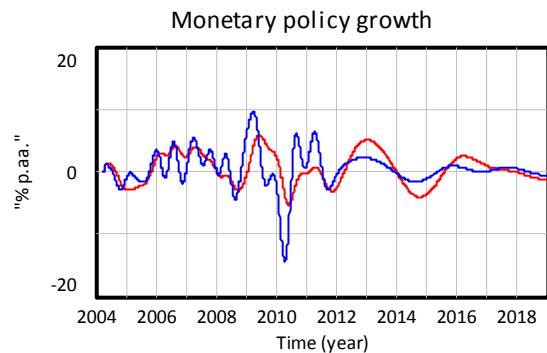
Inflation expectations : Base - new BCB strategy — (blue line)
 Inflation expectations : Base - old BCB strategy — (red line)



Growth inflation : Base - new BCB strategy — (blue line)
 Growth inflation : Base - old BCB strategy — (red line)

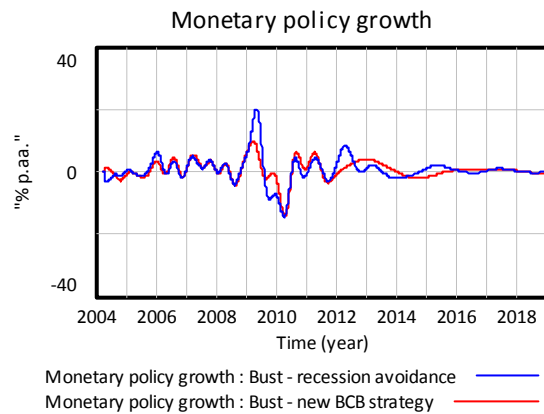
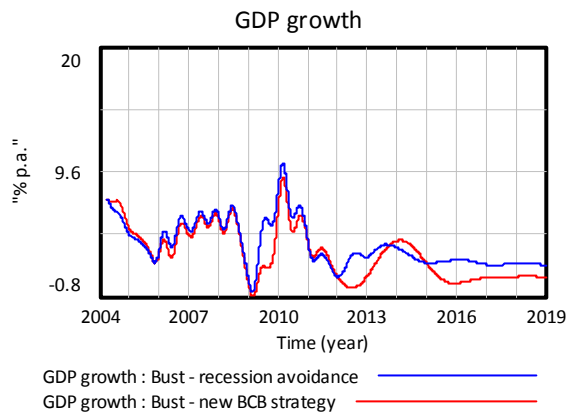
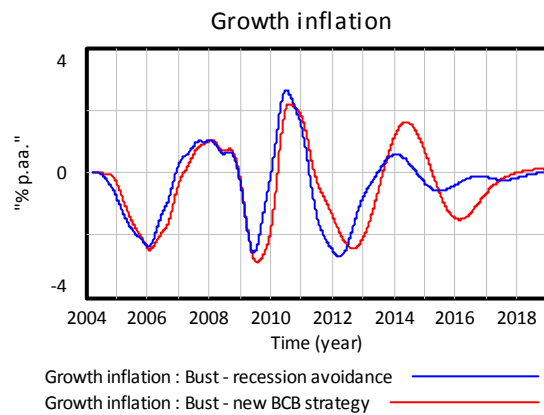
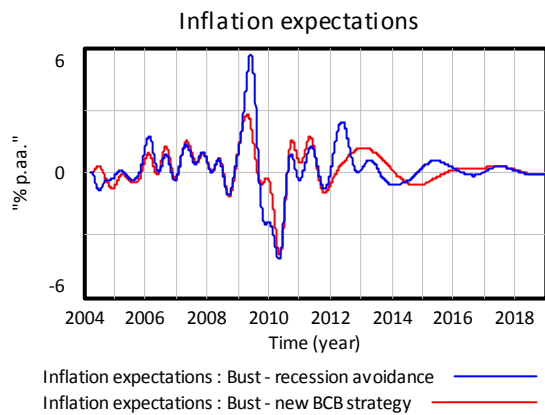
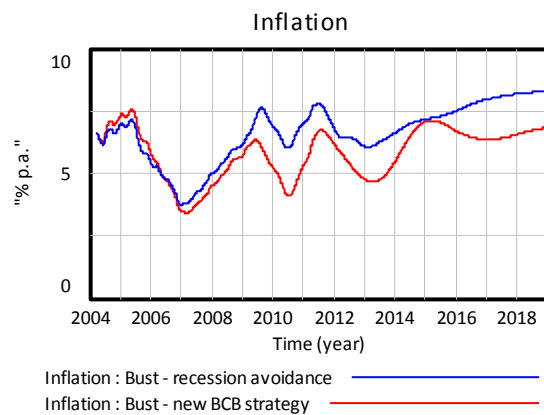
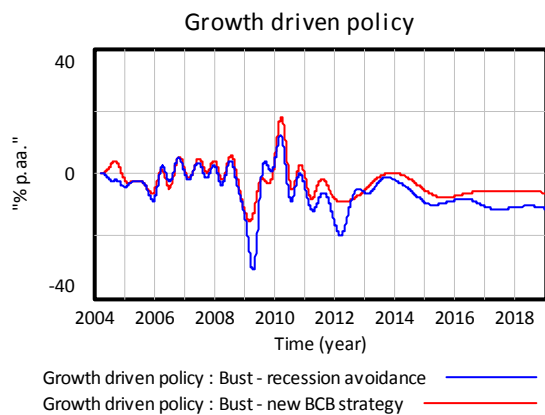
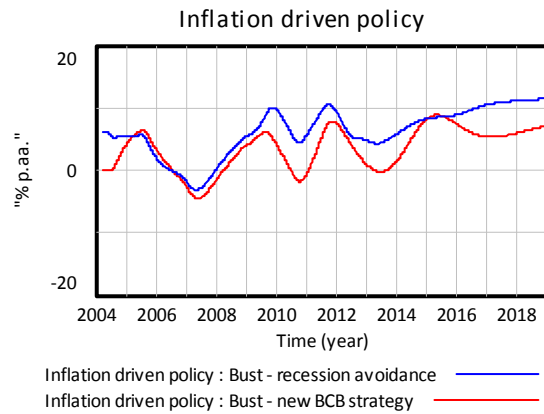
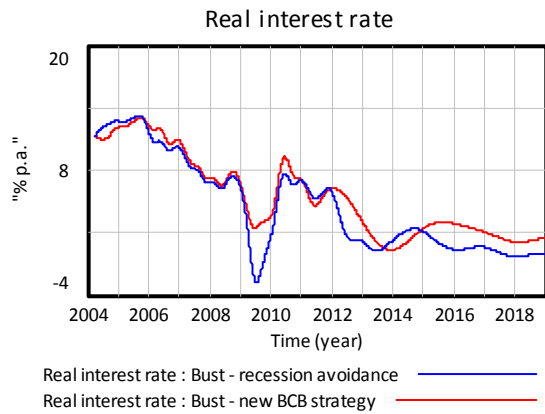


GDP growth : Base - new BCB strategy — (blue line)
 GDP growth : Base - old BCB strategy — (red line)

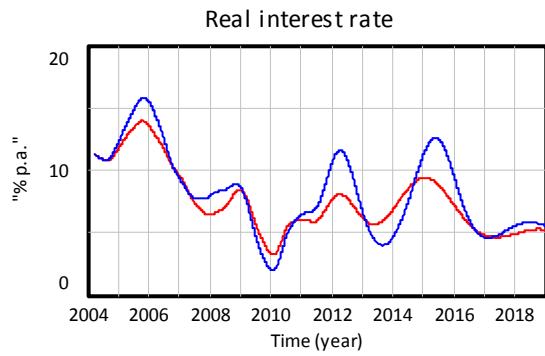


Monetary policy growth : Base - new BCB strategy — (blue line)
 Monetary policy growth : Base - old BCB strategy — (red line)

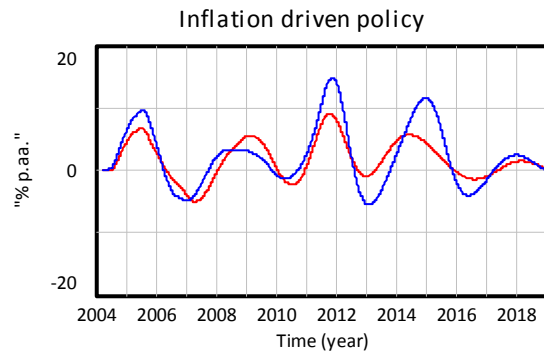
B.4.3. Bust scenario – new BCB strategy and inflation avoidance



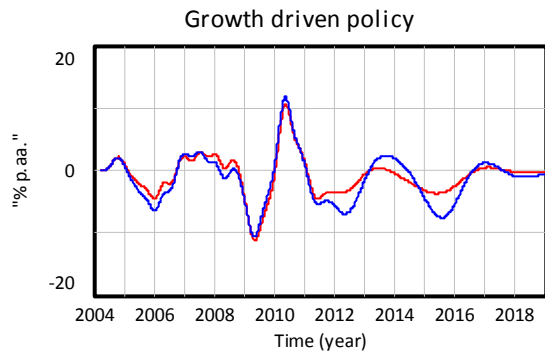
B.4.4. Boom scenario – old BCB strategy and inflation avoidance



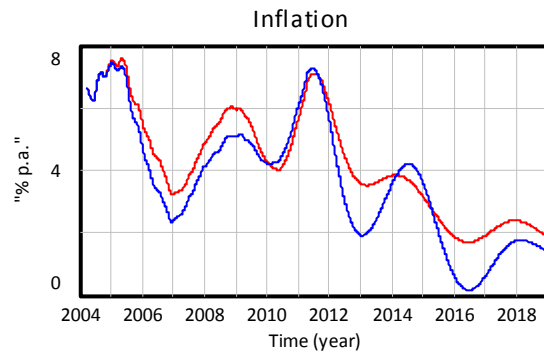
Real interest rate : Boom - inflation avoidance — (blue line)
 Real interest rate : Boom - old BCB strategy — (red line)



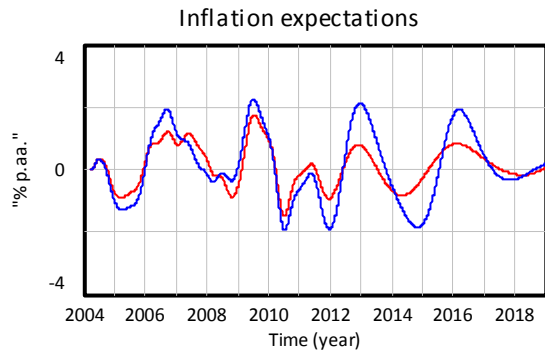
Inflation driven policy : Boom - inflation avoidance — (blue line)
 Inflation driven policy : Boom - old BCB strategy — (red line)



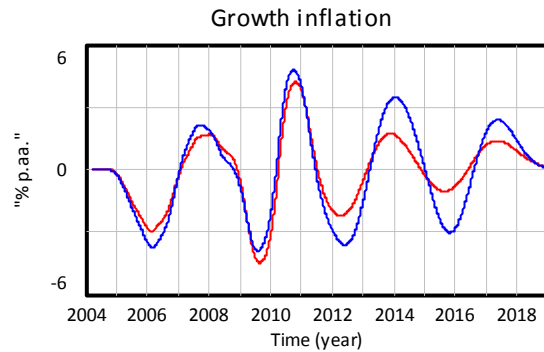
Growth driven policy : Boom - inflation avoidance — (blue line)
 Growth driven policy : Boom - old BCB strategy — (red line)



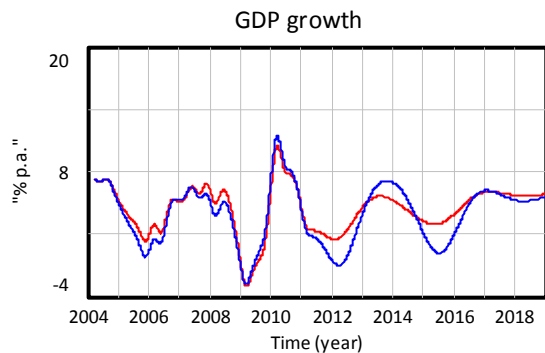
Inflation : Boom - inflation avoidance — (blue line)
 Inflation : Boom - old BCB strategy — (red line)



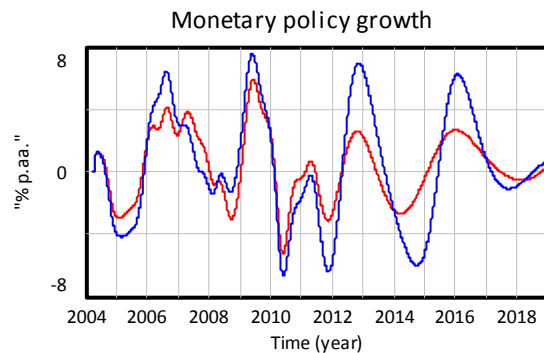
Inflation expectations : Boom - inflation avoidance — (blue line)
 Inflation expectations : Boom - old BCB strategy — (red line)



Growth inflation : Boom - inflation avoidance — (blue line)
 Growth inflation : Boom - old BCB strategy — (red line)



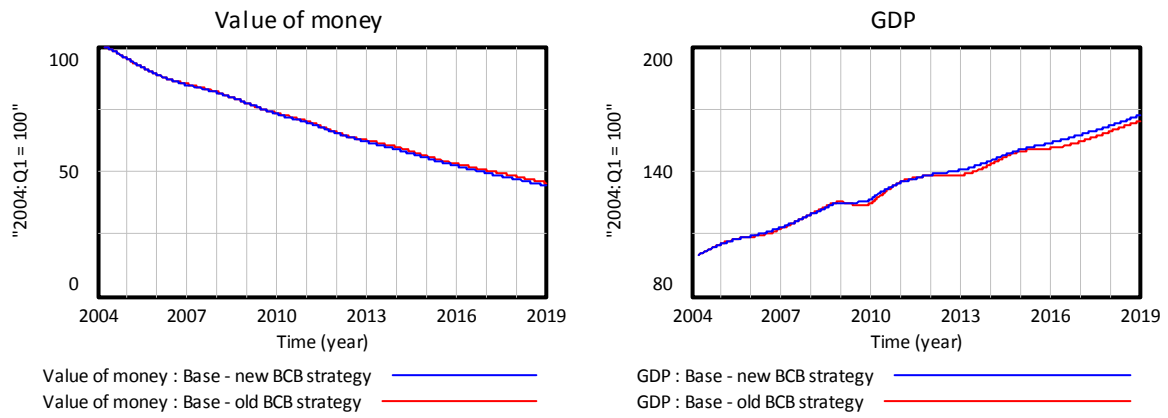
GDP growth : Boom - inflation avoidance — (blue line)
 GDP growth : Boom - old BCB strategy — (red line)



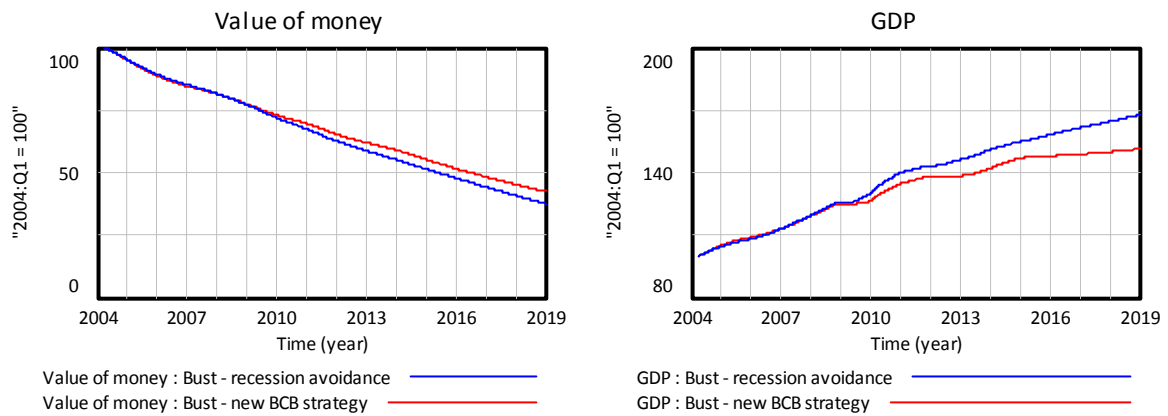
Monetary policy growth : Boom - inflation avoidance — (blue line)
 Monetary policy growth : Boom - old BCB strategy — (red line)

B.4.5. Welfare comparison

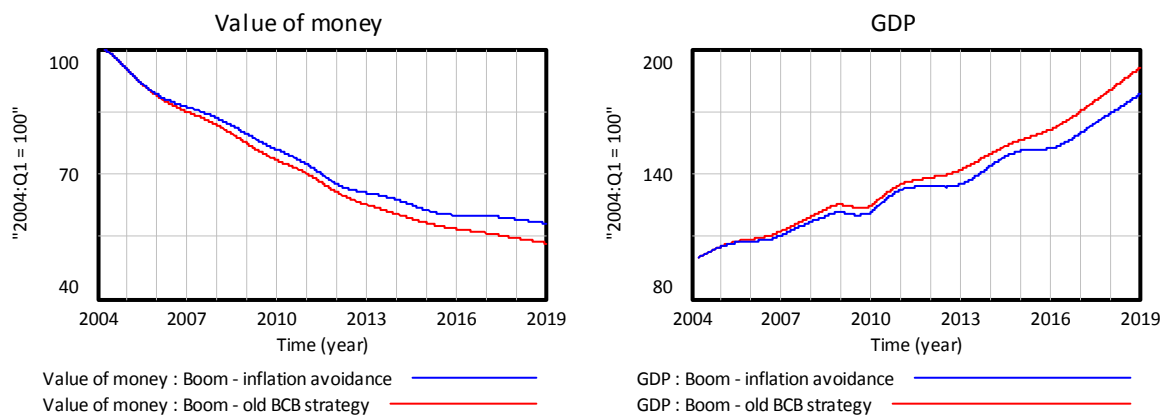
Base scenario – old and new BCB strategy



Bust Scenario – new BCB strategy and recession avoidance

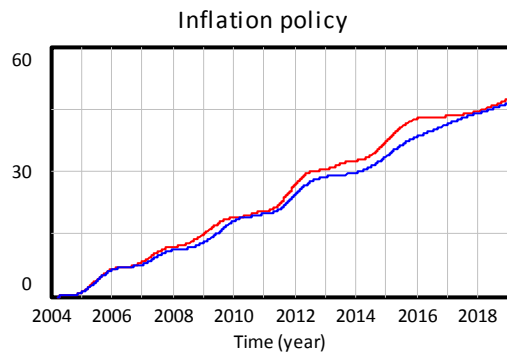


Boom scenario – old BCB strategy and inflation avoidance

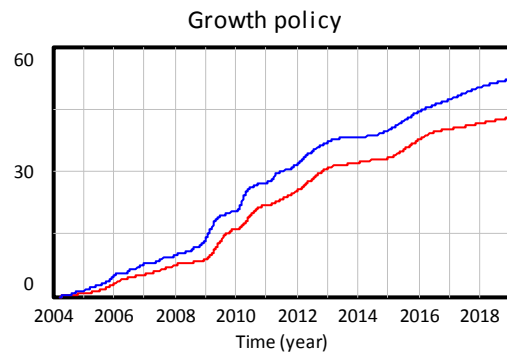


B.4.6. Monetary policy moves comparison

Base scenario – old and new BCB strategy

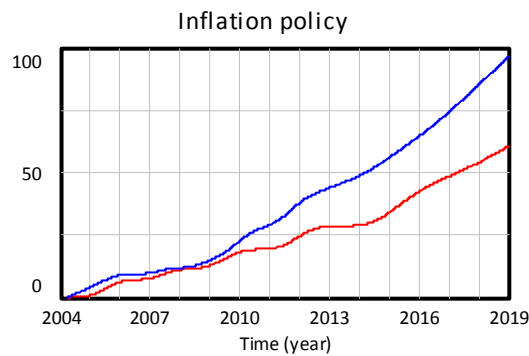


Inflation policy : Base - new BCB strategy ————
 Inflation policy : Base - old BCB strategy ————

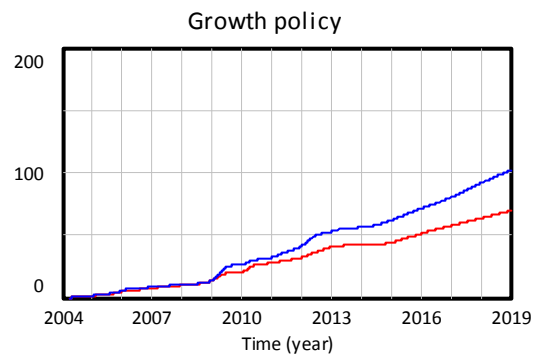


Growth policy : Base - new BCB strategy ————
 Growth policy : Base - old BCB strategy ————

Bust Scenario – new BCB strategy and recession avoidance

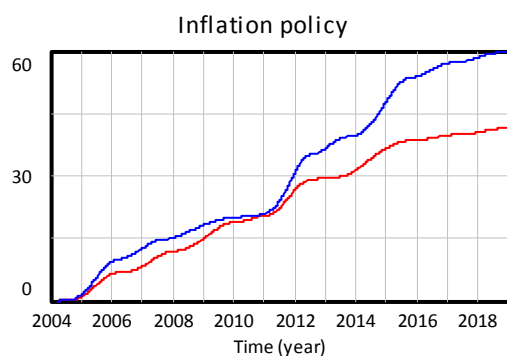


Inflation policy : Bust - recession avoidance ————
 Inflation policy : Bust - new BCB strategy ————

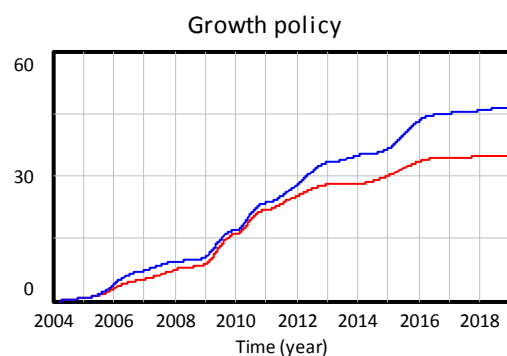


Growth policy : Bust - recession avoidance ————
 Growth policy : Bust - new BCB strategy ————

Boom scenario – old BCB strategy and inflation avoidance



Inflation policy : Boom - inflation avoidance ————
 Inflation policy : Boom - old BCB strategy ————



Growth policy : Boom - inflation avoidance ————
 Growth policy : Boom - old BCB strategy ————