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Medium-Size Macroeconomic Model for the Brazilian Economy*

Marcelo Kfoury Muinhos**

Sergio Afonso Lago Alves**

Abstract

This paper presents a medium-scale macroeconomic model of the Brazilian economy with more than 30 equations. Potential output is derived from a Cobb-Douglas production function, while the demand side is divided into estimated equations for: household consumption, investment in machinery and construction, government spending and net exports. The estimated Phillips curve has an interesting feature: a step dummy variable captures the macroeconomic break in pass-through that occurred after the change of the exchange rate regime in 1999. There are long-run equilibrium conditions for the external and fiscal debt and also for the real interest rate. External and supply shocks were simulated in order to generate impulse responses for the medium size model.

Key words: macroeconomic model, interest rate equilibrium, and potential output.
JEL Classification: E12, E27, F43, F47

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1. Introduction

Small-scale macroeconomic models are very useful for forecasting the short run, but they are not very useful for anchoring the key variables in the long run. They are not able to answer questions about the macro equilibrium of the economy, nor to establish fiscal or external constraints. Larger macroeconomic models work better in providing information about the interaction of stabilization and growth in the medium run. Questions concerning technology, investment, labor markets and the current account balance are better addressed by a more comprehensive model. Micro-founded models are also able to present long run properties consistent with economic agents' optimal behavior. On the other hand Keynesian models are important because they can be used to simultaneously determine the equilibrium levels of output, employment, inflation, current account, rate of investment and fiscal balance. However, in Keynesian models the long-run equilibrium of some key variables such as the interest rate and exchange rate are not endogenously determined.

Many Central Banks have built micro founded structural models. Examples include the Bank of Canada's QPM, the Bank of England's MM (*Macroeconomic Model*) and also the IMF's Multimod. These models are in general divided into two parts. A steady-state part assures long-run equilibrium, which is based on the optimal behavior of economic agents, while a dynamic section describes the equilibrium path of the economy using an error correction framework.

The steady-state model of the QPM is an overlapping-generation model with only one good[1]. The Multimod is very similar and for the first five years uses the outcome from the World Economic Outlook as a baseline. The dynamic section of the Multimod uses a non-linear Phillips curve and also ensures long-run growth consistent with sustainable external debt service.

The special features of the FRB-US are the non-arbitrage conditions in the financial markets. In the goods sector, the expectational variables are model consistent. The dynamic model is also based on an error-correction approach. VAR expectations are also taken into account to describe transitory shocks. The steady-state section of the model is not a dynamic general equilibrium model (DGE) but an ad-hoc baseline case.

Among the models in the Keynesian paradigm, one example is the Financial Programming model of the International Monetary Fund, which uses the monetarist approach to the balance of payments. This model was used in the creation of an entire generation of IMF programs and is still being applied. The bottom-line is to set a goal for the central bank's net domestic assets as a way to avoid growth of the money supply well above the floor for international reserves. The World Bank has a line of two-gap growth models (domestic saving and external saving) called RMSM-X. In Brazil, IPEA has set up a Keynesian macroeconomic model, based on the national accounts, especially the balance of payments and the fiscal budget. A quarterly version of this model has been released recently.

The Central Bank of Chile has built a Keynesian model very similar to the one presented in this paper. The major difference between the models is in the derivation of the steady-state equilibrium. In the Chilean model, consumption is divided into durable and non-durable goods, which is a future goal for our model.

The main contributions of our model, compared to other macroeconomic models developed in the Central Bank of Brazil, are:

- Aggregate demand is calculated by estimating: (1) household consumption, investment in (2) machinery and (3) construction, (4) net exports, (5) government spending, (6) government taxes, (7) changes in inventories;
- The model uses a Phillips curve that includes dummies for the structural break in the pass-through coefficient in 1999 and a proxy for labor productivity (unit labor cost);
- Potential output is estimated by a Cobb-Douglas production function;
- The model includes an estimated exchange rate error correction mechanism converging to the Uncovered-Interest-Parity (UIP) equation on the long run, measured in real terms, together with an equation for the risk premium, to which responses for changes in fiscal and external conditions are added;[2]
- The model includes ad-hoc steady-state conditions for the current account deficit and the primary fiscal surplus.

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[1] It relies on indirect tax and share of imported consumption to include inflation and the exchange rate in the model.

[2] Muinhos, Alves and Riella (2002) have similar equations for UIP and Risk premium.

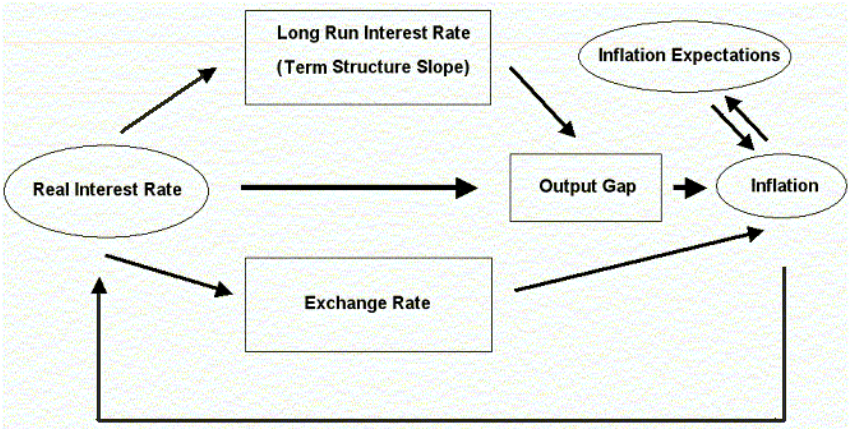
Some simulations for different Taylor rules and impulse responses for a temporary cost-push shock are presented.

The paper is organized as follows. Section 2 presents the diagrams of the small macroeconomic and the medium size models, showing the monetary policy transmission mechanisms and presenting some discussion about the long run equilibrium conditions for the external sector. Section 3 presents estimated and calibrated equations for the demand, supply, external and monetary-fiscal blocks of the model. Section 5 shows some simulation exercises and the last section concludes the paper.

2. Diagrams of The Transmission Mechanisms and Equilibrium Conditions

In order to compare the monetary transmission mechanisms of the medium-scale and the small-scale models, it is necessary to explain the mechanisms in the latter model, as shown in Figure 1. The model includes the traditional channel, via output gap, and a second channel, via exchange rate. The IS curve shows that an increase in the real interest rate will negatively affect the output gap, directly and indirectly via the term structure of interest rates. A more negative output gap will decrease inflation via the Phillips curve. By the UIP non-arbitrage condition, an increase in the interest rate causes an appreciation of the exchange rate in the spot market, and, via the Phillips curve, a decrease in imported prices will generate lower inflation.

Figure 1 ***Small Model Transmition Mechanism***

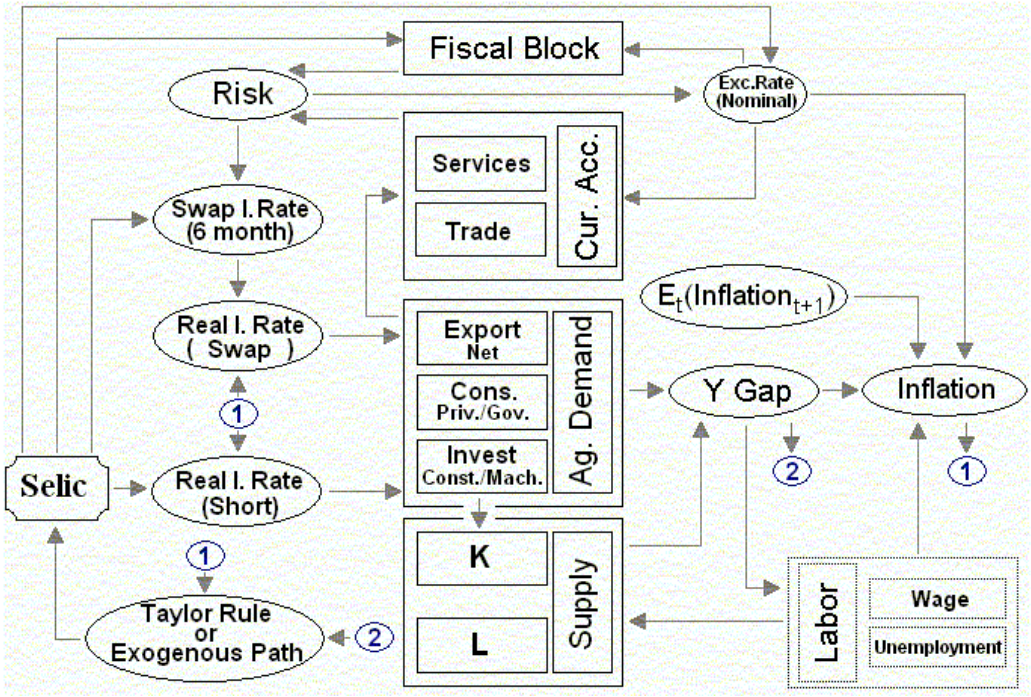


The two monetary transmission mechanisms described for the small model also occur in the medium model, shown in Figure 2[3]. But now it is possible to distinguish between supply and demand effects. An increase in the interest rates will affect household consumption and investment in construction and machinery through the term structure, generating a decrease in aggregate demand. A higher interest rate will cause an exchange rate appreciation and a decrease in net exports, decreasing aggregate demand. On the supply side, the effects of a higher interest rate will take more time to occur, because a lower level of investment will cause a decrease in the growth rate of the capital stock, affecting potential output growth. The decrease in aggregate demand leads to a drop in inflation through a more negative output gap. But this drop would be partially offset by the decrease in potential output growth.

The exchange rate mechanism is still available in the medium size model. But now the fiscal and external variables also affect the exchange rate via the risk premium. An increase in the interest rate that worsens the fiscal accounts will generate an increase in the risk premium and a depreciation of the exchange rate that might offset the aggregate demand channel. The current account deficit also affects the risk premium and consequently, the exchange rate and inflation. Rapid GDP growth may cause an increase in inflation via the output gap and also via a worsening of the trade balance.

[3] Although the main blocks of the medium model are represented in Figure 2, there are some interactions between variables not shown in the figure in order to obtain a clean representation of the model. Nevertheless, the model equations are commented in the text. As this is still a work in progress, our blocks are subject to future improvements.

Figure 2 ***Medium Model Transmition Mechanism***



We also include the labor market as a monetary transmission channel. An increase in the labor force may increase potential output via the Cobb-Douglas production function. In addition, an increase in productivity measured by Total Factor Productivity will increase GDP and decrease inflation, allowing for a loosening of monetary policy.

The absence of micro-founded behavior equations does not allow us to find endogenous steady state values for variables such as the interest rate or exchange rate. The exchange rate, for instance, is modeled with an error correction mechanism with UIP as the level relation, driving the system to the long run equilibrium steady-state exchange rate, defined as the exchange rate that leads to an ad-hoc long-run current account/GDP ratio. This ratio, in turn, is consistent with a steady-state ratio of external liabilities/GDP. For the interest rate, the use of the Taylor rule assures a long-run equilibrium compatible with the inflation target and a neutral output gap.

3. Modeling the Brazilian Economy

The IBGE[4] began releasing a quarterly series of the income components of GDP in the third quarter of 2001. The sample starts in 1991:01. This has made it possible to construct and run more detailed macro models for the Brazilian economy. However,

[4] Brazilian Institute of Geography and Statistics.

studies using these new quarterly data are very recent and the constructed models are still based on a new Keynesian paradigm, using ad hoc relations between the variables rather than micro-founded structural relationships. However, even considering that our results are subject to the Lucas critique in some sense, it is still worth working on the model, due to the fact that it can be used to simultaneously determine the levels of output, employment, inflation, current account, rate of investment and fiscal balance. And it is in line, in some parts, with other models developed using this new Brazilian quarterly data, as in Cavalcanti, Kai and Carvalho (2002). The use of micro-founded models is on our agenda for the next generation of the Central Bank of Brazil's structural models.

The estimation samples depend upon the availability and behavior of the data. We choose not to homogenize the starting point of the estimations. We are estimating each equation separately and if we do not consider the full series we would be throwing information away. Nevertheless when there are severe structural breaks that cannot be fixed with dummy variables, we decide to exclude the series before the break. Inflation before 1994 is a good example of this problem. As we did not estimate the equations in a system, simultaneity bias was avoided using two stage estimations or considering only lagged variables on the right side of the equations.

3.1. The Aggregate Demand Side

Aggregate demand is determined by its definitional identity, shown in Equation 1. In this section, we will model each of its components and related variables such as taxes, government expenditures and the fiscal deficit (primary concept).

$$Y_t = C_t + G_t + I_t + X_t^{net} + \Delta S_t \tag{1}$$

Where:

Y_t	*output;*
C_t	*household consumption;*
G_t	*government consumption;*
I_t	*investment;*
X_t^{net}	*net exports;*
ΔS_t	*inventory investment.*

Although the IBGE releases both nominal and real data, the real income components do not sum to meet Equation 1[5]. As a solution, we estimated real income components using their nominal income share applied to real income. This method guarantees Equation 1, in real terms, for the whole sample.

3.1.1. Household Consumption

Household consumption is by far the most important income component, since it accounts for more than 60% of output. Although this initial model's formulation is new Keynesian, the traditional literature strongly indicates that consumption should be a function of permanent rather than contemporaneous income. On the other hand, empirical results suggest that some factors may also cause consumption decisions to be based on contemporaneous income variables. For example, difficulties in obtaining loans and weak forward-looking behavior by some agents may cause this behavior.

In this context, we used a very simple specification: a level equation, in logarithms, with the ratio of consumption-to-disposable income on the left side, as shown in Equation 2. In order to capture a permanent income effect, we used potential output[6], which we considered a reasonable measure. Contemporaneous income was also tried, but it failed as a regressor[7], so we decided to use the real interest rate to capture the same behavior. An increase in the real interest rate should decrease the income growth rate and, in response, the consumption growth rate. Theory indicates that we should consider medium or long-term interest rates rather than short-term interest rates. We could obtain the former considering the 6-month swap market, but this would force us to use a smaller series since we only have 6-month interest rates from 1994Q4 on. Therefore we decided to use the short-term interest rate. Additionally, we used a step dummy variable to capture the increase in the consumption-to-disposable income ratio after 1996, which may have resulted from an improved outlook related to the recent

[5] Even when changing base period values in order to guarantee the income identity in some quarters, there are always some periods in which the income identity does not fit. This is probably due to the fact that the individual series are not deflated with the same deflator as the income series.

[6] See Section 3.2.

[7] We tried a weighted average of permanent and contemporaneous income, with weights to be estimated in the regression, but contemporaneous income was not significant. This is probably due to colinearity between GDP and potential GDP.

stabilization of the economy. The outcome of the estimation, which used an outlier pulse dummy for 1994Q1[8], is shown in Table 1, in.

$$\ln\left(\frac{C_t}{\overline{Y}_{t-1}^d}\right) = \alpha_0 + \alpha_1 \cdot \ln\left(\frac{C_{t-1}}{\overline{Y}_{t-2}^d}\right) + \alpha_2 \cdot r_{t-1} + \sum_{i=1}^{3} \beta_i \cdot Seas_i + \alpha_3 \cdot D_{96} \tag{2}$$

Where:

C_t *household consumption;*

$\overline{Y}_t^d$ *disposable potential income:* $\overline{Y}_t^d = \overline{Y}_t - T_t^d$ *;*

T_t^d *direct taxes;*

$\overline{Y}_t$ *potential output;*

r_t *short term real interest rate*[9]*:* $r_t = \frac{Selic_t}{4} - \begin{cases} \pi_t & , \textit{from } 1991Q1 \textit{ to } 1995Q1 \\ \sum_{i=0}^{3} \frac{\pi_{t-i}}{4} & , \textit{from } 1995Q2 \textit{ on} \end{cases}$ *;*

$Selic_t$ *annualized Brazilian over night nominal interest rate;*

D_{96} *step dummy from year 1996 on.*

Table 1 ***Equation 2***

Method: *OLS*			**Sample:** *1991:3 to 2002:2*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	-0.308	0.045	-6.873	0.000
α_1	0.254	0.123	2.068	0.046
α_2	-0.737	0.262	-2.817	0.008
β_1	0.060	0.020	2.933	0.006
β_2	0.080	0.018	4.559	0.000
β_3	0.103	0.017	6.070	0.000
α_3	0.055	0.018	3.060	0.004
$D_{94:01}$	0.168	0.040	4.172	0.000
$R^2 = 0.782$			$R^2_{Ajust.} = 0.740$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.065 (p =0.356)
Jarque-Bera Normality Test: 1.160 (p =0.244)
White Heteroskedasticity Test: F = 1.170 (p =0.351)

[8] Without the dummy variable, all fitting and residual (serial correlation and heteroskedasticity test) statistics seemed to be acceptable, but we nevertheless observed a huge residual value in 1994Q1 of about 3 times the regression standard error. This could indicate an outlier. Running the regression with a pulse dummy for that period, we find that the new coefficients do not significantly change, but fitting and residual statistics are much better.

[9] We considered two measures for the ex-ante real interest rate to correct distortions caused during the hyperinflation period. In post Real Plan period, the 4-quarter inflation average would represent an adaptative ex-ante inflation expectation with 75% (calibrated) backward looking. If this procedure were to be used for the previous period, it would lead to false negative real interest rate, with huge absolute values, from 1994Q3 to 1995Q1. It is due to the fact that the former procedure is incorrect to generate ex-ante interest rate in hyperinflationary periods, during which past values averages systematically underestimate current inflation.

3.1.2. Investment

Like household consumption, investment has an important role in determining economic activity since it affects both output directly, and potential output indirectly via capital accumulation. We break the investment series into its construction and machinery components and model each separately. These two series are best explained by the 6-month real interest rate. Even though the sample size for these series is smaller, as explained in the last section, the regressions seemed to have good explanatory power - good fit and good residual statistics – and we considered them as acceptable representations of reality. Construction and machinery investment are represented in Equations 3 and 4, respectively, and estimation results are shown in Tables 2 and 3, respectively. Total investment is determined by the identity in Equation 5.

The behavior of investment seems to have been passed through changes related to the way its components (machinery and construction) were affected by the real interest rate and seasonal movements from 1999 on. Up to 2000Q2, construction investment is affected by 2-lags of the real interest rate; from 2000Q2 forward, it is also affected by 1-lag of the real interest rate. With respect to machinery investment, it does not seem to be affected by the real interest rate in 1995.

$$\ln\left(\frac{IC_t}{Y^d_{t-1}}\right) = \alpha_0 + \alpha_1 \cdot \ln\left(\frac{IC_{t-1}}{Y^d_{t-2}}\right) + \alpha_2 \cdot r^{Swap6}_{t-2} + \alpha_3 \cdot r^{Swap6}_{t-1} \cdot D_{2000} + \sum_{i=1}^{3} \beta_i \cdot Seas_i + \beta_4 \cdot Seas_1 \cdot D_{1999} \tag{3}$$

$$\ln\left(\frac{IM_t}{Y^d_{t-1}}\right) = A_0 + A_1 \cdot \ln\left(\frac{IM_{t-1}}{Y^d_{t-2}}\right) + A_2 \cdot r^{Swap6}_{t-1} \cdot D_{1996} + \sum_{i=1}^{3} B_i \cdot Seas_i + B_4 \cdot Seas_2 \cdot D_{1999} \tag{4}$$

$$I_t = IC_t + IM_t \tag{5}$$

Where:

I_t *total investment;*

IC_t *construction investment;*

IM_t *machinery investment;*

Y_t *real income;*

r_t^{Swap6} *medium run real interest rate:*

$$r_t^{Swap6} = \frac{i_t^{Swap6}}{4} - \begin{cases} \pi_t & , \ until\ 1995Q1 \\ \sum_{i=0}^{3} \frac{\pi_{t-i}}{4} & , \ from\ 1995Q2\ on \end{cases};$$

i_t^{Swap6} *annualized 6 month swap interest rate;*

D_{yyyy} *step dummy for year "yyyy" on.*

Table 2 ***Equation 3***

Method: *OLS*			**Sample:** *1995:2 to 2002:2*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	-1.393	0.312	-4.466	0.000
α_1	0.336	0.159	2.112	0.047
α_2	-1.010	0.502	-2.011	0.057
α_3	-2.300	0.629	-3.658	0.001
β_1	0.097	0.034	2.806	0.011
β_2	0.161	0.019	8.554	0.000
β_3	0.124	0.020	6.351	0.000
β_4	0.073	0.029	2.524	0.020
$R^2 = 0.831$			$R^2_{Ajust.} = 0.775$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.841 (p =0.186)
Jarque-Bera Normality Test: 0.948 (p =0.623)
White Heteroskedasticity Test: F = 0.468 (p =0.889)

Table 3 ***Equation 4***

Method: *OLS*			**Sample:** *1995:1 to 2002:2*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
A_0	-1.458	0.309	-4.716	0.000
A_1	0.497	0.120	4.142	0.000
A_2	-1.625	0.717	-2.265	0.033
B_1	0.171	0.023	7.568	0.000
B_2	0.212	0.025	8.562	0.000
B_3	0.119	0.021	5.600	0.000
B_4	-0.065	0.028	-2.303	0.031
$R^2 = 0.902$			$R^2_{Ajust.} = 0.877$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.765 (p =0.478)
Jarque-Bera Normality Test: 1.264 (p =0.532)
White Heteroskedasticity Test: F = 0.601 (p =0.767)

3.1.3. Net Exports

Since nominal exports and imports, in US dollars, are modeled in Sections 3.3.3 and 3.3.4, modeling real exports and imports is quite simple. We only have to transform the currency into Brazilian real and deflate the series, as described in Equations 6 and 7. Net exports are determined by the definition in Equation 8.

$$\Delta ln(X_t) = \Delta ln(Exports_t) - \Delta e_t - \pi_t \tag{6}$$

$$\Delta ln(M_t) = \Delta ln(Im\,ports_t) - \Delta e_t - \pi_t \tag{7}$$

$$X_t^{net} = X_t - M_t \tag{8}$$

Where:

$Exports_t$	*nominal US dollar exports;*
$Imports_t$	*nominal US dollar imports;*
e_t	*exchange rate (logarithm);*
π_t	*IPCA inflation rate;*

3.1.4. Government Consumption

Brazil's fiscal surplus (primary concept) is defined as total tax revenues minus non-interest government expenditures. The former are divided, as usual, into direct and indirect taxes and the latter are divided into government investment and government consumption.

We model total taxes as a function of lagged total taxes and lagged income in a simple specification described in Equation 9. In order to capture the most recent behavior of tax policy, the estimation sample was very short; the result is shown in Table 4. A step dummy was used to model a level change that occurred from 1999 on and a pulse dummy was used to capture a 1997:04 outlier. Direct taxes, modeled in order to have a measure of disposable income $\left(Y_t - T_t^d\right)$, are modeled by a similar specification, described in Equation 10. Its output is shown in Table 5. Government investment, as a ratio of total taxes, is modeled as a AR(3) process described in Equation 11, with outlier dummies. The result is shown in Table 6. Government consumption is calculated as a residual, in Equation 12, since we determined an exogenous path for the fiscal deficit (primary concept) as a GDP ratio (annual average).

$$T_t^T = \alpha_0 + \alpha_1 \cdot T_{t-1}^T + \sum_{i=1}^{3} \beta_i \cdot Y_{t-i} \tag{9}$$

$$T_t^d = \alpha_0 + \alpha_1 \cdot T_{t-1}^d + \sum_{i=1}^{3} \beta_i \cdot Y_{t-i} \tag{10}$$

$$\frac{I_t^G}{T_t^T} = \alpha_0 + \alpha_1 \cdot \frac{I_{t-1}^G}{T_{t-1}^T} + \alpha_2 \cdot \frac{I_{t-2}^G}{T_{t-2}^T} + \alpha_3 \cdot \frac{I_{t-3}^G}{T_{t-3}^T} \tag{11}$$

$$G_t = \sum_{j=0}^{3} \left(T_{t-j}^T\right) - FSPR_t \cdot \sum_{j=0}^{3} Y_{t-j} - \sum_{j=1}^{3} G_{t-j} \tag{12}$$

Where:

T_t^T	*total tax;*
T_t^d	*direct tax;*
I_t^G	*government investment;*

$FSPR_t$ fiscal deficit (primary concept).

Table 4 ***Equation 9***

Method: *OLS*			**Sample:** *1996:1 to 2001:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	-25.297	12.177	-2.077	0.053
α_1	-0.391	0.097	-4.050	0.001
β_1	0.464	0.079	5.889	0.000
β_2	-0.290	0.083	-3.475	0.003
β_3	0.371	0.079	4.697	0.000
D_{99}	-4.782	1.004	-4.762	0.000
$D_{97:04}$	-10.449	1.684	-6.205	0.000
$R^2 = 0.926$			$R^2_{Ajust.} = 0.899$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.560 (p =0.242)
Jarque-Bera Normality Test: 2.274 (p =0.321)
White Heteroskedasticity Test: F = 0.516 (p =0.850)

Table 5 ***Equation 10***

Method: *OLS*			**Sample:** *1996:1 to 2001:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	-29.538	11.458	-2.578	0.020
α_1	-0.449	0.104	-4.333	0.000
β_1	0.342	0.075	4.546	0.000
β_2	-0.231	0.083	-2.779	0.013
β_3	0.288	0.078	3.675	0.002
D_{99}	4.224	1.000	4.226	0.001
$D_{97:04}$	-9.587	1.674	-5.726	0.000
$R^2 = 0.899$			$R^2_{Ajust.} = 0.863$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.031 (p =0.381)
Jarque-Bera Normality Test: 4.323 (p =0.115)
White Heteroskedasticity Test: F = 0.470 (p =0.881)

Table 6 ***Equation 11***

Method: *OLS (White Heteroskedasticity-Consistent Standard Errors & Covariance)*			**Sample:** *1996:1 to 2001:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	0.031	0.012	2.497	0.022
α_1	0.509	0.142	3.584	0.002
α_2	0.447	0.173	2.581	0.019
α_3	-0.320	0.171	-1.871	0.078
$D_{96:02}$	0.032	0.003	9.171	0.000
$D_{97:04}$	0.072	0.002	31.423	0.000
$R^2 = 0.859$			$R^2_{Ajust.} = 0.820$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 2.125 (p =0.152)
Jarque-Bera Normality Test: 0.122 (p =0.941)
White Heteroskedasticity Test: F = 3.084 (p =0.029)

3.1.5. Inventory Investment

We define the inventory dynamics as follows:

$$S_t = (1-\delta)\cdot S_{t-1} + \Delta S_{t-1} \tag{13}$$

Where:

S_t *inventory level;*

ΔS_t *inventory investment;*

δ *depreciation rate, invariant over time.*

The basic hypothesis is that firms produce in order to maintain a minimum inventory as a long run time invariant demand ratio $\frac{S}{Z}$, where $Z_t = Y_t - \Delta S_t$. Keeping this assumption in mind and dividing both sides of Equation 13 by Z_t , we obtain the result described in Equation 14, considering that $Z_{t+1} = Z_t \cdot \left(1 + g_{t+1}^{Z}\right)$.

In the steady state, the ratio $\frac{S}{Z}$ should converge. Hence, in Equation 15, equilibrium ratio $\frac{\Delta S}{S}$ depends on the depreciation rate plus the quarterly Z growth.

$$\frac{S_{t+1}}{Z_{t+1}} - \frac{S_t}{Z_t} = -g_{t+1}^{Z} \cdot \frac{S_{t+1}}{Z_{t+1}} - \delta \cdot \frac{S_t}{Z_t} + \frac{\Delta S_t}{Z_t} \tag{14}$$

$$\left(\delta + g_{t+1}^{Z}\right) \cdot \frac{S_t}{Z_t} = \frac{\Delta S_t}{Z_t} \quad \therefore \quad \frac{\Delta S_t}{S_t} = \left(\delta + g_{t+1}^{Z}\right) \tag{15}$$

Where:

$Z_{t+1} = Z_t \cdot \left(1 + g_{t+1}^{Z}\right)$

g_t^{Z} *quarterly Z_t growth rate.*

Assuming that the inventory dynamics over the last decade (1991/2001) have behaved on average as indicated by Equation 15, we can estimate two latent variables related to inventory formation: the initial inventory (1991:01) and the depreciation rate (δ). Note that if the ratio $\frac{\Delta S}{S}$ is supposed to be constant over the sample, the sum of the quadratic deviations from the sample average must be minimized. In this context, we just have to find the values of those two non-observed variables that minimize the previous sum, since the values of g_{t+1}^{Z} are known. Doing this we find $S_{91:01} = 59{,}82$ and $\delta = 8{,}62\%$ *(annual basis).*

3.1.5.1 Estimating a Dynamic Inventory Investment Model

A deviation of inventory investment from the long run relationship means that the economy is growing faster or slower than expected, should inventory investment be below or above the long run relationship, respectively[10]. Consider the case, for example, when the growth of demand is slower than expected. Since firms, on the other side, have already decided to produce in order to achieve the expected demand plus the long run inventory investment, there must be a positive gap between actual and long run $\frac{\Delta S}{S}$ ratio. What happens next? Firms decide to produce less, running in the opposite direction, correcting the gap until it is closed again. This may produce an over shooting dynamic behavior for the $\frac{\Delta S}{S}$ gap, as has been observed in the Brazilian inventory investment series. On the other hand, production decisions may also be negatively affected by the real interest rate.

Hence, we model the $\frac{\Delta S_t}{S_t}$ gap as a function of it own lags and of the real interest rate. Potential $\frac{\Delta S_t}{S_t}$ is modeled with the potential Z_t growth rate, considering that it must equal the potential output growth rate in the long run, as shown in Equation 16. Table 7 shows the estimations, which include a dummy to reflect a reduction in the level that occurred from 1994Q1 to 1997Q4.

$$g_t = \sum_{i=1}^{3} \alpha_i \cdot g_{t-i} + \alpha_4 \cdot \left(r_{t-3} - r^{eq} \right) \tag{16}$$

Where:

g_t *inventory investment ratio gap, defined as:* $g_t = \frac{\Delta S_t}{S_t} - \left[\delta + \left(\frac{\overline{Y}_t}{\overline{Y}_{t-1}} - 1 \right) \right]$;

$\overline{Y}_t$ *potential output;*

r^{eq} *short run equilibrium real interest rate.*

[10] Indeed, it can be used as a leading indicator for the output gap, due to the cited reasons.

Table 7 ***Equation 16***

Method: *OLS*			**Sample:** *1992:2 to 2002:2*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_1	-0.930	0.126	-7.377	0.000
α_2	-0.793	0.139	-5.685	0.000
α_3	-0.622	0.117	-5.320	0.000
α_4	-0.431	0.221	-1.947	0.059
D_{9497}	-0.052	0.014	-3.691	0.001
$R^2 = 0.646$			$R^2_{Ajust.} = 0.597$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.630 (p =0.539)
Jarque-Bera Normality Test: 1.805 (p =0.406)
White Heteroskedasticity Test: F = 1.820 (p =0.103)

3.2. The Supply Side

The supply side was modeled using a traditional Cobb-Douglas production function approach and a Phillips type curve.

3.2.1. Cobb-Douglas Production Function

A Cobb-Douglas production function, with capital and labor, was modeled as described in Equation 17.

$$Y_t = A_t \cdot (K_t \cdot uci_t)^{\alpha_t} \cdot (L_t)^{1-\alpha_t} \tag{17}$$

Where:

$$L_t = PEA_t \cdot (1 - u_t)$$

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

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

PEA *labor force (Age ≥ 15 years)*[11]*;*

u *unemployment rate (%)*[12]*;*

uci *installed industrial capacity used (%)*[13]*;*

δ *depreciation rate*[14]*.*

[11] Released on a monthly basis by the *Brazilian Institute of Geography and Statistics* (IBGE), the *População Economicamente Ativa* (PEA) is the potential labor force in the economy, accounting for employed people and unemployed who looked for a job in the last 30 days, both older than 15 years.

[12] Released on a monthly basis by the *Brazilian Institute of Geography and Statistics* (IBGE).

[13] Released on a quarterly basis by the *Brazilian Fundação Getúlio Vargas* (FGV).

[14] We considered, for simplification sake, that capital inventory depreciates by the same rate estimated in the inventory investment section.

The total factor productivity (TPF) series is extracted as a residual of Equation 17, since the GDP, PEA, u, uci and α_t series are known. It is important to emphasize here that the TPF series (A_t) depend only on the latent values of β_i and on the initial capital inventory (K_0). Knowing the TPF series, we can define potential output as in Equation 18. The output gap[15], written in a logarithmic form $h_t = \ln\left(\frac{Y_t}{\overline{Y}_t}\right)$, can be easily derived as described in Equation 19[16].

$$\overline{Y}_t = A_t \cdot \left(K_t \cdot uci_{fe}\right)^{\alpha_t} \cdot \left(L_t^{fe}\right)^{1-\alpha_t} \tag{18}$$

$$h_t = \alpha_t \cdot \left[\ln\left(uci_t\right) - \ln\left(uci_{pe}\right)\right] + \left(1-\alpha_t\right) \cdot \left[\ln\left(1-u_t\right) - \ln\left(1-\overline{u}\right)\right] \tag{19}$$

Where:

$L_t^{fe} = PEA_t \cdot \left(1-\overline{u}\right)$

$\overline{u}$ *natural unemployment rate (%);*

fe *full employment index.*

Note that each quarter's investment contributes to capital formation up to 4 quarters ahead. The intuition behind this modeling is that certain investments may be converted into capital faster than others. However, we restricted the investment percentage lag to be between 2 and 4 quarters.

In this model, we use a dynamic behavior for α, the capital share yield. Actually this series had a structural break in 1994 as shown in Graph 1, which plots annual values[17]. In order to obtain α quarterly values, we considered an alternative procedure that assured a smooth pattern and annual quarterly values average restriction, as described and justified in Appendix 1. A visual comparison between annual and quarterly estimated values is presented in Graph 2. Due to the fact that the IBGE has only released data up to 2000, we used α forecasts simulated by Equation 26 in order to estimate the output gap and potential output through 2001.

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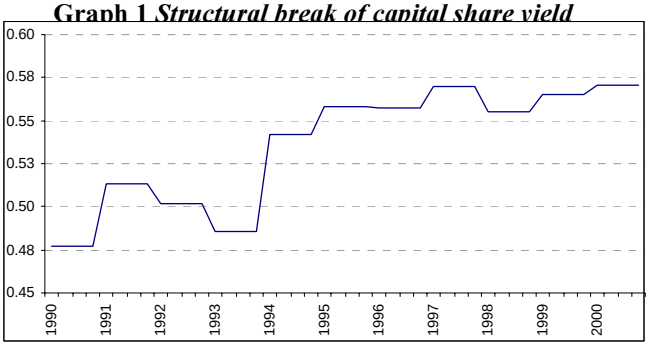
[15] "Hiato" in Portuguese.

[16] Note that output gap can be view as a weighted average of the utility capacity gap and the employment rate gap. However, in the simulations, we did not model u_t and uci_t. Hence, the simulations of the output gap are obtained from aggregate demand, output and the potential output described here.

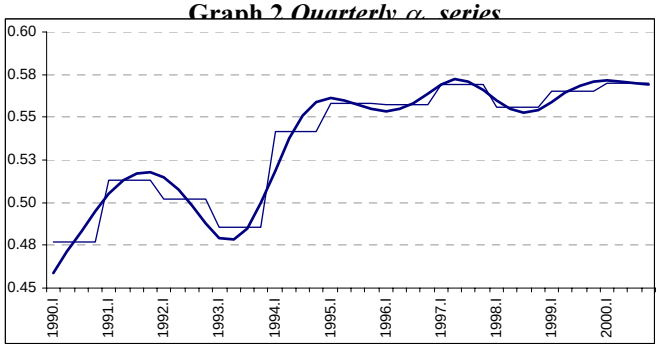
[17] Released on a annual basis by the *Brazilian Institute of Geography and Statistics* (IBGE) on "Table 4 - Composição do Produto Interno Bruto sob as três óticas - 1996-2000", Contas Nacionais do Brasil.

In the following, we will present some results based on Solow's growth model considering the effect of a volatile path for α. First, we rewrite the potential output equation considering labor efficiency (E_t), as in Equation 21. Equation 22 shows the last equation transformed into a logarithm first difference. It is a well-known result that, in steady state, k_t^{fe} and E_t should grow at the same rate. Accepting that the first difference in the natural logarithm equals the growth rate, we may expect that in the steady state or in a sufficiently large sample, Equation 22 converts to Equation 23[18].

Graph 1 ***Structural break of capital share yield***



Graph 2 ***Quarterly α series***



$$\bar{y}_t = \left(k_t^{fe}\right)^{\alpha_t} \cdot \left(E_t\right)^{1-\alpha_t} \tag{21}$$

$$\Delta \ln\left(\bar{y}_t\right) = \alpha_t \cdot \Delta \ln\left(k_t^{fe}\right) + \ln\left(k_{t-1}^{fe}\right) \cdot \Delta\left(\alpha_t\right) + \left(1-\alpha_t\right) \cdot \Delta \ln\left(E_t\right) - \ln\left(E_{t-1}\right) \cdot \Delta\left(\alpha_t\right) \tag{22}$$

$$\Delta \ln\left(\bar{y}_t\right) = \Delta \ln\left(k_t^{fe}\right) + \left[\ln\left(k_{t-1}^{fe}\right) - \ln\left(E_{t-1}\right)\right] \cdot \Delta\left(\alpha_t\right) \tag{23}$$

Where:

$$E_t = \left(A_t\right)^{\frac{1}{1-\alpha_t}} \qquad \bar{y}_t = \frac{\bar{Y}_t}{L_t^{fe}} \qquad k_t^{fe} = \frac{K_t \cdot uci_{fe}}{L_t^{fe}}$$

Regarding Equation 23, where both sides are functions of non-observed variables (K_0, β_i, uci_{fe} and $\bar{u}$)[19], its empirical validation depends heavily upon the estimates – or calibrations – of those latent variables. Hence, we decided that the estimation of these variables should include an optimization process aimed at reducing the deviations between both sides, over a sample in which we could validate the main hypothesis of this result, namely that k_t^{fe} and E_t grow by approximately the same rate. There was

[18] A particular case is when α_t is time invariant, the second term on the right side vanishes and we obtain the known result that k_t^{fe} and $\bar{y}_t$ grow by the same rate as well as E_t.

[19] Remember that δ is already estimated.

another restriction that should be considered here. However, it is a restriction present in the Phillips curve modeled in the next section. After modeling this curve, we will present the latent variables estimation process.

3.2.2. Phillips Curve Modeling

A Phillips curve, as usual, should consider an expected inflation rate, a measure of the level of activity such as the output gap, and also a pass-through component, to capture changes in import prices. Concerning this last component, we model a structural break in the pass-through coefficient after the move to a floating exchange rate regime in January 1999. We assume that, under the new regime, movements in exchange rates will not be perceived to be as permanent as they were in the crawling peg regime. Thus, expecting this coefficient to be smaller under the floating exchange rate regime, we introduced a step dummy in a non-linear pass-through coefficient in order to capture the structural break.

With respect to inflation expectations, we should make some remarks concerning administrative prices. In Brazil, administrative prices have a high weight in the IPCA[20] basket, averaging around 30% of the total index. Forecasting these prices is more accurate one year ahead, mainly because of the readjustment clauses contained in the contracts governing these prices. In this context, our Phillips curve models just the "free prices"[21], which should respond to monetary policy[22]. But free price inflation expectations must be a function of full inflation, with backward and forward components. A final feature of the specification is a verticality long run restriction: there must be no intercept coefficient, and backward and forward coefficients and the pass-through coefficient must sum to 1. The absence of an intercept coefficient is the final restriction to be used on the latent variables estimation mentioned earlier. This restriction should be considered in the estimation described in the next section. Attempting to capture all those features, the Phillips curve specification is given in Equation 24[23].

[20] Measured and released on a monthly basis by the Brazilian Institute of Geography and Statistics (IBGE), IPCA is the consumer price index chosen for the purpose of gauging yearly inflation targets in the Inflation Target system.

[21] Purging government prices.

[22] In our simulations, we considered the government inflation forecasts up to one year ahead based on the contracts. But, for longer forecasting horizons, we assume that government prices should move together with free prices.

[23] The Phillips curve estimation output will be shown in Table 8 Section 3.2.3.

$$\pi_t^{free} = \alpha_1 \cdot \pi_{t-1} + \left(1 - \alpha_1 - \alpha_3 - \alpha_4 \cdot D_{fl}\right) \cdot E_t \pi_{t+1} + \alpha_2 \cdot h_{t-1} + \left(\alpha_3 + \alpha_4 \cdot D_{fl}\right) \cdot \left(\Delta e_t + \pi_t^*\right) \tag{24}$$

Where all variables are specified in logarithms:

π_t^{free} *free inflation rate, considering the IPCA;*

π_t *full inflation rate, considering the IPCA;*

π_t^* *foreign inflation rate, considering the US PPI;*

h_t *output gap (hiato in Portuguese);*

e_t *exchange rate;*

D_{fl} *step dummy: 0 before exchange rate regime changing and 1 after.*

3.2.3. Estimation of Non-Observed Variables

As commented in Boone, Juillard, Laxton and N'Diaye (2002), NAIRU estimation processes that do not exploit information about inflation may result in inefficient historical measures of the NAIRU, biased parameter estimates, as well as inefficient forecasts of the NAIRU. In this work, rather than taking into account the path of the NAIRU, we assumed a constant natural rate of unemployment. Nevertheless, as this last critique suggests, we must use inflation information to estimate the latent variables. In this sense, we considered a Phillips curve restriction described as follows:

As previously mentioned, the latent variables estimation process must approximate both sides of Equation 23, over a sample in which we could validate the main hypothesis of this result, meaning that k_t^{fe} should converge. On the other hand, Equation 24 should have no intercept. We assume here that the only reason why the Phillips curve should have a significant intercept is from a misestimated output gap. Hence, in each interaction of the estimation process, there are two phases: the first consists of a optimization process in which we estimate the latent variables in order to minimize the quadratic sum of the difference between both sides of Equation 23, as described in System 25. The sample used in the optimization process is from 1995:1 to 2001:4, because in this period k_t^{fe} seemed to be very stable.

$$\min.\ \sum_t \left\{ \Delta \ln(\bar{y}_t) - \left[\Delta \ln\left(k_t^{fe}\right) + \left[\ln\left(k_{t-1}^{fe}\right) - \ln\left(E_{t-1}\right)\right] \cdot \Delta(\alpha_t) \right] \right\}^2$$
$$\textit{Subject to:} \tag{25}$$
$$0 \le \beta_i,\ uci_{fe}\ \textit{and}\ \bar{u} \le 1$$

The second phase of each interaction consists of estimating Equation 24 with an intercept. Assuming that the only misestimated variable is the output gap generated in the first phase, and assuming that this error should be related to the uci_{ef} , the intercept value should be equal to $\alpha_2 \cdot \varepsilon_h \cdot \bar{\alpha}$, where $\varepsilon_h \cdot \bar{\alpha}$ is the uci_{ef} error multiplied by average α_t. Therefore, we could estimate the uci_{ef} error, and a new measure of uci_{ef} . With the new uci_{ef} estimated, we could run phase one again but with the restriction that uci_{ef} should be equal to the estimated value.

The process generates another value for the natural rate of unemployment that should be consistent with the imposed uci_{ef}. With new estimates, we could do phase 2 again restarting the cycle of interactions. It is important to note that, in each second phase, the intercept got less and less significant. With the estimated parameters, we could estimate[24] Equation 24 without an intercept term, but including two outlier dummies, as shown in Table 8. In convergence, the process estimated:

$$K_0 = 904.25 \quad uci_{fe} = 84.93\% \quad \bar{u} = 5.29\% \quad \beta_4 = 0 \quad \beta_3 = 0 \quad \beta_2 = 1$$

Table 8 ***Equation 24***

Method: *TSLS*			**Sample:** *1995:1 to 2001:3*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_1	0.212	0.122	1.743	0.096
α_2	0.311	0.062	5.009	0.000
α_3	0.510	0.148	3.452	0.002
α_4	-0.453	0.149	-3.046	0.006
$\alpha_{99:04}$	0.026	0.009	2.927	0.008
$\alpha_{00:03}$	0.018	0.008	2.079	0.050
$R^2 = 0.809$			$R^2_{Ajust.} = 0.763$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): $N \cdot R^2 = 0.615$ ($p = 0.735$)
Jarque-Bera Normality Test: 2.17 ($p = 0.337$)
White Heteroskedasticity Test: $F = 0.587$ ($p = 0.833$)

[24] This equation was estimated using Two-Stage Least Squares with lagged inflation and inflation forecasts made by a univariated model, as instrumental variables for the forward component. The results are robust and we could confirm that pass-through coefficient reduced from about 51% to 6% after changing the exchange rate regime.

3.2.4. Modeling the Components of the Cobb-Douglas Production Function

Regarding the fact that there was no prior information about the future dynamics of α_t, we simply estimated an ARIMA (3;1;0) model with no intercept in order to avoid a non-justified trend, as shown in Equation 26. The estimation outcome is described in Table 9. The total factor productivity (A_t) was modeled, in logarithm, by a seasonal ARIMA (2;1;0), as shown in Equation 27 and its estimation outcome is described in Table 10. PEA was modeled in logarithms with an autoregressive component, linear trend and seasonality. In an effort to account for a level change that occurred after 1994:3, we introduced a step dummy. The specification is shown in Equation 28 and the estimation outcome is described in Table 11. And, finally, the capital inventory, obtained by the estimated parameters into its definition in Equation 5, is shown in Equation 29.

$$\Delta\alpha_t = \beta_1 \cdot \Delta\alpha_{t-1} + \beta_2 \cdot \Delta\alpha_{t-2} + \beta_3 \cdot \Delta\alpha_{t-3} \tag{26}$$

$$\Delta \ln(A_t) = \beta_0 + \beta_1 \cdot \Delta \ln(A_{t-1}) + \beta_2 \cdot \Delta \ln(A_{t-2}) + \sum_{i=1}^{3} \alpha_i \cdot Seas_i \tag{27}$$

$$\ln(PEA_t) = \beta_0 + \beta_1 \cdot \ln(PEA_{t-1}) + \beta_2 \cdot Trend_{91:01} + \sum_{i=1}^{3} \alpha_i \cdot Seas_i + \beta_3 \cdot D_{94:03} \tag{28}$$

$$K_t = 0.98 \cdot K_{t-1} + I_{t-2} \tag{29}$$

Table 9 ***Equation 26***

Method: *OLS*			**Sample:** *1995:1 to 2000:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
β_1	2.200	0.117	18.784	0.000
β_2	-1.926	0.176	-10.930	0.000
β_3	0.619	0.090	6.851	0.000
$R^2 = 0.985$			$R^2_{Ajust.} = 0.983$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.281 (p =0.758)
Jarque-Bera Normality Test: 0.529(p =0.337)
White Heteroskedasticity Test: F = 0.905 (p =0.768)

Table 10 ***Equation 27***

Method: *OLS*			**Sample:** *1995:1 to 2001:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
β_0	-0.052	0.012	-4.294	0.000
β_1	0.745	0.182	4.082	0.000
β_2	-0.380	0.148	-2.568	0.017
α_1	0.083	0.020	4.160	0.000
α_2	0.080	0.017	4.626	0.000
α_3	0.056	0.017	3.316	0.003
$R^2 = 0.673$			$R^2_{Ajust.} = 0.602$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.166 (p =0.852)
Jarque-Bera Normality Test: 0.886 (p =0.642)
White Heteroskedasticity Test: F = 0.536 (p =0.797)

Table 11 ***Equation 28***

Method: *OLS*			**Sample:** *1991:1 to 2001:4*	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
β_0	6.2527	1.805	3.464	0.001
β_1	0.6225	0.109	5.710	0.000
β_2	0.0014	0.000	2.947	0.006
α_1	-0.0058	0.003	-2.017	0.051
α_2	0.0041	0.003	1.434	0.160
α_3	0.0027	0.003	0.979	0.334
β_3	0.0090	0.004	2.470	0.018
$R^2 = 0.987$			$R^2_{Ajust.} = 0.985$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.889 (p =0.420)
Jarque-Bera Normality Test: 0.055 (p =0.973)
White Heteroskedasticity Test: F = 1.170 (p =0.345)

3.3. External Block

The exchange rate and sovereign risk premium are modeled in the next two subsections on a monthly basis in order to capture their movements more precisely. In quarterly analysis, important information may be lost. In that case, it is important to re-estimate quarterly coefficients in order to keep the same impulse response features, which are not guaranteed when we consider the same autoregressive and error correction coefficients in the monthly and quarterly specifications.

The procedure is very simple. Long run coefficients, excluding those that are autoregressive, should be the same in both frequencies, and convergence velocities must be the same as well. If in the monthly specification the autoregressive coefficient is 0.7, for instance, it should be (0.7)^3 in the quarterly specification. Another example is the error correction term. If in the monthly specification it takes 9 months to achieve half-life, for instance, it should take 3 quarters in the quarterly specification.

When it is not that easy to derive quarterly coefficients, we recommend a optimization procedure, in which the coefficients are chosen in order to minimize a fitting function[25] between the quarterly average of monthly values of the original impulse response and quarterly values of the quarterly impulse response, generated by the coefficients to be determined.

3.3.1 Exchange Rate

We modeled the exchange rate with an equation based on a UIP non-arbitrage condition. As described completely in Muinhos, Alves and Riella (2002)[26], there is a strong short run first difference relationship between the Brazilian exchange rate, C-Bond spread over treasury[27] and interest rate differential, all in nominal vales[28]. But, surprisingly, despite the fact that all coefficients are significant and have the expected sign, they are all greater than unity, in absolute values, as predicted by UIP, even when correcting for the sovereign risk premium. This may be a result of frictions and assymetric information.

Nevertheless, the UIP condition should prevail in the long run. With this in mind, we carry out an error correction model for the first difference of the real exchange rate , capturing the short and long run dynamics. The long run and the error correction first difference specifications are described in Equation 30a and 30b, respectively. Their outcome estimations are shown in Table 12a and 12b, respectively.

We observed that, in the long run level specification; permanent shocks to the risk premium produce an over-shooting behavior, since there is a strong contemporaneous response that then decreases after one period. It is interesting to note that the permanent coefficient is very close to the 1, as predicted by UIP. As reported in the empirical literature, the real interest rate differential is not significant, but has the correct sign. As

[25] Absolute errors sum, squared errors sum, fourth power errors sum, and so on, depending on the influence of smaller errors is intending to affect the fitting function.

[26] In this paper, we comment about the UIP puzzle, the literature about exchange rate, and some results cited here.

[27] The authors found out that C-Bond spread over treasury should embody the information of the Brazilian sovereign risk and should be free of exchange rate risk, as justified in the cited paper.

[28] A first difference logarithm equation is the left-hand side variable, because the authors could not reject the null hypothesis that exchange rate has a unit root in the used sample. The exchange rate expectation was modeled as a lagged exchange rate plus the expected inflation differential, in order to maintain the real exchange rate constant. The risk premium was modeled as a linear function of the C-Bond spread over treasury. And, instead of imposing a unitary interest rate differential coefficient, with negative signal, they dropped this arbitrage condition and estimated the coefficients.

a solution, we imposed a UIP predicted coefficient equal to -1. Regarding the expectation term, we considered an adaptative weighted average with a backward-looking component, a forward-looking component and a long run equilibrium real exchange rate. The latter is calibrated as the real exchange rate necessary to achieve an ad hoc current account surplus in the long run in each simulation.

The short run specification, in first difference, is purely backward looking, but no theory coefficient was imposed. It is interesting to note that real exchange rate changes are affected by the change of one-lagged real interest rate differential instead of the contemporaneous differential. All coefficients were significant and with the correct sign, but as in Muinhos, Alves and Riella (2002), much greater than the1[29] as predicted by UIP. And the error correction term is slightly greater than one, indicating an over-shooting returning to the equilibrium, with a vanishing oscillatory behavior, which confirms empirical evidence in Brazil. Note that those coefficients represent monthly behavior, which is more volatile than the quarterly behavior. When quarterly coefficients are calculated by the procedure described previously, this volatility is smoothed. We also added two dummy variables in order to capture outliers.

$$\varepsilon_t = (1-\alpha_1-\alpha_2)\cdot\varepsilon_{eq} + \alpha_1\cdot\varepsilon_{t-1} + \alpha_2\cdot E_t\varepsilon_{t+1} - \left(r_t - r_t^f\right) + \alpha_3\cdot SCBond_t + \alpha_4\cdot SCBond_{t-1} + \mu_t \tag{30a}$$

$$\Delta\varepsilon_t = A_1\cdot\Delta\varepsilon_{t-1} + A_2\cdot\Delta\left(r_{t-1} - r_{t-1}^f\right) + A_3\cdot\Delta SCBond_t + A_4\cdot\mu_{t-1} \tag{30b}$$

Where all variables are specified in logarithms:

ε_t *real exchange rate;*

ε_{eq} *equilibrium real exchange rate;*

r_t *short run real interest rate:* $r_t = \frac{Selic_t}{12} - \sum_{i=0}^{11}\frac{\pi_{t-1}^{IPCA}}{12}$;

r_t^f *foreign short run real interest rate:* $r_t^f = \frac{FedFunds_t}{12} - \sum_{i=0}^{11}\frac{\pi_{t-i}^{PPI}}{12}$;

$SCBond_t$ *C-Bond spread over treasury;*

μ_t *error term, supposed to be random.*

[29] In absolute values.

Table 12a Equation 30a

Method: *TSLS*		**Sample:** *Mar1999 to Sep2002*		
Instruments: $\varepsilon_{t-i}(i = -1 \text{ to } -12)$ $r_{t-1} - r^f_{t-1}$ $SCBond_{t-i}(i = -1 \text{ to } -12)$				
Coefficient	**Estim. Value**	**St. Deviation**	**T**	**P-Value**
α_1	0.692	0.072	9.578	0.000
α_2	0.278	0.073	3.811	0.000
α_3	20.559	7.097	2.897	0.006
α_4	-19.620	7.085	-2.769	0.009
$R^2 = 0.978$			$R^2_{Ajust.} = 0.976$	

*Breusch-Godfrey Serial Correlation LM Test (2 lags): Obs*R-squared = 4.414 (p =0.110)*
Jarque-Bera Normality Test: 0.076 (p =0.963)
*White Heteroskedasticity Test: Obs*R-squared = 19.787 (p =0.071)*

Table 12b Equation 30b

Method: *TSLS*		**Sample:** *Apr1999 to Oct2002*		
Instruments: $\Delta\varepsilon_{t-1}$ $\Delta(r_{t-1} - r^f_{t-1})$ $SCBond_{t-i}(i = -1 \text{ to } -12)$ μ_{t-1} $CurAcc/GDP_{t-i}(i = -1 \text{ to } -12)$				
Coefficient	**Estim. Value**	**St. Deviation**	**T**	**P-Value**
A_1	0.826	0.134	6.171	0.000
A_2	-3.900	2.015	-1.936	0.061
A_3	16.384	7.016	2.335	0.025
A_4	-1.317	0.281	-4.683	0.000
$D_{01:11}$	-0.058	0.020	-2.892	0.006
$D_{02:07}$	-0.058	0.021	-2.812	0.008
$R^2 = 0.859$			$R^2_{Ajust.} = 0.840$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.500 (p =0.237)
Jarque-Bera Normality Test: 3.242 (p =0.198)
White Heteroskedasticity Test: F = 1.481 (p =0.185)

3.3.2 Risk Premium

We modeled C-Bond spread over treasury, used in Equations 30 and 31, in order to capture sovereign risk perceptions generated by fiscal variables, external trade and solvency/liquidity variables.[30] The downward trend in the C-bond yield curve as it gets closer to its maturity was not considered in the simulations. Using a parsimonious criterion, we focused on relevant variables and avoided over fitting estimations. In the best-fit estimation, foreign reserves (%GDP), public debt (%GDP) and current account balance (%GDP) coefficients were significant and representative of fiscal variables, external trade and solvency/liquidity indicators [31]. The specification is described in Equation 31 and its output estimation, by TSLS, is shown in Table 13.

[30] For a detailed description of the treatment on the risk premium see Muinhos, Alves and Riella (2002),

[31] Defying intuition, exchange rate volatility did not have significant explanatory power for the risk premium.

$$SCBond_t = \alpha_0 + \alpha_1 \cdot SCBond_{t-1} + \alpha_2 \cdot \Delta \mathrm{Re}s / GDP_t + \\ + \alpha_3 \cdot \Delta PD / GDP_t + \alpha_4 \cdot CurAc / GDP_t \tag{31}$$

Where:

Res/GDP_t foreign reserves ($\%GDP^{12\ month}$);

PD/GDP_t public debt ($\%GDP^{12\ month}$);

$CurAc/GDP_t$ 12 month accumulated current account balance ($\%GDP^{12\ month}$).

Table 13 ***Equation 31***

Method: *TSLS*			**Sample:** *Jan1996 to Dec/2001*	
Instruments: $SCBond_{t-1}$, Res/PIB_{t-1}, Res/PIB_{t-2}, $\Delta DLT/PIB_t$, $TCor/PIB_t$ e Δe_{t-1}				
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	-0.0004	0.0044	-0.0821	0.9348
α_1	0.8597	0.0472	18.2134	0.0000
α_2	-0.8396	0.4274	-1.9646	0.0536
α_3	0.1360	0.0788	1.7259	0.0890
α_4	-0.2536	0.1074	-2.3608	0.0212
$R^2 = 0.874$			$R^2_{Ajust.} = 0.867$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1.586 (p =0.212)
Jarque-Bera Normality Test: 19.412 (p =0.000)
White Heteroskedasticity Test: F = 0.910 (p =0.543)

3.3.3 Exports

In this section and in the next, we present our nominal net export modeling in US dollars. For simplification sake, we modeled export and import quantities. Prices are modeled as ARMA processes, as described in Muinhos, Alves and Riella (2002). Equation 32 presents the quarterly estimates for the export quantity index. The sample starts in 1988 and the coefficients and the t statistics are in Table 14. In the literature there are some papers that also estimate the price (real exchange rate) and income (world GDP) elasticities for exports. Pastore e Pinotti (1999) e Gonzaga e Bevilacqua (1997) found similar coefficients for the income elasticity. However the price elasticity of 0.14 was smaller than found for those papers. Pastore e Pinnoti (1999) for example estimated at 0.24 for the price elasticity and 0.81 for the world income elasticity.

$$\exp_t = \alpha_0 + \alpha_1 \cdot \exp_{t-1} + \alpha_2 \cdot y_t^* + \alpha_3 \cdot \theta_{t-1} + \alpha_4 \cdot lpxt_t + \sum_{j=1}^{3} \beta_j \cdot Seas_j + \\ + \alpha_5 \cdot D_{91:03} \tag{32}$$

Where:

exp_t	*quantitative index of exports for period t;*
y_t^*	*world GDP for period t, measured as the log of the world imports;*
θ_t	*real exchange rate for period t;*
$lpxt_t$	*price index of exports for period t;*
$Seas_j$	*seasonal dummies;*
$D_{91:03}$	*outlier dummy for 1991:03.*

Table 14 ***Equation 32***

Method: *OLS*			**Sample:** 1988:01 to 2001:02	
Coefficient	**Estim. Value**	**St. Deviation**	**T**	**P-Value**
α_0	-0.572	0.804	-0.711	0.481
α_1	0.559	0.081	6.865	0.000
α_2	0.445	0.085	5.249	0.000
α_3	0.139	0.054	2.561	0.014
α_4	-0.257	0.137	-1.874	0.067
β_1	-0.090	0.024	-3.729	0.001
β_2	0.151	0.026	5.822	0.000
β_3	0.098	0.022	4.554	0.000
α_5	-0.239	0.056	-4.307	0.000
$R^2 = 0.954$			$R^2_{Ajust.} = 0.946$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 1226 (p =0.303)
Jarque-Bera Normality Test: 2.17 (p =0.95)
White Heteroskedasticity Test: F = 1.156 (p =0.36)

3.3.3 Imports

Equation 33 presents the estimations of the import quantity index, with coefficients and t statistic value shown in Table 15. The quantity index for imports presents a structural break in the first half of nineties, which makes it necessary to introduce a level dummy in order to avoid a unit root process.

Our coefficient for the real exchange rate is smaller that the one usually seen in the literature. However the income-elasticity is closer to other estimations. Pastore e Pinotti (1999) found the price-elasticity of (-0,96) and their income elasticity is 1,02 (taking into account industrial production). Even considering a level dummy after 1993, it seems that the income elasticity still presents a structural break after that year. When we shrink the sample, this coefficient almost doubles.

$$imp_t = \alpha_0 + \alpha_1 \cdot imp_{t-1} + \alpha_2 \cdot y_t + \alpha_3 \cdot \theta_{t-1} + \sum_{j=1}^{3} \beta_j \cdot Seas_j + \\ + \alpha_4 \cdot D_{imp} + \sum_{aa:tt} \beta_{aa:tt} \cdot D_{aa:tt} \tag{33}$$

Where:

imp_t *quantitative index for imports in period t;*

y_t *domestic GDP in period t;*

θ_t *real exchange rate in period t;*

$Seas_j$ *seasonal dummies for the period j;*

Dimp *step dummy that is 0 until 1993:4 and 1 after 1994:3 being 0.5 in between ;*

Daa:tt *outlier dummies for 95:03, 97:01 and 99:01.*

Table 15 ***Equation 33***

Method: *OLS*			**Sample:** *1988:01 to 2001:02*	
Coefficient	**Estim. Value**	**St. Deviation**	**T**	**P-Value**
α_0	-3.077	1.610	-1.911	0.063
α_1	0.568	0.081	7.039	0.000
α_2	1.170	0.413	2.831	0.007
α_3	-0.191	0.082	-2.337	0.024
β_1	-0.102	0.038	-2.675	0.011
β_2	-0.016	0.036	-0.442	0.661
β_3	0.024	0.040	0.595	0.555
D_{imp}	0.332	0.099	3.367	0.002
$D_{95:03}$	-0.189	0.094	-2.004	0.051
$D_{97:01}$	-0.305	0.090	-3.382	0.002
$D_{99:01}$	-0.206	0.089	-2.302	0.026
$R^2 = 0.985$			$R^2_{Ajust.} = 0.982$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 2.516 (p =0.09)
Jarque-Bera Normality Test: 0.67 (p =0.71)
White Heteroskedasticity Test: F = 1.37 (p =0.21)

3.3.4 Foreign Direct Investment

Equation 34 presents the estimated equation for Foreign Direct Investment, with outcomes shown in Table 16. The presence of profit and the first difference of the risk premium in the FDI equation are important, not only in terms of significance but also with expected sign. An increase in the risk premium is a leading indicator of a decrease in FDI, while an increase in profit remittances is an indicator of an increase in FDI.

$$FDI_t = \alpha_0 + \alpha_1 \cdot FDI_{t-1} + \alpha_2 \cdot \Delta(SCBond_{t-1}) + \alpha_3 \cdot y_{t-1} + \alpha_4 \cdot lucro_{t-1} \tag{34}$$

Where:

FDI_t Foreign Direct Investment in period t , in 2000 US$;

$\Delta(SCBond_t)$ first difference in the spread of C-Bond in period t;

y_t GDP in period t;

$lucro_t$ net profit in the Balance of Payment in period t, is 2000 US$.

Table 16 ***Equation 34***

Method: *OLS*		**Sample**: *1994:03 to 2001:01*		
Coefficient	**Estim. Value**	**St. Deviation**	**T**	**P-Value**
α_0	-18.840	8.663	-2.175	0.041
α_1	0.616	0.095	6.478	0.000
α_2	-14.936	4.015	-3.720	0.001
α_3	3.942	1.906	2.068	0.051
α_4	0.454	0.109	4.164	0.000
$R^2 = 0.904$			$R^2_{Ajust.} = 0.887$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 0.296 (p =0.747)
Jarque-Bera Normality Test: 0.342 (p =0.843)
White Heteroskedasticity Test: F = 0.9180 (p =0.565)

3.3.5 Monetary and Fiscal Block

For simulation purposes, the interest rate follows a standard Taylor rule described in Equation 35, where γ_1 is the weight on the persistence of the interest rate, γ_2 is the weight on inflation and γ_3 is the weight on the output gap. The variable i_t^{Eq} is the long run equilibrium of the interest rate, and it was set to be around 6%. In the baseline scenario, the values were chosen in an ad-hoc manner and γ_1 is 0.8, γ_2 is 1.3 and γ_3 is 0.8.

$$i_t = \gamma_1 \cdot i_{t-1} + (1-\gamma_1) \cdot \left\{ \gamma_2 \cdot \left[\sum_{i=1}^{4} \left(\pi_{t-i} - \pi_{t-i}^{T\arg et} \right) \right] + \gamma_3 \cdot h_{t-1} + i_t^{Eq} \cdot \right\} \tag{35}$$

Although the traditional method of forecasting 6-month rates is by extracting information from the term structure, empirical results suggest that, due to the low liquidity in the market for futures contracts, yield curve information is not a good forecaster for future 6-month rates. Hence, we modeled the 6-month interest rate as a function of the contemporaneous Selic rate and contemporaneous and lagged risk premium values, as described in Equation 36. Outlier dummies were also used. The estimation outcome is shown in Table 17. Fiscal debt can be broken into three components: external fiscal debt, internal debt indexed to the change in exchange rate plus a risk premium, and internal debt denominated in the Selic rate. Thus, we modeled these fiscal debt components, subtracting the fiscal surplus, as in Equation 37.

$$Swap6_t = \alpha_0 + \alpha_1 \cdot Swap6_{t-1} + \alpha_2 \cdot Selic_t + \alpha_3 \cdot Selic_{t-1} + \alpha_4 \cdot \Delta SCBond_t \tag{36}$$

$$
\begin{aligned}
D_t^{Ext} &= D_{t-1}^{Ext} \cdot \left(1 + i_t^f\right) \cdot \left(1 + Risk_t\right) \\
D_t^{Int} &= D_{t-1}^{Int\,(No\ \text{exchange rate variation})} \cdot \left(1 + Selic_t\right) + \\
&\quad + D_{t-1}^{Int\,(With\ \text{exchange rate variation})} \cdot \left(1 + Risk_t\right) \cdot \left(1 + \Delta E_t^{\%}\right) \\
D_t &= D_t^{Ext} + D_t^{Int} - FS_t
\end{aligned}
\tag{37}
$$

Table 17 ***Equation 36***

Method: *OLS*			**Sample:** 1988:01 to 2001:02	
Coefficient	**Estim. Value**	**St. Deviation**	**t**	**P-Value**
α_0	0.029	0.008	3.599	0.001
α_1	0.731	0.122	5.999	0.000
α_2	0.416	0.151	2.764	0.008
α_3	-0.293	0.078	-3.763	0.000
α_4	2.054	0.487	4.215	0.000
$D_{98:08}$	-0.038	0.019	-2.030	0.047
$D_{99:01}$	0.043	0.013	3.230	0.002
$D_{99:02}$	0.072	0.014	5.270	0.000
$R^2 = 0.955$			$R^2_{Ajust.} = 0.950$	

Breusch-Godfrey Serial Correlation LM Test (2 lags): F = 104.846 (p =0.000)
Jarque-Bera Normality Test: 1.191 (p =0.551)
White Heteroskedasticity Test: F = 0.562 (p =0.849)

4 Simulations

The model is simulated in a Matlab/Simulink environment until 2100:4, but we will only show the first 30 years of results for simplicity. Our closure rule is an ad-hoc end-point for the current account/GDP ratio, which brings us to a long-run equilibrium value for the real exchange rate. The current account surplus was set at 0% for the last period of the simulation. The primary fiscal surplus follows an exogenous vanishing path to the long run. We also assumed that world and domestic growth converge in the long run.

In the first simulation, whose graphics are in the Appendix (see Simulation 1), we set different weights for the Taylor rule. The baseline simulation presents $\gamma 1$, $\gamma 2$ and $\gamma 3$ as 0.85, 1.30 and 0.30, respectively. A more aggressive rule against inflation sets $\gamma 1$, $\gamma 2$ and $\gamma 3$ equal to 0.85, 1.50 and 0.10, respectively, meaning more weight in the inflation gap from the target and less weight in the output gap. An opposite rule with higher weight on the output gap is $\gamma 1$, $\gamma 2$ and $\gamma 3$ as 0.85, 1.10 and 0.50, respectively. The results show a good convergence of the model. Inflation goes toward the target, GDP grows close to the potential, and fiscal debt is decreasing in the medium run. The

comparisons between the three Taylor rules show that the more aggressive monetary policy leads to lower GDP growth and a lower fiscal surplus.

The second simulation (see Simulation 2) is presented in terms of impulse responses. Three types of impulse shocks are simulated: a temporary positive shock to the nominal Selic interest rate, a temporary positive shock to the C-Bond spread and a temporary positive shock to administered prices.

An increase in the Selic interest rate has the greatest impact on inflation with a lag of 7 quarters. Risk premium shocks affect inflation through different channels. The first is the exchange rate channel, which causes an increase in inflation via the pass through channel. The second channel is the medium run interest rate; in this channel, an increase in the risk premium causes an increase in the medium term interest rate and a corresponding slight decrease in inflation (Swap06) via a decrease in the output gap and the GDP growth rate. But the average impact of an increase in the risk premium on inflation is positive until it vanishes in the long run.

Administered price shocks cause an increase in inflation, as expected. Administered price shocks instantly decrease the real interest rate, increasing the GDP growth rate and inflation. But this is followed by an increase in the nominal interest rate, in order to bring inflation back to the target, which increases the real interest rate, decreasing the GDP growth rate. This oscillatory path of the GDP growth rate continues, depending on the weight of the output gap in the Taylor rule, but in a vanishing path.

Those temporary shocks have temporary effects on the real exchange rate, but permanent effects on the nominal exchange rate. Positive risk premium and administered price shocks depreciate the nominal exchange rate while positive nominal interest rate shocks cause nominal appreciation.

Positive nominal interest rate shocks increase the sovereign risk premium by worsening the public debt. Indeed, the effects of positive nominal interest rate shocks on public debt, although not permanent, take so long to vanish that they appear permanent. Positive administered price shocks decrease the public debt, as expected, via the inflationary tax effect.

5. Conclusion and Next Steps

The objective of this paper was to present the main features of the Keynesian macroeconomic model in development at the Central Bank of Brazil. As this paper is still a work in progress, we have many more steps to accomplish and close conclusions. The model with disaggregated demand and potential output with a production function demonstrates good convergence. We still can detect problems with the import and consumption equations. The simulations simultaneously brought about consistent paths for output, employment, inflation, the current account, the rate of investment and the fiscal balance. However the long-run equilibrium of some variables are dependent on the end-points for the interest rate and exchange rate. Another problem that we have with this kind of model is that it is not robust to the Lucas critique. Some of the parameters may vary through the sample period due to policy changes. Aware of this limitation we still consider Keynesian models useful tools for identifying the transmission mechanism of the monetary policy. The simulations have to be considered with caution especially for Brazilian economy, because there are many cases of structural breaks and policy swings.

As future goals we can point out:

- Consumption disaggregated in durable and non-durable goods;
- A forward looking rational expectations term for inflation in the Phillips curve and for the exchange rate in the UIP equation;
- More equations for the wage sector, using the Phillips curve that includes the unit labor cost;
- A more structured fiscal block;
- A production function with more than one kind of capital.

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Appendix 1 Obtaining α Quarterly Values For The Production Function

In order to obtain quarterly values for α, three alternatives were available. The first is to maintain the annual values in each quarter. However, as the resulting quarterly series present a step shaped pattern, with abrupt level changes on the first quarter of every year, this alternative was discarded because we expect a smoother behavior. A natural choice, as a second alternative, is to consider a filtered series, obtained by a HP filter, for instance, instead of the original one. Again, however, this resulted in a undesired behavior: although the average quarterly values of each year should be equal to the original annual values, this was not the case when using the regular filtering process. Hence, we considered a third alternative that assured the following two features: the smoothness and the restriction on the average of the annual quarterly values. This alternative was based on the quarterly data generating process, based on an annual frequency data, presented in Alves (2001) and is described in System 38.

$$\begin{cases} \alpha^{A} \equiv \text{Annual capital share yield series, with n observations} \\ \alpha_{t}^{A} \equiv \text{Particular value for } \alpha^{A} \text{ in year t}: \quad t \in [1, n] \end{cases}$$

One wishes to estimate the quarterly capital share yield series α^{Q} such as:

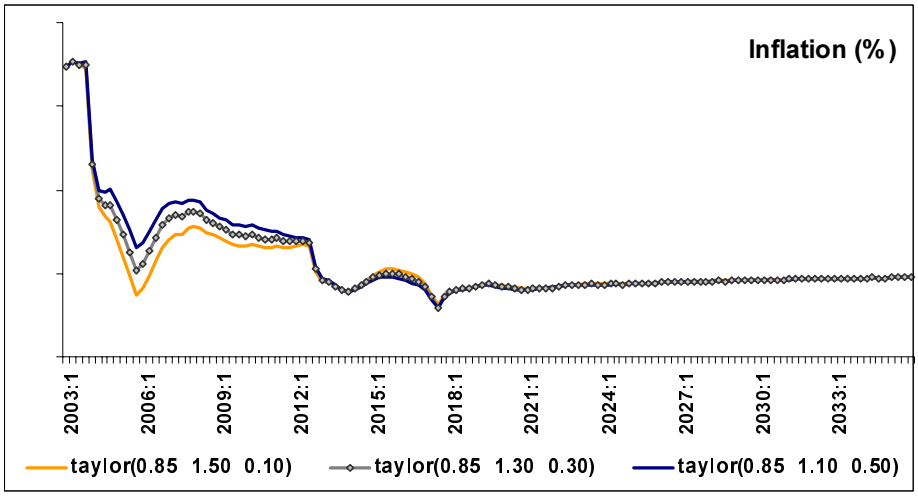
$$\begin{cases} \alpha^{Q} \equiv \text{Quarterly capital share yield series, with 4n observations} \\ \alpha_{t,Q}^{Q} \equiv \text{Particular value for } \alpha^{Q} \text{ in quarter Q of year t}: \quad t \in [1, n], \quad Q \in [1, 4] \end{cases} \tag{38}$$

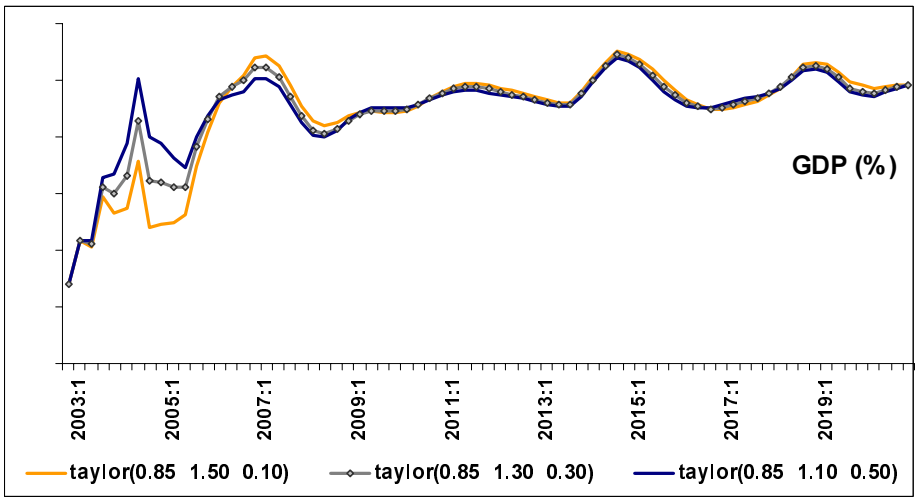
$\alpha_{t,Q}^{Q}$ series should ensure that:

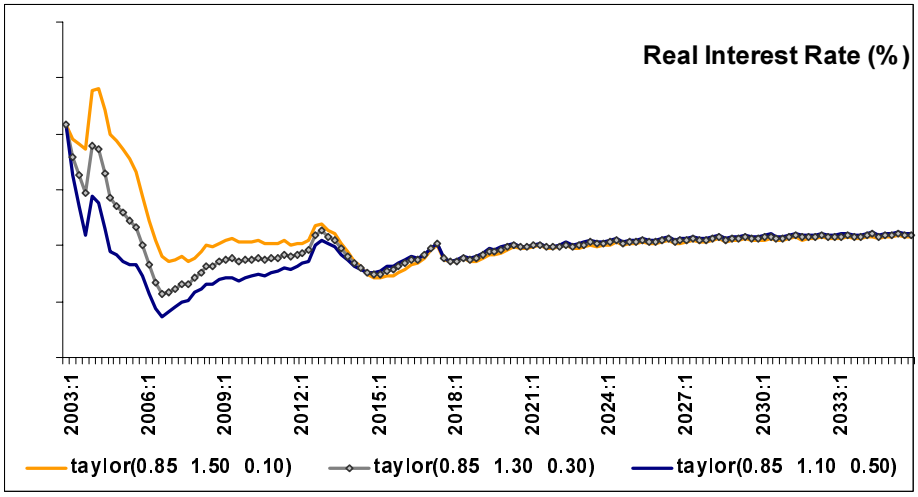
$$\begin{cases} \text{Minimize} \qquad L = \sum_{t=1}^{n} \sum_{Q=1}^{4} \left(\Delta^{2} \alpha_{t,Q}^{Q} \right)^{2} \\ \text{Subject to} \qquad \sum_{Q=1}^{4} \alpha_{t,Q}^{Q} = 4 \cdot \alpha_{t}^{Q} \ , \quad \forall \ t \in [1, n] \end{cases}$$

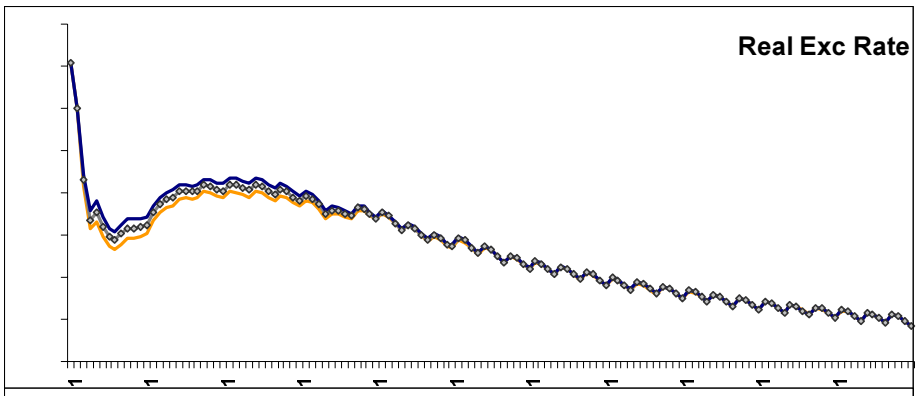
Appendix 2 Simulation Graphics

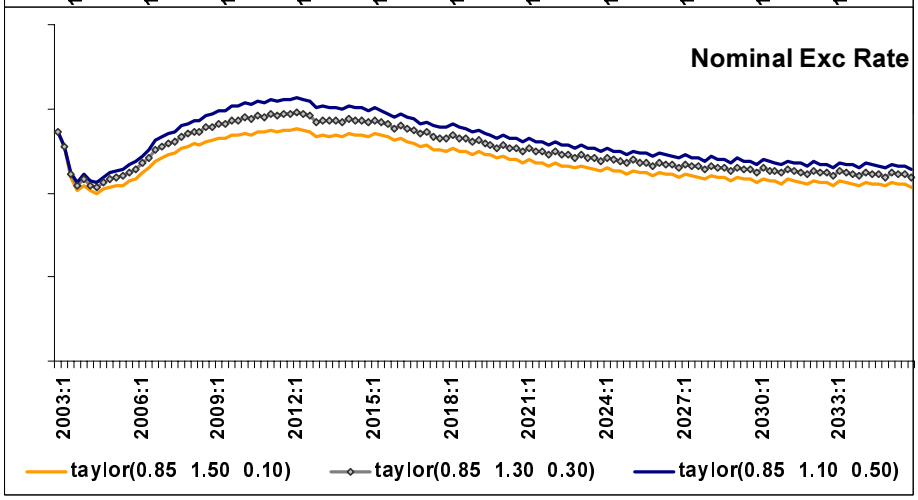
Simulation 1

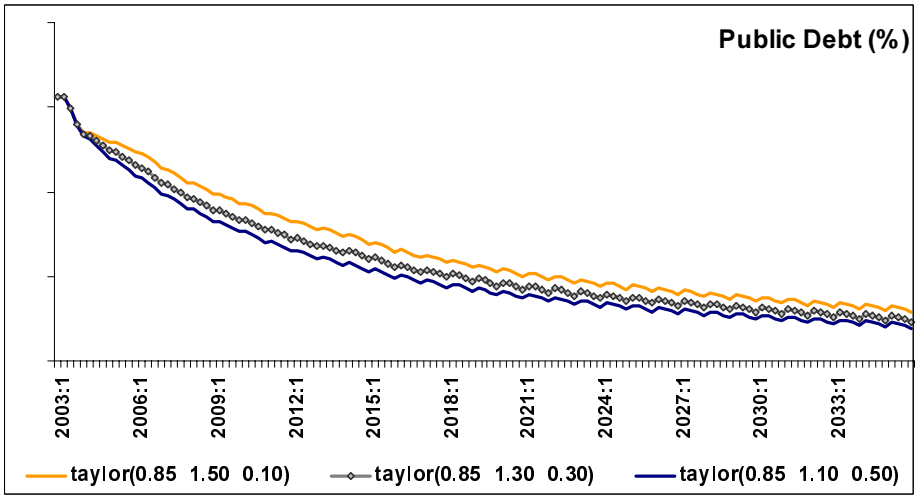






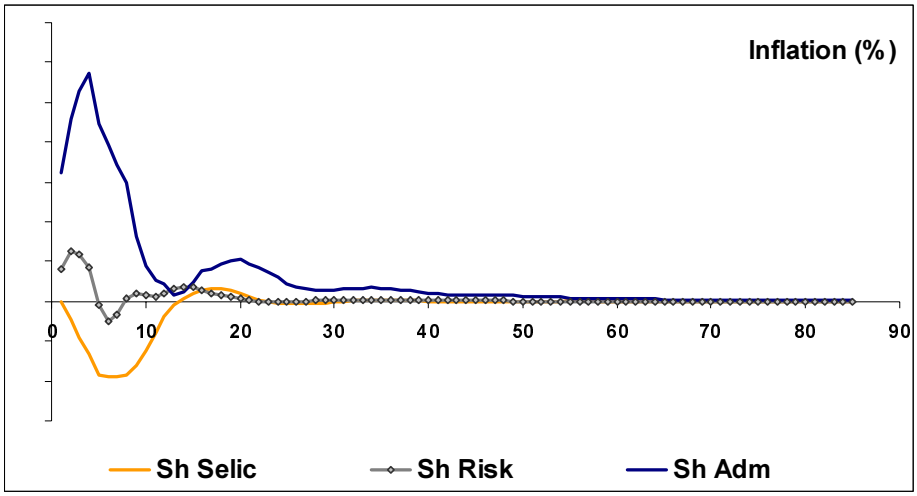

Real Exc Rate

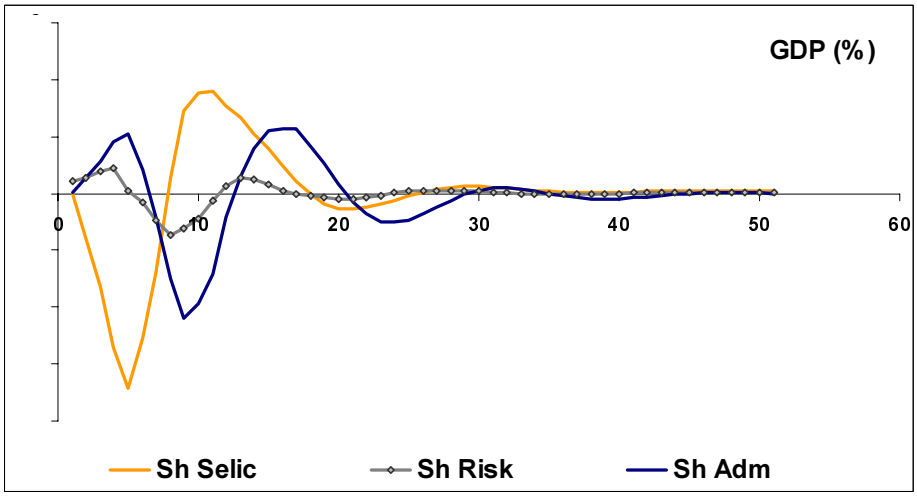

Nominal Exc Rate
2003:1
2006:1
2009:1
2012:1
2015:1
2018:1
2021:1
2024:1
2027:1
2030:1
2033:1
taylor(0.85 1.50 0.10)
taylor(0.85 1.30 0.30)
taylor(0.85 1.10 0.50)

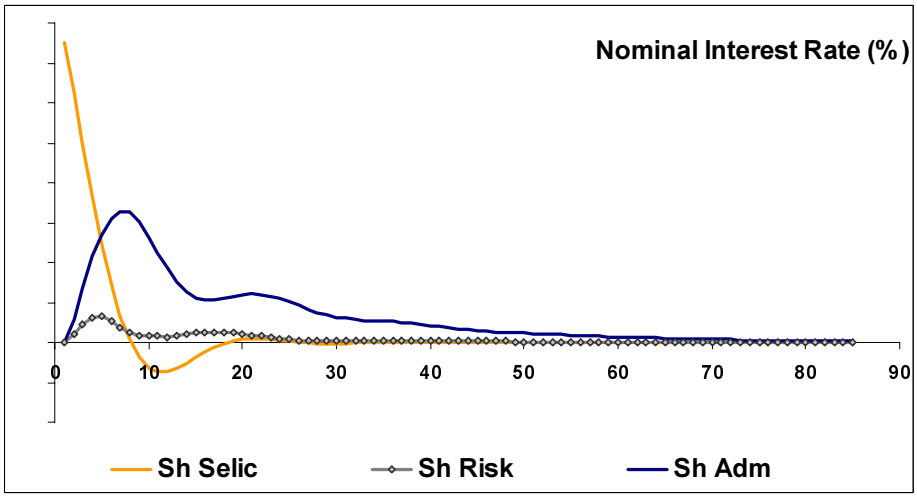

Public Debt (%)
2003:1
2006:1
2009:1
2012:1
2015:1
2018:1
2021:1
2024:1
2027:1
2030:1
2033:1
taylor(0.85 1.50 0.10)
taylor(0.85 1.30 0.30)
taylor(0.85 1.10 0.50)

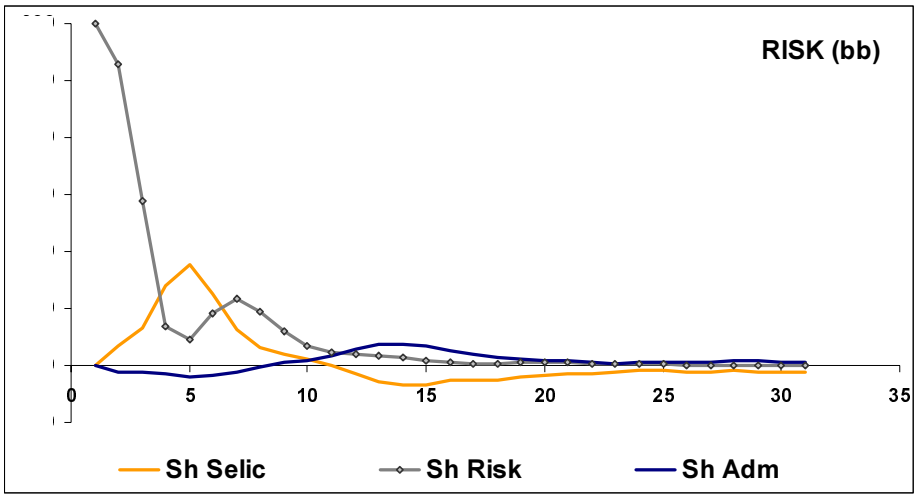
Simulation 2

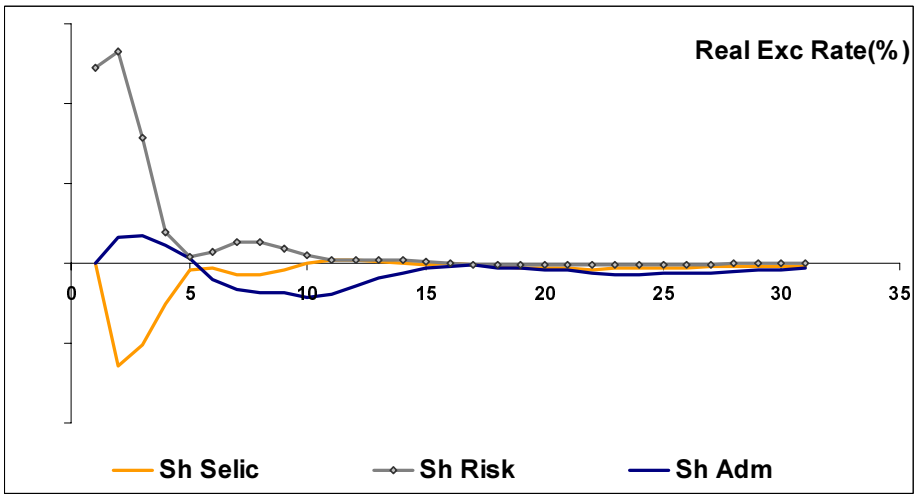
(Quarters in horizontal axis)

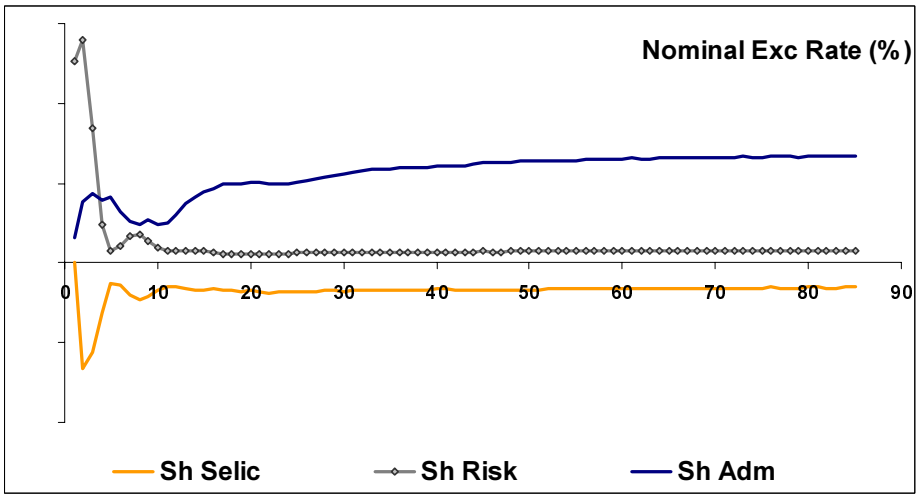


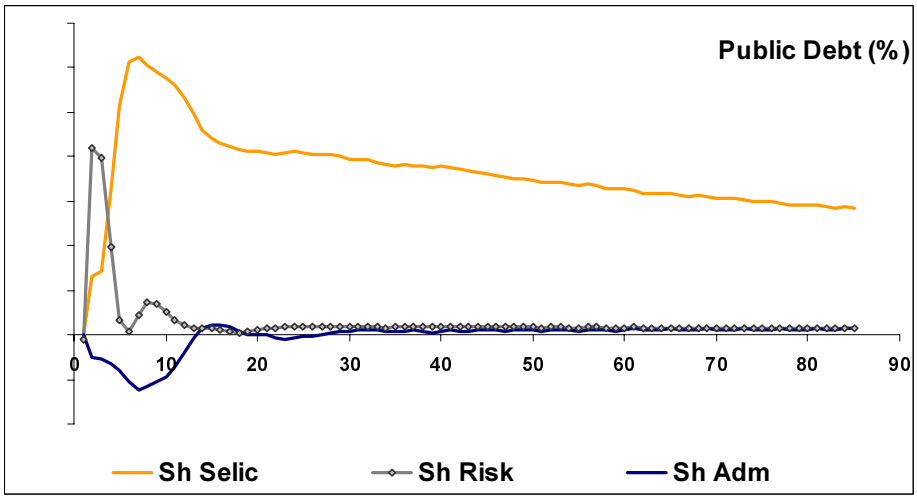


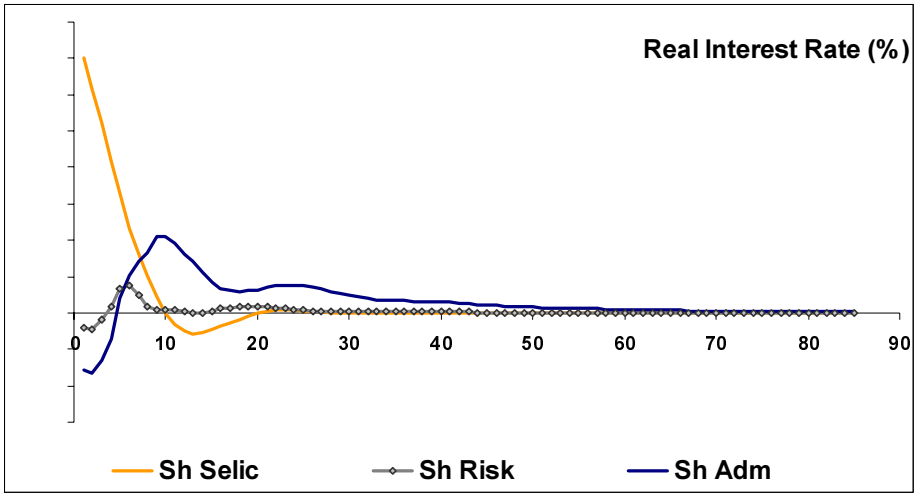



RISK (bb)
0
5
10
15
20
25
30
35
Sh Selic
Sh Risk
Sh Adm


Real Exc Rate(%)
0
5
10
15
20
25
30
35
Sh Selic
Sh Risk
Sh Adm


Nominal Exc Rate (%)
0
10
20
30
40
50
60
70
80
90
Sh Selic
Sh Risk
Sh Adm


Public Debt (%)
0
10
20
30
40
50
60
70
80
90
Sh Selic
Sh Risk
Sh Adm


Real Interest Rate (%)
0
10
20
30
40
50
60
70
80
90
Sh Selic
Sh Risk
Sh Adm

Banco Central do Brasil

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