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Identification of Monetary Policy Shocks in the Brazilian Market for Bank Reserves*

Adriana Soares Sales**
Maria Tannuri-Pianto***

Abstract

We estimate an identified VAR (SVAR) with contemporaneous restrictions derived from a model of the market for bank reserves, which allows us to disentangle monetary policy shocks from demand shocks for reserves in Brazil. The main results are: i) the Central Bank of Brazil acts in order to smooth the bank reserve market interest rate (Selic); ii) the spread between the Selic rate and the discount rate provides information to estimate the demand curve for borrowed reserves; iii) overidentifying restrictions show that we cannot reject, for any period or model, the interest rate operational target hypothesis, even during the fixed exchange rate regime; iv) the impulse response functions show that shocks to the demand for reserves and to borrowed reserves generate statistically significant responses in real output and the inflation rate; v) all models display the liquidity effect and a small inflation rate puzzle.
Keywords: Monetary Policy Shocks, Bank Reserves, SVAR, Brazil.
JEL Classification: C51; E52 and E58.

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1. Introduction

Considering innovations in short term interest rates instead of those in the money stock as a monetary shock measure is currently a well disseminated practice.[4] The demand for money is likely affected by prices and income, as well as interest rate shocks. Innovations in the stock of money (Leeper e Roush, 2003, and Leeper *et al.,* 1996) are a combination of policy shocks and other shocks.

The objective of this paper is to obtain empirical evidence of how monetary policy shocks are identified and transmitted to other variables in the Brazilian economy. We do so by using information from the operational procedures of the Central Bank of Brazil for the bank reserve market. The adopted methodology is based on Structural (Identified) Vector Auto-Regressive (SVAR) models.

A common econometric approach to the transmission mechanism of monetary policy is to decompose the variance-covariance matrix of the Vector Autoregressive (VAR) via Choleski decomposition. This approach generates a series which represents the monetary policy shock. Using this methodology, Bernanke and Blinder (BB) (1992) argue that the Fed Funds[5] rate is a good parameter to measure monetary policy in the US. On the other hand, Christiano, Eichenbaum and Evans (CEE) (1996) use non-borrowed reserves, originated in open market transactions, to identify monetary policy. For Brazil, Minella (2001) treats the interest rate as the only measure of monetary policy shocks, *a priori*.

Leeper and Roush (2003) show that models that omit money (generally M1) or do not identify it properly can confuse monetary policy shocks and demand for money shocks. Therefore, the VAR innovations may be reactions to shocks in demand for bank reserves and the results would be more accurate if one separates *ex-ante* shocks in supply from shocks in demand for bank reserves. This article we "put money back" into the VAR by using aggregates over which the Central Bank has more direct control – borrowed reserves, with origins in discount operations, and non-borrowed reserves[6]. Therefore, this article can identify monetary policy innovations when Central Bank actions and the stock of money are endogenous. We follow Bernanke and Mihov (BM) (1995, 1998) and use a

[4] See Soderlind (2003) and Walsh (1998).
[5] Interest rate of the market for bank reserves in the US.
[6] We build and use both series in this article.

specification for the bank reserve market that can include a range of alternative operational procedures in order to identify monetary policy measures among a set of indicators.

Because we identify additional sources of monetary policy variations, we are able to disentangle changes in reserves and in interest rates that result from exogenous policy actions from changes that reflect shifts in money demand. Besides testing if the BM (1995,1998) identification strategy gives a sense of how policy shocks affect the Brazilian real output and inflation rate, we pose the following questions: i) during the period considered, what was the operational target adopted by the Central Bank?; ii) what is the relationship between bank reserves and short term interest rates in Brazil?; iii) what is the reaction function of the Central Bank in the bank reserves market?; iv) what is the demand for discount window funding in Brazil?; v) does there exist a "liquidity puzzle"[7] in the models considered or is the liquidity effect present?

Our empirical model specification assumes the traditional mechanism for monetary policy transmission. There is a vast literature, besides that already mentioned, that adopts a similar methodology for other countries: Leeper, Sims and Zha (1996) for the United States; Kasa and Popper (1997) for Japan; De Arcangelis and Di Giorgio (1999) for Italy; Fung and Yuan (2000) for Canada; Bernanke and Mihov (BM) (1997) and Clarida and Gertler (1996)[8] for Germany.

The main findings are as follows. First, with the exception of the 1994-1998 period, in which the Central Bank pursued the non-borrowed reserves target and discount rate target, the interest rate operational target was the most relevant for the period studied, but the stock of reserves also contains information about monetary policy. Second, the demand for reserves is considerably inelastic to interest rates, given the level of reserve requirements in Brazil, and the demand for borrowed reserves depends on the spread between the Selic[9] rate and the discount rate. Third, the demand for total reserves and for borrowed reserves cannot be ignored in these models because shocks to demand for bank reserves cause important variations in the inflation rate and real output. Fourth, the

[7] The liquidity puzzle occurs when monetary policy shocks do not generate negative short-term correlations between nominal interest rates and stock of money. See, for example, Leeper and Gordon (1992), Thornton (2001) and Jalil (2004).

[8] Clarida and Gertler (1996) use a vector error-correction (VEC) specification.

[9] Selic rate is the rate used as inter-bank payment for reserves. These operations use federal public bonds (TFP) as "collateral".

impulse-response functions show impacts of a shock in monetary policy, independent of the order of the variables in the models. With the Choleski decomposition, the impulse-response functions are often not robust to the order in which the monetary aggregates and the Selic rate enter the model. [10]

This article is organized as follows. Section 2 presents the methodology and model specification. Section 3 describes the data and some preliminary tests. Section 4 shows the results, and section 5 concludes.

2. Methodology

We apply the methodology developed by Bernanke and Mihov (BM) (1995, 1998), using a vector of policy variables in a structural VAR (SVAR), instead of only a scalar defined *a priori*.

Our assumption is that the economy can be represented by the following structural macroeconomic model that is an unrestricted dynamic linear model:

$$\mathbf{Y_t} = \sum_{i=0}^{k} \mathbf{B_i Y_{t-i}} + \sum_{i=0}^{k} \mathbf{C_i P_{t-i}} + \mathbf{A^Y v_t^Y} \qquad (1)$$

$$\mathbf{P_t} = \sum_{i=0}^{k} \mathbf{D_i Y_{t-i}} + \sum_{i=0}^{k} \mathbf{G_i P_{t-i}} + \mathbf{A^P v_t^P} \qquad (2)$$

where $\mathbf{Y_t}$ is a vector of non-policy variables and $\mathbf{P_t}$ is the vector of monetary policy variables. The block of policy variables should include all the variables potentially useful as an indicator of monetary policy measures (*e.g.*, M1, interest rate, etc.). The Central Bank does not need to have full control of the policy variables, but should have a significant influence over these variables within the current period. The **v**-vectors, $\mathbf{v_t^P}$ and $\mathbf{v_t^y}$, are mutually non-correlated (orthogonal) structural shocks, and one of them is a policy shock (vector) $\mathbf{v_t^P}$.

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[10] The impulse-response is robust only if the VAR correlation matrix of residuals shows low correlation between the residuals of those variables.

The system represented by (1) and (2) is not identified.[11] The structural model is identified by imposing restrictions on the variance-covariance matrix of structural shocks and on the contemporaneous relations between the non-policy and policy blocks, and within the policy block, respectively: i) assuming the structural shocks are orthogonal; ii) imposing that the macroeconomic variables do not react contemporaneously to monetary variables, while allowing a simultaneous feedback in the opposite direction, iii) imposing restrictions on the monetary policy block of the model.

Implementing (ii), we assume that $C_0 = 0$, that is the monetary market adjusts more rapidly, and the goods market more slowly.

Using matrix notation, (1) and (2) can be written as:

$$\begin{bmatrix} (\mathbf{I}-\mathbf{B_0}) & \mathbf{0} \\ -\mathbf{D_0} & (\mathbf{I}-\mathbf{G_0}) \end{bmatrix} \cdot \begin{bmatrix} \mathbf{Y_t} \\ \mathbf{P_t} \end{bmatrix} = \sum_{i=1}^{K} \begin{bmatrix} \mathbf{B_i} & \mathbf{C_i} \\ \mathbf{D_i} & \mathbf{G_i} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{Y_{t-i}} \\ \mathbf{P_{t-i}} \end{bmatrix} + \begin{bmatrix} \mathbf{A^y} & \mathbf{0} \\ \mathbf{0} & \mathbf{A^p} \end{bmatrix} \begin{bmatrix} \mathbf{v_t^y} \\ \mathbf{v_t^p} \end{bmatrix} \tag{3}$$

Inverting the left side (l.s.) matrix of the system, we have:

$$\begin{bmatrix} (\mathbf{I}-\mathbf{B_0}) & \mathbf{0} \\ -\mathbf{D_0} & (\mathbf{I}-\mathbf{G_0}) \end{bmatrix}^{-1} = \begin{bmatrix} (\mathbf{I}-\mathbf{B_0})^{-1} & \mathbf{0} \\ (\mathbf{I}-\mathbf{G_0})^{-1}\mathbf{D_0}(\mathbf{I}-\mathbf{B_0})^{-1} & (\mathbf{I}-\mathbf{G_0})^{-1} \end{bmatrix}$$

Rewriting (3) as a VAR:

$$\begin{bmatrix} \mathrm{Y_t} \\ \mathrm{P_t} \end{bmatrix} = \sum_{i=1}^{K} \begin{bmatrix} (\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{B_i} & (\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{C_i} \\ (\mathbf{I}-\mathbf{G_0})^{-1}[\mathbf{D_i}+\mathbf{D_0}(\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{B_i}] & (\mathbf{I}-\mathbf{G_0})^{-1}[\mathbf{G_i}+\mathbf{D_0}(\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{C_i})] \end{bmatrix} \begin{bmatrix} \mathbf{Y_{t-i}} \\ \mathbf{P_{t-i}} \end{bmatrix} +$$

$$\begin{bmatrix} (\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{A^y} & \mathbf{0} \\ (\mathbf{I}-\mathbf{G_0})^{-1}\mathbf{D_0}(\mathbf{I}-\mathbf{B_0})^{-1}\mathbf{A^y} & (\mathbf{I}-\mathbf{G_0})^{-1}\mathbf{A^p} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{v^y} \\ \mathbf{v^p} \end{bmatrix} \tag{4}$$

[11] There is a total of $(k+1)n^2$ parameters in B, C, D and G, n parameters in the constant term when it exists, and n(n+1)/2 parameters in the symmetric variance-covariance matrix of the v's. In the reduced form, there are kn^2 in the VAR coefficients and n in the constant, and n(n+1)/2 in the VAR variance-covariance matrix of residuals. This means that it is necessary to impose at least n^2 restrictions on the structural parameters for identification.

Equation (4) above can be written more compactly as

$$\begin{bmatrix}\mathbf{Y_t}\\ \mathbf{P_t}\end{bmatrix} = \sum_{i=1}^{k}\begin{bmatrix}\mathbf{H_i^y} & \mathbf{H_i^p}\\ \mathbf{J_i^y} & \mathbf{J_i^p}\end{bmatrix}\cdot\begin{bmatrix}\mathbf{Y_{t-i}}\\ \mathbf{P_{t-i}}\end{bmatrix} + \begin{bmatrix}\mathbf{I} & \mathbf{0}\\ [(\mathbf{I}-\mathbf{G_0})^{-1}\mathbf{D_0}] & \mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{u_t^y}\\ \mathbf{u_t^p}\end{bmatrix} \tag{5}$$

where the coefficients and error terms (non-orthogonal) are defined by a direct correspondence with equation (4).

We are interested in extracting the residual component orthogonal to $\mathbf{u}^y$[12]

$$\mathbf{u_t^p} = (\mathbf{I}-\mathbf{G_0})^{-1}\mathbf{A^p}\mathbf{v_t^p} \tag{6}$$

Equation (6) represents a standard SVAR, which associates observed VAR residuals, **u**, with non-observed structural shocks, **v**, one (or more) of which is the policy shock, v^n. The equation for $\mathbf{P_t}$ in (5) is the policy reaction function.

Inserting the policy structural shock in the left side of (6), we have:

$$\mathbf{v_t^p} = (\mathbf{A^p})^{-1}(\mathbf{I}-\mathbf{G_0})\mathbf{u_t^p} \tag{7}$$

The models are estimated by a two-stage procedure. First, each VAR equation in (5) is estimated by OLS. In the second stage, we apply a structural decomposition to the VAR variance-covariance matrix, which results in a system of non-linear equations that is estimated by *Full Information Maximum Likelihood* (FIML) (see Appendix A.2, equation 3). The maximum likelihood functions are maximized numerically, using three algorithms: the Simplex, the Genetic and the Broyden-Fletcher-Goldfarb-Shanno (BFGS)[13] method.

[12] Only some elements of $\mathbf{u^p}$ are the VAR residuals corresponding to the policy block and are orthogonal to the VAR residuals corresponding to the non-policy block $\mathbf{u^y}$. From (5), all the residuals corresponding to the policy block are equal to a linear combination of orthogonal and non-orthogonal components.

[13] In general lines, the genetic algorithm uses a stylized model of evolution, with random mutations. Here, the population is a vector of parameters that is compared to another vector (successor) at each iteration. The vector, which provides the best function value, continues in the iteration. There are different schemes to generate a successor, but all require that at least one of the parameters suffer a

2.1 Model Specification

To apply the previous methodology, one must decide which variables to include in the block of policy variables (**P**). BM (1998) includes only reserve market variables, such as total reserves, non-borrowed reserves and the interest rate. From July of 1996 to February 1999, the Brazilian Committee of Monetary Policy (Copom), during its monthly meeting, used to define the discount rate (Central Bank Basic rate – TBC and also the Central Bank Assistance rate – TBAN), instead of setting an explicit target for the Selic rate. During this period, the exchange rate was relatively fixed and there was an informal lower bound for the Selic rate, which worked as a threshold for open market interventions of the Central Bank. After 1999, the floating exchange rate regime was implemented and the TBC and TBAN were extinguished[14]. There was a period during which the bank discount rate was near zero. It therefore seems appropriate to alter the standard model for the bank reserves market in Brazil.

The Brazilian Central Bank participates in open market operations that influence the supply of bank reserves (non-borrowed reserves) and the Selic interest rate. Movements in the Selic rate influence the interest rate in other markets, the same way that variations in the total amount of bank reserves are related to movements in more broad monetary aggregates (M1, M2 etc). When the Central Bank intervenes in the reserves market it affects the supply of money, the market interest rate and the inflation rate.

We adopt a model for the reserves market that incorporates Bernanke and Blinder's (1992), Strogin's (1995), and Christiano, Eichenbaum and Evans' (1996) models. The equilibrium level of reserves is determined by supply and demand interactions. In Brazil, we assume the demand for reserves is determined by the requirement that banks maintain reserves at a pre-determined proportion of its demand deposits. This required proportion of demand deposits is set by the Central Bank (called the reserve requirement).

Even though the required reserves account for the majority of the reserves a bank holds, the total amount of reserves is above the legal requirement, generating "excess reserves" that are costly to retain. The total amount of reserves is then made up of required

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mutation, *i.e.*, that a random number is added to it. The BFGS algorithm, on the other hand, is part of a "Quasi-Newton" models class.

[14] They existed after 1999 not for monetary policy purposes, but just as an adjustment index for previous contracts.

reserves and excess reserves. On the supply side, total reserves is equal to the amount of reserves banks can borrow directly from the Central Bank, the borrowed reserves,[15] plus the reserves supplied via open market operations – the non-borrowed reserves.

We estimate two classes of models: one without the external sector of the economy and another with it. There are two models without the external sector, one with and one without the discount rate (the model without the discount rate is nested in the one that includes it). The exclusion of the discount rate can be justified by the fact that currently it does not play an important role in monetary policy decisions. During the TBC and TBAN period, the discount rate did and that is why we consider both specifications. On the other hand, there is strong evidence from other countries that the demand for borrowed reserves depends not only on the market rate for bank reserves, but also on the spread between that rate and the discount rate. As pointed out by Goodfriend (1983), in addition to the spread, the existence of other non-pecuniary costs is also relevant to determine the equilibrium amount of borrowed reserves. In Brazil, for discount operations that have TFP (public bonds) as collateral, there are no non-pecuniary costs. During the TBC and TBAN period there was a pecuniary cost – a differential to the amount loaned[16].

In the models with the external sector, we justify the use of the exchange rate because Brazil is a "small open economy".

Model 1: Without the external sector and without the discount rate.

The standard model with neither the external sector nor the discount rate has the following set of equations for contemporaneous innovations.[17]

Demand for reserves: $u^{RT} = -\alpha\, u^{R} + v^{d}$ (8)

Demand (supply) for discount: $u^{BR} = \beta\, (u^{R} - u^{D}) + v^{b}$ (9)

Supply of non-borrowed reserves: $u^{NBR} = \phi^{d}\, v^{d} + \phi^{b}\, v^{b} + v^{n}$ (10)

[15] Despite being part of the reserves supply, borrowed reserves are a standing facility and can be demanded by banks.

[16] This problem was minimized by using a discount rate weighted by the financial amounts negotiated. Previously to the TBC, there was a cost related to usage (amounts, frequency etc).

[17] For simplification, the t subscript was removed from the equations.

Equation (8) states that the demand for total reserves (u^{RT}) depends on the cost of reserves – the Selic rate (u^R) – and on the orthogonal shocks – the ones that change the demand for money by the public. For simplification, aggregate income and prices are part of the error term, as well as non-anticipated shocks in required reserves.

Equation (9) states that the demand for discount (u^{BR}) depends on the spread between the Selic rate (u^R) and the discount rate (u^D), which is zero in this model, and on a shock in the amount of borrowed reserves.[18] For Brazil, only during the period from July of 1996 to December of 1997 (and then only occasionally) was the discount rate below the Selic rate. In general, this rate is usually higher than the Selic, leading one to expect very low quantities of borrowed reserves. During the period considered, however, the amount of borrowed reserves was greater than zero because some banks borrow from the Central Bank at the end of the day because of stochastic flow of funds, imperfect access to the bank reserve market, etc., and because of this one expects equation (9) to hold.[19, 20]

Equation (10) is a "reaction function" for the open market operations table. It shows that, even in short periods, the Central Bank can control the amount of non-borrowed reserves (u^{NBR}) by observing and compensating shocks to the bank reserve market. There also exists an autonomous shock to the supply of non-borrowed reserves, v^n, which is the **policy shock** of this model.

Assuming that the equilibrium condition, $u^{BR} = u^{RT} - u^{NBR}$, is always satisfied for all the models, the matrices $(\mathbf{I}\text{-}\mathbf{G_0})\mathbf{u}^p$ and $\mathbf{A}^p\mathbf{v}^p$ from (6) become:

$$\begin{bmatrix} 1 & 0 & a \\ 1 & -1 & -b \\ 0 & 1 & 0 \end{bmatrix} . \begin{bmatrix} u^{RT} \\ u^{NBR} \\ u^{R} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ f^d & f^b & 1 \end{bmatrix} . \begin{bmatrix} v^d \\ v^b \\ v^n \end{bmatrix}$$

[18] Christiano, Eichenbaum and Evans (1998) argue that there should be an innovation for non-borrowed reserves as an additional variable in equation (9). In a more general model, the function for discount depends on current and future interest rates, and non-borrowed reserve innovations may contain information about future spreads. This model is not confirmed in the Brazilian case because, when dealing with federal public bonds (TPF), the frequency of utilization is unimportant.

[19] During the TBC and TBAN period there existed a quota system which limited borrowing to meet required reserves at the TBC rate to a percentage of demand and time deposits. To borrow greater amounts banks could only borrow from the Central Bank at the greater TBAN rate.

[20] Equation (9) holds in the sense that even small quantities of non-borrowed reserves can be explained by the spread. Since $u^D = 0$ in the model, v^b only contains shocks in the Selic rate.

The following cases cover those found in the literature, as suggested by BM (1995).

Case 1: Interest rate target (FF target). When the interest rate is the central bank's operational target, $\phi^b = -1$ and $\phi^d = 1$.

From (8) to (10):

$$u^R = -\frac{1}{a+b}[v^n + (1+f^b)v^b - (1-f^d)v^d] \qquad (11)$$

The above restrictions imply that a shock to borrowed reserves leads to an equal but opposite response in non-borrowed reserves such that the interest rate remains fixed. A shock to the demand for reserves leads to an equivalent change in the supply of reserves through adjustments in the amount of non-borrowed reserves. However, the interest rate will be determined if the above restrictions are satisfied.

Case 2: Non-borrowed reserves operational target (NBR target). Non-borrowed reserves only respond to policy shocks, which implies that $\phi^d = 0$ and $\phi^b = 0$.
In this case (11) yields,

$$u^R = -\frac{1}{a+b}[v^n + v^b - v^d] \qquad (11')$$

Here, interest rate innovations reflect policy changes and shocks to the demand for both borrowed and total reserves. That is, if $v^d > 0$ leads to an increase in M1 (for example) then interest rate innovations can be positively correlated with M1 innovations, which would explain the liquidity puzzle.

Case 3: Borrowed reserves operational target (BR target).

Equations (8) to (10) yield:

$$u^{BR} = -\frac{1}{a+b}[bv^n - (a - b\,f^b)v^b - b\,(1 - f^d)v^d] \tag{12}$$

In this case, the BR target policy consists in setting $\phi^d = 1$ and $\phi^b = \alpha/\beta$, in order to adjust the non-borrowed reserves so that borrowed reserves are isolated from all non-policy shocks. That is, non-borrowed reserves are adjusted to accommodate fluctuations in the total demand for reserves. The interest rate obeys:

$$u^R = -\frac{1}{a+b}[v^n + (1+\frac{a}{b})v^b]\,. \tag{11''}$$

Case 4: Strongin (1995). This specification corresponds to $\alpha=0$ and $\phi^b=0$ (NBR/RT target).

Case 5: The "just identified" model. A model in which only $\alpha=0$ and one verifies how the parameter estimates compare to those from cases 1 to 4.

For all three models, our strategy is to estimate the "just identified" model (case 5) to obtain parameter estimates. For the following models (with the discount rate and the external sector, respectively) cases 3 and 4 are not tested because we assess low probability that the BCB has set a borrowed reserve target during the period. Strogin's (1995) model (case 4) can be tested within case 2.

Model 2: Without the external sector and with the discount rate

In this model there are two shocks which can be interpreted as **policy shocks**: the non-borrowed reserves innovation, v^n, and the discount rate innovation, v^s. The model is comprised of the following set of equations:

Demand for reserves: $u^{RT} = -\alpha\, u^R + v^d$ (8)

Demand (supply) for discount: $u^{BR} = \beta\,(u^R - u^D) + v^b$ (9)

Supply of non-borrowed reserves: $u^{NBR} = \phi^d v^d + \phi^b v^b + \phi^s v^s + v^n$ (10')

Discount rate: $u^D = \gamma^d v^d + \gamma^b v^b + \gamma^n v^n + v^s$. (13)

In this model, $u^D > 0$. Equation (10') adds the positive discount shock to equation (10). Equation (13) describes how the central bank determines the discount rate. This equation is unrestricted, allowing the central bank to use the discount rate to compensate other shocks in the reserves market as well as autonomous innovations in the discount rate.

The matrices from (6) become:

$$\begin{bmatrix} 1 & 0 & a & 0 \\ 1 & -1 & -b & b \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} u^{RT} \\ u^{NBR} \\ u^{R} \\ u^{RD} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ f^d & f^b & 1 & f^s \\ g^d & g^b & g^n & 1 \end{bmatrix} \cdot \begin{bmatrix} v^d \\ v^b \\ v^n \\ v^s \end{bmatrix}$$

For a large part of the sample period, the discount rate was equal to the Selic plus a fixed percentage, which made it appear that the Brazilian Central Bank did not adjust the discount rate to changes in the Selic. Hence, we also employ the following model for the discount rate:

Discount rate: $u^D = \theta u^R + v^s$. (13')

The cases considered are:

Case 1: Interest rate target. The restrictions are:

$1 - f^d + bg^d = 0; \quad 1 + f^b - bg^b = 0; \quad f^s = b$ (14)

Solving the system of equations (8), (9), (10'), (13) and (14) for the interest rate yields:

$$u^R = \frac{1}{a+b}[(1-f^d + bg^d)v^d - (1+f^b - bg^d)v^b - (1-bg^n)v^n - (f^s - b)v^s] \quad (15)$$

The first two equations of (14) are a modification of Model 1 and imply that the interest rate does not respond to shocks in either the demand for reserves nor discount. The third restriction states that the interest rate is isolated from discount rate shocks ($\phi^s = \beta$).[21]

Case 2: Non-borrowed reserves operational target. The restrictions are:

$$\phi^d = 0; \phi^b = 0; \phi^s = 0 \quad (16)$$

That is, the non-borrowed reserves depend on only their autonomous shocks and are not systematically adjusted in response to contemporaneous shocks in the bank reserves market.

Case 3: Discount rate operational target (D target). One imposes:

$$\gamma^d = 0; \gamma^b = 0; \gamma^n = 0 \quad (17)$$

Case 4: "Just identified" model. Two restrictions are necessary to exactly identify Model 2. Since the discount rate can be used passively to adjust the bank reserve market's interest rate and actively as a signal or policy instrument, one can imagine that it should respond to demand shocks and policy shocks. In this way, γ^d e γ^n should not be equal to zero. It is therefore reasonable to suppose that adjustments to shocks in the amount of borrowed reserves be made by varying the supply of non-borrowed reserves more slowly than the discount rate. In this way, identification can be achieved by setting γ^b=0 and α=0.

[21] We also tested $\phi^s = 0$ and the results did not change.

Model 3: With the external sector and without the discount rate

The model with the external sector and innovations is given by:

Demand for reserves: $u^{RT} = -\alpha\, u^{R} + v^{d}$ (8)

Demand (supply) for discount: $u^{BR} = \beta\,(u^{R} - u^{D}) + v^{b}$ (9)

Supply of non-borrowed reserves: $u^{NBR} = \phi^{d} v^{d} + \phi^{b} v^{b} + \phi^{x} v^{x} + v^{n}$ (10'')

Exchange rate: $u^{EX} + \varphi^{d} u^{RT} + \varphi^{n} u^{NBR} + \varphi^{R} u^{R} = v^{x}$. (18)

Once again $u^{D} = 0$. Equation (10'') incorporates the orthogonal innovation in the exchange rate, v^{x}. Equation (18) simply states that innovations in the exchange rate are related to innovations in all the other policy variables as well as an exogenous shock in the exchange rate.

For this model equation (6) becomes:

$$\begin{bmatrix} 1 & 0 & \alpha & 0 \\ 1 & -1 & -\beta & 0 \\ 0 & 1 & 0 & 0 \\ \varphi^{d} & \varphi^{n} & \varphi^{R} & 1 \end{bmatrix} \cdot \begin{bmatrix} u^{RT} \\ u^{NBR} \\ u^{R} \\ u^{EX} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \phi^{d} & \phi^{b} & 1 & \phi^{x} \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} v^{d} \\ v^{b} \\ v^{n} \\ v^{x} \end{bmatrix}$$

Only two cases (other than the "just identified" model) will be considered for this model, which is only slightly different from Model 1. The restrictions for the interest rate target case are $\phi^{d} = 1$ and $\phi^{b} = -1$. We also assume that the supply of non-borrowed reserves does not respond to innovations in the exchange rate ($\phi^{x} = 0$). If the non-borrowed reserves target is implemented we have $\phi^{d} = 0$, $\phi^{b} = 0$ and $\phi^{x} = 0$. Finally, we obtain the "just identified" model by setting $\alpha = \phi^{x} = 0$.

3. Data

All three models were estimated using monthly data on the Brazilian economy from 1994:07 to 2004:11. In this paper, vector **Y** in section 2 contains the Industrial Production Index – IPI – calculated by IBGE (Y) and the percentage variation of the Consumer Price Index – IPCA – also by IBGE (P)[22]. The policy variables include, for the various specifications, total reserves (RT), non-borrowed reserves (NBR), a short-term nominal interest rate (Selic)[23], a discount rate (D), and the nominal exchange rate (EX). Following BM (1998), total reserves and non-borrowed reserves were divided by a two months moving average of the total reserves, because of the linear structure of the identification scheme[24]. A detailed description of the variables is presented in Appendix A.1.The original series are plotted in Figure A.1, Appendix A.3, after seasonal adjustments.

Non-borrowed reserves are obtained from borrowed reserves and total reserves. The output and exchange rate series are used in log-level in the VAR, while all other variables are used in level. All the rates in our data set are monthly averages of daily observations, annual rates (only inflation rate that is a monthly rate). Both the output and inflation rate series were seasonally adjusted.

Two observations are worth making. First, in Brazil throughout the period under consideration, there also existed a type of voluntary deposit that the banks could make at the Central Bank at the end of the day with their excess reserves. The remuneration rate for these deposits was lower than the Selic rate. Since these voluntary deposits represent a very small amount, this standing facility was not included with the total borrowed reserves (if included it would have a negative sign). Second, the amount of borrowed reserves used here also includes the borrowed reserves provided by the Central Bank open market operations table, provided at the end of the day and without a pre-specified rate. This represents a significant amount of borrowed reserves and ignoring it would result in important measurement error.

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[22] This is different from the policy vector **P**.
[23] Leeper *et al.* (1996) have shown that with the inclusion of a long-term interest rate in the VAR it becomes difficult to distinguish between the policy equation and the arbitrage conditions.
[24] The identification scheme is linear and therefore one should not apply the log transformation to the policy variables. Actually, BM (1995, 1998) uses a 36 months moving average, but because of our sample size, it was not possible to use such a long period moving average in our paper. We tried moving averages from two to six months and the results were similar. In order to preserve degrees of freedom we chose the two months period, as did Strongin (1995).

As usual, we study the unit root properties of the series and the possibility of using a VEC model. However, because of the suspicion of structural breaks, we used Perron (1997), which does not require *a priori* dates for changes in the intercepts and the slopes.

For the variables considered stable by Perron (1997) – output, inflation rate, Selic rate, discount rate and total reserves – we also applied Augmented Dickey-Fuller (ADF) tests. We find that the output and the Selic rate are I(1).[25] The exchange rate and the non-borrowed reserves are I(1), while total reserves is I(0). The auto-regressive vectors are estimated in level with I(1) and I(0) variables. We do not estimate a VEC model, since this would result in super-consistent estimates[26]. We also looked for possible cointegration relations among the series.[27,28]

4. Results

In relation to the theoretical models of Section 2.1, the estimates consist of verifying monetary policy shocks for each sample period by performing the tests which have been discussed. We also obtained impulse response functions for some economic variables, including those of the bank reserve market, and Central Bank of Brazil (BC) policy reaction functions.

[25] The ADF test could reject the null of a unit root at a significance level of 5%, but not 1%, for the Selic rate.

[26] In the sense that its asymptotic variance is $O(1/T^2)$ instead of $O(1/T)$) and it captures the cointegration relations. The VAR estimation in level is recommended because the series could be almost non-stationary. Sims, Stock e Watson (1990) show that most traditional tests for large samples could be applied to unit root series, even if cointegrated, if the VAR is estimated in level.

[27] We applied cointegration tests for Models 1 and 2. The Johansen test indicates the presence of 2 and 3 cointegration vectors (based on λ_{max} and λ_{trace}, respectively), in both models 1 and 2, but the results are very sensitive to specification. Besides, one should be careful with model 1, since it has an exogenous variable. We found structural breaks in Model 3 and, therefore, we did not apply traditional cointegration tests, as we will discuss later.

[28] Sometimes it is convenient to consider systems with both I(0) and I(1) variables, as in Lutkepohl (1999). In this case, the cointegration concept is extended to be any I(0) linear combination of variables. Neglecting cointegration relations is not a serious problem in the context of this paper, because we are interested in the short-term dynamic responses of the system. When one excludes cointegration restrictions, the long-term responses of some variables could take divergent paths, even though the short-term analysis is still valid. The specification in differences is inconsistent if some of the variables are cointegrated.

4.1 Underlying VAR – Diagnosis

We estimate all of the full sample VAR models with a constant and 2 lags[29]. Models 1 and 3 add a dummy that takes the value one before December 1998, and zero otherwise. The rationale behind the inclusion of the dummy is that the inflation targeting regime was adopted in 1999 and the exchange rate regime was also changed. We have tested other dummies for all models, including impulse dummies for the second semester of 2002 to control for the confidence crisis during that period.[30] We also include a level dummy that assumes the value one for April 2002, and zero otherwise, to account for the launching of the New Brazilian Payment System (SPB). As the results stay the same after including the dummies and there was no enhancement of the VARs diagnostics we have decided to use those model specifications with all dummies dropped except for the one for the inflation targeting regime.

Tables A.I, A.II and A.III in Appendix A.3 report the residual analysis. We test the residuals for serial correlation, conditional heteroskedasticity and normality. At the 5% level, Model 1 presents serial correlation in the first lag. Model 2 has serial correlation only in one lag (at the 5% level, but not at the 1% level) and Model 3 for the full sample presents serial correlation in the initial lags and in the fifth one. The conditional heteroscedasticy tests of order equal to or higher than the number of lags indicate the presence of conditional heteroskedasticity in the residuals for Model 3. The results indicate the absence of normality for the system, but indicate normal residuals for some equations.[31]

Instability in the model structure (presence of breaks) or in the parameters may give rise to serious misspecification errors. To avoid this problem, we conducted a Bai-Perron test (2003) of multiple unknown structural breaks for a vector of policy indicators, **P**, to the equations of Models 2 and 3. These results are in Table A.IV in Appendix A.3. None of the breaks overlap with the exception of the end of 1997, when there was evidence of policy changes for bank reserves and for the Selic interest rate in Model 3 (which includes the exchange rate). In this case, Model 3 may be incorporating the Asian Crisis in October

[29]We selected lag length based on Akaike Information Criteria (AIC).
[30]Minella *et al.* (2003) argue that, in the last months of 2002, the inflation rate suffered from a structural break. A Bai-Perron (2003) VAR test for Model 2 indicates that the best break date for the inflation rate series is 2002:06, and the two best breaks are 1997:06 and 2002:06, respectively.
[31]The reported results in Table A.III from the Appendix A.3 use the Doornik-Hansen ortoghonalization (1994).

1997, when the Monetary Policy Committee (Copom) raised the TBAN to a 45% annual rate from 19%. The Asian Crisis is captured in total bank reserves and non-borrowed reserves in Model 2, as evidenced by the two best break points.

Surprisingly, the best break point for the Selic rate in Models 2 and 3 is at the end of 1995 and not in 1999, when the exchange rate regime changed. This is also true for Model 3, which may indicate that Mexican Crisis had an important effect on the economy. The exchange rate equation shows the best break point in November 1998, a few months before the floating exchange rate regime launched. In general, as the breaks do not overlap, we do not expect any instability problems in the VAR parameters except for the full sample Model 3.

In order to implement the results of the Bai-Perron (2003) tests we perform another test with only one unknown structural break point for the VAR estimation. The stability analysis was performed with the LM-type tests of Andrews-Quandt and of Andrews-Ploberger using a heteroskedasticity robust weighted matrix. We perform tests of each variable on the lags of all variables for the three Models. Besides testing for individual coefficient stability we also follow an equation-by-equation procedure (joint coefficients and residual variance).

For Model 1, in 28% of the cases the null hypothesis of coefficient stability is rejected at the 5% level (60 equations). The most frequent rejections are in the inflation rate equations (P) and NBR[32]. The null hypothesis of joint coefficient stability and residual variance stability cannot be rejected for any equation at the 10% level. For Model 2, we can reject 14% of the cases, which are concentrated in the NBR equation. Again, joint tests of coefficients and of the residual variance are unable to reject the null hypothesis of stability. Model 3 rejects about 58% of cases, which are spread over several equations. Even though the joint test for coefficients and residuals cannot reject H_0, there is evidence that this model is not stable, as the Bai-Perron tests indicate. Therefore, we substituted the sub-sample after December 1998 for the full sample[33].

The VAR estimation of the sub-sample Model 3 uses 4 lags, which were selected using the absence of serial correlation as a criterion. Usual tests of serial correlation,

[32] At the 1% level the output equation also demonstrates relevant instability.
[33] Herein Model 3 refers only to the period beginning in January 1999.

conditional heterokedasticity and normality of the residuals are satisfactory for the sample starting from 1999.

4.2 Structural specification

4.2.1 Over-identification Tests

Table I reports the p-value corresponding to the overidentifying restriction test (OIR), which is a likelihood ratio test, and the values of the likelihood functions (restricted and unrestricted) for each model and sample period[34]. The sub-periods chosen correspond broadly to periods identified as possibly distinct operating regimes, since the inflation-targeting regime was launched in 1999[35]. The selected sub-periods are consistent with the Andrews-Quandt and Andrews-Ploberger tests of Section 4.1.

Table I – Test for Over-identifying Restriction (OIR)

Models	Model 1			Model 2			Model 3
Periods \ Procedures	1994:09 – 2004:11	1994:09 – 1998:12	1999:01 – 2004:11	1994:09 – 2004:11	1994:09 – 1998:12	1999:01 – 2004:11	1999:01 – 2004:11
FF Targeting (p-*value)*	0.81492	0.96778	0.24809	0.49650	0.33947	0.91665	0.12353
logL restricted	1021.25	392.95	933.90	966.70	386.84	844.31	1220.30
logL unrestricted	1021.28	392.95	934.56	966.93	387.30	844.31	1221.48
NBR Targeting (p-*value)*	0.00000	0.00001	0.06735	0.00589	0.32185	0.04850	6.2E-40 [1/]
logL restricted	998.17	383.17	932.89	963.14	386.81	842.37	1131.21
logL unrestricted	1021.28	392.95	934.56	966.93	387.30	844.31	1221.48
NBR/TR Targeting (p-*value)*	0.02614	0.10371	0.10454	-	-	-	-
logL restricted	1018.80	391.63	933.24				
logL unrestricted	1021.28	392.95	934.56				
BR Targeting (p-*value)*	0.81492	0.96778	0.24809	-	-	-	-
logL restricted	1021.25	392.95	933.90				
logL unrestricted	1021.28	392.95	934.56				
D Targeting (p-*value)*	-	-	-	0.00004	0.85531	0.05452	-
logL restricted				958.52	387.28	842.46	
logL unrestricted				966.93	387.30	844.31	

[1/] We have used $\alpha \geq 0$. The VAR's for Model 1 have lags of 2, 2 and 4, respectively. For Model 2, lags of 2, 2 and 2. For Model 3, a lag of 4.
Obs.: The description of the each model case is in section 2.1.

[34] We have also estimated the alternative Model 2 (see section 2.1). As the results in terms of parameter space, signs and impulse-responses are poor, it has not been considered.
[35] The inflation targeting regime was officially adopted in June 1999 in Brazil, but the break date considered was January 1999.

For Model 1 the VAR for the 1994-98 sub-sample uses 2 lags. For the 1999-2004 sub-sample it uses 4 lags, the only one for which significant serial correlation in the residuals is not observed. For Model 2 the VARs for both sub-samples use 2 lags.

Table I shows that only the Bernanke-Blinder model (1992, FF target) is not rejected at the 5% level neither for the full sample nor for half sample, which means that the interest rate is the best policy indicator. For Model 2, the second sub-sample displays that the BC has strongly adhered to an interest rate targeting procedure after 1999. Although we cannot reject the Selic interest rate targeting hypothesis, Model 3 (which includes the exchange rate) performs worst.

We cannot reject the Christiano-Eichenbaum model of non-borrowed reserves (1996, NBR target) for the sub-sample from 1994 to 1998 to Model 2 that is we cannot affirm that non-borrowed reserves are not a good policy indicator for the sample period. For all other periods and sub-samples the hypothesis is rejected except for the second sub-sample for Model 1 at the 10% level.

The Strogin Model (1995, NBR/RT targeting) is more flexible in that the response of non-borrowed reserves to shocks in the demand for total reserves is a free parameter, f^d, even though the model imposes the constraint that the demand curve for total reserves is vertical. For the full sample, Model 1 rejects the hypothesis that the BC adhered to the ratio NBR/RT as a targeting procedure. However, this procedure cannot be marginally rejected for the sub-samples.

We cannot empirically disentangle the borrowed-reserve targeting procedure (named BR) from the FF targeting since the p-values are identical[36]. Theoretically we encounter this result in Walsh (1998): for a model similar to Model 1; the borrowed reserves and the interest rate shocks are not separable when the shock to the demand for reserves is small.

Differently from BM (1997), in this paper it was possible to distinguish the discount-rate targeting procedure from the interest-rate targeting procedure, since the p-value rejects the discount rate as a targeting procedure for Model 2. Surprisingly the sub-sample before 1999 does not reject discount rate targeting. Given that from July 1996 to the beginning of 1999 the Copom meeting had the TBC and TBAN rates as a target there is

[36] BM (1995) has found analogous result.

some evidence that the model is capturing the facts. Additionally, during that period the discount rate (TBC) was not a punitive rate. When the discount rate returned to above market values, the model rejects the hypothesis of the discount-rate targeting procedure.

In spite of some caution being necessary regarding the tests for the sub-samples (because of small sample size), the findings seem very reasonable. Also, all results are robust to changes in the lags of the underlying VAR.

4.2.2 Parameter Estimates

After testing the overidentifying restrictions, Table II reports parameter estimates from Models 1, 2 and 3. The estimates give the policy reaction function of the Central Bank in the market for bank reserves and the demand curve for borrowed reserves. We employ the just-identified model and the Strongin assumption (1995) that the demand for excess reserves is inelastic to the interest rate ($a = 0$). Figure 1 displays the relationship between excess reserves and the monthly growth rate of reserve requirement on demand deposits[37].

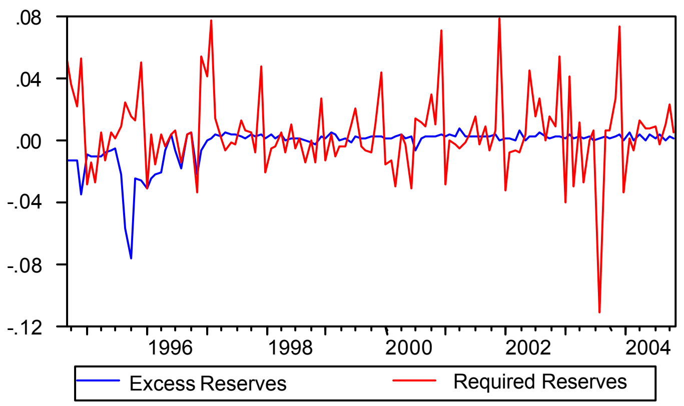


Figure 1 – Excess Reserves and Required Reserves

During almost the entire period the growth rate of the reserve requirement on demand deposits and the excess reserves are of different orders, suggesting that in our case the demand for reserves may be inelastic to the interest rate. Linear regression of the excess

[37] The excess reserves are measured as log(total reserves /reserve requirement$_t$) and required reserves as log(reserve requirement$_t$)-log(reserve requirement$_{t-1}$). The excess reserves are defined as the amount above the average of the required reserves over the maintenance period.

reserves on the Selic rate confirms this fact as the Selic coefficient is -0.00044. The Bai-Perron test for the excess reserves (Table A.IV of the Appendix A.3) displays a structural break after Proer launched and not, as expected, after SPB implementation (April 2002).

The Table II displays the FIML parameter estimates for the three just-identified models described in the Section 2.1.

Table II: Parameter Estimates

Parameters	β	ϕ^d	ϕ^b	ϕ^s	γ^d	γ^n
Model 1	0.000562	1.006818	-1.00311	-	-	-
	(0.9279)	(0.0000)	(0.0000)	-	-	-
Model 2	-0.0103	0.99128	-0.9283	-0.00077	-10.9746	-51.4743
	(0.3242)	(0.0000)	(0.0000)	(0.0374)	(0.0426)	(0.0000)
Model 3	0.02262	0.929847	-0.401698	-	-	-
	(0.01515)	(0.0000)	(0.18901)	-	-	-

Obs.: *P-values* are in parenthesis.

The estimates of f^d and f^b indicate a high degree of Selic-rate smoothing for all models. The result is even clearer in Model 1. In this model the ß coefficient – very low – has the expected (although non-statistically significant) sign.

In Model 2, the only coefficient not statistically significant is ß, which presents an unexpected sign. The value of f^s is near zero. At the first glance f^s has an unexpected sign since a discount-rate shock tends to reduce the amount of borrowed reserves and increase the amount of non-borrowed reserves in order to keep the interest rate constant. However, we cannot reject the hypothesis that f^s is equal to zero (using the just-identified model) at the 1% level. The g^d and g^n coefficients are negative and the latter is very high, which shows that movements in the discount rate are primarily driven out by monetary policy shocks. We might also imagine that g^d has an unexpected sign. However, under the interest-rate targeting procedure, shocks to the demand for reserves have been counterbalanced by a rise in non-borrowed and borrowed reserves. The increase in borrowed reserves is due to the reduction of the discount rate (and spread increases). In other words, the Central Bank is substituting discount rate volatility for Selic rate volatility[38].

Model 3 displays a high value of the b coefficient. Although non-significant, the value of f^b demonstrates less interest rate smoothing, which may be a result of the inclusion of the exchange rate. For this model the FF targeting procedure is less evident as Table I has already indicated.

As the just-identified model places an exclusion restriction on a, Table III reports point estimates of both a and b using the genetic algorithm for the FF targeting procedure.

Table III – Parameter Estimates with FF Targeting

Models \ Parameters	α	ß
Model 1	0.00352	0.00131
Model 2	0.00365	0.10841
Model 3	-0.01780	0.00001

From the Table III, the estimate of a is near zero for Models 1 and 2 and it has the expected sign. For Model 3 its sign is unexpected and also close to zero.[39] Looking at the correlation matrix in Table A.V of Appendix A.3, the contemporaneous correlation between the innovations of the estimated VAR for the Selic rate and for the demand for total reserves is positive instead of negative in Model 3. As far as the FF targeting procedure is concerned, we would expect a negative correlation as interest-rate shocks only reflect monetary policy shocks.

[38] As the discount rate is a fixed percentage above the Selic rate, it seems that such an explanation is not reasonable. However, at least from July 1996 to February 1999, the two rates were chosen independently. In addition the amount of reserves supplied by the discount window of the BC open market desk is not negligible, and this rate does not have a very stable relationship with the Selic rate. Data show that since the beginning of the new, real time gross settlement payments system, SPB, that component of borrowed reserves has increased. The reduction of the discount rate might occur in such a way that maintains the rate as a punitive one. In other words, the BC may have accommodated rising demand through open market operations and, at the end of the day, through discounting operations at a less punitive discount rate.

[39] For an estimation using a model similar to Model 1, CEE (1998, p. 74) found an estimate of -0.003.

The major difference among the three models is in the ß coefficient, which increases significantly when we consider discount rate innovations[40].

4.2.3 Robustness Tests

The advantage of using a model which extracts information about monetary policy from data on bank reserves and the interest rate is that the parameter space has a straightforward economic interpretation. Therefore we can use adequate prior information in order to restrict the acceptable identification schemes. To verify if our identification scheme generates an admissible parameter space, we consider the following inequality constraints, which weaken the constraints imposed by BM (1995, 1997, 1998):

$\alpha \geq 0$ (19)

$\beta \geq 0$ (20)

$\phi^d \geq 0$ (21)

$\phi^b \leq 0$ (22)

These constraints imply that: for (19), the demand curve for total reserves is non-positive; for (20), the borrowed reserves function has a non-negative slope in the space of borrowed reserves and spread; for (21) and (22) that the BC performs interest-rate smoothing to some degree (or, in the case of Model 2, aims at smoothing) or at least it does not respond to disturbances in the market for reserves. Table IV displays the results for Models 1, 2 and 3.

Table IV – Inequality Restrictions – *P* – v*alue* for OIR Tests

Models	$\alpha\geq0, \phi^d\geq0, \phi^b\leq0$	$\alpha\geq0, \beta\geq0, \phi^d\geq0, \phi^b\leq0$
Model 1	1	1
Model 2	0.57261	0.72237
Model 3	0.99994	1,00000

[40]This estimate is very close to the BM (1995) estimation for the sample period 1775:1-1981:6 in the USA.

Note that all models demonstrate well-behaved demand and supply curves and some degree of interest-rate smoothing. Model 2 has a smaller p-value and its constraints f^d and f^b do not exactly correspond to the model of interest-rate targeting, as Section 2.1 shows.

Robustness tests are also performed with the sample size from 1994 to 2004:07. The results are robust to the sample size. We do not change the order of the variables because there is no theoretical reason to do so.[41] As inflation targeting in Brazil is aimed at the IPCA rate (a consumer price index produced by IBGE) we employ this rate in our estimations.[42]

4.3 Impulse Response Functions

The monetary policy measure generated by the structural decomposition allows us to examine the behavior of the economy after monetary policy shocks. It is worth stating that in this article an innovation in the monetary policy measure is a linear combination of VAR estimation policy block innovations (of the total reserves, non-borrowed reserves, Selic rate, discount rate and exchange rate) as equation (7) shows.

It is possible that the absence of the liquidity puzzle is related to the proper identification of the contemporaneous correlations of VAR, a fact that we can verify with the impulse response functions. Since we use the inflation rate instead of the price level, we can only test if an inflation rate puzzle occurs.

Figures 2 and 3 show the impulse response functions (solid lines) generated by a standard-deviation shock to the structural innovations in Models 2 and 3. Each column represents the responses of the different variables to a specific shock. The responses are shown in the time interval from 0 to 23 months. For the variables that are in log-level, the vertical axis indicates the percentage deviation of each variable from the benchmark case without a shock (0.02 represents a 2% deviation). For the variables that are in level, the vertical axis indicates deviation in percentage points from the benchmark case. The two-standard-error bands (dashed lines) are computed as in Sims and Zha (1999), through Monte Carlo integration with 2500 draws. All responses present mean reversion.

[41]In fact, CEE (1998) shows that what matters is if the variables come before or after the policy variables. The intra-block order is not relevant in terms of impulse response functions.
[42]In Model 2 we also substitute IGP-M for IPCA and the results keep the same.

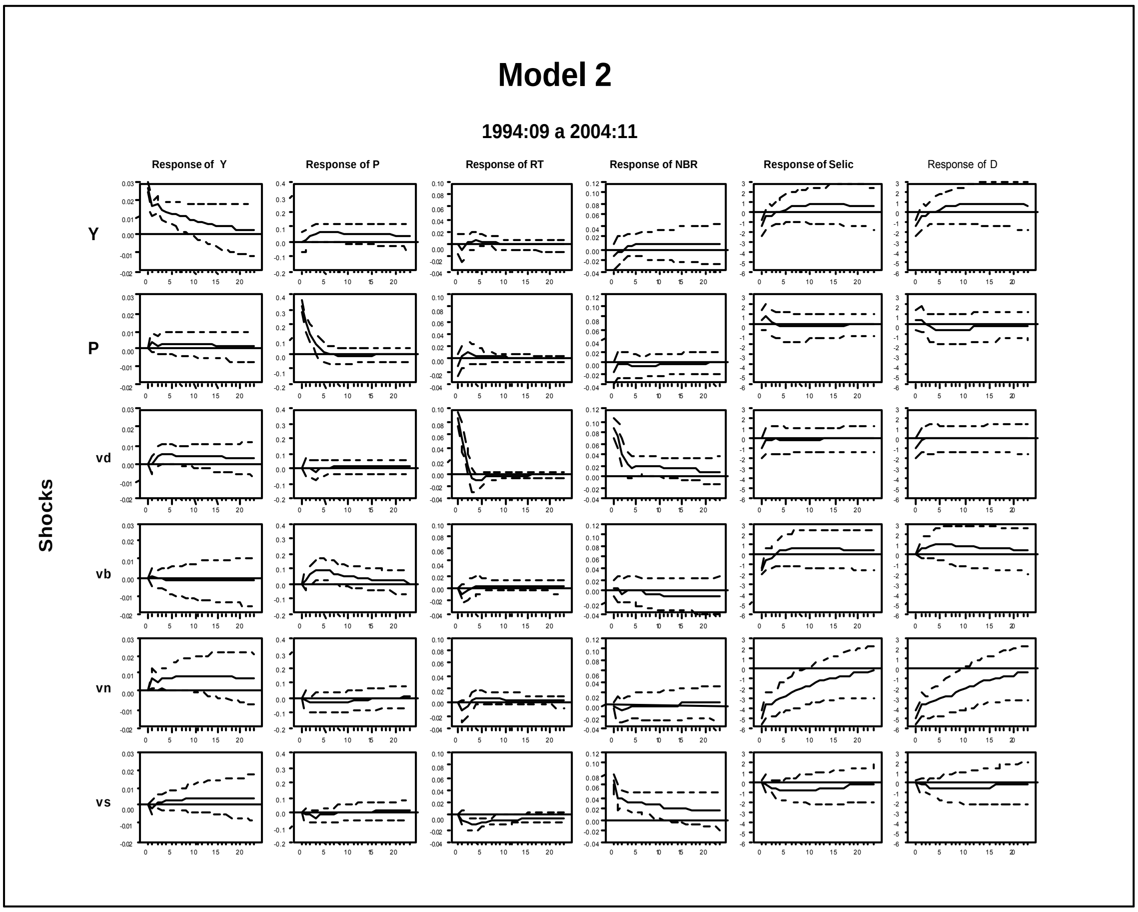
4.3.1 Benchmark Model (Model 2)

a) Market for Bank Reserves

Figure 2 displays the dynamic responses of all variables to different shocks for the VAR estimation of Model 2 (Benchmark Model). Since the hypothesis that the Central Bank has the interest rate as a target cannot be rejected in any model and for any period, the monetary policy shock is the one-standard deviation of v^n, with $v^n > 0$. For the sample period 1994-1998 it would be reasonable to also consider v^s as a monetary policy shock, but some caution is necessary due to a possible small sample bias.

A positive monetary policy shock should increase the total reserves, reduce the Selic rate and increase price and output. Because of our identification scheme, the increase in the total reserves only occurs some months later, and the initial response is a reduction.

Figure 2



The response to the v^n shock displays a small inflation rate puzzle, but the statistical uncertainty concerning this result is very large. The puzzle seems smaller for the discount rate shock.[43] The v^n shock, on the other hand, produces an output increase for a time-horizon of more than 24 months. The v^s shock generates a smaller, non-statistically significant, increase. The response to the v^n is fast since the output already increases from the second month onward. The maximum output increase occurs at about the 10^{th} month, differently from Minella (2001) who finds a maximum response between three and seven months. In quantitative terms, the negative variation of one percentage point in the Selic rate (expressed p. y.), due to a shock of 0.187 standard deviation in v^n, follows a maximum output increase of about 0.19%.

A positive shock to the demand for reserves – v^d – does not affect the Selic or the discount rates (in spite of a small initial decrease) and it increases the total and non-borrowed reserves. The path of both reserves is almost the same, which means that the amount of borrowed reserves stays constant. These findings are consistent with the interest rate targeting procedure. It is worth mentioning that shocks to the demand for reserves lead to an increase in the real output and have no effect on the interest rate, a finding similar to the calibrated model of Leeper and Roush (2003).

A shock to borrowed reserves – v^d – does not affect the non-borrowed reserves and reduces the Selic rate, which is consistent with the non-borrowed targeting procedure, although the total of reserves only increases later on. This behavior may be related to the fact that if we use a specific sub-sample we cannot reject the non-borrowed reserves targeting hypothesis The results are also consistent with the hypothesis of an interest rate target since the total of reserves hardly changes and the variation in the non-borrowed reserves is not statistically significant. However, the decrease in the interest rate is only significant in the initial period, which may be indicating that when the shock comes from the borrowed reserves, the BC does not smooth the interest rate. The shock to borrowed reserves leads to a statistically significant increase in the inflation rate.

[43] Bernanke and Mihov (1997) found a large price puzzle for v^n and none for v^s.

b) Inflation Rate

For the full sample the response of the inflation rate to its own shock lasts about seven months as Figure A.1 in Appendix A.3 displays. After 24 months, the initial shock is responsible for an increase of 0.000658 percentage point in the inflation rate p.m. For the two sub-samples, before and after 1999, the persistence seems larger for the fixed exchange rate period, as we can see in the same Figure. This finding is consistent with Minella *et al.* (2003) and provides evidence that the implementation of the floating exchange rate regime might have reduced inflationary persistence.

c) Reaction of the Selic Rate to Shocks to Real Output and to the Inflation Rate

It seems that the BC is more likely to react with some delay to output shocks as the Selic rate begins to increase only after some months. The total reserves do not change in response to shocks in Y, which is expected since in Brazil most of demand for reserves comes from the reserve requirements.

A shock to the inflation rate generates a small increase in the Selic rate in the initial period, although the result is not statistically significant. However, the response of the nominal interest rate is smaller than the increase of the inflation rate and, therefore, the ex-post real interest rate is negative.[44] As we have strong evidence that the Central Bank smoothes the Selic rate (see Section 4.2.1), one may think that the Central Bank does make an instantaneous adjustment of the interest rate to its optimal level to avoid jumps.

For the first time periods, total and borrowed reserves respond negatively to an inflation rate shock.

d) Liquidity Effect

We can find clear evidence of the liquidity effect using the identified model of this paper. Nowadays it is recognized that a positive short-run correlation between money and interest rate may reflect an endogenous response of the central bank to money demand shocks, under some degree of smoothness of the interest rate. The endogeneity issue leads

[44] As noted earlier, the Selic rate is expressed p. y. while the inflation rate is p. m.

to the rejection of the liquidity effect in traditional VAR with the Choleski decomposition.[45]

There is a significant liquidity effect in Model 2, as Figure A.2 in Appendix A.3 shows:[46] one-standard error in v^n produces an initial decline in the Selic rate of 5.3 percentage points for the sample from 1994:09 to 2004:11, and this statistically significant effect lasts for more than eight months. In addition the liquidity effect is present in both samples and is more pronounced in the first sample, as we can see in the same Figure.

4.3.2 Model 3

The impulse response functions for this model should be considered with some caution because of the small sample problem (71 observations). Any unexpected results may be due to a simultaneity issue between the exchange rate and the interest rate and the BC policy reaction to exchange rate changes.

Beginning with the monetary policy shock v^n, we can see the liquidity effect in Figure 3 above. The shock generates an increase in the non-borrowed reserves and a decrease in borrowed reserves, as the total reserves are constant. The response in output is not statistically significant. The shock is also associated with an unexpected nominal appreciation of the exchange rate and reduction in the inflation rate, which turns out to be statistically significant only after six months. The Selic rate declines for several months after the initial policy shock, although the statistical uncertainty concerning this result is not negligible.

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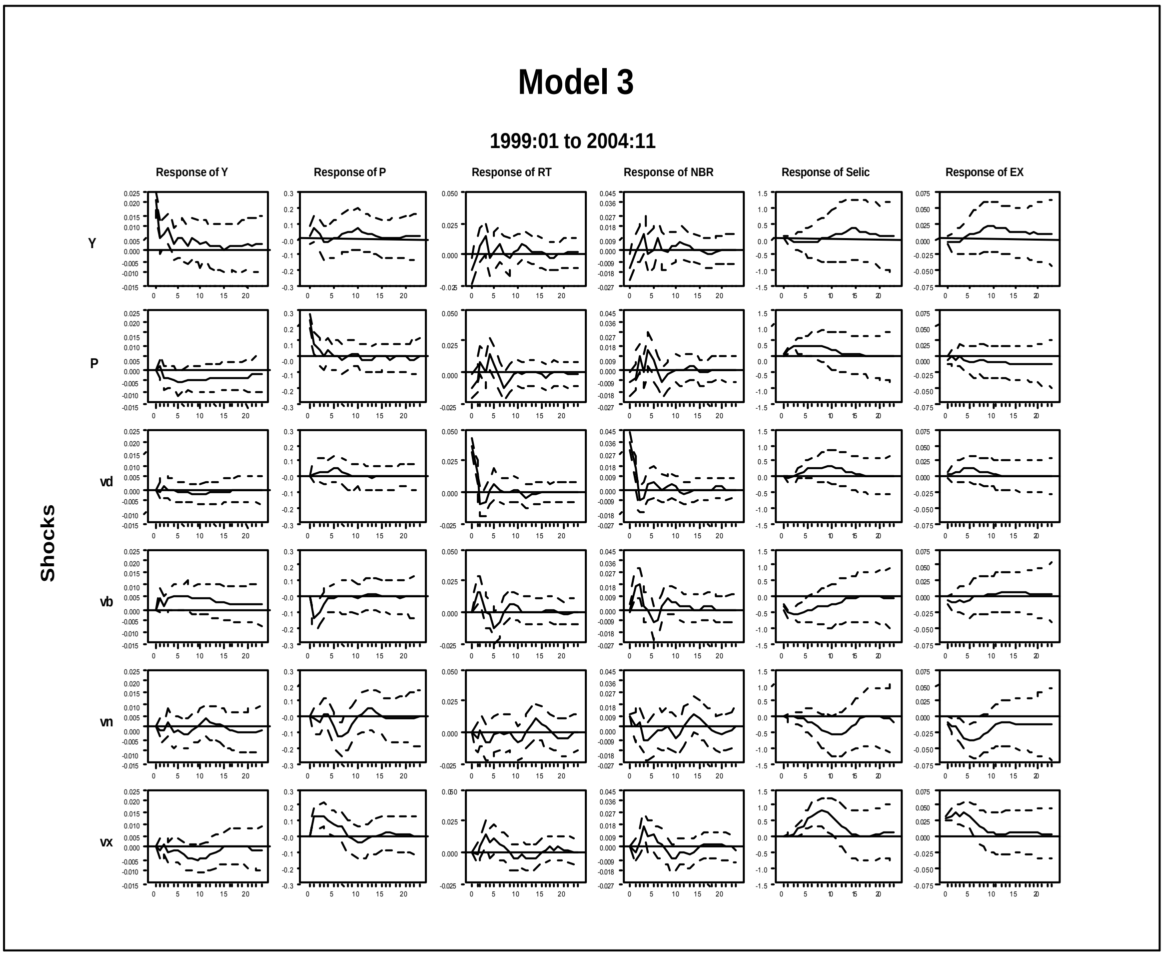
[45]The models were re-estimated with lags of 2, 2 and 4 periods, respectively, using the Choleski decomposition and two orders for the variables RT and NBR. In the first, RT comes before NBR and in the second, the opposite occurs. The order of the variables Y, P, Selic, D and EX stays the same. Only for the VAR whose non-borrowed reserves come before the total reserves is the liquidity effect significant in some period. The model with the exchange rate does not display the liquidity effect at the beginning. The relevance of the liquidity effect depends on the order of the variables in the decomposition.

[46]With a =0, only a shock in the demand for reserves produces contemporaneous effect in total reserves in the money market. Therefore, we define the liquidity effect as a short-run negative correlation between interest rate and non-borrowed reserves.

Figure 3



The shock to the exchange rate – v^x – represents depreciation and generates a statistically significant increase in the inflation rate. In other words, twelve months after the initial shock to the exchange rate of 2.5%, the inflation rate displays a cumulative increase of 0.5 percentage points. The lagged output decrease is not significantly significant. The exchange rate depreciation is followed by an increase in non-borrowed and in total reserves and the response of these variables is stronger than their response to the policy shock v^n. The Selic rate increases in the following periods.

The shock to the demand for reserves – v^d – increases the amount of total and non-borrowed reserves, while the non-borrowed reserves stay almost constant. The Selic rate and the exchange rate have small changes. There is no remarkable effect in the output and in the inflation rate.

The shock to the borrowed reserves – v^b – does not initially change the total reserves. It provokes a small reduction in the total reserves, which is consistent with interest rate targeting. The Selic and the exchange rate decrease, although this decline is not statistically significant. The inflation rate also falls off. The response for output is not statistically significant.

Model 3 shows a degree of inflation rate persistence similar to the sub-sample Model 2 (starting from 1999). The response of the Selic rate to an inflation rate shock is as expected (positive) and that of the output is very small. The responses of the exchange rate to the same variables are not accurately estimated.

5 Conclusions

Contemporaneous correlations between reserves (money) and the interest rate are relevant since reserves are strongly correlated with future prices and output. Recursive identification schemes perform an extreme decomposition of the structural shocks which are not robust to the order that the variables enter into the decomposition: (a) if money is predetermined to interest rate, then no correlation is attributed to the monetary policy shock; (b) if the interest rate is predetermined to money, all correlation is attributed to the policy shock. As we simultaneously identify the interest rate and reserves it is not necessary to impose either (a) or (b), although estimates might result in (a) or (b). Given that, in our model, the correlation between interest rate and bank reserves derives from the interaction between supply and demand in that market, it is easy to disentangle the policy shock from the shock to the demand for reserves (and for discounting).

There is evidence that we were able to extract a less "contaminated" policy shock since the responses of real output and of the inflation rate to shocks to the demand for reserves and borrowed reserves are statistically significant.

During the full sample period, we find strong evidence that the BC has the interest rate (Selic rate) as its operational goal, even when the Monetary Policy Committee announced the discount rates (TBC and TBAN) instead of the Selic rate.

The estimation of the borrowed reserves curve in a multivariate context shows that the spread between the Selic rate and the discount rate produces information for estimating the amount of discount. In addition, as expected, the monthly demand for reserves is inelastic to the interest rate. The estimates of the reaction function of the BC open-market desk and of the borrowing function display the expected signs. An important finding is that the discount rate is important in monetary policy studies.

The liquidity effect is present in all the empirical models we have tested, being larger in Model 2 (with the discount rate). In addition, the common finding that persistence of the inflation rate seems to have decreased after the implementation of the floating exchange rate regime in 1999 is corroborated.

The responses of the monetary policy shocks on output are as expected and statistically significant. The effect on the inflation rate is less conclusive, and there is a small inflation rate puzzle. If one does not incorporate shocks to the demand for money (reserves) in a model that includes some money aggregate, the results might be different from those found in this paper regarding the size and the length of response of the policy shock on real output.[47]

Another main conclusion is that, due to structural breaks, it may be harmful to consider the full sample period after the Real Plan in Model 3, which includes the exchange rate. When the exchange rate is not present, structural breaks are not detected.

Finally, the launch of the Brazilian Payment System does not affect the results, although banks might have begun to manage bank reserves in a different way.

[47] See Minella (2001).

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A Appendix
A.1 Time Series: Description

We have constructed the series RT, NBR and D from data of the Central Bank of Brazil. All data are available through the Internet on the site www.bcb.gov.br.

Y – the IPI variable was deseasonalized by a SARIMA Model, beginning from 1994:07;

P – the IPCA variable (percentage change p.m.) was deseasonalized by a SARIMA Model, beginning from 1994:07;

RT – sum of bank reserves and bank's vault cash, average of daily balances;

NBR – this variable is the difference between total reserves and borrowed reserves. Borrowed reserves are the loans that the BC grants to banks to supply their short-run liquidity needs. We add the borrowed reserves from two periods. For the period before 1996:07, we have considered lending facilities up to the draft limit. From 1996:07 onwards, we have considered the operations based on TBC and TBAN rates, which have treasury bonds as collateral, and the discount window daily operations after 1999, also backed by treasury bonds. In the whole period we have included the operations performed by the BC open-market desk at the end of the day and with individual banks. The data are monthly average of daily balances;

R – interest rate of the market for bank reserves (named Selic rate), monthly average per year;

D – discount rate. The traditional discount rates are a non-weighted average of daily discount rates, disregarding the daily financial volumes (data not available). The discount rate set by the open-market desk is weighted by financial volumes. The final discount rate is weighted by the monthly financial volumes of the two pieces of discount window (the traditional and the one from the desk);

EX – purchase exchange rate R$/USD, monthly average.

A.2 Relation between Orthogonal and Observed Innovations in the A-B Model

Usually, an identified VAR model is a class of differential stochastic linear equation models:

$$\Gamma(L)y_t = v_t \tag{1}$$

where y_t is a vector of stochastic process that has an AR representation of finite order; Γ is a matrix polynomial with positive exponent of the lag operator L and Γ_0 is full rank matrix. For identified VAR, $\Sigma = Var(v_t)$ must be diagonal, that is E(v_t v_t'| y_{t-s}, s**>**0) = **D**; E(v_t |y_{t-s}, s**>**0) = 0, $\forall$ t and the errors v_t are Gaussian.

Let's assume that if (1) is multiplied by Γ_0^{-1} we will have the reduced form (VAR) of the model:

$$\Gamma_0^{-1}\Gamma(L)y_t = C(L)y_t = \Gamma_0^{-1}v_t = u_t \tag{2}$$

Let A and B be n-order invertible matrices, such that Au_t =Bv_t. Therefore from (2), Γ_0=B^{-1}A. The A matrix makes a linear transformation in u_t, generating a new vector that is linear combinations (via B) of n orthogonal shocks. The model in the form above is the A-B Model (vide Amisano and Giannini, 1997).

The likelihood function, in log, has the form:

$$l(C, B^{-1}A) = -\frac{1}{2}T\log(2p) + T\log|B^{-1}A| - \frac{1}{2}tr(\sum u_t(C)ut(C)' A' B^{-1'} B^{-1}A) \tag{3}$$

Integrating out the function in relation to C, the marginal p.d.f. is proportional to:

$$-\frac{1}{2}(T-k)\log(2p) + (T-k)\log|B^{-1}A| - \frac{1}{2}tr(\sum \hat{u}_t(C)\hat{u}t(C)' A' B^{-1'} B^{-1}A) \tag{4}$$

where k is the number of variables on the right side of the equation and $\hat{u}_t$ are the OLS estimates of u_t. If we concentrate the likelihood in relation to C, keeping constant

$\Gamma_0 = B^{-1}A$, we obtain the same expression as before, except that T-k substitutes T. In short, the function is:

$$L(A,B) = c + \frac{T}{2}\log[|A|^2] - \frac{T}{2}\log[|B|^2] - \frac{T}{2}tr(A'B^{-1}{}'B^{-1}A\hat{\Sigma})$$

Where $\hat{\Sigma} = \hat{A}^{-1}\hat{B}\hat{B}\hat{A}^{-1'}$

A.3 Results

Table A.I – Test LM for Serial Correlation

Models	Model 1		Model 2		Model 3 (full sample)	
Lags	Statistics	Prob.	Statistics	Prob.	Statistics	Prob.
1	47.4645	0.0043	54.1823	0.0264	80.6059	0.0000
2	36.5614	0.0635	43.4732	0.1831	50.7630	0.0523
3	34.8065	0.0918	42.9581	0.1977	37.7311	0.3900
4	28.1701	0.3001	39.6854	0.3091	40.9424	0.2625
5	36.1113	0.0699	43.6759	0.1776	52.8501	0.0347
6	26.5078	0.3809	39.2722	0.3254	33.7435	0.5764
7	34.8655	0.0907	45.0103	0.1442	40.0726	0.2943
8	14.7094	0.9479	21.5236	0.9731	23.1164	0.9524
9	23.5278	0.5468	25.2812	0.9091	32.4763	0.6370
10	26.2985	0.3918	38.5765	0.3539	30.0637	0.7462
11	14.3177	0.9559	23.7054	0.9425	21.5885	0.9724

Table A.II – Test for Normality of Residuals (Jarque-Bera)

	System	Y	P	RT	NBR	R	D	EX
Model 1	83.1419	5.5339	17.5516	1.2086	28.3825	30.4654		
	(0.0000)	(0.0629)	(0.0002)	(0.5465)	(0.0000)	(0.0000)		
Model 2	77.0977	5.8423	14.1859	2.0859	27.1688	21.9100	5.9048	
	(0.0000)	(0.0539)	(0.0008)	(0.3524)	(0.0000)	(0.0000)	(0.0522)	
Model 3	70.6421	6.8281	6.7113	2.1755	23.1456	25.1863		6.5954
	(0.0000)	(0.0329)	(0.0349)	(0.3370)	(0.0000)	(0.0000)		(0.0370)

Table A.III – Test for Conditional Heterokedasticity

Series		Y	P	RT	NBR	R	D	EX
Model 1								
ARCH(2)	F(2.116)	0.4979	0.3718	0.6353	3.1143	1.9810		
	χ^2	0.9957	0.7437	1.2705	6.2286	3.9620		
		(0.6078)	(0.6895)	(0.5298)	(0.0444)	(0.1379)		
ARCH(6)	F(6.108)	0.5273	0.2658	1.4367	6.4835	1.2137		
	χ^2	3.1640	1.5947	8.6204	38.9012	7.2825		
		(0.7880)	(0.9530)	(0.1961)	(0.0000)	(0.2955)		
Model 2								
ARCH(2)	F(2.116)	0.1216	0.3113	0.7695	2.9123	1.2102	0.7651	
	χ^2	0.2433	0.6225	1.5389	5.8245	2.4204	1.5301	
		(0.8855)	(0.7325)	(0.4633)	(0.0544)	(0.2981)	(0.4653)	
ARCH(6)	F(6.108)	0.3264	0.2065	2.0454	7.2385	0.7061	0.3919	
	χ^2	1.9587	1.2393	12.2724	43.4311	4.2363	2.3515	
		(0.9235)	(0.9749)	(0.0562)	(0.0000)	(0.6447)	(0.8847)	

Model 3 (full sample)								
ARCH(2)	F(2.116)	0.2311	0.1357	0.6866	3.2989	2.3271		18.6219
	χ^2	0.4623	0.2714	1.3732	6.5979	4.6542		37.2438
		(0.7936)	(0.8731)	(0.5033)	(0.0369)	(0.0976)		(0.0000)
ARCH(6)	F(6.108)	0.3177	0.2341	1.4594	6.7154	1.5066		6.1094
	χ^2	1.9063	1.4044	8.7561	40.2924	9.0398		36.6563
		(0.9281)	(0.9656)	(0.1878)	(0.0000)	(0.1714)		(0.0000)

Obs.: P-*values in parenthesis*.

Table A.IV – Bai-Perron Test (2003) for Multiple Structural Changes

Model 2				
Statistics	RT	NBR	R	D
Best break point	12/1996	12/1996	09/1995	09/1995
SSR	0.54336	0.81484	1325.23606	1800.92584
BIC	-4.40496	-3.99974	3.39437	3.70108
Two best points	08/1996 e 12/1997	07/1996 e 11/1997	09/1995 e 09/1998	09/1995 e 09/1998
SSR	0.34544	0.38058	547.25753	864.86083
BIC	-4.34931	-4.25242	3.01855	3.4762

Model 3				
Statistics	RT	NBR	R	EX
Best break point	12/1996	12/1996	11/1995	11/1998
SSR	0.53951	0.79791	1229.15054	0.12296
BIC	-4.33383	-3.94248	3.39735	-5.81261
Two best points	07/1996 e 01/1998	07/1996 e 11/1997	12/1995 e 11/1997	11/1998 e 04/2002
SSR	0.31394	0.38783	666.3439	0.05434
BIC	-4.32756	-4.11618	3.33281	-6.08151

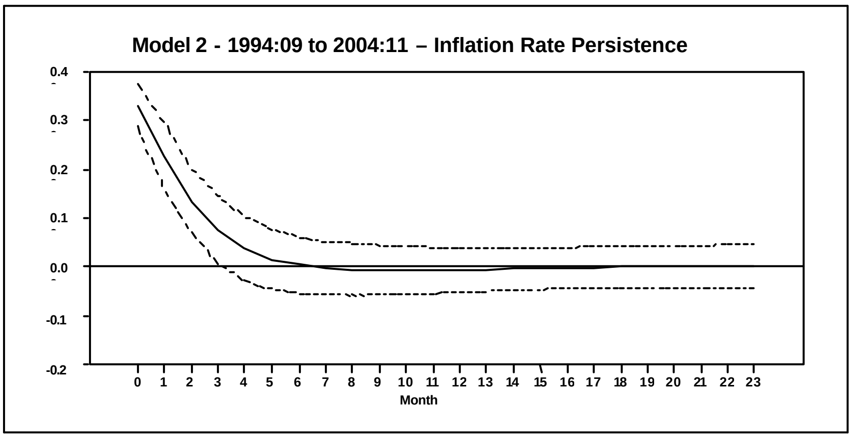
Statistics	**Excess Reserves**
Best break point	04/1996
SSR	0.00668
BIC	-9.66374
Two best points	08/1995 e 01/1997
SSR	0.00355
BIC	-10.21794

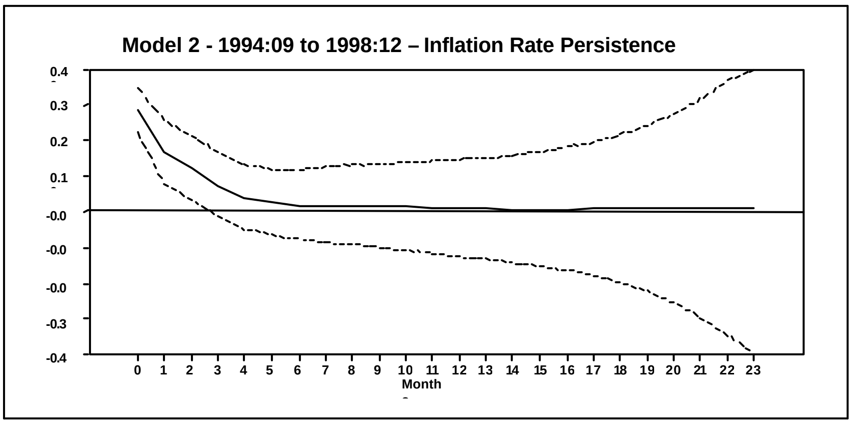
Table A.V – Contemporaneous Correlation Among Monetary Aggregates and Rates

Models	Variables	RT	NBR
Model 1	R	-0.211759915	-0.188457808
Model 2	R	-0.214787204	-0.209534796
	D	-0.183178375	-0.158670778
Model 3	R	0.266333916	0.279017079
	EX	0.161198241	0.114825742

Obs: Correlations from the VAR residuals of lags 2. 2 e 4. respectively.

Figure A.1


Model 2 - 1994:09 to 2004:11 – Inflation Rate Persistence
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month


Model 2 - 1994:09 to 1998:12 – Inflation Rate Persistence
0.4
0.3
0.2
0.1
-0.0
-0.0
-0.0
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month

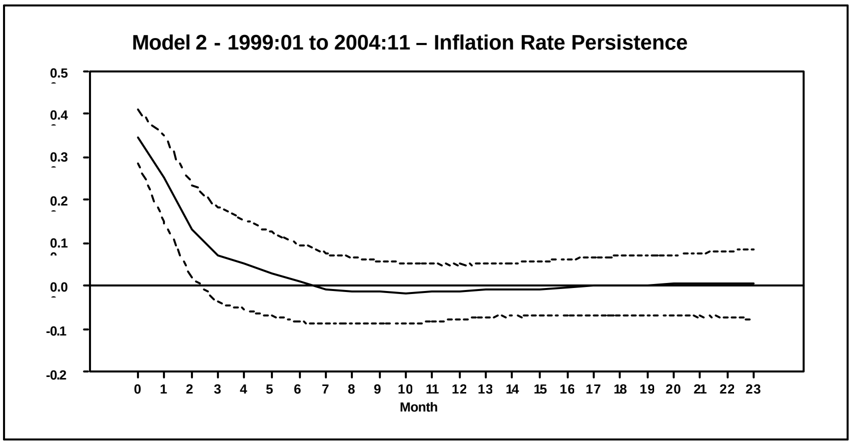
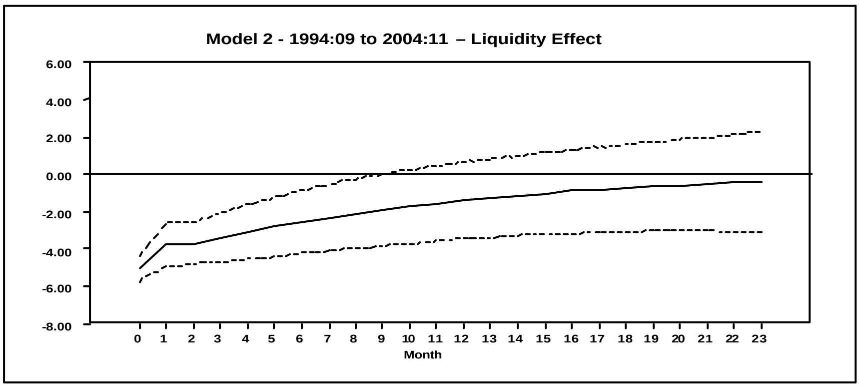
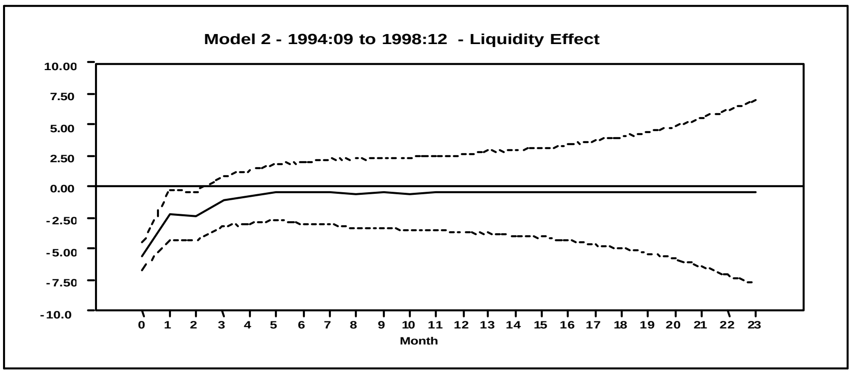
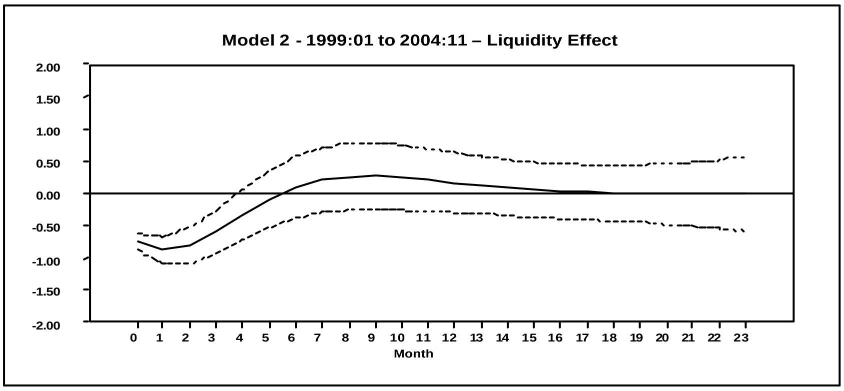

Model 2 - 1999:01 to 2004:11 – Inflation Rate Persistence
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month

Figure A.2


Model 2 - 1994:09 to 2004:11 – Liquidity Effect
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month


Model 2 - 1994:09 to 1998:12 - Liquidity Effect
10.00
7.50
5.00
2.50
0.00
-2.50
-5.00
-7.50
-10.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month


Model 2 - 1999:01 to 2004:11 – Liquidity Effect
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Month

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