

149

DISCUSSION PAPER

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MONETARY POLICY, INFLATION AND THE LEVEL OF ECONOMIC ACTIVITY IN BRASIL AFTER THE REAL PLAN: STYLIZED FACTS FROM SVAR MODELS

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DISCUSSION PAPER

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SUMMARY

SINOPSE

ABSTRACT

1 INTRODUCTION 1

2 BRAZILIAN STYLIZED FACTS AND VARs: A BRIEF REVIEW OF THE LITERATURE 2

3 ESTIMATION PROCEDURE AND DATA 3

4 "CONTEMPORANEOUS CAUSATION" AND THE IDENTIFICATION OF
STRUCTURAL VARs 4

5 CAUSAL INFERENCE AND THE SPIRITES-GLYMOUR-SCHEINES MODEL 6

6 MONETARY POLICY DEVELOPMENTS SINCE THE REAL PLAN 11

7 BENCHMARK MODEL AND RESULTS FOR THE FIRST SUBSAMPLE—1996/07-1998/08 15

8 BENCHMARK MODEL AND RESULTS FOR THE SECOND SUBSAMPLE—1999/03-2004/12 18

9 CONCLUDING REMARKS 20

BIBLIOGRAPHY 21

SINOPSE

Este artigo investiga as relações estocásticas e dinâmicas de um grupo de variáveis macroeconômicas brasileiras (índices de preços, produção industrial, taxa de câmbio nominal, taxas de juros de curto e médio prazo, e M1) para o período após o Plano Real (1996-2004). Adota, como é usual na literatura, vários modelos SVARs (VAR estruturais) para determinar os fatos estilizados relativos aos impactos de curto prazo das fontes exógenas de flutuação identificadas para esse grupo de variáveis.

O artigo inova ao empregar Grafos Acíclicos Direcionados (DAG) na obtenção das relações causais contemporâneas entre as variáveis e ao considerar que as alterações da política monetária, ocorridas após o Plano Real, tornam essencial a divisão da nossa amostra em dois subperíodos (1996/07-1998/08 e 1999/03-2004/12).

Os resultados principais são: *a*) em resposta a uma inovação positiva na taxa de juros de curto prazo (Selic), durante o subperíodo 1999-2004, a produção e o nível de preços caem — porém, a resposta da produção é mais rápida que a do nível de preços, que só acontece com uma defasagem de aproximadamente quatro meses; *b*) para o período 1996-1998, o efeito mais provável de uma inovação positiva na taxa de juros de curto prazo é a redução do nível de preços — também com uma defasagem de quatro meses, embora haja uma grande incerteza em relação a essa resposta — e da produção; *c*) as inovações na taxa de juros de curto prazo (Selic) estão entre as fontes mais importantes da flutuação do nível de atividade econômica em ambos os subperíodos; e *d*) os choques exógenos na taxa de câmbio e na taxa de juros de médio prazo (*Swap* Pré x CDI) são, para o período 1999-2004, as fontes mais importantes da flutuação da taxa de inflação.

ABSTRACT

This article investigates the stochastic and dynamic relationship of a group of Brazilian macroeconomic variables (price and industrial production indexes, nominal exchange rate, short and medium-run nominal interest rates) for the period after the Real Plan (1996-2004). We adopt, as has become usual in the literature, several SVAR (structural VAR) models to uncover stylized facts for the short-run impacts of the identified exogenous sources of fluctuations of this selected set of variables.

A distinctive feature of this article is the employment of Directed Acyclic Graphs (DAG) to obtain the contemporaneous causal order of the variables used to identify the SVAR models. Another distinguishing characteristic is the careful attention paid to monetary policy developments after the Real Plan when splitting our sample in two subsamples (1996/07-1998/08 and 1999/03-2004/12).

The main results are: *a*) in response to a positive short run interest rate innovation, during the 1999-2004 subperiod, the output and the price level decrease—however, the output response is faster and the price level responds with a lag of near four months; *b*) for the 1996-1998 subperiod, the most likely effect of a positive short run interest rate innovation is the reduction of the price level (also with a four months lag), even though there is a large uncertainty in this response, and the reduction of output; *c*) short run interest rate innovations are one of the most important sources of temporary fluctuations in the level of economic activity for both subsamples; and *d*) exogenous shocks to the exchange rate and to the medium term interest rate are for the 1999-2004 period, the most important sources of inflation rate fluctuation.

1 INTRODUCTION

This article investigates the stochastic and dynamic relationship of a group of Brazilian macroeconomic variables (price and industrial production indexes, nominal exchange rate, short and medium-run nominal interest rates) for the period after the Real Plan (1996-2004). We adopt, as has become usual in the literature, several SVARs (structural VARs) models to uncover stylized facts for the short-run impacts of the identified exogenous sources of fluctuations of this selected group of variables.

There are many recent empirical studies about the dynamic relationship of sets of macroeconomic variables in Brazil employing SVARs as the framework of their analysis [Fiorencio, Lima and Moreira (1998), Rabanal and Schwartz (2001), Arquete and Jayme Jr. (2003) and Minella (2003), among others]. With the exception of Fiorencio, Lima, and Moreira (1998), all of them use Cholesky decompositions of the covariance of reduced form VAR disturbances to identify the model. What distinguishes our article from the existing Brazilian literature is the adoption of a data oriented procedure to select over-identifying restrictions to estimate our SVARs. These restrictions follow from directed acyclic graphs (DAG) estimated by the TETRAD software developed by Spirtes, Glymour and Scheines (1993 and 2000) using as input the covariance of reduced form VAR disturbances. Another distinguishing characteristic of our article is the careful attention paid to monetary policy developments after the Real Plan in the selection of the appropriate subsamples. The first subsample goes from 1996/07 to 1998/08, the period with exchange rate “mini-bands” combined with the adoption of the TBC rate as an informal target for the Selic rate. The second subsample goes from 1999/03 to 2004/12, the period with free-floating exchange rate and explicit Selic targeting.

Over the last years there has been a growing interest on graphical models and in particular on those based on DAGs as a general framework to describe and infer causal relations, exploring the connection between causal structure and probability distributions [see, for example, Spirtes, Glymour and Scheines (1993 and 2000), Pearl (2000) and Lauritzen (2001)]. These methods have been used in a variety of fields but are unfamiliar to most economists. Swanson and Granger (1997) were the first to apply graphical models to identify contemporaneous causal order of a SVAR, although they restrict the admissible structures to causal chains. Bessler and Lee (2002) use error correction and DAGs to study both lagged and contemporaneous relations in late 19th and early 20th century United States data. Demiralp and Hoover (2003) evaluate the PC algorithm employed by TETRAD in a Monte Carlo study and conclude that it is an effective tool of selecting the contemporaneous causal order of SVARs. Awokuse and Bessler (2003) use DAGs to provide over-identifying restrictions on the innovations from a VAR and compare their results with the ones of Sims (1986). Moneta (2004) use DAGs and the data set of Bernanke and Mihov (1998) to identify the monetary policy shocks and their macroeconomic effects in the United States.

The main results are: *a*) in response to a positive short run interest rate innovation, during the 1999-2004 subperiod, the output and the price level decrease—however, the output response is faster and the price level responds with a lag of near four months; *b*) for the 1996-1998 subperiod, the most likely effect of a

positive short run interest rate innovation is the reduction of the price level (also with a four months lag), even though there is a large uncertainty in this response, and the reduction of output; *c*) short run interest rate innovations are one of the most important sources of temporary fluctuations in the level of economic activity for both subsamples; and *d*) exogenous shocks to the exchange rate and to the medium term interest rate are for the 1999-2004 period, the most important sources of inflation rate fluctuation.

The article is organized as follows. Section 2 presents a brief review of the Brazilian literature on macro variables and VARs. Section 3 describes the data and the estimation procedures used. Section 4 explains how the identification of contemporaneous causation allows the identification of VARs. Section 5 presents the Spirtes-Glymour-Scheines Model. Section 6 describes monetary policy developments that followed the Real Plan. Sections 7 and 8 present the benchmark model and results for the first and the second subsamples, respectively. Finally, we offer some concluding remarks on Section 9.

2 BRAZILIAN STYLIZED FACTS AND VARs: A BRIEF REVIEW OF THE LITERATURE

In this section we present a brief review of the recent Brazilian literature related to VARs and groups of macroeconomic variables.

Within the classical approach to VARs we have the studies of Rabanal and Schwartz (2001), Arquete and Jayme Jr. (2003), and Minella (2003), while Fiorencio, Lima and Moreira (1998) use a Bayesian VAR (BVAR) in their analysis.

Fiorencio, Lima and Moreira (1998) use BVAR models to analyze the impacts of monetary and exchange rate policies on unemployment and the price level after the Real Plan. The benchmark model was estimated for the period between January 1991 and May 1997, with and without intervention on July and August 1994, using as variables the price level (IPCA), the unemployment rate, the exchange rate, the interest rate over capital financing (*capital de giro*) and the spread between capital financing and private bonds (CDBs) rates. Employing a non-recursive identification they find that exchange rate shocks have significant impacts over the price level and unemployment and that monetary policy shocks do reduce the price level and increase unemployment (in the model with intervention).¹ According to them the results suggest that there has been a change of regime after the Real Plan and that the effects of economic policy shocks in the model are sensitive to the way this change of regime is represented.

Rabanal and Schwartz (2001) use a VAR to analyze the effectiveness of overnight interest rate (Selic) as a monetary policy instrument in Brazil and its effects on other interest rates, output, and prices for the period between January 1995 and August 2000. The variables included in the VAR are real output, inflation (IPCA), Selic rate, lending spreads, and money (M1), used in this order in the recursive

1. The impacts of monetary policy shocks over the price level and unemployment are reversed in the model without intervention.

(Cholesky) decomposition of the variance-covariance matrix of errors.² They conclude that the Selic rate has a significant and persistent effect on output and lending spreads but interest rate shocks seemed to increase inflation “price puzzle”.

Arquete and Jayme Jr. (2003) evaluate the impact of monetary policy on inflation and output, covering the period between July 1994 and December 2002. As variables of the model they used inflation (IPCA), Selic rate, and output gap, employed in this order in the recursive decomposition of errors.³ In some of their analysis they also included a fifth variable (alternatively the nominal exchange rate, the real exchange rate, and the international reserves at the Central Bank) intended to capture external constraints in Brazil. According to them monetary policy have real effects, external restrictions and exchange rate volatility are important to the Central Bank reaction function but interest rate shocks increase inflation.

Minella (2003) investigates the macroeconomic relationships involving output, inflation, interest rate, and money, comparing three different periods: January 1975/July 1985, August 1985/June 1994, September 1994/December 2000. His benchmark model includes output, inflation (IGP-DI), nominal interest rate (Selic rate), and money (M1), used in this order in the Cholesky decomposition. His main results are that monetary policy shocks have significant effects on output but are not able to induce a reduction of inflation, with evidence suggesting the “price puzzle” in the second subperiod.

3 ESTIMATION PROCEDURE AND DATA

Our VARs reduced forms were estimated equation by equation using ordinary least squares (OLS). Following the results of Sims and Uhlig (1991) and Sims, Stock and Watson (1990) we do not performed unit root tests or cointegration analysis.

The models were estimated using monthly data divided into two subsamples: the first goes from 1996/07 to 1998/08 and second from 1999/03 to 2004/12.⁴ The following variables were selected to be part of the benchmark model: the Selic interest rate (short run rate fixed by the Brazilian Central Bank (BCB), annualized rate); the nominal exchange rate (end of period buying rate; source: BCB); the IPCA (official price index used for targeting inflation—source: IBGE); the 180 days Swap rate (PRE x CDI—annualized rate with 252 working days—basic source BM&F but collected from <http://www.risktech.com.br/>); the Industrial Production index, used as a proxy for output (source: IBGE); net foreign reserves (liquidity concept, as measured by the BCB); and a monetary aggregate (M1, working days average).

2. Another ordering is also analyzed: Selic rate, lending spreads, output, inflation, and money, but the results do not change much.

3. An alternative order analyzed was: output gap, inflation, Selic rate.

4. The reasons for splitting the sample into two subsamples and the particular choice of dates are based on monetary policy developments and are discussed on Section 6.

4 "CONTEMPORANEOUS CAUSATION" AND THE IDENTIFICATION OF STRUCTURAL VARs

4.1 THE REDUCED FORM VAR MODEL

Let x_t be the data vector—there are 5 variables in the model, therefore x_t has dimension 5×1 —for each period t : $x_t = [r_t, e_t, p_t, rs_t, Y_t]'$, where: r_t = Selic rate; e_t = exchange rate; p_t = IPCA index; rs_t = swap rate (180 days); and Y_t = industrial production index.

The reduced form VAR model is given by the following set of equations:

$$B(L) x_t = \mu + \phi Z_t + v_t \quad (1)$$

$$v_t \sim N(0, \Sigma) \text{ and } E(v_t v_s') = 0, \forall t \neq s$$

where: $B(L) = I - \sum_{i=1}^3 B_i L^i$ and L is the lag operator; Z_t = seasonal dummies vector;

v_t = reduced form residuals; and μ = constants' vector.

This representation of the model does not allow for the identification of the effects of exogenous independent shocks to the variables since the VAR reduced form residuals are contemporaneously correlated (the Σ matrix is not diagonal).⁵ That is, the reduced form residuals (v_t) can be interpreted as the result of linear combinations of exogenous shocks that are not contemporaneously (in the same instant of time) correlated. It is not possible to distinguish whose exogenous shocks affect the residual of which reduced form equation. The residual can be the result, for example, of an exogenous and independent shock to the exchange rate, an exogenous and independent shock to the interest rate, or a linear combination of both shocks. In evaluations of the model (and of economic policies) it only makes sense to measure exogenous independent shocks. Therefore, it is necessary to present the model in another form where the residuals are not contemporaneously correlated. A VAR where the residuals are not contemporaneously correlated is called a structural VAR and some of its equations have, in general, a behavioral interpretation. The same is not true for reduced form VARs.

4.2 THE STRUCTURAL FORM VAR MODEL

The model in structural form is given by:

$$A(L) x_t = \rho + \theta Z_t + \varepsilon_t \quad (2)$$

$$\varepsilon_t \sim N(0, D), D \text{ (diagonal)}$$

and:

$$E(\varepsilon_t \varepsilon_s') = 0, \forall t \neq s$$

where: $\rho = A_0 \mu$, $\theta = A_0 \phi$, $A(L) = A_0 B(L)$, $\varepsilon_t = A_0 v_t$, A_0 is a full rank matrix with each element in its main diagonal equal to 1.

5. These shocks are primitive and exogenous forces, with no common causes, that affect the variables of the model.

The relationships between the residuals ε_t and v_t , and the covariances D and Σ , are given by:

$$v_t = A(0)^{-1} \varepsilon_t \text{ or alternatively, } v_t = [I - A_0] v_t + \varepsilon_t \quad (3)$$

$$A_0 \Sigma A_0' = D \quad (4)$$

Given an estimate of A_0 it is possible to estimate structural form parameters from estimates of reduced form parameters. When the reduced form VAR is estimated restricting only the number of lags (chosen as the same in all equations and for all variables), with no further restrictions, the structural VAR estimation proceeds in two steps.⁶ In the first step the reduced form VAR is estimated and this comprise the estimation of the equation's coefficients and of the covariance matrix of the reduced form residuals $\hat{\Sigma}$. In the second step the matrices A_0 and D are estimated using only the information given by the estimate of the covariance matrix of reduced form residuals (estimated in the first step).

There are in general a large number of full rank matrices A_0 and D (D diagonal) that allow us to reproduce $\hat{\Sigma}$. That is, there are several conditional dependency and independency contemporaneous relations ("markov kernels") between the variables—given by different specifications of which parameter in A_0 is free and which is equal to 0—that allow us to reproduce the partial correlations observed for the reduced form residuals.⁷ In order to estimate the structural model it is necessary to identify a number of conditional independence relations (that is, parameters equal to 0 in A_0) to satisfy the order condition for identification. Therefore, identifying A_0 is equivalent to identifying the conditional distributions ("Markov kernels") of reduced form residuals from information about their joint distribution. These conditional distributions can be interpreted either distributionally or causally. The causal interpretation requires the knowledge that the conditional distributions would remain invariant under intervention.⁸ For SVARs to be useful, as we will show below, these conditional distributions must have a causal interpretation.

With A_0 it is also estimated the orthogonal innovations of the structural form and identified the linear combinations between them that generate the reduced form residuals [first version of equation (3)]. Alternatively, the residual of each reduced form equation in period t is modeled as the sum of a single innovation (an exogenous

6. This two step procedure can be adopted because the restrictions imposed to estimate the orthogonal residuals do not imply restrictions on the coefficients of the reduced form equations. They imply restrictions only on the variance of v_t .

7. The matrices A_0 and D cannot have, together, a number of free parameters bigger than the number of free parameters in the symmetric matrix Σ . If n is the number of endogenous variables of the model then, to satisfy the order condition for identification of matrices A_0 and D , it is necessary that the number of free parameters to be estimated in A_0 be no bigger than $n(n-1)/2$ (matrix D is diagonal with n free parameters to be estimated). When n is smaller than $n(n-1)/2$ the model is over-identified. There exists no simple general condition for local identification of the parameters of A_0 and D . However, as has been shown by Rothenberg (1971), a necessary and sufficient condition for local identification of any regular point in R^l is that the determinant of the information matrix be different from 0. In practice, evaluations of the determinant of the information matrix at some points, randomly chosen in the parameter space, is enough to establish the identification of a certain model.

8. For an interesting discussion of this topic, see Freedman (2004), Hausman and Woodward (1999), and Woodward (1997 and 2001).

structural shock independent of the other structural shocks),⁹ in period t , plus a linear combination of the remaining reduced form shocks in the same period t [second version of equation (3)]. In this step it is thus important to establish a set of contemporaneous causal relations (conditional dependency and independency relations with a causal interpretation) between the reduced form residuals. That is, we need to determine, for example, whether contemporaneously (within a month, if the model uses monthly data) a shock to the reduced form residual of the exchange rate equation affects the reduced form residual of the interest rate, or the other way around, or whether there is bi-directional causality.

Obtaining stylized facts from VARs requires the identification of the structural form model. The critical question is: is it possible to obtain these contemporaneous causality relations, from the data, using just the contemporaneous correlation of the reduced form residuals, as summarized by their covariance matrix? We describe next how the methodology developed by Spirtes, Glymour and Scheines (1993 and 2000) [hereafter SGS] can help in the identification of the VAR structural form.

5 CAUSAL INFERENCE AND THE SPIRTEs-GLYMOUR-SCHINES MODEL

5.1 CAUSATION AND ASSOCIATION IN OBSERVATIONAL DATA

Common statistical wisdom dictates that causal effects cannot be consistently estimated from observational data (non-experimental data) alone unless one has substantial previous knowledge about the data generating mechanism. For this reason the contemporaneous causality restrictions, necessary for the identification of structural VARs, have been traditionally based on a priori restrictions, some of them arbitrary, others with some help of economic theory. However, SGS and Pearl and Verma (1991) claimed that it is possible to make causal inferences based on associations observed in non-experimental data without previous knowledge. Moreover, if the causal relations can be represented by DAGs, SGS have shown that under some weak conditions—sufficient large sample and distribution of random variables “faithful” to the causal graph—there exist methods for identification of causal relations that are asymptotically (in sample size) correct. The results of SGS are discussed in several articles [see, for example, Humphreys and Freedman (1996 and 1999), Korb and Wallace (1997), Spirtes, Glymour and Scheines (1997), Robins and Wasserman (1999), and Robins et al (2003)].

Robins and Wasserman (1999) use Bayesian methods to show that SGS implicitly admit that, for the set of studied variables, the probability of no unmeasured common causes is positive and not small relative to the sample size. If this is not true then causal relations cannot be identified using only data. They claim that in studies with observational data, as those in economics and other areas, the assumption that this probability is small relative to the sample size, better reflects the position of researchers. Robins et al (2003) use classical methods to analyze carefully

9. The exogenous shocks, in each period t , are represented by the vector ε_t . The VAR model is a formalization of the relationship between the vector ε_t and the vector of observed data x_t . Employing the terminology adopted in the Real Business Cycle literature, the ε_t are “impulses” (or orthogonal innovations) and the matrices in $A(L)$ [equation (2)], capture the propagation mechanism of the economy.

the asymptotic properties of SGS methodology. They show that in addition of being asymptotically consistent, the procedures are pointwise consistent, although not uniform consistent. They also show that there exists no causality test, based on associations of non-experimental data, which is uniform consistent (that is, for any finite sample, it is impossible to guarantee that the results of the proposed tests or any other causality test will converge to the asymptotic results).¹⁰

In this article we abandon the classical criteria of uniform consistency [Robins et al (2003)] and implicitly adopt Bayesian consistency criteria. That is, we assume that the probability of no unmeasured common causes, for the set of variables analyzed, is positive and not small relative to the sample size. This assumption justifies our use of the procedures proposed by SGS. Nevertheless, we agree with the view that this hypothesis maybe too strong and that the search for a more robust method, to identify matrix A_0 , should continue. We believe the economic theory, in its present stage, does not establish a set of fully acceptable restrictions that allows for the identification of A_0 . One possible extension of the present work would be to develop Bayesian estimation methods, similar to the ones proposed by Robins and Wasserman (1999), that would allow for the combination of prior information and the information in the data.

The SGS procedures allow us to establish the conditional independence relations that are equivalent to determining whose coefficients of matrix A_0 are equal to 0. The framework developed by SGS does not rule out the possibility of finding alternative sets of conditional independence relations for a given data set. In this case we arrive at a set of matrices A_0 that are observationally equivalent. It may be the case that the found conditional independence relations are not enough to allow for the identification of the matrices. However, in all applications of the methodology we found at most two alternative matrices A_0 and the implied restrictions were enough to arrive at an over-identified model.

5.2 THE SPIRITES-GLYMOUR-SCHEINES MODEL

We present below a brief description of the SGS model taken from Robins et al (2003).

A (causal) directed graph is a picture that represents a causal flow, indicated by arrows (directed edges) between some pair of vertices (variables). An edge in a graph can be either directed (marked by a single arrowhead on the edge) or undirected (unmarked). If all edges of a graph are directed, we say that it is a directed graph. Arrows represent causal relationships: if there is an arrow pointing from X_i to X_j it means that X_i has a direct causal effect on X_j , relative to all vertices. A directed path of length n between vertices X and Y is a sequence of n vertices starting at X and ending at Y of the form $X \rightarrow V_1 \rightarrow V_2 \rightarrow \dots \rightarrow V_{n-2} \rightarrow Y$ or of the form $X \leftarrow V_1 \leftarrow V_2 \leftarrow \dots \leftarrow V_{n-2} \leftarrow Y$. A DAG¹¹ is a directed graph with no directed cycle, in that one cannot start at a vertex (variable) and follow a directed path back to that vertex. The vertex X_i is in the set of “parents” of a variable X_j in a DAG G , denoted by $PA_G(X_j)$, if there is an edge

10. It is important to point out that these negative results apply to any method, not just to SGS methodology. No kind of search, no kind of model selection, no kind of test (like the t-test), can get around these limitations. Nor can any informal method based on human judgment or insight escape these limitations.

11. References on DAG include Lauritzen (1996) and Pearl (2000).

$X_i \rightarrow X_j$ in G . X_j is a “descendent” of X_i in G if there is a directed path from X_i to X_j or $X_i = X_j$.

The SGS model begins with a triple $\langle G, V, P \rangle$, where G is a DAG with a non-empty set of vertices (variables) $V = \{X_1, X_2, \dots, X_k\}$ is a vector of random variables—and P is a joint probability distribution for V . It is also used the *Causal Markov Condition* and the assumption that P is “faithful” to G . These two concepts and some auxiliary concepts are defined below.

Definition (Distribution Markov to G or “compatible” with G): A distribution P with density function p is “Markov” to G if $p(x_1, \dots, x_k) = \prod_{i=1}^k p\{x_i \mid pa_G(x_i)\}$, where $p\{x_i \mid pa_G(x_i)\} = p(x_i)$ when $pa_G(x_i) = \emptyset$. This formula is called the “Markov factorization” of P according to G .

Let $P(G)$ be all distributions that are Markov to G . If P is in $P(G)$ then P is “compatible” with G .

The next proposition was first stated in Pearl and Verma (1991), but it is implicit in the works of Kiiveri, Speed and Carlin (1984) and others.

Proposition 1

The Causal Markov Condition: Any Distribution Generated by a Markovian Model G is Markov to G ¹²

A model is “Markovian” [Pearl (2000)] if it can be represented by a DAG and all the error terms are jointly independent. The *Causal Markov Condition* states that if G represents the data generating mechanism for P , and G is Markovian, then $P \in P(G)$. A simple proof of Proposition 1 is given in Pearl (2000, p. 30).

Let $P \in P(G)$ and let $\varphi(P)$ represent all independence and conditional independence relations that hold for the variables in V under P . Let φ_G be all independence and conditional independence relationships that are common to all the distributions in $P(G)$.

Definition (faithfulness) P is “faithful” to G if $\varphi(P) = \varphi_G$.

Therefore P is faithful if it does not possess extra independence relationships not shared by all the other distributions in $P(G)$. As Spirtes-Glymour-Scheines say: “the Faithfulness Condition can be thought of as the assumption that conditional independence relations are due to causal structure rather [than] to accidents of parameters values”.

A convenient way of characterizing the set of distributions that belongs to $P(G)$ is to list the set of all independence and conditional independence relations that belongs to φ_G . These independencies can be read off G using a graphical criterion called *d*-separation [where *d* stands for directional, Pearl (1988)]. Consider three disjoint sets of variables X , Y , and Z , which are represented as vertices in G . To test whether X is independent of Y given Z in any distribution that belongs to $P(G)$, we need to test whether the vertices corresponding to variables Z “block” all paths from vertices in X to vertices in Y . Blocking is to be interpreted as stopping the flow of

12. For a discussion of the concept of causality used here (due to Judea Pearl and others) see Woodward (2001).

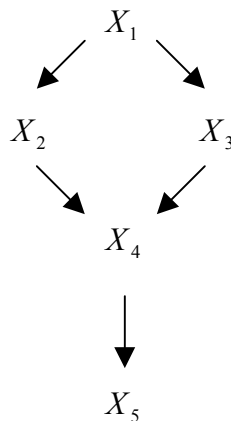
information (or of dependency) between the variables that are connected by such paths, as defined next.

Definition (*d*-separation): A path p is said to be *d*-separated (or blocked) by a set of vertices Z if and only if:

1. p contains a chain $i \rightarrow m \rightarrow j$ or a fork $i \leftarrow m \rightarrow j$ such that the middle vertex m is in Z ; or
2. p contains an inverted fork (or collider) $i \rightarrow m \leftarrow j$ such that the middle vertex m is not in Z and such that no descendant of m is in Z .

A set Z is said to *d*-separate X from Y if and only if Z blocks every path from a vertex in X to a vertex in Y .

FIGURE 1



In Figure 1, $X=\{X_2\}$ and $Y=\{X_3\}$ are *d*-separated by $Z=\{X_1\}$, because both paths connecting X_2 and X_3 are blocked by Z . The path $X_2 \leftarrow X_1 \rightarrow X_3$ is blocked because it is a fork in which the middle vertex X_1 is in Z , while the path $X_2 \rightarrow X_4 \leftarrow X_3$ is blocked because it is an inverted fork in which the middle vertex X_4 and all its descendants are outside Z . However, X and Y are not *d*-separated by the set $Z'=\{X_1, X_5\}$: the path $X_2 \rightarrow X_4 \leftarrow X_3$ (an inverted fork) is not blocked by Z' , since X_5 , a descendant of the middle vertex X_4 , is in Z' .

In order to distinguish between the probabilistic notion of conditional independence and the graphical notion of *d*-separation, we will use $(X \perp\!\!\!\perp Y \mid Z)_P$ to denote the independence of X and Y given Z in the former notion and $(X \perp\!\!\!\perp Y \mid Z)_G$ for the later notion. The following proposition due to Verma and Pearl (1988) and Geiger, Verma and Pearl (1990) shows that there is a one-to-one correspondence between the probabilistic and graphical notions of conditional independence:¹³

13. For a sketch of the proof see Pearl (2000).

Proposition 2

For Any Three Disjoint Subsets of Vertices (X, Y, Z) in a DAG G and for all Probability Functions P , we have:

a) $(X \perp\!\!\!\perp Y | Z)_G \Rightarrow (X \perp\!\!\!\perp Y | Z)_P$, whenever $P \in P(G)$; and

b) if $(X \perp\!\!\!\perp Y | Z)_P$ holds in all distributions in $P(G)$ (faithfulness), then it follows that $(X \perp\!\!\!\perp Y | Z)_P \Rightarrow (X \perp\!\!\!\perp Y | Z)_G$.

SGS developed algorithms, for inferring causal relations from data, that are embodied in computer program used in this paper, called TETRAD.¹⁴ The program takes as input the joint distribution of the variables and its output is a set of DAGs over these variables that are observationally equivalent.¹⁵ TETRAD can handle two kinds of sample data: a) independent, identically distributed multivariate Gaussian observations, or, b) independent, identically distributed multinomial observations. In the identification of SVARs TETRAD uses as input the covariance matrix of reduced form VAR residuals.

In our application TETRAD begins with a “saturated” graph, where any pair of nodes (variables) are joined by an undirected edge. If the null hypothesis of 0 conditional correlation cannot be rejected—at, say, the 5% level, using Fisher’s z test—the edge is deleted.¹⁶ After examining all pair of vertices, TETRAD move on to triples, and so forth. TETRAD also orients the edges left in the graph.

5.3 DAGS AND THE IDENTIFICATION OF STRUCTURAL VARs

Next we show how DAGs can be used to impose restrictions that allows for the identification of SVARs. In the example below we assume that the VAR has four endogenous variables.

The relationship between reduced form and structural form residuals in a VAR is given by equation (3):

$$v_t = [I - A_0] v_t + \varepsilon_t$$

where: v_t = column vector, with dimension 4×1 , with reduced form VAR residuals at period t ;

ε_t = column vector, with dimension 4×1 , with structural form VAR residual at period t ; and

A_0 = full rank matrix with the relationship between the two types of residuals.

The above equations are a system of linear equations, where each variable (reduced form residual) is a linear function of its direct causes and an error term

14. The program is available for download at www.phil.cmu.edu/projects/tetrad/index.html. We used TETRAD III in this paper.

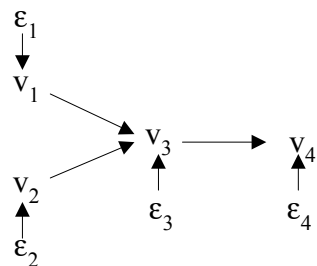
15. Two linear-normal recursive SEMs are observationally equivalent if and only if they entail the same sets of 0 partial correlations.

16. Based on simulation tests with random DAGs, SGS suggests setting the significance level at 20% for sample size smaller than 100; at 10% for sample size between 100 and 300; and at 0.5% (or smaller) for larger samples. We followed their suggestion and set the significance level at 20%.

(structural residual), with error terms independent of each other. If the graph G that represents the model has no cycles (is a DAG) then the variables are generated by a Markovian model. Therefore, the model satisfy the property that guarantees the compatibility between its distribution function and graph G .¹⁷ Because conditional independence implies 0 partial correlation, Proposition 2 translates into a graphical test for identifying those partial correlations that must vanish in the model.¹⁸ Therefore, equations (3) can be structured according to a DAG G , and the partial correlation coefficient $\rho_{V_1V_2.V_3}$ vanishes whenever the vertices corresponding to the variables in V_3 d -separate vertex V_1 from vertex V_2 in G .

We present below an example of the relationship between a DAG (the graph below), equation (3) and the coefficients that are considered different from 0 in A_0 .¹⁹

FIGURE 2



$$\begin{aligned} v_1(t) &= \varepsilon_1(t) \\ v_2(t) &= \varepsilon_2(t) \\ v_3(t) &= -A_{31}v_1(t) - A_{32}v_2(t) + \varepsilon_3(t) \\ v_4(t) &= -A_{43}v_3(t) + \varepsilon_4(t) \end{aligned}$$

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ A_{31} & A_{32} & 1 & 0 \\ 0 & 0 & A_{43} & 1 \end{bmatrix}$$

6 MONETARY POLICY DEVELOPMENTS SINCE THE REAL PLAN²⁰

The Real Plan introduced several changes in the rules of monetary policy to achieve inflation stabilization. The Provisional Measure (PM) 566 of July 29th of 1994, which implemented these changes, established quarterly limits for money expansion

17. For a sketch of the proof see Pearl (2000).

18. The partial correlation coefficient of X and Y , controlling for Z is given

by $\rho_{XY.Z} = (\rho_{XY} - \rho_{XZ}\rho_{YZ}) / (1 - \rho_{XZ})^{1/2}(1 - \rho_{YZ})^{1/2}$.

19. ε_i is the structural error term of equation i ($i = 1, 2, 3, 4$).

20. As source of information this section used Lopes (2003), several issues of the *Boletim do Banco Central do Brasil* for the period, the provisional measures cited in the text, Central Bank of Brazil (1999), the *IMF Survey* (Nov. 1998), the *Boletim de Conjuntura IPEA* (Jan. 1999), as well as information contained in the homepage of the Central Bank of Brazil (www.bcb.gov.br).

in the new currency, the real.²¹ Starting in the first quarter of 1995 the procedure of setting monetary limits was substituted for a monetary programming with quarterly projections for the expansion of monetary base (restricted and extended), M1, and M4 (the broadest monetary aggregate), formulated by the Central Bank and submitted to the Congress for evaluation, after approval by the National Monetary Council (CMN).

Although the new currency (the Real) was introduced at a rate of one-to-one to the United States dollar, there was no official commitment to any exchange rate policy. At first the Central Bank did not intervene in the foreign currency market and the Real appreciated vis-à-vis the dollar. The Central Bank reports that it began intervening in the exchange rate market in the second half of September [see Central Bank of Brazil (1999)] On March 10th of 1995 the Central Bank introduced a formal 0.88-0.93 exchange rate band with the commitment to intervene only on its limits, after an unsuccessful attempt to introduce a narrower band a day before when it lost US\$ 4 billion in international reserves (see Figure 3). At the same time the Selic interest rate was sharply increased in order to prevent any speculation against the real (see Figure 4).

On June of 1995 a new 0.91-0.99 exchange rate band was announced together with the introduction of a new mechanism of intervention in the foreign exchange market, the “spread-auction”, that in practice resulted in an exchange rate peg (see Figure 5) through what became known as “mini-bands”.²² There was no official rule for the speed of the crawling but it was understood that it was being set so as to slowly devalue the real.

On June 20th of 1996 the Monetary Policy Committee (Copom) was created with the objective of setting the stance of monetary policy and the short-term interest rate. The design of monetary policy operational procedure was modified with the introduction of two new interest rates—the TBC and the TBAN.²³ According to Lopes (2003), in this setup inspired in the Deutsche Bundesbank the TBC, the rate at which banks could have financial assistance through rediscount window of the Central Bank, played the role of an interest rate floor, and the TBAN the ceiling. In principle, the Selic rate would be allowed to fluctuate freely inside this interest rate band, with the values of both TBC and TBAN rates being determined by the Copom. However, in practice the Central Bank managed to put the Selic rate close to the TBC rate most of the time (see Figure 6).

21. The ceilings for monetary base in the third and fourth quarters of 1994 were set at R\$ 7,5 billion and R\$ 8,5 billion, respectively. However, the same PM allowed the CMN to authorize an extra margin of up to 20% of these limits. Neither the PM 566 nor the PM 596 (its update), defined how the monetary ceilings should be measured. This was set as responsibility of the CMN, who later chose the daily average balance concept. In the July-September quarter the monetary base—measured by average daily balances—reached R\$ 8,9 billion, slightly below the R\$ 9 billion ceiling once the 20% extra margin was approved by the CMN on August 24th [the monetary base measured by end of period balances reached R\$ 12,8 billion at the end of the third quarter of 1994]. The monetary limit for the last quarter of 1994 was reviewed twice. The PM 681 of October 27th of 1994 substituted the original limit of R\$ 8,5 billion substituted by a new limit that allowed an increase of 13.33% over the balances observed at the end of September, meaning that the new limit was R\$ 14,5 billion. Then, on December 21st the CMN approved a new ceiling of R\$ 15,1 billion. The average daily balance of the monetary base of the October-December quarter reached R\$ 14,8 billion. The PM 681 also introduced the concept of extended monetary base together with the establishment of a 0 growth rate for it during the last quarter of 1994 [the extended base adds federal government securities in the market (except LBC-E) to the traditional concept of monetary base]. The CMN authorized on December 21st a growth rate of 3.5% for the extended base, whose effective growth reached 1.9%.

22. Notice that the “mini-bands” are not pictured in Figure 5, only the “regular” bands.

23. The TBC was created on July 1st of 1996 and the TBAN on August 28th of 1996.

FIGURE 3
INTERNATIONAL RESERVES, FROM JULY 1994 TO FEBRUARY 1999. (NOTE: THE AMOUNTS PICTURED ABOVE INCLUDE US\$ 9.3 BILLION RECEIVED ON DECEMBER 1998 AS PART OF THE FINANCIAL PROGRAM COORDINATED BY THE IMF)

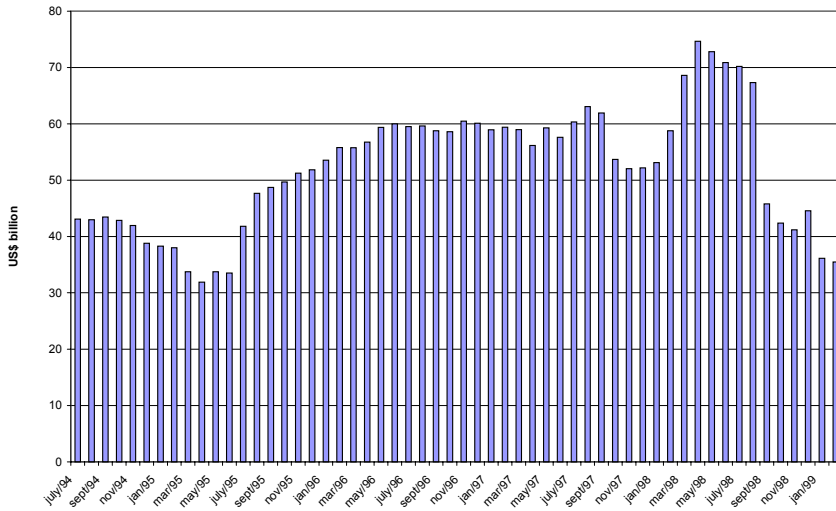


FIGURE 4
SELIC OVERNIGHT INTEREST RATE, ANNUALIZED

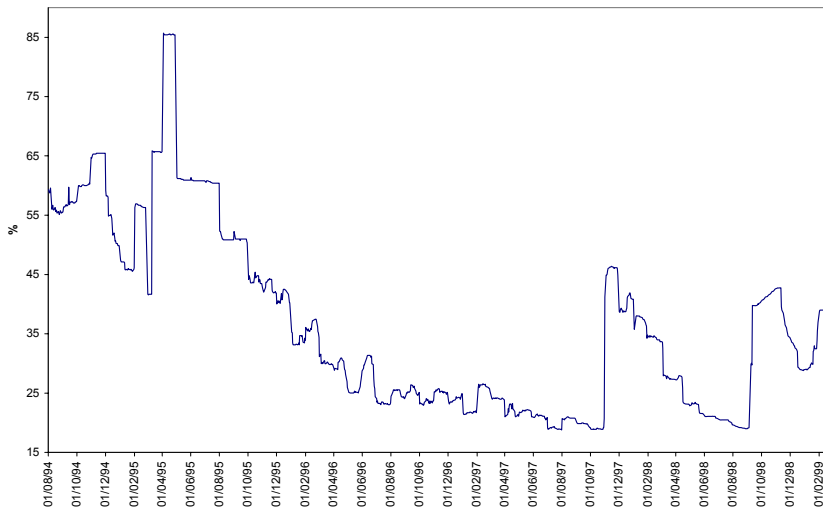


FIGURE 5
EXCHANGE RATE (R\$/US\$), FROM JULY 1994 TO JANUARY 1999

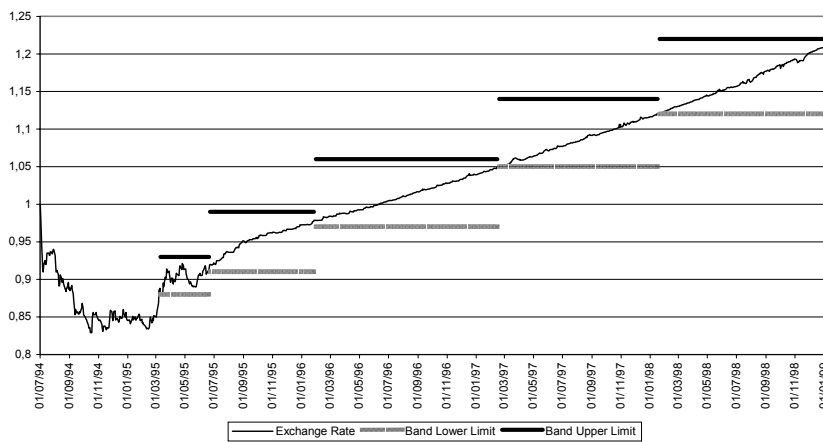
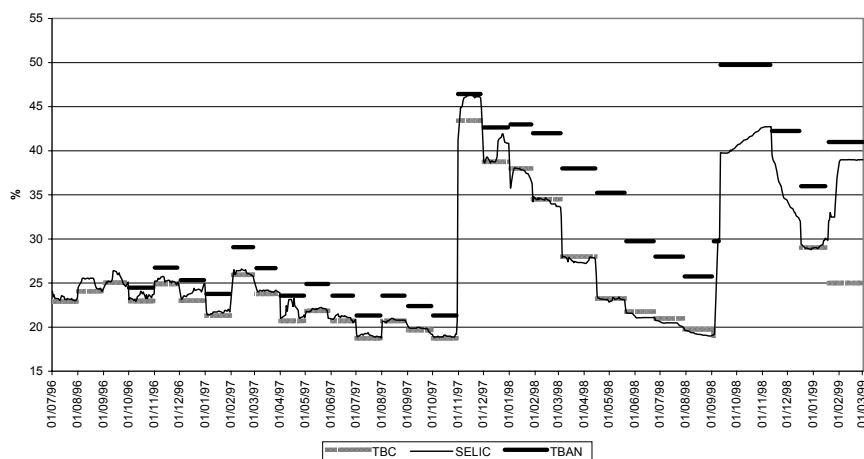


FIGURE 6
OVERNIGHT INTEREST RATES, ANNUALIZED – FROM JULY 1996 TO MARCH 1999



Note: the TBC rediscount window was closed from September 4th of 1998 to December 16th of 1998.

The Asian Crisis²⁴ and the Russian default²⁵ affected Brazil through the loss of international reserves, which caused sharp interest rate increases on October 1997 and September 1998. The monetary policy during these periods was dominated by the Brazilian government attempt to defend the real. On September 4th, 1998 there was a change in the operational procedure of the Central Bank: the rediscount window at the TBC rate was closed, making the Selic rate jump to the TBAN rate. Despite the government's efforts, the international reserves kept sliding. On November 13th, 1998 Brazil and the International Monetary Fund (IMF) announced the conclusion of negotiations on a financial program that provided support of US\$ 41.5 billion over the next three years, making US\$ 37 billion available, if needed, over the next 12 months. The Central Bank gave up defending the exchange rate on January 15th, 1999 and announced the free-floating as the new exchange rate regime on January 18th, 1999.

On March 4th of 1999 both TBC and TBAN rates were extinguished and the Central Bank started a new monetary policy operational procedure of targeting the Selic rate, with its value been determined by the Copom. Since 1996, the Copom's composition and objectives, and the frequency of its meetings, have undergone a number of changes. Brazil implemented a formal inflation targeting framework for monetary policy on June 21 of 1999. Under the inflation targeting regime, the Copom's monetary policy decisions have as their main objective the achievement of the inflation targets set by the CMN. If inflation breaches the target set by the CMN,

24. In the wake of the Asian Crisis Brazil lost near 15% of its foreign reserves on October 28th of 1997 (see Figure 3). In response, the Central Bank increased sharply interest rates with the Selic overnight rate reaching more than 45% per annum (it was near 20% before, see Figure 6) and started to operate in the dollar futures market in order to defend the exchange rate. Despite the negative effect of the interest rate hike over the public debt, it induced a huge increase in international reserves, which moved from US\$ 52 billion in November 1997 to near US\$ 75 billion in April 1998 (see Figure 3).

25. On August 17th of 1998, the rouble devaluation and the Russian default provoked an international financial crisis. According to Lopes, the Central Bank responded increasing interest rates in four stages (see Figure 6). First, on September 2nd, the TBAN rate was increased from 25.75% to 29.75% per annum. In the second stage, on September 4th, the rediscount window at the TBC rate was closed, making the Selic rate jump to the TBAN rate. In the third stage, on September 4th, the TBAN rate was increased to 49.75%. In the last stage, the Selic rate was gradually increased through open market operations, reaching 42.75% on November 4th.

the Governor of the Central Bank is required to write an open letter to the Minister of Finance explaining the reasons why the target was missed, as well as the measures required to bring inflation back to the target, and the time period over which these measures are expected to take effect. The Selic target is fixed for the period between regular Copom meetings. The Copom can also establish a monetary policy bias at its regular meetings; a bias (to ease or tighten) authorizes the Central Bank's Governor to alter the Selic interest rate target in the direction of the bias at anytime between regular Copom meetings.

As seen above, Brazil experienced several changes in policy regime in the period after the Real Plan. Therefore, in order to appropriately conduct an empirical analysis of this period it is important to divide it in subsamples sharing common features. Unfortunately, some of these subsamples are too short to allow for any type of econometric analysis. Based on the exchange rate regime and monetary policy operational procedures, we decided to partition our sample into two subsamples. The first one goes from 1996/07 to 1998/08, the period with exchange rate “mini-bands” combined with the adoption of the TBC rate as an informal target for the Selic rate. The second one goes from 1999/03 to 2004/12, the period with free-floating exchange rate and explicit Selic targeting.

7 BENCHMARK MODEL AND RESULTS FOR THE FIRST SUBSAMPLE—1996/07-1998/08

The variables selected for the Benchmark Model of the first subsample are: Selic, international reserves, price level, money (M1), output, a constant, and seasonal dummies. The chosen lag length of the model is one, following the Schwarz Information Criterion (SIC).

7.1 CONTEMPORANEOUS CAUSAL ORDERING

Applying TETRAD at the 20% significance level and assuming that the variables selected for the model are causally sufficient,²⁶ we obtain what is known as a *pattern*,²⁷ shown in Figure 7. The pattern is a graphical representation of the set of observationally equivalent DAGs containing the contemporaneous causal ordering of the variables. According to Figure 7 the Benchmark Model (BM) has four observationally equivalent DAGs, displayed on Figure 8. Each of these DAGs is a valid representation of the contemporaneous causal ordering of the BM of the first period according to TETRAD. In what follows we will restrict our attention to the

26. A set of variables V is said to be causally sufficient if every common cause of any two or more variables in V is in V . TETRAD has a bias towards excluding causal relations present in the data, to overcome this problem it is suggested that a 20% significance level be used.

27. A pattern is a partially oriented DAG, where the directed edges represent arrows that are common to every member in the equivalent class, while the undirected edges are directed one way in some DAGs and another way in others. Undirected edges mean that there is causality in one of the two directions but not on both, while double oriented edges (\leftrightarrow) mean causality on both directions.

causal ordering displayed on figure 8(B) but we would like to stress that the results discussed next do not change much when other causal orderings are used.²⁸

FIGURE 7

PATTERN OF THE FIRST SUBSAMPLE

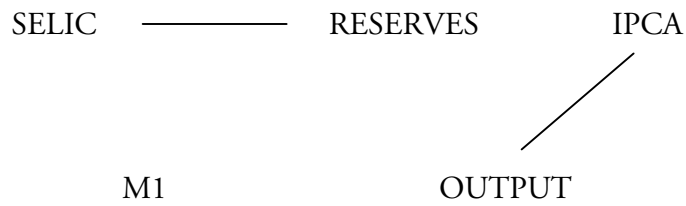
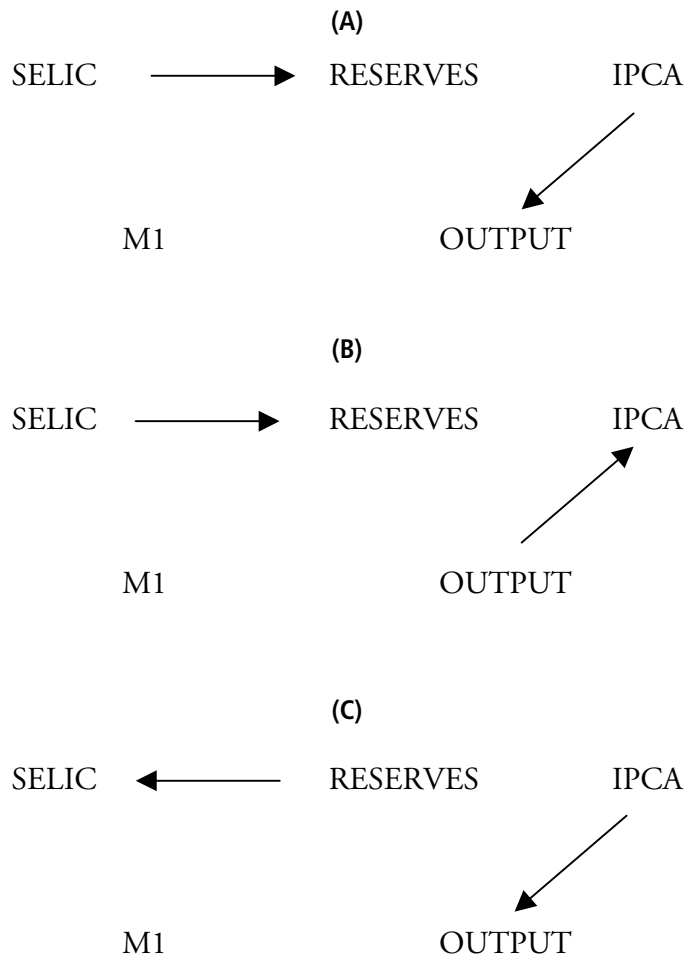
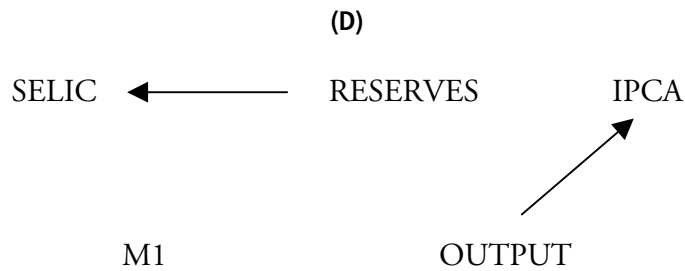


FIGURE 8

OBSERVATIONALLY EQUIVALENT DAGs FROM THE PATTERN OF THE FIRST SUBSAMPLE



28. We estimated an alternative model with the same variables of the BM using a different subsample that starts at 1995/05 and ends at 1998/12. We noticed that TETRAD's identification of the contemporaneous causal ordering showed some sensibility to whether the IMF loan of US\$ 9.3 billion given to Brazil on December of 1998 was included or not. The exclusion of the loan led to the exclusion also of the edge between Selic and reserves in the respective pattern.



7.2 IMPULSE RESPONSE ANALYSIS

Using the contemporaneous causal ordering of Figure 8(B) to identify the BM, we compute and analyze in this section the impulse response functions of economic variables to exogenous and independent shocks.²⁹

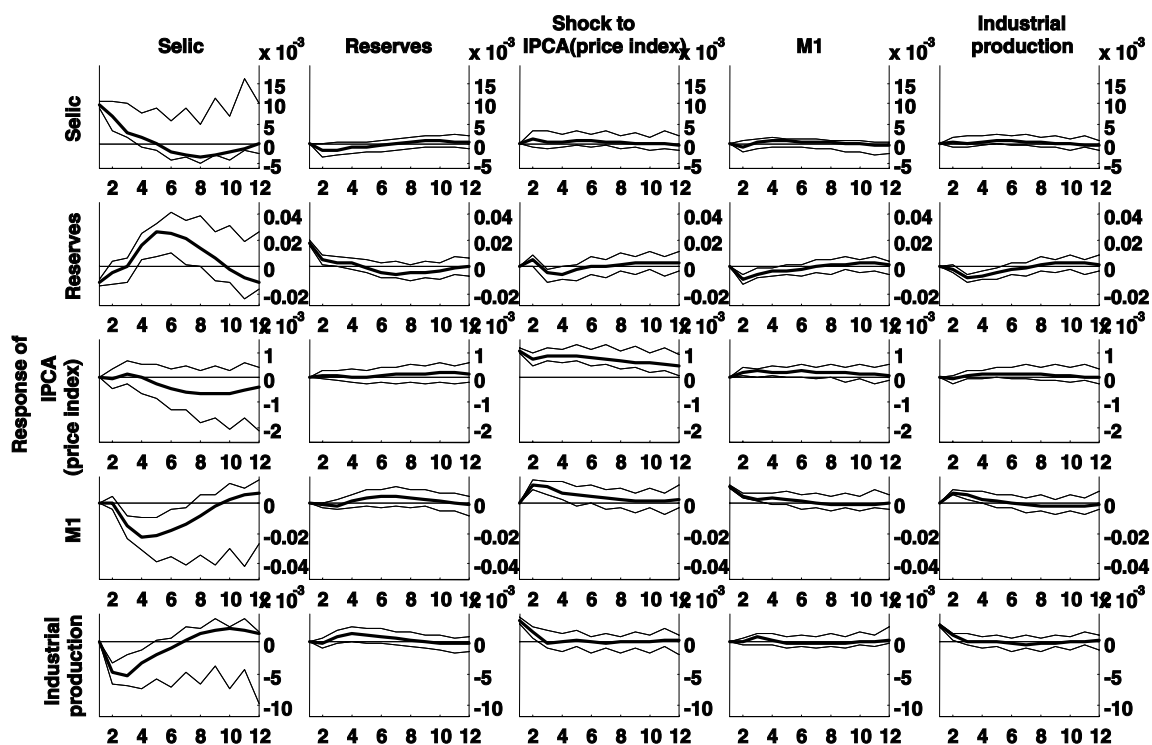
The impulse response functions (IRF) displayed on Figure 9³⁰ show that output and money fall in response to a Selic shock. The large uncertainty of the response of the price level to a Selic shock (reflected in large probability bands) is not surprising, due to the small sample size, and indicates that we should be cautious when inferring what is the response of the price level to a Selic shock. However, the most likely result (indicated by the solid line between the bands) is that the price level goes down in response to a Selic innovation.³¹ Money shocks on the other side have a more immediate effect over prices but no significant effect on the Selic rate (this is called liquidity puzzle). International reserves shocks decrease interest rates and stimulate economic activity, leading to an increase in inflation. Therefore, in this period the Selic shock is the better candidate for a monetary policy shock.

29. We will not present and discuss the parameters estimates of the model because of the difficulties associated with their interpretation, specially the estimates of the Central Bank reaction function. For a discussion of the pitfalls in interpreting estimated monetary policy rules, see Christiano et al (1999).

30. The error bands for impulse responses were constructed following the methodology suggested by Sims and Zha (1999).

31. In an alternative model for the 1995/05-1998/12 subperiod, where the exchange rate and the Swap rate were used instead of international reserves and M1, we observed an increase in the price level in response to a Selic shock, without taking into account the uncertainty of the period.

FIGURE 9
IRFs OF THE BENCHMARK MODEL 1996/07-1998/08, WITH 50% PROBABILITY BANDS



8 BENCHMARK MODEL AND RESULTS FOR THE SECOND SUBSAMPLE—1999/03-2004/12

The variables selected for the BM of the second subsample are not all the same as those chosen for the first period. The differences are that we substituted international reserves for the exchange rate, given that now there is free floating, and substituted money for medium term interest rate (Swap) because the Central Bank started targeting (explicitly) the interest rate. Therefore, the BM is now composed by: Selic, exchange rate, price level, Swap, output, a constant, and seasonal dummies. The chosen lag length of the model is two, following, as in the first period, the SIC.

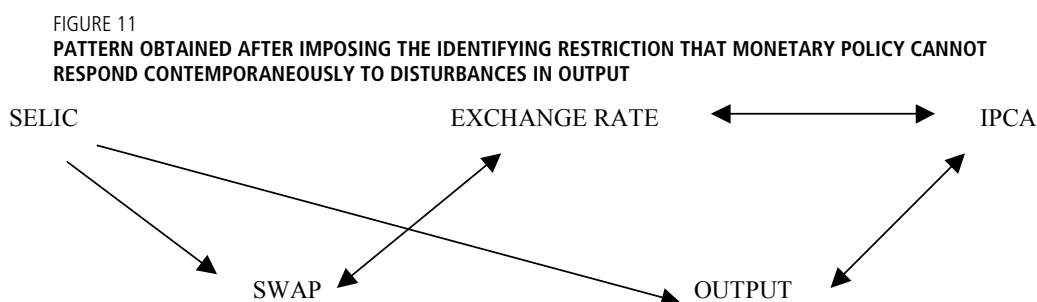
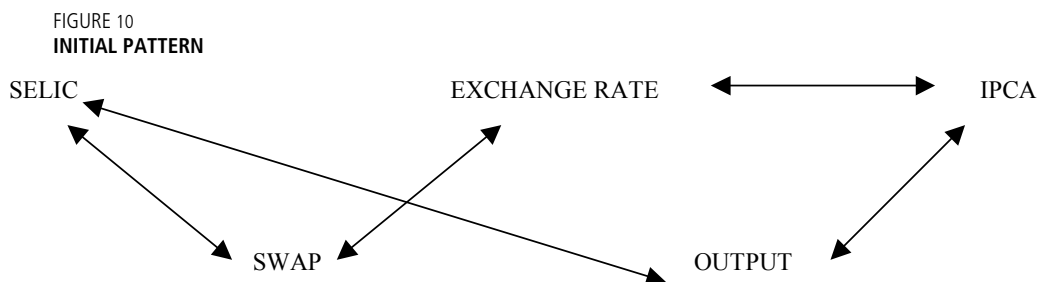
8.1 CONTEMPORANEOUS CAUSAL ORDERING

Using TETRAD to find out the contemporaneous causal ordering of the BM of the second subsample, we obtain the pattern displayed on Figure 10, containing just one DAG.³² At this point we assume that monetary policy cannot respond contemporaneously to disturbances in output, due to the absence of contemporary data of output at the time policy decisions have to be made.³³ Running TETRAD again imposing the assumption that output cannot affect contemporaneously Selic, we get a new pattern shown in Figure 11 displaying the contemporaneous causal

32. Remember that double oriented edges (\leftrightarrow) mean causality in both directions.

33. This assumption is part of the identifying restrictions made, for example, by Sims and Zha (1996).

ordering used to identify the BM of the second subsample. With this identification we obtained the IRFs of the BM of the second subsample, discussed next.³⁴



8.2 IMPULSE RESPONSE ANALYSIS

As can be seen in Figure 12, the responses to a Selic innovation are in line with the results that one would expect from monetary policy shocks: the price level goes down, output decreases, and there is an exchange rate appreciation. It is interesting to note the lag with which the price level responds to a Selic shock: it takes near four months until the IPCA starts to fall, despite the immediate contraction of economic activity. Swap shocks have effects similar to monetary policy shocks and one possible explanation for this is that the Swap rate is anticipating movements in the Selic rate that cannot be inferred by the chosen set of variables.

Exchange rate shocks induce an immediate increase in the Swap rate together with a reduction in the level of economic activity. After a period of near five months, inflation starts to increase in response to the persistent exchange rate depreciation, despite the immediate increase in the Swap rate and the increase in the Selic rate four months after the shock. In fact, exogenous shocks to the exchange rate and to the Swap rate are for the 1999-2004 period, the most important exogenous sources of inflation rate fluctuation.

The increase in the price level in response to output shocks suggests that they are associated with demand shocks. This inflationary effect together with exchange rate devaluation explain why interest rates goes up in response to output shocks during the second subsample.

34. We would like to point out that the behavior of the IRFs does not change much if the initial pattern (Figure 10) is used to identify the BM.

We estimated alternative models using the same variables of the BM employing different lag lengths (lags 1, 3, 4, 5). Using TETRAD to identify each model without imposing any additional identifying restriction, we computed the respective IRFs (without error bands). Of these IRFs, only those associated with the model with lag 1 didn't present the price puzzle, that is, an increase in the price level in response to a Selic shock. We also computed the IRFs of each model using the identification that TETRAD provided to the other lags. Only the IRFs of models with lags 1 and 2 didn't present the price puzzle, irrespective of the identification used.³⁵

9 CONCLUDING REMARKS

This article identifies the dynamic responses of a set of economic variables to policy shocks and establishes some stylized facts for the Brazilian economy. It is important to have in mind that these stylized facts refer to the response of the variables to unanticipated and unsystematic changes in policy and that any attempt to apply them to project the responses to *systematic* policy changes is unwarranted.

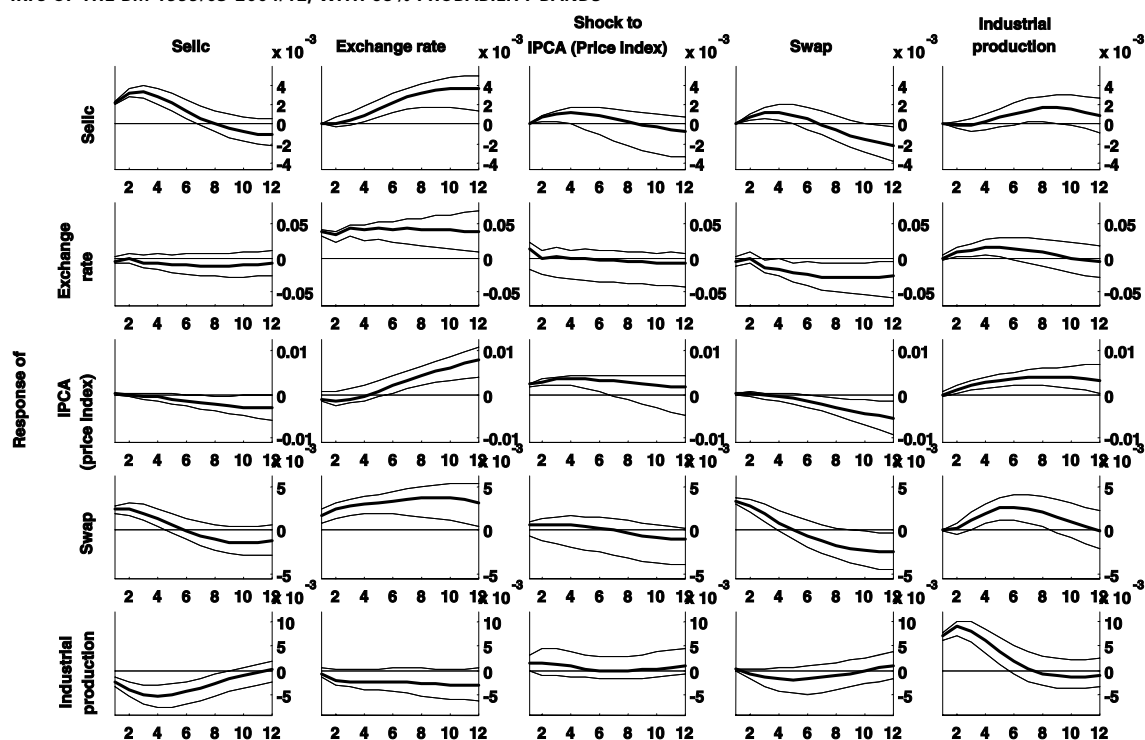
We found that monetary policy shocks (identified as Selic innovations in SVARs) in the second subsample (1999-2004) have a significant impact on the price level reducing it with a four months lag. For the 1996-1998 subperiod, the most likely effect of monetary policy shocks is the reduction of the price level (also with a four months lag), even though there is a large uncertainty in this response—not surprising given the small sample size. In addition, monetary policy shocks are one of the most important sources of temporary fluctuations in the level of economic activity for both subsamples. An unexpected monetary policy contraction induces an exchange rate appreciation (in the second period) and a temporary reduction in the level of economic activity (in both periods).

As is well known in the literature, the identification of VARs requires the imposition of “a priori” restrictions on the causal contemporaneous relationships that exist among the variables of the model. This is a critical problem for the VAR methodology and one that so far has not been addressed satisfactorily. In this article we explored a new methodology—based on DAGs—for determining from the data the contemporaneous causal ordering of the variables of the VAR.³⁶ Although we recognize the present limitations involved in this technique, we think that DAGs and the search of new methods for making causal inference from observational data, when combined with relevant “a priori” knowledge, can represent an interesting approach in the search for solutions for the problem of identification of SVARs.

35. In this case we employed the initial pattern (Figure 10) as the identification chosen by TETRAD for the model with lag 2.

36. Another interesting approach is the sign restrictions on impulse responses proposed by Uhlig (2005).

FIGURE 12
IRFs OF THE BM 1999/03-2004/12, WITH 68% PROBABILITY BANDS



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