Has monetary policy been so bad that it is better to get rid of it? The case of Mexico

Marco Del Negro, Francesc Obiols-Homs *
Instituto Tecnológico Autónomo de México

First Draft: September 1999
Third Draft: April 2000

Abstract

Motivated by the dollarization debate in Mexico, we estimate an identified vector autoregression for the Mexican economy, using monthly data from 1976 to 1997, taking into account the changes in the monetary policy regime which occurred during this period. We find that: i) exogenous shocks to monetary policy have had no impact on output and prices; ii) most of the shocks originated in the foreign sector; iii) disturbances originating in the U.S. economy have been a more important source of fluctuations for Mexico than shocks to oil prices. We also study the endogenous response of domestic monetary policy by means of a counterfactual experiment. The results indicate that the response of monetary policy to foreign shocks played an important part in the 1994 crisis.

1 Introduction

Many Latin American countries are considering adopting the U.S. Dollar as legal currency, and some, like Ecuador, have taken concrete steps in that direction. Proponents

*PRELIMINARY. Corresponding author: Marco Del Negro, CIE-ITAM, Camino Sta. Teresa 930, Mexico D.F. 10700, Phone: +52 5 6284197 E-mail: delnegro@master.ster.itam.mx. The paper was originally prepared for the conference, "Optimal Monetary Institutions for Mexico," organized and sponsored by the Instituto Tecnológico Autónomo de México. Comments received during that conference, as well as during presentations at ITAM and Banamex, have greatly improved the paper. We are grateful to Jordi Galí, Eric Leeper, Sergio Luna, Alejandro Werner, Tao Zha, and especially Chris Sims for helpful suggestions. We also thank Alfonso Guerra for help with the data. All remaining errors are ours.

of dollarization generally hold the view that domestic monetary policy has been the primary cause for the economic instability experienced by these countries in the past three decades. Yet, at least for Mexico, very few empirical studies have tried to *identify* the role of monetary policy.

The existing empirical literature on Mexican monetary policy consists mainly of single equation estimations (see Calvo and Mendoza [8] and Kamin and Rogers [15]), or of reduced form vector autoregressions (see Copelman and Werner [10] and Hernandez [14]).[1] The first class of models is silent on the impact of monetary policy on the rest of the economy. The second class of models by definition cannot identify monetary policy. In addition, all previous literature has either ignored the issue of changes in regime, or has confined itself to the study of monetary policy within regimes. This despite the fact that some of Mexico's major crises occurred during the passage from one regime to an other. A proper evaluation of the impact of monetary policy on the Mexican economy requires that these critical transition periods are considered.

This paper attempts to fill the existing gap by estimating an identified vector autoregression (VAR) model for the Mexican economy. The model is a "small-open-economy" VAR, in the vein of Cushman and Zha [11]. This approach makes it possible to account for the impact of foreign shocks on the Mexican economy. We use monthly data from 1976 to 1999. We develop a methodology that extends the standard identified VAR framework in order to take into account the changes in monetary policy regime which occurred during this period.

The paper addresses two specific questions. First, how large has the impact of *exogenous* shocks to monetary policy been on economic activity? Second, did the *endogenous* response of monetary policy mitigate or exacerbate the impact of disturbances originating elsewhere? If erratic movements in monetary policy have been the source of large fluctuations in real activity, proponents of dollarization can argue that adopting the U.S. Dollar may bring more stability of the economy. Likewise, if we find that the lack of an adequate response on the part of the Banco de México to domestic or external shocks has been detrimental for the economy, then adopting a different "policy rule", for instance the one imposed by dollarization, may be welfare-enhancing for Mexico. Needless to say, even if we find that monetary policy in Mexico has been "bad" in the sense just discussed, this would not necessarily imply that dollarization is the best option for Mexico. However interesting, the issue of analyzing the best alternative to

[1] The only exception is Torres [30] [31], who estimates an identified VAR.

the current system is beyond the scope of this paper.

In regard to the first question, we find that exogenous shocks to monetary policy have had a small impact on real activity, as well as on prices. Friedman's view that erratic movements in monetary policy are the primary source of business cycle fluctuations finds little empirical support. This finding is consistent with the evidence obtained for the U.S. (see Leeper *et al.* [17], and Sims [24]) and for other industrialized countries (Kim[16]). Our results also indicate that international business cycles as a whole, and not only movements in commodity prices, have had a strong impact on the Mexican economy. A related question concerns the effect of U.S. monetary policy on countries other than the United States. While our work does not directly address this issue, it suggests that it is worthwhile investigating.

Because of the Lucas critique, our approach is limited in its ability to study the implications of alternative policy regimes. Following Bernanke *et al.* [4], Leeper and Zha [18], and Sims [24] we tackle this issue by means of a counterfactual example. We ask whether the 1994 crisis could have been averted had the monetary policy regime not changed in December 1994. The experiment suggests that it would have been averted. While it is dangerous to take the results of the experiment for their face value, the exercise suggests that the endogenous response of monetary policy to foreign shocks played an important role in the 1994 crisis.

The paper continues as follows: section 2 illustrates the model and the identification structure; section 3 describes the data; section 4 analyzes the results; section 5 concludes.

2 The model

The model is a "small open-economy" vector autoregression, similar to the one successfully adopted by Cushman and Zha [11] in their study of Canadian monetary policy. We extend their framework by allowing for changes in the monetary policy regime.

The structural system is of the following linear stochastic dynamic form:

$$A(L)y(t) = \mu + e(t) \tag{1}$$

where $y(t)$ is a $n \times 1$ vector, $A(L)$ is a $n \times n$ matrix polynomial in the lag operator, μ

is a $n \times 1$ mean vector, and $e(t)$ is a $n \times 1$ vector of structural shocks, with:

$$E[e(t)|y(t-s), s>0] = 0,\ E[e(t)e(t)'|y(t-s), s>0] = I.$$

The vector $y(t)$ and the associated disturbances can be decomposed as follows:

$$y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix},\ e(t) = \begin{bmatrix} e_1(t) \\ e_2(t) \end{bmatrix},$$

where the subscripts 1 and 2 denote domestic and foreign variables respectively. The "small open-economy" assumption implies that the first block $y_1(t)$ (domestic variables) does not affect the second block $y_2(t)$ (foreign variables) either contemporaneously or with lags. In terms of the matrix $A(L)$, the block exogeneity restrictions imply that its SW block is identically zero:

$$A(L) = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ 0 & A_{22}(L) \end{bmatrix}.$$

The domestic block includes the exchange rate (Exc), money supply (M), the interest rate (R), the price level (P), and output (y). In some specifications of the model we also include exports (Tx) and imports (Tm) in the domestic block. The foreign block consists of the U.S. interest rate (R^*), the U.S. price level (P^*), U.S. output (y^*), and an index of international commodity prices (pc^*).[2]

We will now discuss the extent to which we allow for changes in the monetary policy regime. First of all, we assume that there are $\bar{l}$ regimes, and that the dates at which the regime breaks occur are fixed. In particular, we assume that regime l begins and ends at the fixed dates t_l and $t_{l+1}-1$. In applications to the U.S. economy, the assumption of non-stochastic regime switches may be criticized given the uncertainty regarding the dates of the regime changes. Indeed, there is disagreement among scholars on whether regime switches have occurred at all. In the case of Mexico, regime changes have been marked by such portentous events (the debt crisis in 1982, the Salinas disinflation plan, and the 1994 crisis) that there is little uncertainty regarding their dates.[3]

[2]Given the close ties between Mexico and the United States, we treat the United States as being the "rest of the world". Cushman and Zha [11] maintain the same assumption when studying Canada.

[3]Existing VAR models with stochastic regime switches have a much simpler structure than the one considered here (see, for instance, Sims [26]). Estimating a model like ours with stochastic regime switches represents a daunting task from a computational point of view.

We also assume that regime changes represent a surprise to agents. Once the regime change has occurred, agents are assumed to fully understand that they act under a new regime.[4] Our model is consistent with the case in which the public, under the previous regime, attached a positive probability to the possibility of a regime switch. However, the model assumes that these probabilities have not changed within regimes. Time-varying probabilities affect the behavioral equations, and therefore the parameters of the model. In section 3 we discuss these assumptions in the context of recent Mexican economic history.

We assume that changes in regime affect *only* the blocks $A_{11}(0)$ and $A_{12}(0)$ of the $A(0)$ matrix, and the mean vector for the domestic block. This assumption has two implications. First, the foreign block is estimated without changes in regime.[5] Second, in the domestic block the coefficients on lagged values of $y(t)$ in the structural form, that is, the matrices $A_{11}(s)$ and $A_{12}(s)$, $s \geq 1$, are not affected by the regime changes. The assumption is made mainly to economize on degrees of freedom. Allowing for changes in the coefficients of lagged variables in practice means re-estimating the VAR for each sub-period, and there are not enough degrees of freedom to do so given the dimension of our system.[6] From now on, the subscript l on the matrices $A^l_{11}(0)$ and $A^l_{12}(0)$ will make it explicit that these matrices vary across regimes.

Our specification is not as restrictive as it may initially appear. Let us focus for

[4]This assumption reflects the fact that the monetary authorities marked the new regime with clear announcements about the new exchange rate regime. These assumptions are at odds with the view about regime changes espoused in Sims [24]. Sims argues that from the perspective of the public the parameters determining the policy rule of the monetary authorities are random variables. Consequently, once a regime change occurs the public will not be immediately able to distinguish it from a sequence of random shocks to monetary policy. While this view is appealing, particularly for the U.S., we argue that the regime changes in Mexico have been so dramatic that the public could distinguish them from policy shocks.

[5]This assumption is made also in Cushman and Zha [11]. The assumption is in part justified by recent research (Sims [26], Bernanke and Mihov [5]). Sims' finding suggest that there is no strong evidence that coefficients in the policy function of the U.S. monetary authorities have changed over time. However, he finds that the variance of the shocks to the policy function has changed. Bernanke and Mihov find on the contrary evidence in favor of breaks in the structural equations, but find "..[no] strong evidence against stability of the reduced-form VAR system ... over the 1965-1996 sample" (Bernanke and Mihov [5], p. 889). As we do not make any attempt to identify the foreign block, the estimation of the foreign block is equivalent to the estimation of a reduced-form VAR.

[6]Alternatives exist to this approach. One possibility would be to reduce the dimension of the system by, for example, eliminating the foreign block and treating Mexico as a closed economy. We prefer to maintain a rich specification of the foreign block given its importance for the Mexican economy.

instance on the equation representing the reaction function of monetary authorities, which can be rewritten as:

$$a^l.(0)y(t) + \sum_{s=1}^{k} a.(s)y(t-s) = \mu.^l + e.(t) \tag{2}$$

where $a^l.(0)$, $a.(s)$, $\mu.^l$ and $e.(t)$ represent the rows of $A^l(0)$, $A(s)$, μ^l, and $e(t)$, corresponding to that specific equation. After normalizing (2) with respect to one of its variables, for example the interest rate $R(t)$ (assuming that the corresponding coefficient, $a^l._R(0)$, is not zero), we can rewrite it as:

$$R(t) + b^l.(0)y(t) + \alpha^l(\sum_{s=1}^{k} a.(s)y(t-s)) = m^l + \alpha^l e.(t) \tag{3}$$

with $\alpha^l \equiv 1/a^l._r(0)$, and $m^l \equiv \mu.^l/a^l._r(0)$, where the coefficients $b^l.(0)$ correspond to the elements of $a^l.(0)$, excluding the coefficient of $r(t)$, divided by $a^l._R(0)$. Our specification implies that the response of the monetary authorities to any contemporaneous shock is free to vary across regimes. It also implies that the response to past shocks *does* vary across regimes in a proportional fashion, via changes is α^l. This specification is not much more restrictive than the one adopted in a recent paper by Sims [26] analyzing breaks in U.S. monetary policy, although it has the potentially unpleasant implication that the variability of the error term is proportional to the sensitivity to past shocks.[7] Since we allow all the non zero elements in the matrices $A^l_{11}(0)$ and $A^l_{12}(0)$ to change, each equation in the domestic block has the same degree of flexibility.

The model we estimate is therefore of the following form:

$$A^l_{11}(0)y_1(t) + A^l_{12}(0)y_2(t) + \textstyle\sum_{s=1}^{k} A_{11}(s)y_1(t-s) + \sum_{s=1}^{k} A_{12}(s)y_2(t-s) = \mu^l_1 + e_1(t)$$

$$A_{22}(0)y_2(t) + \textstyle\sum_{s=1}^{k} A_{22}(s)y_2(t-s) = \mu_2 + e_2(t) \tag{4}$$

where $l = 1, ..., \bar{l}$.

[7]The specification in Sims [26] is of the form:
$r(t) + m^l + \sum_{s=1}^{k} a.(s)r(t-s) + \alpha^l(\sum_{s=0}^{k} a.(s)p(t-s)) = \sigma^l e.(t)$
where Sims considers only a bivariate model in prices and interest rates. The main difference between our specification and Sims' is that he allows for differences between α^l and σ^l. We tried to allow for differences between α^l and σ^l, but have not succeeded due to the computational complexities of the model.

Next, we discuss the identification structure. As standard in the identified VAR literature, we do not place any restriction on the coefficients of lagged variables, that is, on $A(s)$, for $s \geq 1$. The baseline restrictions on the $A(0)$ matrix are the same ones imposed by Cushman and Zha [11], and are described in table 1 (imports and exports are in parenthesis as they are not present in all specifications). We maintain the same set of identification restrictions across regimes, as the rationale for these restrictions does not depend on the specifics of each monetary policy regime.

Table 1: The identification structure

Money demand	$d_1(M-P) - d_1 y + a_1 R = e_d$
Money supply	$d_2 R + a_2 M + a_3 Exc + a_4 R^* + a_5 pc^* = e_s$
Information market	$d_3 Exc + a_6 M + a_7 R + a_8 P + a_9 y + (a_{10} Tx + a_{11} Tm) + ...$
equation	$... + a_{12} y^* + a_{13} P^* + a_{14} R^* + a_{12} pc^* = e_i$
Production sector	normalized in the lower-triangular order of (Tm, Tx), y, and p
Foreign sector	normalized in the lower-triangular order of pc^*, y^*, P^*, and R^*

The money demand equation is of the classic form $M - P = y - \gamma R$. The money demand is an arbitrage condition between interest-bearing Peso denominated assets and assets that can be used for transaction purposes, namely M. This specification of the money demand equation is correct even if the public holds Dollar denominated assets, as long as these assets cannot be used for transaction purposes. To our knowledge transactions in Mexico during the sample period have been mainly conducted using the domestic currency.

In the money supply equation we allow the monetary authorities to respond to all the information available within the month: domestic and foreign interest rates, commodity prices, and the exchange rate. Data for domestic and foreign output and inflation are not available within the same month, so monetary policy is allowed to respond to shocks in these variables with a delay of at least one month (see also Sims [23]). These restrictions are very general and do not depend on the specifics of the exchange rate regime. We chose to do so because Mexico has never had a "clean" fixed exchange rate regime: even in the periods when the exchange rate depreciation was predetermined, the rate of depreciation was often changed by the authorities. Of course, the parameters of the reaction function will reflect the differences among exchange rate regimes. Indeed, the impulse-responses presented in section 4 show that during the predetermined exchange rate regimes the authorities maintained the exchange rate constant in face of external shocks.

The third equation in table 1 is the so-called "information market equation" (Sims and Zha [27]). This equation summarizes the fact that in efficient markets, under a flexible exchange rate regime, the exchange rate should respond to shocks in every relevant variable, including output and prices.[8] Under a fixed, or predetermined, exchange rate regime the rationale for this equation remains, with the difference that it is the quantity (M) to move in reaction to news, rather than the price (Exc), which is determined by the Central Bank.[9]

Following many previous authors (Bernanke et. al [4], Sims and Zha [27], and Sims [24]), we assume that the variables in the production sector of the domestic economy respond only with a lag to shocks in financial variables and commodity prices. This assumption can be justified by adjustment costs on the part of firms: firms do not react within the same month to news in financial variables due to menu costs and adjustment costs in investment and employment (the model presented in Sims and Zha [27] provides a formal justification for this assumption). We do not attempt to separately identify the shocks in the production sector of the domestic economy, which includes output and prices (and in some specifications also exports and imports). For this reason, we normalize this block by means of lower triangular Cholesky decomposition (which does not impose any overidentifying restriction), in the order of (Tm, Tx,) y, and p. Theorem 3 in Zha [34] shows that the response of any variable in this block to shocks in the money supply or in the money demand equation does not depend on the order of triangularization.

The three important assumptions characterizing the identification structure, namely, i) lagged response of monetary authorities to output and consumer prices, ii) information equation, and iii) lagged response of the production sector to news in financial

[8]Thus we are implicitly assuming that investors in foreign exchange markets are able to gather information faster than central bankers. However, as we allow monetary authorities to respond to contemporaneous changes in the exchange rate, we let this information affect monetary policy, albeit indirectly.

[9]Under capital controls, like the "dual exchange rate system" in place from 1982 to 1991 in Mexico (see section 3 for a discussion), the information equation may play a less important role. With the exception of the first few months after the debt crisis in August 1982, however, the capital controls were not particularly severe: a "free" (*libre*) market for the currency continued to exist. Furthermore, from the *Informes* of the Banco de México it appears that the Central Bank was trying to limit the gap between the "official" and the "free" exchange rate, as they wanted to prevent the development of a black market in foreign currency.

variables, have been widely used in the literature. Beside Cushman and Zha, other examples are Sims and Zha [27], Sims [24], Kim [16], and Leeper and Zha [18].

Finally, the foreign block is also normalized by means of lower triangular Cholesky decomposition, in the order pc^*, y^*, P^*, and R^*. Following Cushman and Zha, we do not want the results to be affected by the choice of overidentifying restrictions for the foreign block. Note that commodity prices come first in the order of triangularization. We give an economic interpretation to the order of triangularization and assume that commodity prices are exogenous, at least contemporaneously, to the other variables in the foreign block. This allows us to disentangle shocks to commodity prices and analyze their effect on the Mexican economy.[10] We are not willing to give any economic interpretation to the order in which y^*, P^*, and R^* are triangularized. As a consequence, we are not able to disentangle the separate impact of U.S. output, prices, and interest rates.

We estimate the model using maximum likelihood under the assumption that the shocks are normally distributed. The appendix describes the estimation procedure and shows how to derive the posterior distribution of the parameters which can be used in the construction of the error bands for impulse responses.

3 The data

The data set used in the baseline estimation consists of monthly data from September 1976 to May 1997.[11] Most of the data for Mexico were obtained from the International Financial Statistics (IFS; mnemonics are in parenthesis). In particular the exchange rate Exc corresponds to the end of period Peso/$ exchange rate (ae), output y corresponds to industrial production (66), exports Tx and imports Tm correspond to total exports and imports measured in U.S. Dollars ($70d$ and $71d$, respectively). In the baseline estimation money supply M is measured as seasonally adjusted M1, and is also

[10] An alternative approach, suggested in Zha [34], would be to assume that oil prices represent an exogenous block, that is, are not affected by U.S. variables either contemporaneously or with lags.

[11] We also estimated the model for the period January 1970 -May 1997 and found no qualitative differences in terms of the impulse-responses to monetary policy shocks. We report the results for the September 1976- May 1997 period only because the January 1970 -May 1997 sample included the August 1976 depreciation (see the discussion later in this section). The August 1976 depreciation is an isolated episode in between two periods of exchange rate stability. As such, it does not represent a change in regime in itself. On the other hand, because of the depreciation one cannot treat the seventies as a single fixed exchange rate regime. We addressed this problem by choosing September 1976 as the beginning of our sample.

obtained from the IFS ($34b$). For different measures of monetary supply we also use M2, obtained from Datastream ($mxm2....a$), and monetary base, obtained from the Banco de México. The measure of monetary base obtained from the Banco de México includes only currency. This measure is consistent with the accepted definition of monetary base after 1991, since after this date banks had a zero average reserve requirement, but not necessarily before 1991. The price level P is measured as CPI with base 1978 and is obtained from Datastream ($mxpc78..f$). The interest rate R is obtained from Datastream, and corresponds to the nominal return on one month certificate of deposits (Datastream mnemonic $mxmcd12mf$).[12] Unfortunately this series is discontinued in May 1997. An alternative measure is the interest rates on 1 month CETES (Datastream mnemonic $mxmcet1mf$), the Mexican treasury bill, but this data is available only since August 1982. The data for the foreign block are also obtained from the International Financial Statistics. The variable R^* is measured as the U.S. federal funds rate (66), P^* is measured as the U.S. CPI (64), y^* is measured as seasonally adjusted U.S. industrial production ($66i$). We tried two alternative measures for commodity prices pc^*. One is the world total exports commodity price index ($176axdzf$), which is the same variable used in Cushman and Zha [11]. The other is the spot price of oil, in US$ per barrel ($176aaza$). All the variables are expressed in logarithms, with the exception of the interest rates which are expressed in decimal points. Mexican industrial production and the monetary base are de-seasonalized by means of monthly dummies using the whole available sample (1970-1999).

Some remarks about the different exchange rate regimes in Mexico during the sample period are in order (see also Banco de México [3]). The exchange rate regime varied several times over the sample period. In the time preceding the beginning of the sample period the exchange rate with the Dollar was fixed. In August 1976 the exchange rate was allowed to depreciate. From September 1976, the beginning of our sample, the exchange rate was pegged at a rate that remained almost unchanged until February 1982. In February 1982 this policy was abandoned, and the Peso underwent a large depreciation. After a few months of a flexible exchange rate (February to August 1982), the monetary authorities decided to peg the rate of depreciation of the Peso. From 1982 to November 1991 a dual exchange rate system was in place. Capital controls were particularly tight at the beginning of this period and loosened up towards the end. The

[12]The CPI measure obtained from the IMF (64) has a base year 1994. Given the large increase in prices experienced by Mexico this measure is less accurate for the first part of the sample, but yields essentially the same results. The only interest rate available for Mexico from the International Financial Statistics is the rate on 3 month CETES (government Peso denominated bonds), for which two observations in 1988 are missing.

"official" rate was depreciated at a rate that varied from 13 to 40 cents per day between August 1982 and February 1988 (the authorities depreciated the "official" exchange rate so to keep the gap with respect to the "free" rate within control). In March 1988 monetary policy changed drastically. In December of the previous year the newly elected president Salinas announced the implementation of his economic program, the *Pacto de Solidaridad Económica*, with a clear anti-inflationary stance. The Banco de México followed suit: the currency was depreciated in the months of January and February, but from March to December 1988 the exchange rate remained fixed. In a few months the annualized rate of inflation declined from more than 100%, the pre-stabilization level, to less than 20%. After December 1988 the exchange rate was allowed to depreciate but at a much slower pace (2.6% per month) than before March 1988. In November 1991 the dual system was abolished, and a crawling target zone regime was put in place. In the crawling target zone the lower band remained flat, while the upper band was increased at a constant daily rate (in October 1992 this rate was increased, and consequently the band was widened). Finally, in December 1994 the target zone regime collapsed, and the current flexible regime was adopted. Table 2 summarizes this information, and figure 1 displays the time series of the -logarithm of- the exchange rate and the price level from 1970 to 1998. Major events over the sample period are the nationalization of the banking system (subsequently privatized in early nineties), the debt crisis, both in August 1982, and the free trade agreement (NAFTA) with the U.S. and Canada in 1994.

Table 2: Historical information

Sub-period	FX Regime	Capital Controls	Major Events
09/76-01/82	pegged (*flotación regulada*)	no capital controls	
02/82-02/88	flexible (02/82-07/82) predetermined depreciation (08/82-	dual FX system (12/82-	nationalization of banks, debt crisis (August 1982)
03/88-11/94	-11/91) crawling target zone (11/91-11/94)	-11/91)	banks privatization (1991) NAFTA(1994)
11/94-	flexible	no capital controls	

We divide the sample into four sub-periods, as shown in table 2. Our choice for the sub-periods reflects the events mentioned in the previous paragraph, and the need for a sufficient number of degrees of freedom within each period. We see the large depreciation of 1982, immediately followed by the debt crisis, the nationalization of banks, and the institution of a dual exchange rate system, as marking a change in monetary policy regime. According to the *informes* of the Banco de México it appears that it was clear to both the Central Bank and the public that because of the change in the macroeconomic situation the period of exchange rate stability was over. We see the month of March 1988, in which Salinas' anti-inflationary plan was implemented, as marking a new change in monetary policy regime. The formal change in the exchange rate system of November 1991, with the introduction of the "crawling target zone", is not seen as radically affecting the stance of macroeconomic policy (Torres [30] also considers the period 1988-1994 as one monetary regime). Finally, we take the Peso depreciation of December 1994 as marking the beginning of a new regime.

In section 2 we pointed out that our model is consistent with the case in which the public places a positive probability on the event of a change in regime, as long as these probabilities have not changed within regimes. Figure 2 plots the Mexico/U.S. interest rate differential two years before and after the changes in regime.[13] The figure shows that in the period immediately preceding the 1994 crisis the differential had decreased, suggesting that "the crisis seems not to have been expected by agents, who did not demand higher interest rate premia in the run-up to the currency collapse" (Sachs *et al.* [20], see also Obstfeld and Rogoff [19]). Of course, the debate on the 1994 Mexican crisis is far from being settled.[14] Different working hypothesis on agents expectations would also be interesting to explore. Our claim here is simply that our current hypothesis does not bluntly violate existing evidence.

The behavior of the interest rate differential suggests that the Salinas stabilization plan, in spite of the announcement in December 1987, was not predicted by the public: the differential *increased* in the three months preceding its implementation. Finally,

[13] The differential is the one year CETES/ Federal Funds Rate differential for the first two plots. In the last plot the rate on CD is used for Mexico, as the CETES rate is not available before August 1982.

[14] Many authors (Calvo and Mendoza [8] among others) point at the massive swap of Peso denominated with Dollar denominated government debt (*Tesobonos*) in 1994 as showing that market participants were expecting a devaluation. For a discussion of the 1994 balance-of-payment crisis see Atkeson and Ríos-Rull [2], Calvo and Mendoza [8], Cole and Kehoe [9], Dornbusch and Werner [12], Flood *et al.* [13], Kamin and Rogers [15], and Sachs *et al.* [20].

Figure 1: Peso/US$ exchange rate (log), the price level (log), and dates of regime change

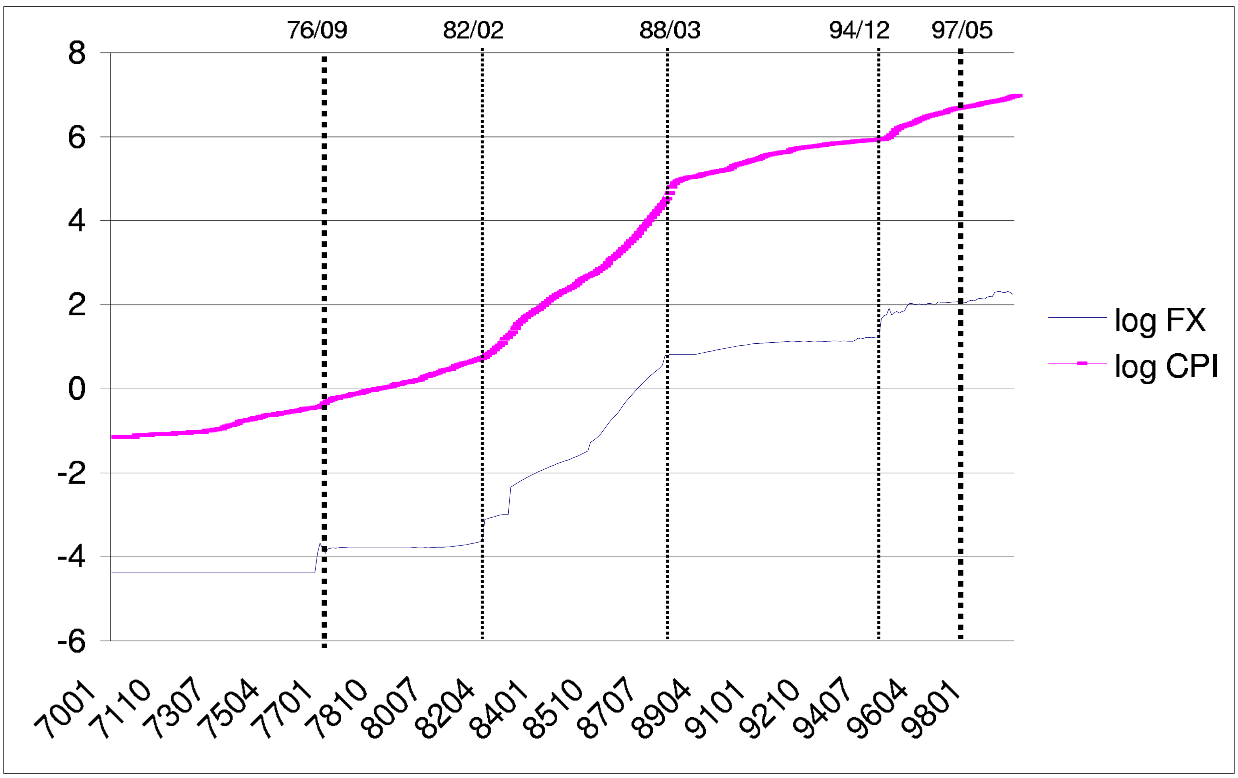
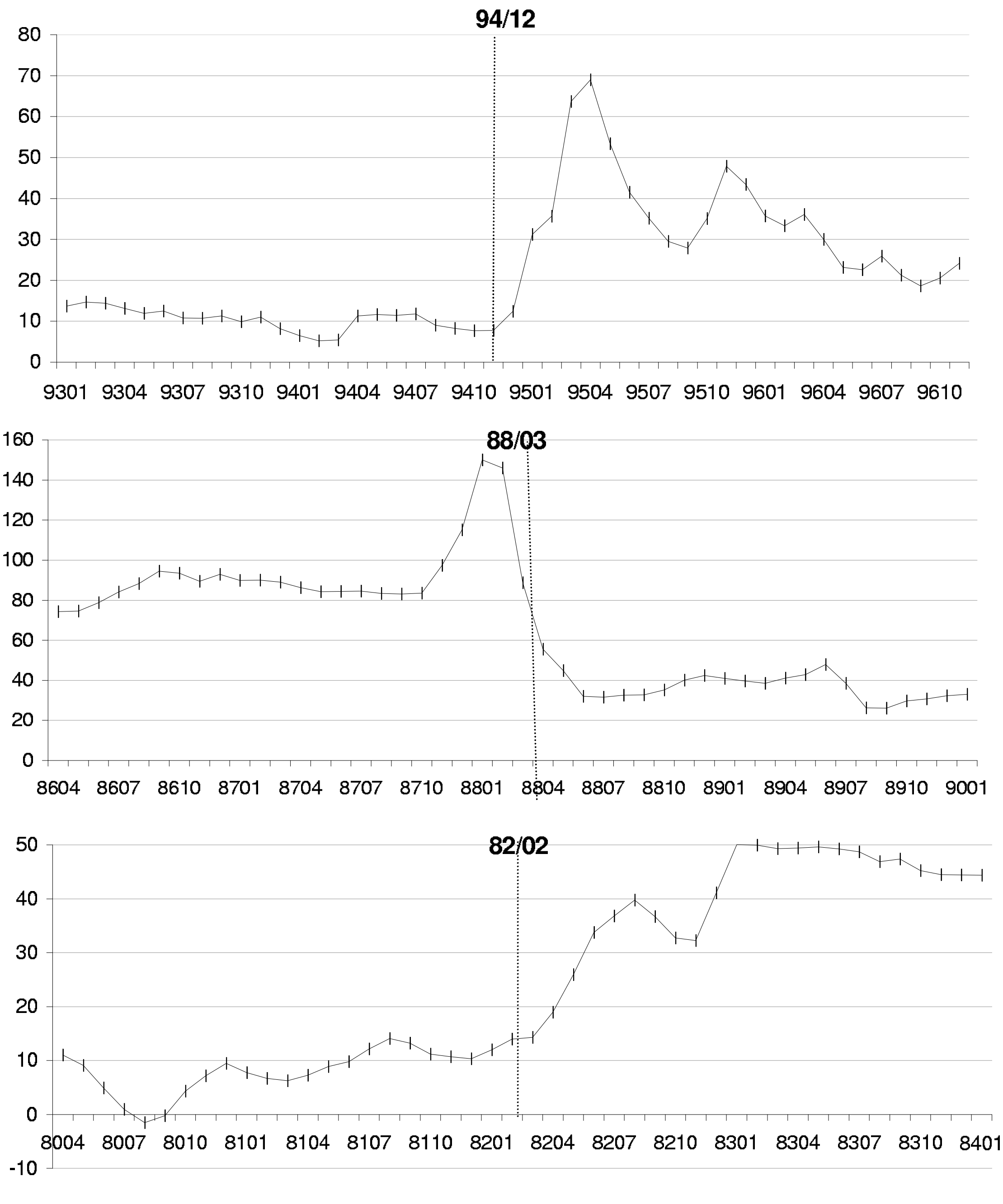


Figure 2: Mexico/U.S. Interest Rate Differential



Note: The differential is the one year CETES/ Federal Funds Rate differential for the first two plots. In the last plot the rate on CD is used for Mexico, as the CETES rate is not available before August 1982.

in the months leading to the devaluations of February 1982 the differential did not substantially increase, indicating once again a lack of predictability of the regime switch. All the plots show that following the regime changes the differential tends to stabilize after a few months, albeit at a level different from the one of the preceding regime. This fact is consistent with the assumption that the public "learns" quite rapidly about the new regime.

4 The results

Following the literature, we assess our identification assumptions by comparing the model's implied dynamic responses to monetary policy disturbances with the predictions derived from theory.[15] Most theoretical models imply that interest rates fall initially and monetary aggregates rise following an expansionary monetary policy shock. Furthermore, it is generally expected that the price level increases, and that the exchange rate depreciates, immediately after a monetary expansion.

Figure 3 displays the responses of the domestic variables to an expansionary shock in the reaction function of the monetary authorities for the baseline specification. In the baseline specification we estimate the model from September 1976 to May 1997, without including imports and exports (including imports and exports imposes a significant cost in terms of degrees of freedom). We use the interest rate on Certificate of Deposits as a measure of the domestic interest rate, M1 as a measure of money supply, and oil prices as as measure of commodity prices. The figure also displays 95% error bands.[16] Given the non stationary behavior of the variables, we introduce the priors described in Sims and Zha [28], namely the "sum of coefficients" and the "dummy initial observation" prior. The priors favor the presence of unit roots and cointegration among the variables, and are introduced as additional dummy observations. As discussed later

[15]The comparison between the impulse-responses to monetary policy shocks and the theoretical predictions is generally done informally. Uhlig [32] provides a methodology for imposing these restrictions in a formal way.

[16]The bands for the impulse response functions are computed following Sims and Zha [29]. We normalize the draws from the posterior distribution according to the procedure described in Waggoner and Zha [33]. As the posterior distribution for the elements of the $A(0)$ matrix is non-standard (see appendix A), we approximate it with a normal multivariate distribution centered at the maximum likelihood. In principle, each draw should be weighted according to the ratio of the actual posterior distribution to the approximate Gaussian p.d.f. (this method is known as "importance sampling"). Consistently with what Sims and Zha report, we also found that the weights vary widely, making the procedure impractical. Therefore in the results shown here the draws are un-weighted.

in this section, the priors play a very important role in the estimation. In the empirical implementation we used 12 lags in the VAR.

In all four sub-periods the expansionary shock is accompanied by a significant depreciation in the exchange rate.[17] Following the expansionary shock money supply increases significantly and by roughly the same amount in all sub-periods. The interest rate has no immediate response to the shock, but declines significantly after approximately three quarters in all but the first sub-period. The response of output is positive, but very small and insignificant. Prices increase significantly a few months after the shock, but their response is also small. The overall conclusion from the analysis of impulse-response function is that the identification scheme adopted here is successful in the sense that no price, interest rate, or exchange rate puzzles are present in our specification.

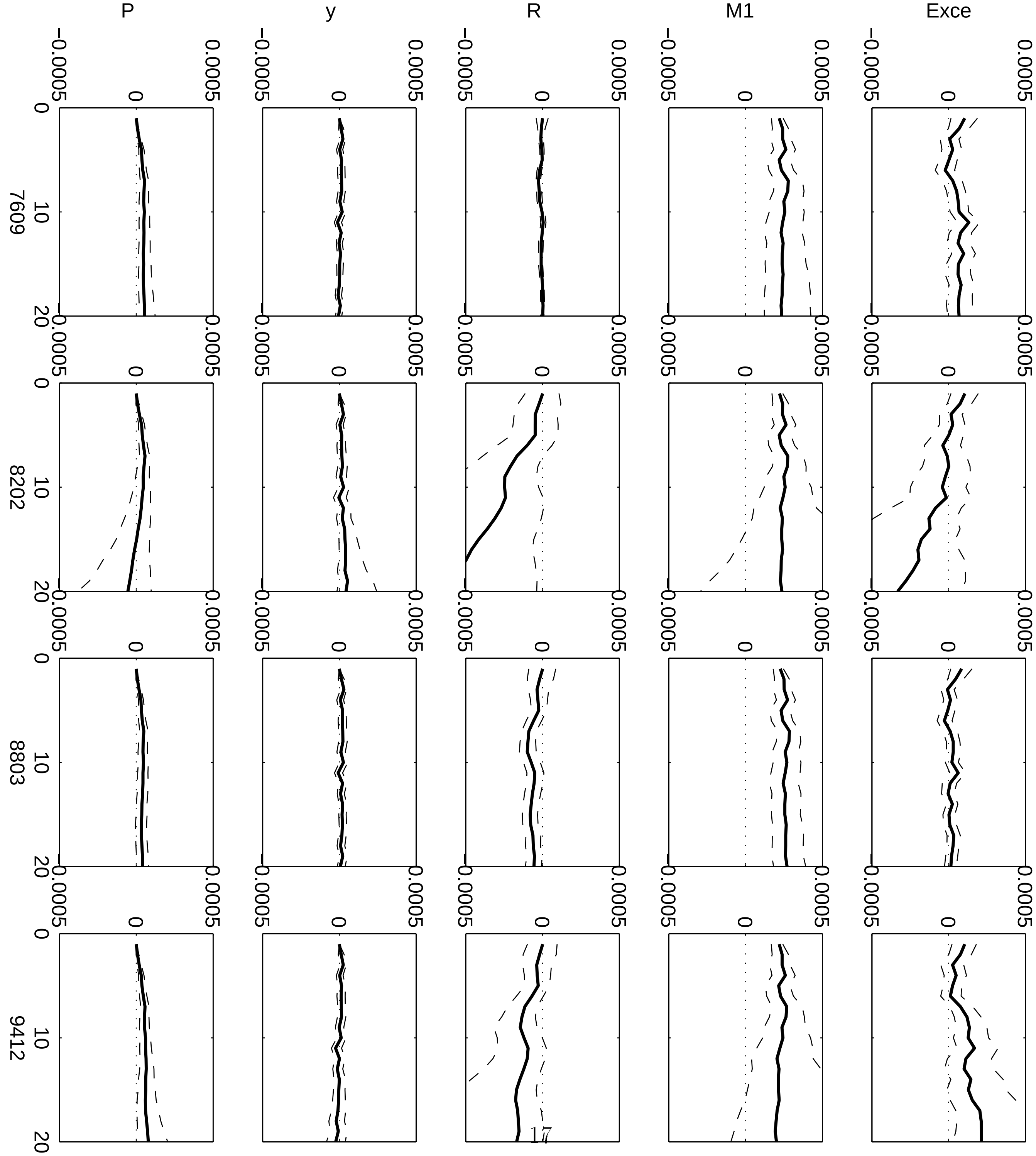
In order to check for the robustness of our results we tried a number alternative specifications. These involve: i) including exports and imports in the vector autoregression, ii) using alternative measures of money supply, such as M2, iii) using alternative measures of commodity prices, such as the world total exports commodity price index from the IFS, iv) using alternative measures of the domestic interest rate, such as the interest rate on one year CETES. In the last alternative specification we estimated the model from August 1982 to December 1998, since the CETES rate is not available before 1982 (this implies that the estimation period covered only three regimes: given the shorter sample we used only six lags in the regression). For all specification we found that the response of all the variables to shocks in the reaction function of monetary authorities is as predicted by the theory, and that the response of output and prices is very small.[18]

Tables 3 and 4 show the forecast variance decomposition for output and prices respectively. Three facts emerge from the analysis of the variance decomposition. First, shocks to monetary policy have a negligible impact not only on output, but also on

[17]In the second and third sub-periods the exchange rate depreciation was predetermined. Nonetheless the authorities changed the predetermined rate of depreciation quite often. Copelman and Werner [10] for instance use the actual depreciation rate of the exchange rate as a measure of monetary policy shocks.

[18]When we include imports and exports the exchange rate depreciates slightly in the first month following an expansionary monetary policy shock, but then appreciates. We also tried to use monetary base as a measure of money supply, but did not manage to achieve convergence in our maximization routine. However, as discussed in section 3, the definition of monetary base changed substantially during the years. The measure that we are using, which corresponds to the current definition of the Banco de México, is likely to be incorrect prior to 1991.

Figure 3: Impulse responses to an expansionary monetary policy shock



95% error bands are displayed.

prices. Second, for all forecast horizons beyond one year foreign shocks are the most important source of disturbances for real activity in Mexico. Third, oil shocks are overshadowed by shocks to the U.S. economy at all forecast horizons. Mexico being an oil producer, it is commonly believed that its economy is at bay of fluctuations in oil prices. Our results contradict this view. Rather, they point at U.S. business cycles as the primary source of shocks for Mexican output.[19] [20]

Table 3: Decomposition of forecast variance for output.

Months	Money Demand	Money Supply	Information	Production	Commodities	Foreign
6	0.82	1.4	4.3	53.1	4.9	35.48
12	0.74	1.4	3.1	31.9	6.3	56.56
24	0.25	0.47	1.2	12.4	5.7	79.98
48	0.12	0.23	0.66	6.73	3.4	88.86
6	2.7	1.2	3.6	37.2	13	42.3
12	7.6	1.2	2	18.7	17	53.5
24	11	2.1	0.74	6.3	3.8	76.06
48	19	3.9	0.44	4.51	1.7	70.45
6	1.3	1.9	2.2	52.6	11	31
12	1.6	2.3	1.8	38.6	21	34.7
24	0.85	1.8	1	29.7	16	50.65
48	0.31	1.1	0.34	16.57	5.6	76.08
6	0.52	0.38	1.2	14.87	2	81.03
12	0.14	0.13	0.3	3.02	2.9	93.51
24	0.31	0.09	0.1	1.12	6.3	92.08
48	3	0.73	0.09	1.21	4.4	90.57

Of course, the results do not imply that the Mexican central bank bears no responsibility for fluctuations in output and prices: the endogenous response of domestic policies

[19] Calvo *et al.* [7] use a principal component model to show that U.S. interest rates are associated with co-movements in business cycles for Latin American economies. See also Buffie and Sangines Krause [6].

[20] Since we do not pretend to identify U.S. monetary policy we do not report the results for U.S. prices, output, and interest rates separately. It is worth mentioning, however, that for several forecast horizons shocks to the Federal Funds rate were the most important source of disturbances in the foreign sector, in spite of being placed last in the recursive ordering.

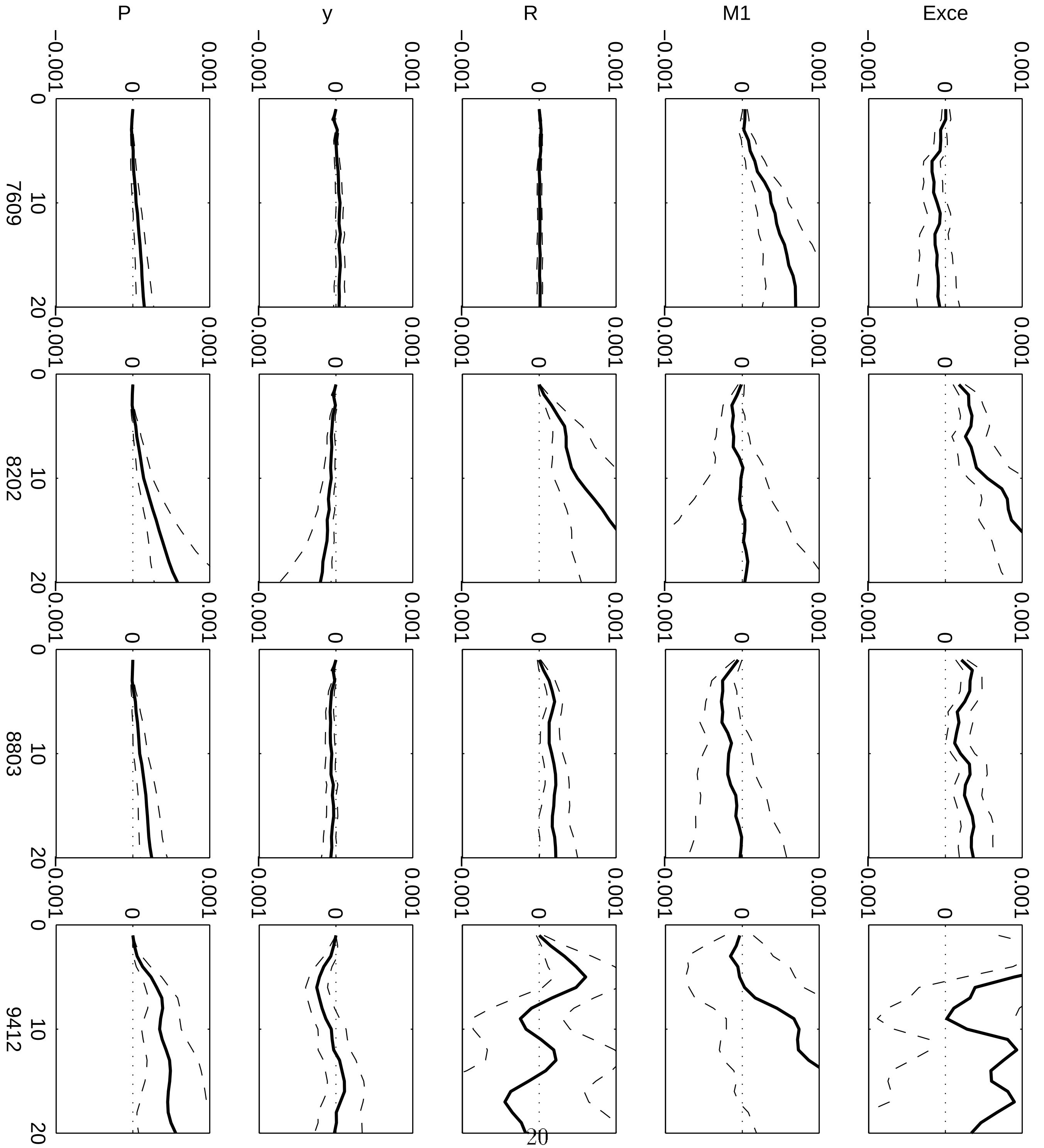
Table 4: Decomposition of forecast variance for prices.

Months	Money Demand	Money Supply	Information	Production	Commodities	Foreign
6	5.6	6.2	1.4	75.26	3.9	7.64
12	17	4.2	0.67	22.72	10	45.41
24	17	0.79	0.31	1.57	2.3	78.03
48	21	3.6	0.43	3.85	0.82	70.3
6	0.16	7.6	1.1	85.38	0.47	5.29
12	0.23	15	0.75	57	3.5	23.52
24	0.25	5.9	0.13	16.9	7.8	69.02
48	0.08	1.3	0.04	3.58	8.9	86.1
6	1.1	4.9	0.99	85.7	0.63	6.68
12	2.2	7	0.82	48.4	2.2	39.38
24	0.69	1.9	0.15	11.61	1.8	83.85
48	0.15	0.3	0.02	2.16	2.1	95.27
6	0.14	1.3	0.27	17.27	0.09	80.93
12	0.02	0.77	0.05	3.44	0.02	95.69
24	0.06	0.45	0.01	1.43	0.03	98.03
48	0.44	0.45	0.02	1	0.88	97.21

to external shocks may have played a key role in their propagation (see Schmitt-Grohé and Uribe [22]). We try to address this point by analyzing the impulse-responses of domestic variables to a positive U.S. interest rate shock, displayed in figure 4. In all but the first sub-period the Mexican interest rises initially, and money supply decreases, following an increase in the Federal Funds rate. In the last sub-period, however, the initial response is followed by a loosening of monetary conditions, with a decline in interest rates and a substantial increase in money supply.[21] These responses imply large differences in the endogenous response of monetary authorities across regimes, and particularly between the third and the last regime. We will return to these results when discussing the 1994 crisis later in the section.

[21]Note that in the first sub-period, where the exchange rate depreciation was predetermined, the exchange rate does not respond immediately to the shocks, and its overall response is smaller than in periods where the exchange rate was flexible. This pattern is found for all shocks other than monetary policy shocks.

Figure 4: Impulse responses to a positive shock in the Federal Funds rate.



95% error bands are displayed.

We now turn our attention to the investigation of the endogenous response of monetary policy during a specific episode of recent Mexican economic history: the December 1994 currency crisis. Figure 5 provides the background for the 1994 crisis. The figure displays the actual and predicted value (as of December 1993) for domestic and foreign variables. The figure shows that the crisis, and specifically the depreciation of the exchange rate, the increase in interest rates and prices, and the decline in output, were not predicted according to the model. It is illustrative to compare figure 5 with figure 6, which shows the same plots when the model is estimated *without priors*. Figure 6 indicates that the deterministic component of the model tracks the actual data very well even in the aftermath of the crisis: according to the model without priors neither the large depreciation nor the following decline in output were surprises to agents! This is obviously a problem, which is common to large scale VAR models when estimated without priors (see Sims and Zha [28] for a further discussion of this point). Figure 5 shows that the priors fully address this problem of "overfitting" by the deterministic component.[22]

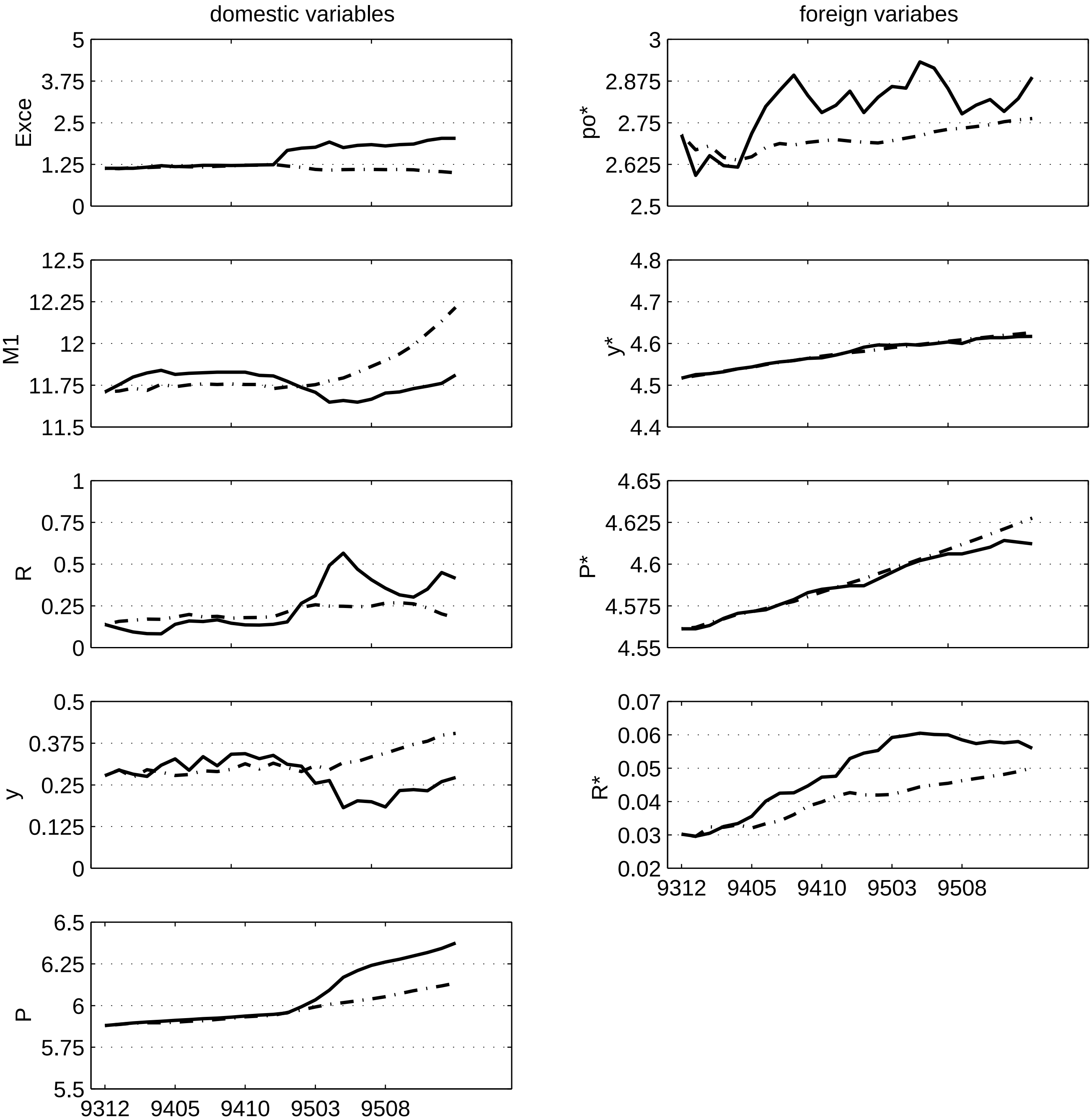
Figure 5 also shows that commodity prices and the federal funds rate were substantially above their predicted values in 1994, while the path of U.S. output and prices was predictable (of course, these are in sample predictions). In particular, according to the model a large part of the 3% interest rate increase can be regarded as a surprise.

What was the relative importance of domestic and foreign shocks in the months preceding and following the 1994 economic crisis? In order to address this question we present the results of two counterfactual experiments: Had no domestic (foreign) shocks hit the Mexican economy since December 1993, what would have been the path of domestic variables? These counterfactual experiments involve no change in the policy rule, but only in the path of exogenous shocks. Therefore, the experiment is subject to the Lucas critique only to the extent that the counterfactual sequence of shocks can be perceived by agents as a change in the stochastic process generating exogenous shocks. However, as the experiment is conducted for a short time period, it may be argued that agents do not have enough time to detect the change in the stochastic process.

Figure 7 shows the actual (solid line) and the counterfactual (dash-and-dotted line) path of domestic variables in absence of domestic and foreign shocks. The figure also

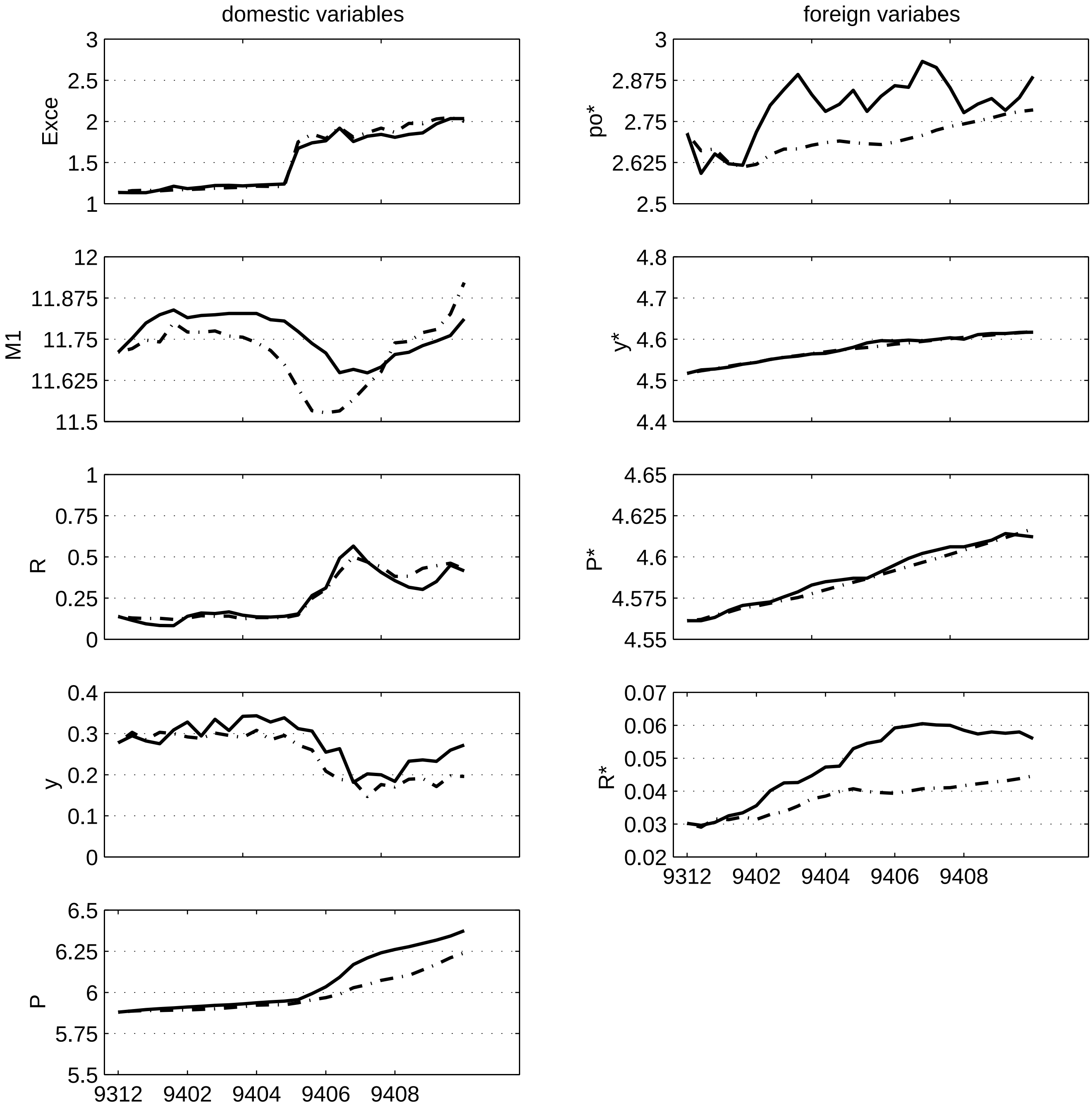
[22] The results of the model without priors, both in terms of impulse-responses to monetary shocks and in terms of variance decomposition, are not very different from the ones shown above. Precisely because of the overfitting problem we chose not to rely on those results.

Figure 5: Actual and predicted value of domestic and foreign variables, 1993:12 - 1995:12



The figure displays the actual (solid line) and predicted (dash-and-dotted line) path of the variables. The predicted values are in-sample predictions using data up to December 1993.

Figure 6: Actual and predicted value of domestic and foreign variables, 1993:12 - 1995:12, without priors



The figure displays the actual (solid line) and predicted (dash-and-dotted line) path of the variables. The predicted values are in-sample predictions using data up to December 1993.

shows the 95% bands for the counterfactual. In absence of domestic shocks we observe that money supply would have been significantly lower in the months preceding the crisis, but otherwise the path of domestic variables, including output and exchange rates, would not have been too different. We checked whether the increase in M1 was due to monetary policy shocks and we found that this was the case (we do not report the results for lack of space). This finding contradicts the results obtained by Kamin and Rogers [15], who conclude that the increase in money supply in 94 was not the result of deviations from the policy rule adopted by the authorities.

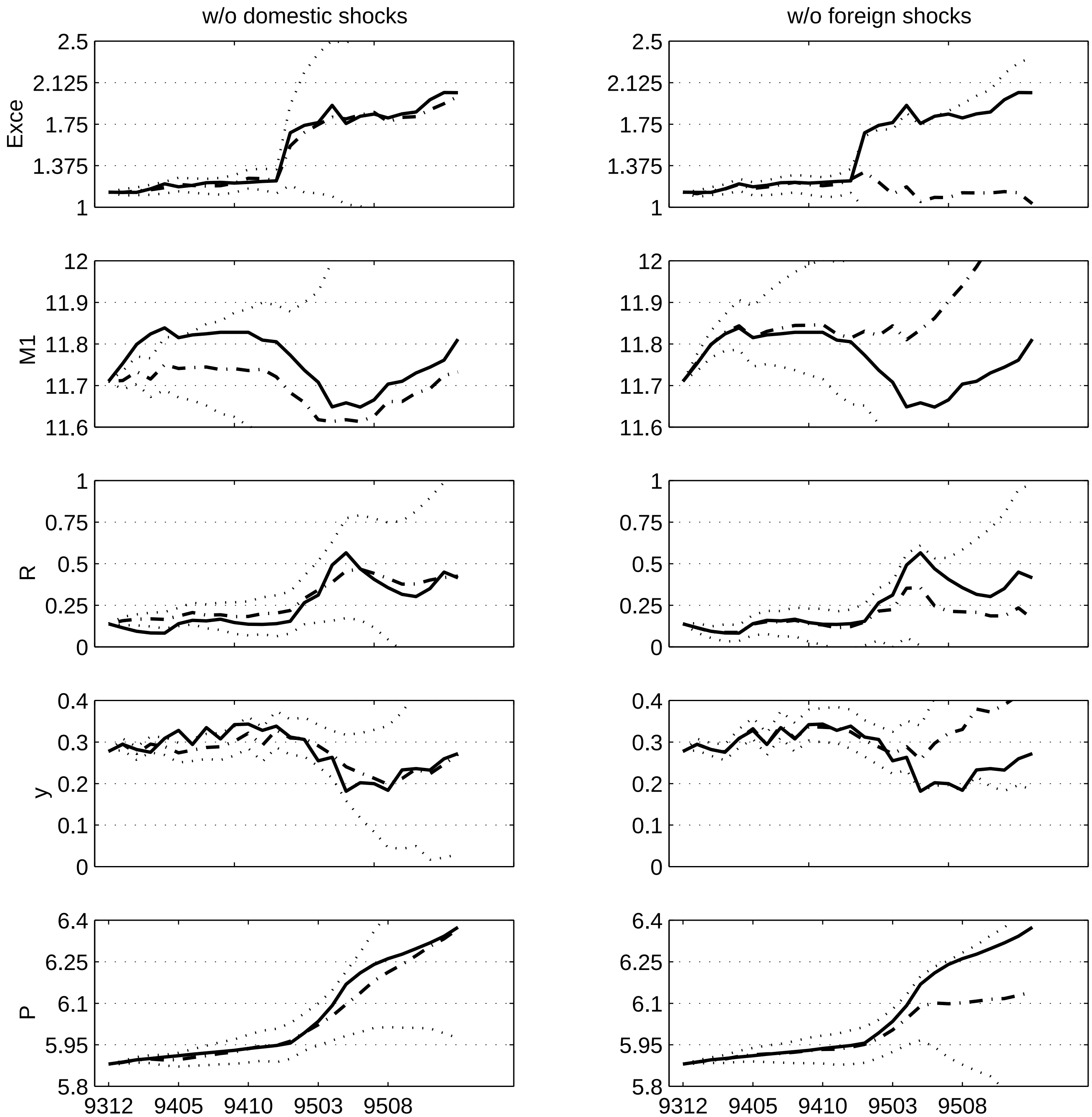
The counterfactual paths of domestic variables in absence of foreign shocks is interesting. The figure suggests that without foreign shocks the depreciation of the exchange rate, the recession and the inflation following the crisis would not have occurred. While the counterfactuals are subject to a considerable uncertainty, both the exchange rate depreciation and the recession are significant, in the sense that the actual path lies outside the 95% bands in the months immediately following the crisis. Overall, the results indicate that foreign shocks played a crucial role in the 1994 crisis. Of course, this might have been the case because of the endogenous response of monetary policy to foreign shocks. We now investigate this issue.

Following the example of Bernanke *et al.* [4],Sims [24], and Leeper and Zha [18], we study the role of the endogenous response of monetary policy to shocks originating elsewhere in the economy by means of a counterfactual experiment.[23] Of course, it is possible to run these counterfactual experiments for many different policy response functions and for many different periods. We choose to focus again on the 1994 crisis, and to run the following counterfactual experiment: Had the reaction function of monetary authorities not changed at all from the previous regime, could the crisis have been averted?

These kinds of counterfactual experiments are subject to the Lucas critique: a counterfactual response of monetary policy implies a change in the behavior of the private sector, and consequently a change in the other parameters of the model. Usually, the econometrician is not able to determine exactly how these parameters have changed, and the validity of the counterfactual experiment rests on the un-checked assumption

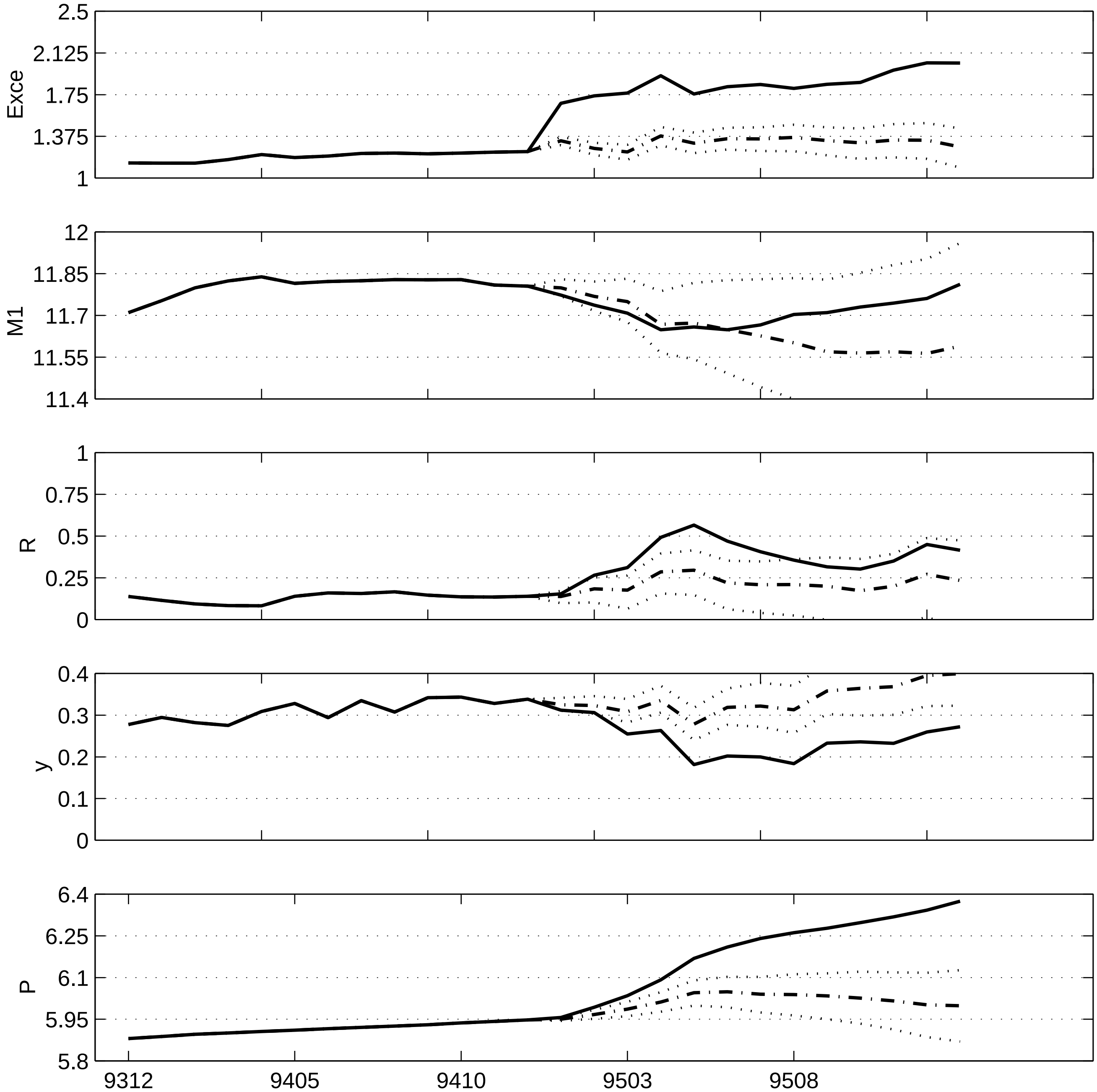
[23]Bernanke *et al.* provide some evidence that the endogenous response of U.S. monetary policy to oil price shocks has be a major cause of the recessions that have accompanied surges in oil prices. Sims shows that the big depression could have been at least in part mitigated, had intra-war central bankers adopted the same reaction function of postwar monetary policy.

Figure 7: Actual and counterfactual path of domestic variables



The figure displays the actual (solid line) and the counterfactual path of domestic variables in absence of domestic (foreign) shocks (dash-and-dotted line).

Figure 8: Domestic monetary policy and the 1994 crisis



The figure displays the actual (solid line) and the counterfactual (dotted line) path of domestic variables.

that the change in the parameters has been small.[24] If our approach to dealing with changes in regime is correct, we can overcome at least in part the Lucas critique, since we have already estimated the model under the old regime. Under the assumption that the only difference between the pre and post December 1994 regimes was the reaction function of the monetary authorities, had such reaction function not changed the behavior of the private sector would not have changed either. As a consequence, the other parameters of the model would not have changed either. Therefore we use for the post 1994 period the same $A(0)$ matrix estimated for the regime before 1994, instead of replacing only the row corresponding to the reaction function of monetary authorities. Since in this model changes in regime are equivalent to changes in the $A(0)$ matrix, this experiment is equivalent to leaving all the parameters of the model unchanged with respect to the pre-1994 regime, and to simulating the behavior of the economy under the sequence of the post-1994 shocks.

Figure 8 shows that the paths of the domestic variables in the immediate aftermath of the crisis would have been very different under the pre-1994 regime. In particular, under the pre-1994 regime the exchange rate depreciation and the recession would not have occurred. The inflation and the increase in interest rates following the crises would have been much milder. For all the variables mentioned above the effect is very significant. Taking the results by their face value, had the Banco de México not responded to external shocks the way it did, the crisis could have been avoided.

What differences between the pre and post 1994 regimes are responsible for this outcome? Given the importance of foreign disturbances, and in particular given the magnitude of the federal funds rate shock in 1994, one can try to answer this question by analyzing the responses of foreign interest rate shocks displayed in figure 4. While in third sub-period the monetary authorities respond to the positive U.S. interest rate shock by contracting money supply and raising the domestic interest rate, in the last sub-period money supply is increased substantially a few months after the shock. The monetary relaxation is followed by a depreciation in the exchange rate and by an increase in the price level.

[24] If one holds the view that from the perspective of the public the parameters of the policy function are also random variables, this counterfactual experiment is not different in nature from the one presented before. It is also true that one can obtain the same counterfactual responses of monetary policy by keeping the reaction function unchanged and by imposing the sequence of shocks that would deliver such response (see Leeper *et al.* [17]). In this sense, this experiment is in principle identical to the one performed above. Many economists, however, would perceive the two experiments as being different.

The validity of this counterfactual experiment rests on the assumption that the only difference between the pre and post December 1994 regimes was the reaction function of the monetary authorities. Also, the VAR model, and therefore the counterfactual, does not include many important variables. What would have happened to domestic banks had the Banco de México not increased money supply following the shock? And what would have been the effect on output had these banks defaulted? Finally, it is important to remember that these results are obtained in a finite sample. For instance, the model seems to attribute a large portion of the crisis to the U.S. interest rate shock. Had the interest rate shock and the crisis been merely coincidental, this would have been detected in a large sample. In a short sample this may not be necessarily the case. Bearing all these caveats in mind, the experiment suggests that the endogenous response of monetary policy to foreign shocks played an important part in the 1994 crisis.

5 Conclusions

The paper contains both a methodological and an empirical contribution. From the methodological point of view, the paper develops an approach for estimating identified vector autoregressions with changes in regime, assuming that the changes occur at fixed dates. This approach can be fruitfully used to analyze monetary policy under different exchange rate regimes, given that this sort of regime changes are explicitly announced by the monetary authorities. The methodological contribution opens the possibility to conduct an empirical study of the Mexican economy from 1976 to 1997.

We find that exogenous shocks to monetary policy have had a negligible impact on output and prices in Mexico. The bulk of the fluctuations in output and prices originate in the foreign sector. A fraction of these is explained by movements in international commodity prices, especially in the price of oil. However, we find that movements in U.S. output, prices, and interest rates are the main cause of fluctuations for the Mexican economy.[25] Our results suggest the possibility that U.S. monetary policy shocks might have been the source of major disruptions abroad. We do not make an attempt to identify U.S. monetary policy disturbances, and therefore we are not in a position to investigate this issue. However, our work indicates that this may be a relevant question

[25]These results confirm the suspicion of the turn of the century Mexican President Porfirio Diaz, who allegedly complained that Mexico was a very unfortunate country, "...so far from God but so close to the United States."

for U.S. policy makers, given their concern for the effect of worldwide crises on the U.S. economy.

The above result does not imply that domestic policies cannot be held responsible for the crises that have recurrently hit the Mexican economy. Models in which the crisis is triggered by external shocks, like interest rate shocks (Antinolfi and Huybens [1]) or sunspots (Cole and Kehoe [9], Sachs *et al.* [20]), emphasize the fact that such shocks can produce devastating effects on the domestic economy only under a specific set of conditions, which depend on domestic policy (financial markets imperfections, high level of domestic debt, *et cetera*). In fact, the results of a counterfactual experiment show that if domestic policy had been different, the 1994 crisis might have been averted. While these results should be taken with caution, they nevertheless show that the endogenous response of monetary policy played a key role.

In the informal debate on dollarization, it is often argued that one of its advantages is that it will help to stabilize the domestic economy. Our findings indeed suggest that the proponents of dollarization may have a point in blaming domestic monetary policy for part of the instability experienced by the Mexican economy in the past twenty years. The question of whether adopting of the U.S. Dollar as legal tender is preferable to the current regime is not addressed in the paper. Our results certainly imply that it is worth investigating.

References

[1] Antinolfi, Gaetano and Elisabeth Huybens (1998) 'On domestic financial frictions, unrestricted international capital flows, and crises in a small open economy,' mimeo, ITAM.

[2] Atkeson, Andrew and José-Víctor Ríos-Rull (1996) 'The balance of payments and borrowing constraints: An alternative view of the Mexican crisis,' *Journal of International Economics*, 41, pp. 331-349.

[3] Banco de México, 'Informe Anual,' 1970 through 1998.

[4] Bernanke, Ben S., Mark Gertler, and Mark Watson (1997) 'Systematic monetary policy and the effects of oil price shocks,' *Brookings Papers on Economic Activity*, 1, pp. 91-157.

[5] Bernanke, Ben S., and Ilian Mihov (1998) 'Measuring monetary policy,' *Quarterly Journal of Economics*, 113, pp. 869-902.

[6] Buffie, Edwards and Allen Sangines Krause (1989) 'Mexico 1958-1986: from stabilizing development to the debt crises,' *Developing country debt and the world economy*, edited by Jeffrey D. Sachs, pp. 141-168.

[7] Calvo, Guillermo A., Leonardo Leiderman and Carmen M. Reinhart (1993) 'Capital inflows and real exchange rate appreciation in Latin America' IMF Staff Papers, Vol. 40, No.1.

[8] Calvo, Guillermo A. and Enrique G. Mendoza (1996) 'Mexico's balance-of-payments crisis: a chronicle of a death foretold,' *Journal of International Economics*, 41, pp. 235-264.

[9] Cole, Harold L. and Timothy J. Kehoe (1996) 'A self-fulfilling model of Mexico's 1994-1995 debt crisis,' *Journal of International Economics*, 41, pp. 309-330.

[10] Copelman, Martina and Alejandro M. Werner (1995) 'The Monetary Transmission Mechanism in Mexico,' *International Finance Discussion Paper*, Board of Governors of the Federal Reserve System, No. 521.

[11] Cushman, David O. and Tao Zha (1997) 'Identifying monetary policy in a small open economy under flexible exchange rates,' *Journal of Monetary Economics*, 39, pp. 433-448.

[12] Dornbusch, Rudiger and Alejandro M. Werner (1994) 'Mexico: stabilization, reform, and no growth,' *Brookings Papers on Economic Activity*, 1, pp. 253-297.

[13] Flood, Robert P., Peter M. Garber, and Charles Kramer (1996) 'Collapsing exchange rate regimes: another linear example,' *Journal of International Economics*, 41, pp. 223-234.

[14] Hernandez, Alfredo A. (1999) 'Does monetary policy affect credit aggregates? Evidence from the Mexican experience,' *mimeo, New York University.*

[15] Kamin, Steven B. and John H. Rogers (1996) 'Monetary policy in the end game to exchange-rate based stabilizations: the case of Mexico,' *Journal of International Economics*, 41, pp. 285-307.

[16] Kim, Soyoung (1999) 'Do monetary policy shocks matter in the G-7 countries? Using common identification assumptions about monetary policy across countries,' *Journal of International Economics*, 48, pp. 387-412.

[17] Leeper, Eric M., Christopher A. Sims, and Tao Zha (1996) 'What does monetary policy do?,' *Brookings Papers on Economic Activity*, 2, pp. 1-63.

[18] Leeper, Eric M. and Tao Zha (1999) 'Identification and forecasting: joint inputs to policy analysis' mimeo, Indiana University.

[19] Obstfeld, maurice and Kenneth Rogoff (1995) 'The mirage of fixed exchange rates' *Journal of Economic Perspectives*, 9 (4), pp. 73-96.

[20] Sachs, Jeffrey, Aarón Tornell, and Andrés Velasco (1996) 'The Mexican peso crisis: Sudden death or death foretold,' *Journal of International Economics*, 41, pp. 265-283.

[21] Santaella, Julio A. and Abraham E. Vela (1996) 'The 1987 Mexican disinflation program: An exchange-rate based stabilization?' IMF Working Paper No. WP/96/24

[22] Schmitt-Grohé, Stephanie and Martín Uribe (1999) 'Stabilization policy and the costs of dollarization,' *mimeo.*

[23] Sims, Christopher A. (1986) 'Are forecasting models usable for policy analysis?' *Quarterly Review of the Federal Reserve Bank of Minneapolis*, 10, pp. 2-16.

[24] Sims, Christopher A. (1998) 'The role of interest rate policy in the generation and propagation of business cycles: What has changed since the 30's? ,' *mimeo, Yale University.*

[25] Sims, Christopher A. (1998) 'Comment on Glenn Rudebusch's "Do measures of monetary policy in a VAR make sense?" ', *International Economic Review*, Vol. 39, No. 4, pp. 933-948.

[26] Sims, Christopher A. (1999) 'Drifts and breaks in monetary policy,' *mimeo, Yale University.*

[27] Sims, Christopher A. and Tao Zha (1995) 'Does monetary policy generate recessions?' *mimeo, Yale University.*

[28] Sims, Christopher A. and Tao Zha (1998) 'Bayesian methods for dynamic multivariate models,' *International Economic Review*, Vol. 39, No. 4, pp. 949-968.

[29] Sims, Christopher A. and Tao Zha (1999) 'Error bands for impulse responses ,' *Econometrica*, Vol. 67, No. 5, pp. 1113-1155.

[30] Torres-García, Alberto (1998) 'Inflation and monetary policy in Mexico,' *mimeo, New York University.*

[31] Torres-García, Alberto (1999) 'Monetary policy in Mexico under the new flexible exchange rate regime,' *mimeo, New York University.*

[32] Uhlig, Harald (1997) 'What are the effects of monetary policy? Results from an agnostic identification procedure,' *mimeo, Tilburg University.*

[33] Waggoner, Daniel F. and Tao Zha (1997) 'Normalization, probability distribution, and impulse responses,' *Federal Reserve Bank of Atlanta Working Paper 97-11*, November.

[34] Zha, Tao (1999) 'Block recursion and structural vector autoregressions,' *Journal of Econometrics*, 90, pp. 291-316.

A Identified VAR with block exogeneity and changes in regime: Maximum Likelihood estimates and the posterior distribution of the parameters of interest

This section describes the methodology for estimating an identified VAR model when the matrix of contemporaneous correlation and the means change across regimes. The model is the VAR with block exogeneity described in section 2, which for convenience we rewrite below:

$$A_{11}^l(0)y_t^1 + A_{12}^l(0)y_t^2 + \sum_{s=1}^k A_{11}(s)y_{t-s}^1 + \sum_{s=1}^k A_{12}(s)y_{t-s}^2 = \mu_1^l + e_t^1$$

$$A_{22}(0)y_t^2 + \sum_{s=1}^k A_{22}(s)y_{t-s}^2 = \mu_2 + e_t^2 \tag{5}$$

$$e_{t/y_{t-s},s>0}^1 \rightsquigarrow N(0,I),\ e_{t/y_{t-s},s>0}^2 \rightsquigarrow N(0,I)$$

where l denotes the regime ($l = 1,..,l^0,..,\bar{l}$). The parameters $A_{11}^l(0)$, $A_{12}^l(0)$, and μ^l are allowed to change across regimes. Regime l begins in period t_l and ends in period $t_{l+1}-1$.

Note that the foreign block can be estimated separately from the domestic block (see also Zha [34]): the errors e_t^1 and e_t^2 are by assumption independent from each other, and there is no feedback from y_t^1 to y_t^2. As mentioned in section 2, we also assume that the matrix of contemporaneous correlation of the foreign block ($A_{22}(0)$) does not change over time. Since the estimation of the foreign block is straightforward, we omit it from the discussion.

In order to find the maximum likelihood estimates for the first block we rewrite it in compact form as:

$$A^l y_t - A x_t = e_t^1 \tag{6}$$

where $y_t \equiv [y_t^1{}' y_t^2{}' 1]$, $A^l \equiv [A_{11}^l(0) A_{12}^l(0) - \mu_1^l]$, $A \equiv [-A_{11}(1).. - A_{11}(k) - A_{12}(1).. - A_{12}(k)]$, and $x_t' \equiv [y_{t-1}^1{}'..y_{t-k}^1{}' y_{t-1}^2{}'..y_{t-k}^2{}']$.

Under the assumption of normality, the likelihood, written as a function of the parameters of interest (omitting all other terms that do not depend on these parameters), is of the form:

$$L(A^l, A) \quad = \quad (\Pi_{t=1}^T |A_{11}^l(0)|) \exp\{-\frac{1}{2}\sum_{t=1}^T (A^l y_t - A x_t)'(A^l y_t - A x_t)\} \tag{7}$$

where the first term comes from the determinant of dy_t^1/de_t^1.

The following theorem is useful in order to obtain the maximum likelihood estimates of the model, as well as the error bands for impulse response functions. The theorem is a straightforward extension of Theorem 1 in Zha [34] to the case of changes in regime.

Theorem 1 *The joint posterior distributions of the parameters of interest, A^l, and A, can be expressed as:*

$$L(A^l, A) = p(A^l)\phi(\bar{a}, \Sigma) \tag{8}$$

where $p(A^l)$ is the marginal posterior distribution of A^l and $\phi(\bar{a}, \Sigma)$ is the conditional distribution of $a \equiv vec(A')$ given A^l. The conditional distribution of a given A^l is normal with mean:

$$\bar{a} \equiv vec((\sum_{t=1}^{T} x_t x_t')^{-1} \sum_{l=1}^{\bar{l}} (\sum_{t=t_l}^{t_{l+1}-1} x_t y_t' A^{l\prime}))$$

and variance:

$$\Sigma \equiv [I_n \otimes (\sum_{t=1}^{T} x_t x_t')^{-1}].$$

Proof. Using the properties of the trace operator, equation (7) can be rearranged as follows:

$$L(A^l, A) = (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l}) \exp\{-\tfrac{1}{2} tr(\textstyle\sum_{t=1}^{T} (A^l y_t - A x_t)(A^l y_t - A x_t)')\}$$

$$= (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l}) \exp\{-\tfrac{1}{2}[\textstyle\sum_{l=1}^{\bar{l}} tr(A^l(\sum_{t=t_l}^{t_{l+1}-1} y_t y_t') A^{l\prime})$$

$$-2\textstyle\sum_{l=1}^{\bar{l}} tr(A(\sum_{t=t_l}^{t_{l+1}-1} x_t y_t') A^{l\prime}) + tr(A(\sum_{t=1}^{T} x_t x_t') A')]\}$$

$$= (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l}) \exp\{-\tfrac{1}{2}[\textstyle\sum_{l=1}^{\bar{l}} tr(A^l(\sum_{t=t_l}^{t_{l+1}-1} y_t y_t') A^{l\prime})$$

$$-2\textstyle\sum_{l=1}^{\bar{l}} vec(A^{l\prime})'(I_n \otimes (\sum_{t=t_l}^{t_{l+1}-1} y_t x_t'))a + a'(I_n \otimes (\sum_{t=1}^{T} x_t x_t'))a]\}$$

where $a \equiv vec(A')$. By defining Σ and $\bar{a}$ as above, we can rewrite the likelihood as:

$$L(A^l, A) = (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l})$$

$$\exp\{-\frac{1}{2}[\sum_{l=1}^{\bar{l}} tr(A^l(\sum_{t=t_l}^{t_{l+1}-1} y_t y_t')A^{l\prime}) - 2\bar{a}'\Sigma^{-1}a + a'\Sigma^{-1}a]\}$$

$$= (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l}) \exp\{-\frac{1}{2}[\sum_{l=1}^{\bar{l}} tr(A^l(\sum_{t=t_l}^{t_{l+1}-1} y_t y_t')A^{l\prime}) - \bar{a}'\Sigma^{-1}\bar{a}]\}|\Sigma|^{\frac{1}{2}}$$

$$|\Sigma|^{-\frac{1}{2}} \exp\{-\frac{1}{2}[\bar{a}'\Sigma^{-1}\bar{a} - 2\bar{a}'\Sigma^{-1}a + a'\Sigma^{-1}a]\}$$

$$= p(A^l)\phi(\bar{a}, \Sigma)$$

where:

$$p(A^l) \equiv (\Pi_{l=1}^{\bar{l}} |A_{11}^l(0)|^{t_{l+1}-t_l})|\Sigma|^{\frac{1}{2}} \exp\{-\frac{1}{2}[tr(A^l(\sum_{t=t_l}^{t_{l+1}-1} y_t y_t')A^{l\prime})$$

$$- \sum_{l=1}^{\bar{l}} \sum_{m=1}^{\bar{l}} tr(A^m(\sum_{t=t_m}^{t_{m+1}-1} x_t y_t')(\sum_{t=1}^{T} x_t x_t')^{-1}(\sum_{t=t_l}^{t_{l+1}-1} x_t y_t')A^{l\prime})]\}$$

■

Theorem 1 implies that for any value of A^l, the maximum likelihood estimate of a is $\bar{a}$. This implies that the maximum likelihood estimates of (8) can be found in two steps. The first step involves finding the the maximum likelihood estimate of a given A^l. The properties of the normal distribution imply that this is $\bar{a}$. The second step involves the maximization of the term $p(A^l)$ with respect to A^l. This is a non-linear problem that can be solved by means of available computer packages.[26] The introduction of the priors does not modify the nature of the problem, since these are introduced as additional dummy observations as described in Sims and Zha [28].

[26]We use the Matlab program *csminwel* which was kindly made available to us by Chris Sims. In order to check for that out maximum was global and not only local, we started the maximization routine from different initial points. Furthermore, we programmed the routine in *Fortran*, using a different maximization algorithm, and obtained the same results.