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ABSTRACT

In this paper we suggest a VAR specification that proves to be successful in resolving the price puzzle featuring in VARs used for monetary policy analysis. We show that augmenting a standard VAR with a small number of variables that have forward-looking informational content is capable of producing theory-consistent responses to monetary policy shocks. The VAR is estimated for the US with data covering the period 1989-2001, which is characterized by a relatively homogeneous monetary policy regime and a pronounced price puzzle in standard VAR specifications. Most important among these forward-looking variables are the federal funds rate future reflecting expectations of future monetary policy and a leading composite indicator providing information about near-term developments in economic activity. In view of the increasing ability of financial markets to better predict monetary policy movements, financial asset prices, such as the federal funds rate futures, are ideal candidates for incorporating parsimoniously a large amount of information into a low-dimension VAR.

Keywords: Monetary transmission mechanism; VAR models; Fed funds futures; price puzzle
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1. Introduction

A large part of the empirical literature on monetary transmission uses identified vector autoregressions (VARs). The great appeal of this approach is that it permits the identification of the effects of policy actions on the basis of a few hypotheses, without requiring the existence of a complete structural model of the economy. In VARs it is the response of variables to exogenous policy actions that one needs to examine in order to estimate the effects of monetary policy on the economy (Rudebusch, 1998). Isolating the economic effects of monetary policy shocks, however, is not straightforward as the response of economic variables to monetary policy impulses reflects the combined effect of the policy actions and of the variables to which policy responds (Christiano *et al*., 1996). This identification problem is addressed with the imposition of a number of identifying restrictions based on economic theory.

In many cases the empirical analysis made on the basis of identified VARs leads to puzzling responses of some of the variables included in the system to a monetary policy innovation. The positive response of the price level to a monetary policy tightening - the price puzzle - is the most often cited puzzle in the literature. This counterintuitive response to the policy shock is often viewed as evidence of a serious misspecification problem in the underlying system and in particular in the model 's equation describing the monetary policy reaction function.

Several proposals to solve the price puzzle have been put forward. Most of them at best only partially deal with the major disadvantages of the VAR approach, i.e. the inadequate description of the central bank's operating procedures and the insufficient amount of information incorporated in the analysis due to the small number of variables that can be included in a VAR system. A problem common to all these approaches is their inability to provide a solution to the price puzzle that is robust across different time periods and country experiences.

In this paper we suggest a VAR specification that proves to be successful in resolving the price puzzle featuring in monetary VARs for the US. We show that augmenting a standard VAR with a small number of variables that have forward-looking informational content is capable of producing theory-consistent responses to monetary policy shocks. The VAR is estimated for the US with data covering the period 1989-2001, a period characterized by a relatively homogeneous

monetary policy regime (Judd and Rudebusch, 1998) and a pronounced price puzzle in standard VAR specifications. Most important among these forward-looking variables are the federal funds rate future reflecting expectations of future monetary policy and a leading composite indicator providing information about near-term developments in economic activity. In view of the increasing ability of financial markets to better predict monetary policy movements, financial asset prices, like the federal funds rate future, are ideal candidates for incorporating parsimoniously a large amount of information into a low-dimension VAR.

The remainder of the paper proceeds as follows. Section 2 reviews the VAR methodology giving emphasis to the issue of the identification of monetary policy shocks. It presents the alternative suggestions in the literature for the solution of the price puzzle, which itself is an indication of a misspecification problem. Section 3 examines the ability of financial asset prices and specifically the federal funds rate future to bring useful forward-looking information into the analysis, in view of the observed trend in US monetary policy toward greater transparency, accountability and credibility over the last decade. Section 4 presents some other variables which contain forward-looking information about monetary policy's intermediate/final targets and are, thus, natural candidates for bringing the central bank's information set, as specified in the VAR, closer to reality. Section 5 presents the empirical results from VARs augmented with forward-looking variables and compares them with the results from standard VAR specifications which are subject to a price puzzle. Finally, Section 6 summarizes the empirical results and concludes.

2. Monetary policy analysis in VARs

2.1 Identifying monetary policy shocks

The largest part of the empirical literature analysing the impact of monetary policy innovations on the economy uses identified vector autoregressions (VARs). At the heart of this approach is the distinction between the endogenous response of monetary policy to macroeconomic conditions and exogenous policy shifts. The ability to separate the systematic from the non-systematic policy component depends crucially on the proper specification of the monetary policy

reaction function, i.e. the function that relates monetary policy makers' actions to the state of the economy. The endogenous variables included in these VARs are assumed to represent both the arguments of the reaction function (intermediate and final targets of monetary policy) and the instrument of monetary policy itself. The estimation of the central bank's feedback rule necessitates the imposition of enough identifying assumptions involving the variables that monetary authorities look at, the operating instrument of monetary policy and the functional form of the rule (Christiano *et al*., 1999).

The exogenous part of monetary policy actions that cannot be considered as a reaction to the state of the economy, is formalized with the notion of a monetary policy shock (Christiano *et al.*, op.cit.).

These policy shocks may reflect:

i) Changes in the preferences of the monetary authorities, e.g. shifts in the reaction function.

ii) Strategic considerations as developed in Ball (1995) and Chari *et al.* (1997) that guide, in several cases, the actions of monetary policy makers, who, in order to avoid the social costs of disappointing private agents' expectations, generate an exogenous source of variation in policy. It is then possible that shocks to private agents' expectations about central bank's policy can be self-fulfilling and lead to exogenous variation in monetary policy.

iii) Measurement errors (Bernanke and Mihov, 1998) in real-time data that are at the disposal of the central bank at the time it makes its decision, or misinterpretation of the contemporaneous flow of incoming information in the context of a preemptive strategy.

The distinction between policy actions of the monetary authorities and monetary policy shocks is of central importance in order to obtain a meaningful description of the monetary transmission mechanism. This distinction can be viewed as a response to the theoretically well-grounded presumption that only the unexpected part of monetary policy can have real effects (Cochrane, 1998). Moreover, it permits the assessment of competing structural models as regards their ability to produce "plausible responses" to an exogenous disturbance. The lack of general consensus about an underlying structural model that describes the economy and that would facilitate the

quantification of the effects of monetary policy actions led researchers to use minimal theoretical assumptions when studying the effect of monetary policy changes. VARs, given their appealing characteristics such the imposition of a small number of restrictions, the use of a few exogenous variables and the ease of implementation, are widely used to disentangle the endogenous from the exogenous component of monetary policy without resorting to a complete structural model of the economy. Thus, the emphasis of the VAR-based approach on "policy innovations arises not because shocks to policy are intrinsically important but because tracing the dynamic response of the economy to a monetary policy innovation provides a means of observing the effects of policy changes under minimal identifying assumptions" (Bernanke and Mihov, 1998).

Within the VAR framework a monetary policy shock is identified with the disturbance term in an equation of the form:

$$s_t = f(\Omega_t) + \beta_s \varepsilon_t^s \qquad (1)$$

where s_t is the policy instrument, e.g. a short-term interest rate, f is a linear function that corresponds to the monetary authorities' feedback rule and Ω_t is the monetary authorities' information set. The random variable $\beta_S \varepsilon_t^S$ is a monetary policy shock (ε_t^s is normalized to have unit variance and β_S is the standard deviation of the monetary policy shock). The identification of such a rule in the VAR depends crucially on our ability to correctly specify the information set Ω_t.

The starting point of the VAR analysis is the estimation of the reduced form underlying the following structural model (cf. Bagliano and Favero, 1998).

$$A\begin{bmatrix} Y_t \\ M_t \end{bmatrix} = C(L)\begin{bmatrix} Y_{t-1} \\ M_{t-1} \end{bmatrix} + B\begin{bmatrix} v_t^Y \\ v_t^M \end{bmatrix} \qquad (2)$$

where Y is a vector of macro (non-policy) variables and M a vector of variables that can be characterized as instruments and intermediate/final targets of monetary policy. These are variables that are controlled by the monetary policy maker and variables that contain information about monetary policy actions. A describes the contemporaneous relationship among the variables

and *C(L)* is a matrix of finite-order lag polynomials. Finally, v is a vector of structural disturbances to monetary policy. Identification is obtained by assuming orthogonality of structural disturbances.

The reduced form of the structural model presented in eq. 2 has the form:

$$\begin{bmatrix} Y_t \\ M_t \end{bmatrix} = A^{-1}C(L)\begin{bmatrix} Y_{t-1} \\ M_{t-1} \end{bmatrix} + \begin{bmatrix} u_t^Y \\ u_t^M \end{bmatrix} \tag{3}$$

Thus, the structural disturbances v are related to the reduced form VAR residuals by the following relation:

$$A\begin{bmatrix} u_t^Y \\ u_t^M \end{bmatrix} = B\begin{bmatrix} v_t^Y \\ v_t^M \end{bmatrix} \tag{4}$$

After the estimation of the reduced form, the identification of the relevant structural parameters requires the imposition of some restrictions on the elements of A and B. The structural model is identified by:

i) assuming orthogonality of structural disturbances,

ii) assuming that macro variables do not react contemporaneously to monetary variables, while the simultaneous feedback is allowed, and

iii) obtaining, if possible, a detailed description of the monetary authorities' operating procedures through the imposition of appropriate restrictions on the reduced form.

After the identification of the structural form, and especially of the monetary policy reaction function, it is possible to trace the response of macroeconomic variables to policy impulses. Nevertheless, some of the assumptions made in order to identify the structural VAR model from its reduced form may not accord well with reality:

1) The assumption that, at the beginning of period t, all economic agents have access to all economic data dated t-1 and earlier. For the proper derivation of the monetary policy shock it is crucial to specify the variables, among those that provide information about the level of economic activity and inflation in period t, for which the central bank has information within the same period and those for which this information comes with a delay.

2) The second and more stringent assumption is that the information set for all economic agents, and in particular the central bank's information set, consists of only the variables included in the VAR model. Unquestionably, the information set of the monetary authorities is much richer than that implied by the VAR specification. The central bank makes its decisions based on an information set that contains many additional variables as well its own information (Romer and Romer, 2000). This cannot be incorporated directly in the VAR analysis[1], either because it is not publicly known which exactly these variables are or because the inclusion of additional explanatory variables in the VAR system would imply problems due to the diminishing degrees of freedom. In any case, it is a difficult task to model properly the decision making process of the central bank and identify the weights which developments in several indicators of economic activity and prices may have in this process. If a significant part of this information is omitted from the VAR, which provides a simplified reduced form expression of the feedback rule, the specification of the estimated innovations is inappropriate for identifying structural shocks (Brunner, 2000)

3) At the same time it is crucial to specify as realistically as possible the time horizon over which the central bank formulates its strategy. The existence of long lags in the effect of monetary policy can induce the central bank to respond to the forecast values of its goals rather than their actual past values. In the last decade (especially after 1993), the Federal Reserve policy was self-described as preemptive – that is, responsive to expected economic trends – which may have allowed for more discretion in the timing of decisions (Bomfin and Reinhart, 2000). It is widely accepted that an increasing number of central banks adopt gradualist approaches by setting targets for medium-term levels of inflation and other variables used as intermediate or final targets. The theoretical appeal of such a behavior has been investigated theoretically *inter alia* by Batini and Haldane (1999) and empirically by Clarida *et al.* (2000) who show that forward-looking rules provide a better account of the recent monetary history.

[1] The use of factor analysis is an important step in this direction, although usually the economic interpretation of the factors is rather ambiguous (see Bernanke and Boivin, 2001 and Bernanke *et al.,* 2002).

If the Fed is forward-looking, the policy response cannot be properly identified unless expectations are taken into account. In this case, the parameters of the policy feedback rule can potentially be functions of all the parameters relevant to the formation of its expectations. This forward-looking behavior can be taken into account explicitly by modeling the Fed's expectation formation process. VARs, however, are not in general well-equipped to handle directly issues related to this forward-looking behavior. The standard specification of the VAR model is based on the information summarized in the contemporaneous and lagged values of the variables included and does not permit the modeling of any forward-looking expectation formation process. Moreover, VARs do not permit an analytical description of the actual operating procedures except for the restrictions imposed that relate to the timing of the interactions among the variables included in the system.

All the above sources of misspecification are often reflected in theoretically implausible patterns of dynamic responses to the policy shock obtained from VAR systems used for monetary policy analysis.

2.2 The price puzzle: a brief survey of the evidence

The price puzzle is one of the most frequently cited empirical puzzles[2]. This puzzle refers to the positive response of the price level to a monetary tightening (Sims, 1992) as well as to the implausibly long, compared with the average duration of price and wage contracts in the economy, time lags for the decline in prices to become statistically significant. As the price puzzle has been attributed by most researchers to the existence of the misspecification problems mentioned in the previous section, it is often used as an informal specification test of the underlying model. A typical interpretation of this puzzle is that central banks have better forecasts of expected inflation than do private agents; in response to what central banks foresee as impending inflation, they raise their interest rates, although to a lesser extent than needed to

[2] In addition to this puzzle, which is addressed in this paper, the 'liquidity', 'exchange rate', and 'forward discount bias' puzzles have also been discussed, see e.g. Strongin (1995) and Eichenbaum and Evans (1995).

completely offset inflationary pressures, in case they are interested in smoothing interest rates[3]. An alternative explanation that has been advanced (Stiglitz, 1992) is that in an imperfectly competitive environment firms have an incentive to increase their prices after a monetary tightening in order to increase their cash flows before economic activity declines, transferring the cost of their behaviour to the future. The empirical literature has suggested ways to ameliorate or solve the price puzzle, although these solutions do not seem to be very robust across different countries or time periods.

In response to the suggestion by Sims (Sims, 1992) that the price puzzle might be explained by the fact that interest rate innovations partly reflect policy responses to inflationary pressures, Gordon and Leeper (1994) and Christiano *et al*. (1996) proposed adding a commodity price index as a proxy for inflationary expectations in the VAR system. However, the inclusion of commodity prices provided only a partial solution to the puzzle within a recursive identification scheme, in the sense that it at least did not generate *a statistically significant* positive response of the price level to a monetary contraction. Thus a number of studies have adopted a non-recursive approach to the identification of the structural shocks (e.g. Cushman and Zha, 1997; Kim, 1999; Kim and Roubini, 2000). This permits more plausible assumptions about the timing of the reaction of variables to several sources of shocks in the system.

Some other work for the US (Eichenbaum, 1991) has proposed alternative methods of identifying monetary policy shocks - better describing the workings in the market for reserves - using non-borrowed reserves instead of the Federal funds rate as a policy instrument. Strongin (1995) pointed out that while a positive innovation in this variable was associated with declining interest rates, the same innovation produced results contrary to *a priori* expectations about the effects of monetary policy on prices, as interest rate innovations also did. He proposed a representation of the Federal Reserve's operating procedures which included additively both the level of total reserves and the mix of borrowed and non-borrowed reserves. In this way, it was possible to identify the exogenous disturbances to monetary policy after taking account of the

[3] This explanation is at odds with the main argument of the identified VAR approach, namely that the dynamic response of a variable after a monetary policy innovation reflects the impact of the non-systematic component of monetary policy, given a proper specification of the central bank's reaction function.

Federal Reserve's short-run accommodation of the total demand for reserves. This measure of monetary policy seemed to have solved the price puzzle and had substantially more explanatory power for output than a pure non-borrowed reserves measure or any other measure based on a single monetary aggregate, accounting for about half of the variance in output over a two-year horizon. However, the empirical results of Bernanke and Mihov (1998) cast doubt on the relevance of the non-borrowed to total reserves ratio as a proxy for the Fed's policy instrument in the post-1988 period.

Bernanke and Mihov (1998) suggested a linear combination of innovations in total reserves, non-borrowed reserves and the federal funds rate as monetary policy shocks that enabled them to take into account the Federal Reserve's response to shocks in the demand for borrowed reserves. Their model encompassed as special cases the identification scheme based on the federal funds rate innovations as well as Strongin's approach. The absence of a price puzzle in their study depended again upon the inclusion of a spot commodity price index.

Departing from the VAR literature, a number of authors constructed measures of monetary policy shocks using independent financial market information. Rudebusch (1998) noted that one can construct a market-based measure of the unanticipated component of the federal funds rate change by using data from the federal funds futures market. He measured the exogenous shock to monetary policy as the part of the unanticipated component of the federal funds rate which was orthogonal to a measure of news about employment. The observed degree of correlation between his measure of monetary policy shocks and shocks derived from a VAR model was not sufficiently high to advocate the use of the latter as a measure of monetary policy shocks.

Alternative non-VAR measures of policy shocks were suggested by Skinner and Zettelmeyer (1996) and Söderlind and Svensson (1997). Skinner and Zettelmeyer identified monetary policy shocks with the changes in the three-month US Treasury bill rates on the days of policy announcements. Söderlind and Svensson proposed the use of the curve of instantaneous forward rates for measuring the expected overnight rates at future dates and generating monetary policy shocks *ex post* by computing the difference between observed and expected overnight rates.

Baglianno and Favero (1998, 1999) investigated the sensitivity of the monetary transmission process to alternative policy shocks by augmenting a standard VAR model to include as

exogenous variables the above three alternative non-VAR measures and by deriving the associated impulse responses. The main features of the monetary policy transmission mechanism obtained from the estimated impulse response functions were not substantially altered by the use of financial market data. The price response to a monetary policy contraction under the alternative measures was negative for the US and Germany but not statistically significant, while the inclusion of commodity prices seemed to be a necessary condition for this observed pattern.

Finally, in response to the criticism that in empirical work analyzing monetary policy, only a limited amount of information is used in comparison with the larger amount of information used by central banks, some researchers employed methods of data dimension reduction, allowing large data sets to be incorporated into the study of monetary policy. Thus Bernanke and Boivin (2001) and Bernanke *et al.* (2002) applied Stock and Watson's methodology on dynamic factor models to the estimation of a small number of factors[4] from three alternative data sets. These factors were then used to augment a standard VAR model in inflation, unemployment and the federal funds rate. The inclusion of the factors in the VAR provided a fairly flexible specification of the Federal Reserve's policy reaction function implicit in the model: one which was consistent with a forward-looking Taylor rule but also one not precluding a direct policy response to any variable in the original data set. The augmented VAR permitted the evaluation of the effects of unsystematic monetary policy. The information contained in the factors in conjunction with the inclusion of the commodity price index as an exogenous variable in the system, was claimed to substantially reduce and often eliminate the price puzzle in the data[5].

3. Coping with misspecification problems

3.1 The role of forward-looking market instruments

In this section we propose a VAR specification that succeeds in solving the price puzzle. Following a contractionary monetary policy shock, this specification implies a gradual decline of

[4] The number of estimated factors was three and these were derived as the first three principal components of the data set. The authors also used up to three lags of the factors in their empirical work.

[5] However no error bands were given for a proper assessment of the success of the factors in solving the puzzle. The authors also noted that commodity prices were insufficient to eliminate the price puzzle for the post-1983 period in the standard VAR (without the factors).

the price level after an initial period of sluggishness, by taking advantage of the forward-looking informational content that some financial market variables and/or other indicators can provide This is achieved without resorting to the use of commodity prices which are not successful in solving the puzzle for the period under consideration[6]. With this specification, we also get plausible responses for the other variables included in the system.

As it has already been pointed out, standard VAR specifications cannot handle properly issues related to the forward-looking behavior of market agents (and the central bank) as well as to incorporate eclectically, as a central bank does, the information included in large datasets. A way to get around this disadvantage of the VAR due to its backward-looking nature is to augment the informational set included in it by using variables that provide useful information about the future path of variables which are considered as intermediate or final targets of monetary policy.

Financial market instruments, especially those related more closely to short-term interest rates, such as the federal funds futures or the eurodollar futures, reflect market expectations about monetary policy changes and thus, implicitly, expectations about near-term developments in a number of variables to which monetary policy responds. By including the price of these instruments in the VAR, we are able to obtain a more realistic account of the information available to the Fed at the time its policy decisions are made[7]. Indeed, we show that the choice of a small number of forward-looking variables - that allow keeping the VAR dimension at a manageable level - combined with the proper modeling of the policy response to innovations in the other variables of the VAR system, leads to a VAR specification that constitutes a parsimonious alternative to considerably larger and more computationally intensive systems[8].

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[6] The specification also deals with the puzzle related to the hump-shaped pattern of the short-term interest rate response to a shock in the interest rate itself.

[7] Prices of financial instruments, and in particular long-term interest rates, have occasionally been used in monetary VAR models without however much success, mainly due to identification problems, see e.g. Bagliano and Favero (1998) and Christiano *et al.* (1999).

[8] Another way to capture the forward-looking behavior of the monetary authorities is to use as a proxy for the Fed's expectations real-time forecasts, as computed by the staff of the Federal Reserve before each Federal Open Market Committee (FOMC) meeting and published in the Green Book. These forecasts included in a VAR can help isolate the forward-looking behavior of the Fed without having to adopt other more complicated modeling approaches. Boivin (2001) includes the Fed's real time forecasts on inflation and unemployment as a convenient way of modeling forward-looking behavior. The major weakness of this approach is that these forecasts are available to the public with a significant time lag (that often exceeds 5 years) thus, limiting the usefulness of this approach for the analysis of

3.2 Factors behind the financial markets' increasing ability to anticipate monetary policy actions

During the past fifteen years significant steps towards greater openness, accountability and transparency of monetary policy have been taken place that increased the ability of the markets to anticipate policy actions.

In the US especially, financial markets have been characterized by an increasing ability to anticipate FOMC's policy changes in recent years. Lange *et al.* (2001), among others, argue that the important shift occurred in the late '80s and early '90s. Through most of the '80s, market prices had predictive power for policy ongoing only about a month ahead and responded substantially to contemporaneous movements in the federal funds rate. More recently, market yields are characterized by an increasing ability to predict monetary policy moves in advance, while their response to contemporaneous policy changes has diminished. Poole and Rasche (2000) and Kuttner (2001) used data from the federal funds futures market to estimate whether this market had anticipated the Fed's actions. Their study looked at the reaction of the federal funds future rate on days when the Fed changed the federal funds rate target. In this way, they estimated the extent to which the market was surprised by the Fed's actions, arguing that markets tend to succesfully forecast future monetary policy.

The markets' improved predictive ability may be attributed to several factors:

First, it could be the outcome of a shift in the nature of shocks hitting the economy. It is likely that shocks to the economy have become more persistent or serially correlated in recent years and thus, if monetary policy reacts systematically to changes in macroeconomic variables, this could increase the predictability of policy changes.

Second, the improved forecasting performance could reflect the adoption of a more gradualist approach in the implementation of monetary policy by the FOMC. Several reasons have been suggested in the literature for the observed gradualism in monetary policy setting, including

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recent developments. Moreover, the inclusion of the forecasted values of the variables, together with their actual values, may potentially be a source of econometric problems e.g. multicollinearity.

parameter and model uncertainty, increased credibility of monetary policy, the need to avoid destabilization of market expectations and sudden fluctuations in financial asset prices.

Third, another factor behind the increased ability of markets to better anticipate monetary policy is related to the increased transparency of monetary policy making by the Fed. Several institutional changes have contributed to this, including the shift away from the borrowed reserves operating regime toward strict federal funds rate targeting as well as the provision of more information by the Federal Reserve in recent years regarding its policy targets and their rationale. Moreover, the FOMC began announcing policy changes on the days of its meetings and offering some explanation for the decisions taken. Since 1994, the speeches and public comments of FOMC members have been providing an increasing amount of information about upcoming policy moves[9].

Partly as a result of the above changes in monetary policy making, market participants have probably improved their understanding of the determinants of monetary policy over the sample period. Indeed, there has been a rapidly expanding literature on estimating and evaluating monetary policy rules following the important contribution of Taylor (1993). One of the major propositions of this literature is that US monetary policy can be reasonably well approximated by simple policy rules describing the response of policy makers to developments in macroeconomic variables. That understanding may have improved further the anticipatory ability of the markets.

3.3 The responsiveness of the prices of financial market instruments to monetary policy moves

The way in which markets respond to monetary policy moves provides significant information about the nature of these moves, and the ability and willingness of the central bank to communicate its policy to the public. The credibility of monetary policy is an important consideration when interpreting policy changes. If policy is fully credible in the sense that the market has firm expectations that the Federal Reserve will successfully pursue certain objectives, then market indicators of inflationary expectations will fluctuate narrowly within a specific range.

[9] Before 1994, changes in the federal funds rate target were not announced on the day of change, but the market typically learned of such decisions through signaling provided by open market operations the following day.

When the Fed's credibility is incomplete, changes in market interest rates will reflect a combination of shifting expectations about the Fed's objectives and the response to the flow of new information. In such a case, we should not expect the market to predict policy decisions accurately.

The analysis of the response of forward-looking market instruments, like the federal funds futures or other contracts written on short- or long-term yields as well as bond yields (Ellingsen and Söderström, 2001), may be particularly useful in evaluating the disturbances hitting the economy and the nature of policy moves (expected vs unexpected). Market participants may revise their expectations of future rate changes in response to an unanticipated target rate change but they would not do so in response to an anticipated change. By including in the analysis such financial market instruments, the prices of which are conditional on expectations of, *inter alia,* future monetary policy moves, we take into account:

i) The information set on the basis of which markets are pricing these assets. This, as indicated above, is wider than the one included in a standard VAR and certainly more forward-looking in nature.

ii) Elements of the monetary policy strategy in the form of pre-emptive moves or gradual policy adjustments, which can be viewed as responses to the observed market sentiment, and stabilization of expectations practices.

3.4 What is special about the federal funds futures?

Federal funds futures hold a prominent position among other forward-looking market instruments in the recent literature as a market-based proxy for the expectations of the Fed's policy actions. At the same time, the federal funds futures (Carlson *et al*., 1995), representing market's expectations about future policy actions, provide potentially useful information to the Fed's policy makers. This information may have significant implications for the conduct of monetary policy when the authorities take into account observed market sentiment. Thus, if the market expects an anti-inflationary policy move, the FOMC may feel compelled to act (even if it

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However, before 1994, discount rate changes were announced on the day of change and the market could then infer the implications for the federal funds rate on the same day.

believes that inflationary pressures will ebb) so as to prevent a flare-up of inflationary expectations.

Over the last decade, several private short-term instruments have surpassed Treasury bills in terms of liquidity. The deepening of futures markets on short-term interest rates since the late 1980s has reduced transaction costs and facilitated arbitrage. The market for the federal funds futures was established in 1989 at the Chicago Board of Trade and current-month and one- to five-month-ahead contracts are traded in this market. Several studies (e.g. Rudebusch, 1998) suggest that the federal funds futures are the most preferable measures of short-run monetary policy expectations as they seem to be relatively unclouded by time-varying term premia or non-federal-funds-market idiosyncratic movements.

Gürkaynak *et al*. (2002) show that the federal funds futures dominate all market interest rates in forecasting near-term changes in the federal funds rate[10]. This difference in the relative forecasting performance is substantial with respect to the first several months, for which the liquidity of the federal funds futures contracts is higher. Gÿrkaynak *et al*. (2002) among others, argue that the risk premia embedded in other instruments, that could be used alternatively to the federal funds futures, are more sizable as these instruments additionally incorporate the credit risk associated with loans with maturities longer than overnight.

Departing from the VAR approach, a strand of the literature uses federal funds futures to disentangle expected from unexpected policy actions based on high frequency data (Faust *et al*., 2001). In this paper, we incorporate the above market-based measure of expectations together with a few other variables some of which are also forward-looking in nature within a standard VAR framework. Specifically, we include as an exogenous variable in the VAR the expected value of the federal funds rate implied by the one-month future contract (written on this rate) at the last trading day of the previous period. We show that a shock to the federal funds rate conditional on its expected value obtained from the futures market and on the information

[10] On the other hand, Söderström (2001) argues that federal funds futures have weaker predictive power. Other studies that investigate the predictive power of future contracts written on the federal funds rate include Carlson *et al.* (1995) and Krueger and Kuttner (1996).

included in the other variables provides a sharper measure of a monetary policy shock, on the assumption that the central bank has at its disposal at least as much information as markets do[11].

4. Other variables in the Fed's information set

In this section, we consider a number of variables, some of which are forward-looking, which are candidates for inclusion in our VAR system helping to approximate in a parsimonious and realistic way the Fed's information set. These variables include a long-term interest rate, a monetary aggregate, an exchange rate and a composite leading indicator of economic activity.

Long-term interest rates

Longer-term financial market instruments are clearly forward-looking and their yield is determined, at least in part, by market expectations about future policy moves. The first stage of the monetary transmission mechanism links policy rates to the term structure of interest rates. In forward-looking financial markets, expectations regarding the future path of short-term interest rates can influence a wide range of longer-term interest rates and other asset prices, thus having a considerable effect on private spending decisions. Woodford (1999) shows that the forward-looking nature of financial markets can have important implications for determining the optimal setting of monetary policy. The extent to which future monetary policy actions are anticipated and built into financial asset prices has been widely studied. Several studies, including Fama (1984), Mishkin (1988) and Hardouvelis (1988), have found that the yield curve contains some information regarding future interest rate changes over particular time horizons[12]. Lange *et al.* (2001) show that during the 1990s even the longer-term yields began to anticipate, in a statistically significant manner, changes in the federal funds rate two or three months ahead and this was reflected in a non-significant response of market interest rates at longer horizons to contemporaneous and imminent Fed funds rate changes. The movement of the prices of long-term instruments in response to policy actions depends on the extent to which market participants were

[11] The Fed is obviously better at processing and interpreting information as it commits far more resources to forecasting than even the largest commercial forecasters (Romer and Romer, 2000) and also has inside information about future monetary policy.

surprised by these actions and were induced to revise their expectations about the future policy stance.

When the Fed adjusts the federal funds rate to a desirable level, through open market operations, interest rates of all maturities typically rise (Cook and Hahn, 1989; Romer and Romer, 2000) A common explanation for this behavior is that the Fed has private information about the likely behavior of inflation and thus the markets revise their expectations of inflation upward just after the disclosure of this information. Ellingsen and Söderström (2001a) investigate theoretically and empirically the relationship between monetary policy and the term structure of interest rates and show that if monetary policy reveals information about shifts in central bank's policy preferences short-term and long-term interest rates move in opposite directions, whereas if the policy move discloses information about the reaction of the central bank to the flow of new information about recent economic developments, then interest rates at different maturities move in the same direction. These results provide, according to the authors, some potential means of directly discriminating between endogenous and exogenous monetary policy moves.

Along these lines, Hanson (1999) incorporates in a VAR model the spread between long-term and short-term rates as the " most natural indicator of future inflation" but finds that this measure of inflationary expectations does not appear to substantially affect the results from his baseline model. Bagliano and Favero (1998) argue that long-term interest rates are an important determinant of the monetary authorities' reaction function but notice the intrinsic difficulty of identifying structural shocks to long-term rates from structural shocks to short-term rates due to the simultaneous feedback between these rates. Balke and Emery (1994) investigate a number of indicators and conclude that the inclusion of the long-short spread in a VAR can, under certain circumstances, resolve the price puzzle.

Monetary aggregates and exchange rates

Similarly, monetary aggregates are often included in VARs used for monetary policy analysis due to their forecasting ability with respect to forthcoming inflationary pressures. The exchange

[12] Other studies show that the yield curve has little predictive power (Campbell and Shiller, 1991).

rate also appears to be useful in forecasting inflation at longer horizons (Hanson 1999). The nominal exchange rate was originally included, along with commodity prices, by Sims (1992) as an inflation indicator due to pass-through effects (increases in the cost of inputs may lead to increases in the prices of final goods) although it is not usually included in VARs analyzing US monetary policy.

Measures of future economic activity

The inclusion of a measure of the expected path of economic activity as summarized by a composite leading indicator can be an additional response to the argument that the information set available to policy makers may include variables useful in forecasting future inflation and output. Being a weighted average of several forward-looking indicators -- that include *inter alia* manufacturing employment, confidence indicators, measures of new orders in the manufacturing sector, a monetary aggregate and the term spread -- related to future economic activity and thus indirectly to inflation expectations, it allows the incorporation in a VAR of a large amount of contemporaneously available information without unduly augmenting its dimension.

5. Empirical Analysis

To evaluate the role of forward-looking variables for the identification of policy shocks, we first estimate a baseline six-variable VAR similar to the one suggested by Christiano *et al.* (1999) and Kim (2001) and compute the impulse response functions of all the variables to a monetary policy shock. The sample used spans the period 1989-2001, which is characterized by a rather homogeneous monetary regime under the Greenspan chairmanship. The system includes industrial production (INDP) as a proxy for economic activity, consumer prices (CPI), a commodity price index (COMP) for primary goods, the federal funds rate (FFR) as the monetary policy instrument, total and non-borrowed reserves (TR and NBR respectively) and a broad monetary aggregate (M2).

Figure 1 displays the estimated impulse response functions of the variables included in the system to a contractionary monetary policy shock, i.e. a rise in the federal funds rate. As can be

seen, the rise in the FFR by 12 basis points on impact (which persists for about 19 months) is accompanied by perverse responses by most of the variables of the VAR. CPI rises gradually remaining above its initial level for almost 2 years and its decline thereafter does not become statistically significant until the end of the time horizon considered (4 years). Industrial production falls below its baseline level after about two quarters, after recording a statistically significant increase of 0.14 percent.

The dynamic response of FFR to a shock in itself is characterized by the so-called "policy innovation paradox", reaching its maximum value 4 months after the initial shock. This pattern suggests that policy makers respond to a policy innovation by following it with additional policy moves in the same direction. Dueker (2002) notices that it is natural to ask why policy makers would systematically react to their own unexpected and perhaps uncalled for increases in the federal funds rate with further increases in this rate. A rather intricate ex-post explanation (that is also applicable to the price puzzle) is that policy makers have access to forecasts that are superior to VAR forecasts and thus the VAR model is inadequate to characterize policy actions as systematic responses to developments in the economy. Finally, the inclusion of alternative measures of commodity prices (such as intermediate or crude material prices) in the baseline system does not alter significantly the empirical results.

The estimation of a smaller system including only industrial production, consumer prices, the commodity price index and the federal funds rate worsens the counter-theoretical responses of the system's variables to the monetary policy shock relative to the Christiano *et al.* (1999) specification[13]. The results for this system are presented in Figure 2.

We next proceed to estimate an alternative system which includes variables that enhance its forward-looking informational content. Specifically, along with industrial production and consumer prices, we also include, as an endogenous variable, the composite index of leading

[13] We choose a 4-variable VAR as a baseline system for two reasons: first, to keep the dimension of the specification proposed in this paper low in view of the relatively small sample size, and, second, to show that the omission of certain variables (non-borrowed reserves, total reserves and money) considered in the literature as contributing to the solution of the puzzle does not prevent our specification from dealing with the problem.

indicators (LCOM)[14] published by the Conference Board (a component of which is the index of commodity prices) and, as an exogenous variable, the expectation of the federal funds rate for the current month as implied by the price of the 1-month ahead future contract written on this rate (FFF) at the last business day of the previous month.

The system is estimated again with monthly data for the same period 1989-2001 as with the baseline system. In selecting this period we are constrained by the availability of data for the federal funds futures. As suggested by the relevant lag selection criteria (Akaike Information Criterion, Schwartz Bayesian Criterion) we use six lags. The Wold causal chain used for the identification of shocks (i.e. {LCOM, INDP, CPI, FFR}) allows for a contemporaneous response of the policy rate to innovations in output, consumer prices and the leading composite indicator. The choice of this ordering is motivated by the fact, that the Fed collects and publishes the data for industrial production, thus having contemporaneous information about the level of this variable (Croushore and Evans, 2003). The contemporaneous response of monetary policy to incoming information about developments in the price level is also plausible in view of the importance of this variable as a policy target and the large amount of resources channeled in forecasting it. The expected federal funds rate in the previous month as implied by the federal funds future is included as an exogenous variable in order to bring its informational content into the analysis without conditioning this expected value on the information set of the VAR.

The orthogonalized residuals of the federal funds rate equation are identified as the monetary policy shock. It is interesting to compare the properties of the estimated time series of monetary policy shocks obtained from our system and the Christiano *et al.* (1999) specification. Figure 3 contains the two time series of the shocks[15]. The two shocks are positively correlated, though with a relatively low correlation coefficient of 0.51. The estimated standard deviation of the policy shock from our system is 0.58, i.e. about 20 per cent lower than that of the Christiano *et al*. system. It should be noted that the two measures of shocks differ significantly, and this difference

[14] Given that information about some of the variables comprising this index is not available but with a lag that exceeds, in many cases, 15 days since the end of the month under consideration, this variable is used with a one-month lag.

[15] We report the centered 3-month moving average of the shock $\left(\left(e_{t-1}+e_t+e_{t+1}\right)/3\right)$.

is more pronounced since the mid-90s, indicating that the federal funds futures play an increasingly important role in bringing additional information in the policy reaction function as specified in the VAR.

Figure 4 reports the impulse responses, over a period of 48 months, of the system's variables to one standard deviation shock in the federal funds rate equation. The main results of this contractionary shock on the other variables in the system can be summarized as follows:

The maximum response of the federal funds rate to a shock in itself occurs contemporaneously and is smaller in magnitude than the one obtained from the Christiano *et al.* specification (10 basis points compared with 15 basis points in the latter). More importantly, the shock dies out very quickly, 4-5 months after the initial impulse so that there is no policy innovation paradox.

The price puzzle is solved (a small but not statistically significant positive response appears for the first 2-3 months) as the price level declines gradually to reach a trough 30 months after the initial shock. The decline becomes significant after 20 months. Finally, industrial production declines steadily after the second month to reach its lowest level 5-6 months later, and returns to its pre-shock level 2 years after the policy impulse. The dynamic path of the industrial production index follows, with a 1-2 months lag, the dynamic pattern of response of the composite index of leading indicators to the policy shock.

As a further step, we extend the previous five-variable specification by including alternatively - for the purpose of keeping the dimension of the system manageable - one of the following variables: (i) the 10-year bond yield (BOY) (ii) the Standard and Poor's 500 total return (SP500) (iii) a monetary aggregate (M3) or (iv) the trade-weighted exchange rate of the dollar against the currencies of the major trading partners of the US. These latter four variables are not crucial for the solution of the price puzzle, although they influence the statistical significance of the dynamic responses. They are used to highlight the economic plausibility of their responses to the monetary policy shock in our augmented system in comparison with the respective response of the same variables in the baseline VAR specification.

The inclusion of the S&P 500 return or the bond yield does not alter qualitatively the results for the other variables, although it appears to decrease the statistical significance of the price level response and the initial size of the policy shock. As can be seen from the impulse responses

(Figure 5), the policy shock is followed by a decline in M3, thus creating a statistically significant liquidity effect, while the S&P 500 return declines on impact by 1 per cent to return to its initial level after 5 months.

The 10-year bond yield reacts very differently compared to the baseline system. The monetary contraction leads to a decline in the long-term rate of about the same size as the policy shock, offering evidence that the federal funds rate innovation in our system is more likely to describe a pure contractionary policy shock and as such to be reflected in lower inflation expectations in the medium term that will permit policy rate cuts in the future.

Overall, our results are in line with the major part of the empirical literature with respect to the finding that the non-systematic part of monetary policy accounts for a small portion of output and price variability. It should be emphasized here that although the policy shock from our specification is 40 per cent smaller in comparison to that of the baseline system, the part of the output forecast error variance decomposition associated with the federal funds rate shock in our system is about 50 per cent higher than in the baseline system.

6. Conclusions

The empirical analysis of monetary policy transmission made on the basis of identified VARs leads, in many cases, to puzzling responses of variables included in such systems to a monetary policy innovation. The positive response of the price level to a monetary policy tightening - the price puzzle - is the most often cited puzzle in the literature and is viewed as evidence of a serious misspecification problem in the underlying system and in particular in the model's equation describing the monetary policy reaction function.

Several proposals to solve the price puzzle have been put forward. Most of them attempt to deal with the major disadvantages of the VAR approach, i.e. the inadequate description of the central bank's operating procedures and the insufficient amount of information incorporated in the analysis due to the small number of variables that can be included in a VAR system.

In this paper we suggest a VAR specification that proves to be successful in resolving the price puzzle featuring in monetary VARs for the US. This specification addresses the

disadvantage of the VAR model associated with its inability to handle directly issues related to the forward-looking behavior of the central bank.

If the Fed is forward-looking, the policy response cannot be properly identified unless expectations are taken into account. In this respect, we show that augmenting a standard VAR with a small number of variables that have forward-looking informational content is a necessary condition for specifying properly the monetary policy reaction function. Most important among these forward-looking variables are the federal funds rate futures reflecting expectations of future monetary policy and a leading composite indicator providing information about near-term developments in economic activity.

Financial market instruments, especially those related more closely to short-term interest rates such as the federal funds futures, reflect market expectations about monetary policy changes and thus, implicitly, expectations about future developments in a number of variables to which monetary policy responds. By including the price of these instruments in the VAR, we are able to obtain a more realistic account of the information available to the Fed at the time its policy decisions are made. The significant steps towards greater openness, accountability and transparency of monetary policy that have been taken during the last fifteen years have increased the ability of the markets to anticipate policy actions and this makes financial market instruments, such as the federal funds rate futures, ideal candidates for incorporating parsimoniously a large amount of information into a low-dimension VAR.

A VAR including expectations about the federal funds rate as implied by the 1-month federal funds futures and expectations about economic activity incorporated in an index of leading indicators is estimated for the US with data that cover the period 1989-2001 -- a period characterized by an homogeneous monetary policy regime and a pronounced price puzzle in standard VAR specifications -- producing theoretically consistent responses for all the variables of the system.

Data Sources

All data series are monthly, beginning in 1989.M1 and ending in 2001.M12. Data on industrial production (INDP), consumer prices (CPI), commodity prices (COMP), federal funds rate (FFR), 10-year bond yield (BOY) , broad money (M2 and M3), non-borrowed and total reserves (NBR and TR respectively), exchange rate (EXCH) and Standard and Poor's 500 total return (SP500) are all from the Federal Reserve System's Database (FRED). Data on the 1-month future contract on the federal funds rate (FFF) were taken from Bloomberg and data on the Conference Board's index of composite leading indicators (LCOM) were taken from Datastream.

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Figure 1

Impulse responses to a FFR shock - Christiano et al. (1999) system

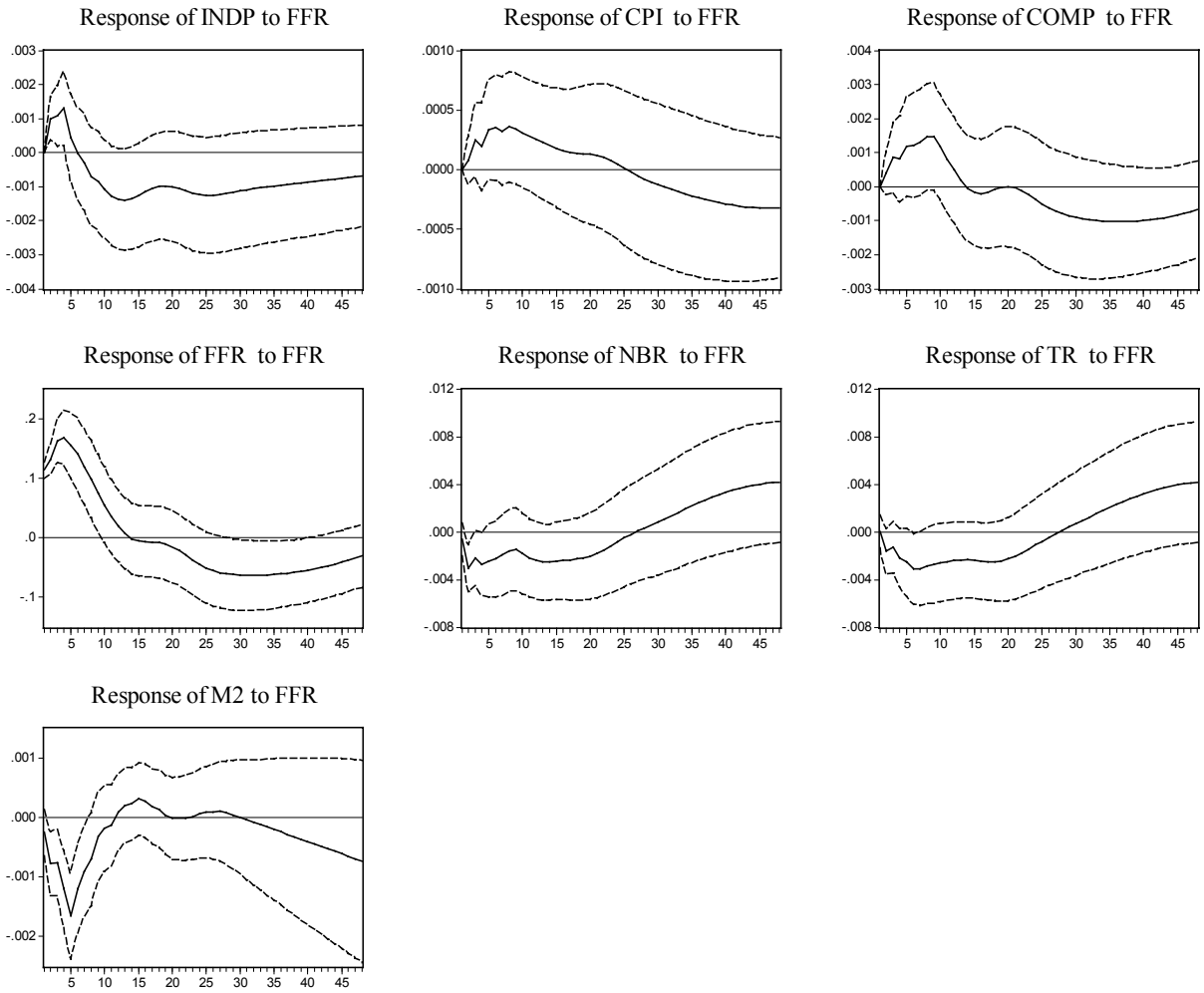


Figure 2

Impulse responses to a FFR shock - Baseline system

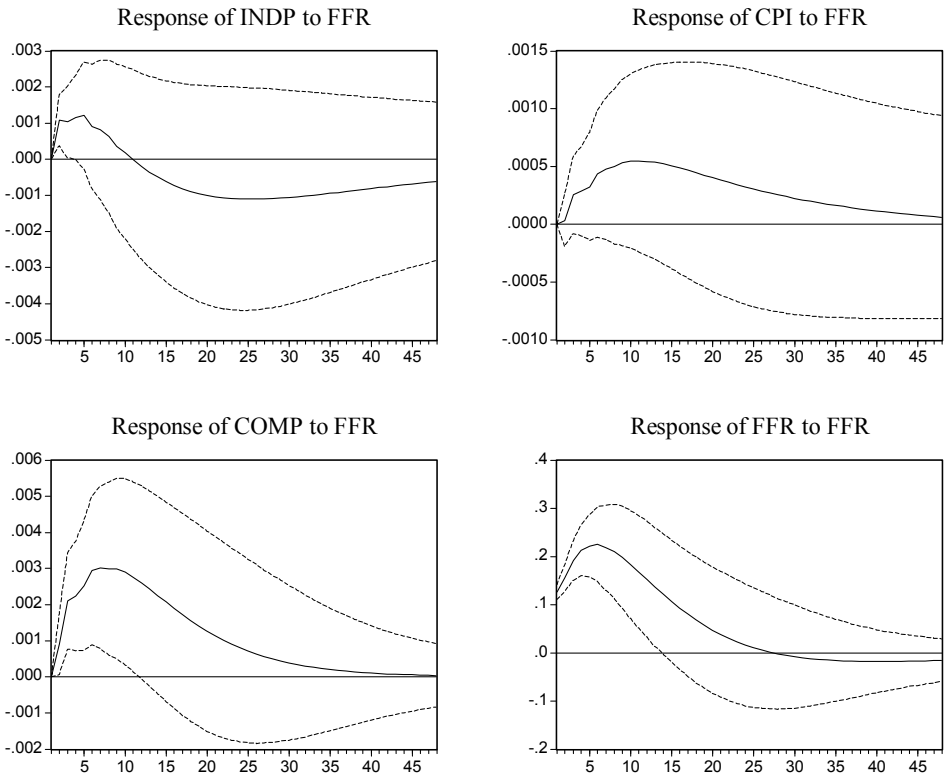


Figure 3

Structural monetary policy innovations from Christiano et al. (1999) and augmented system

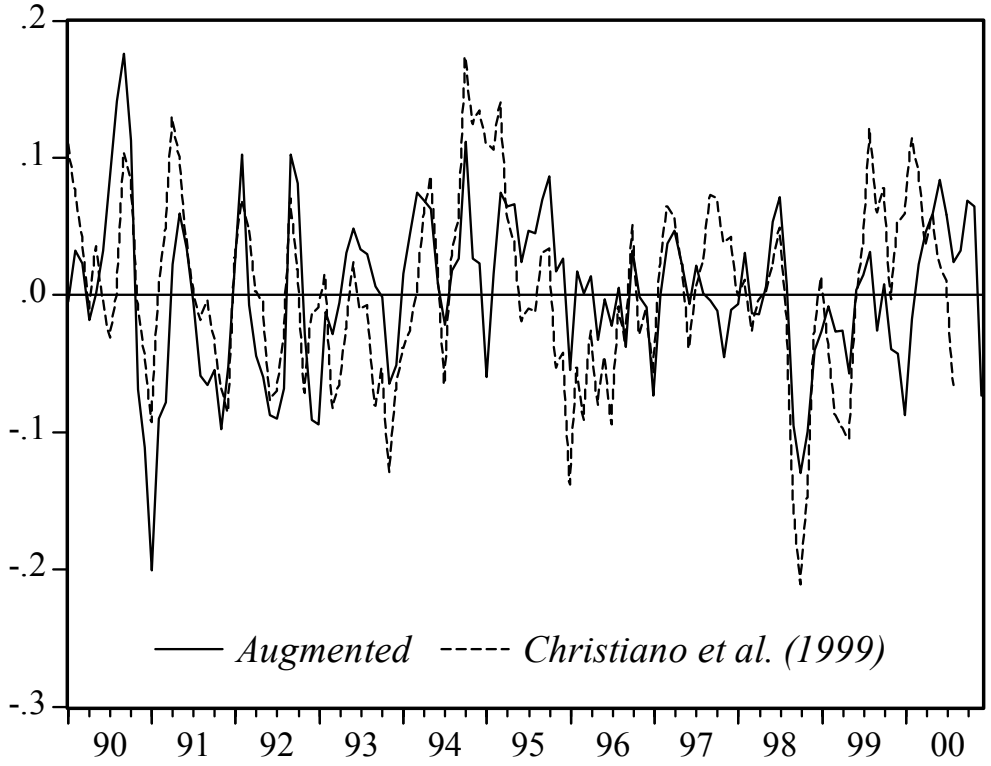


Figure 4

Impulse responces to a FFR shock - Augmented system with FFF as exogenous variable

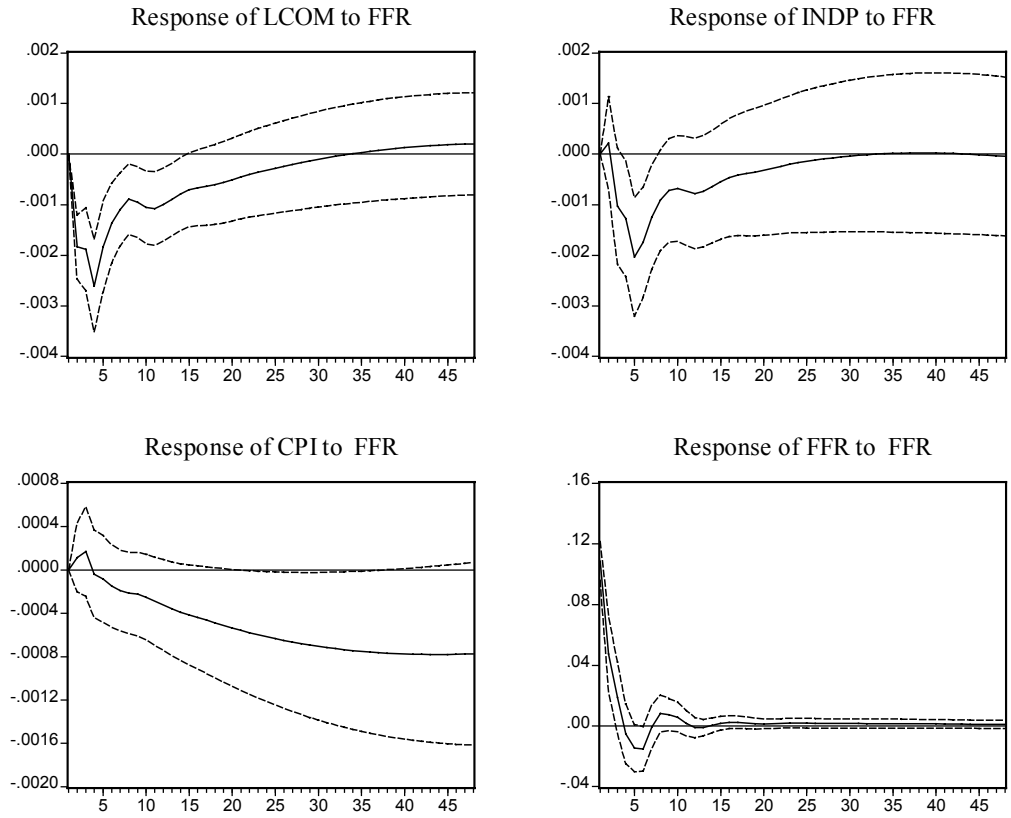
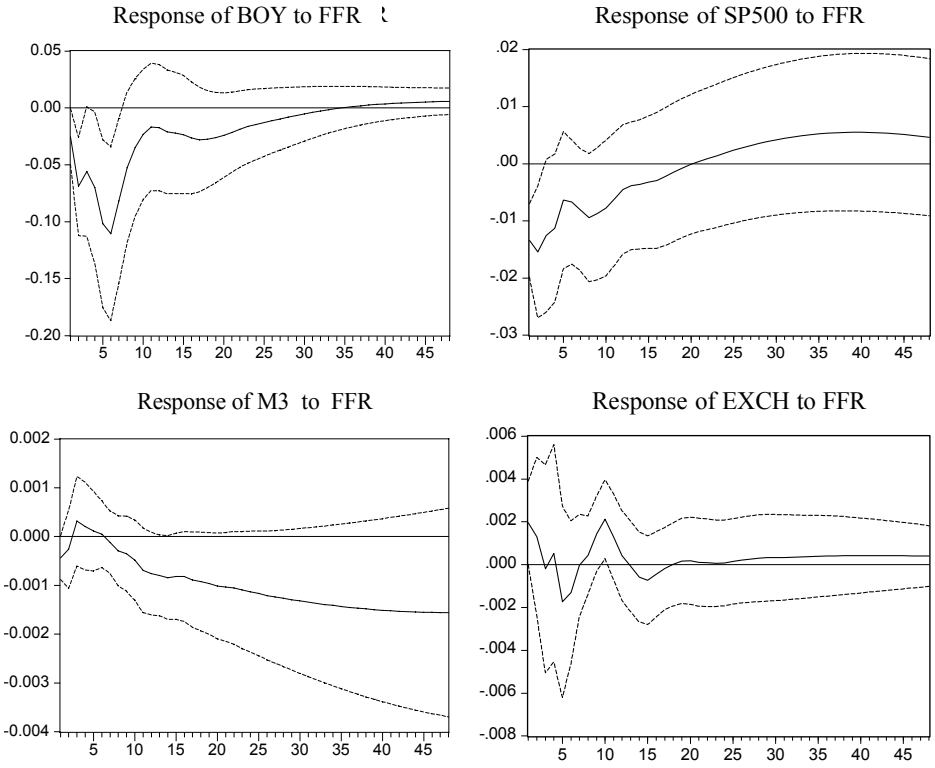


Figure 5

Impulse responses of alternative variables to a FFR shock in the augmented system



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