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DO MEASURES OF MONETARY POLICY IN A VAR MAKE SENSE? (*)

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Abstract

In many VARs, monetary policy shocks are identified with the least squares residuals from a regression of the federal funds rate on an assortment of variables. Such regressions appear to be structurally fragile and are at odds with other evidence on the nature of the Fed's reaction function; furthermore, the residuals from these regressions have little correlation with funds rate shocks that are derived from forward-looking financial markets.

Contents

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(**) Federal Reserve Bank of San Francisco.

1. Introduction (°)

It is easy to quantify the effects of monetary policy actions with a complete structural model of the economy (e.g., Taylor (1993) or Fair (1994)). The lack of general agreement about the nature of these effects reflects the fact that there is no consensus structural model. In response to this lack of consensus, much research has examined the effects of monetary policy using Vector AutoRegressions (VARs), including, most recently, Bernanke and Blinder (1992), Sims (1992), Leeper and Gordon (1994), Christiano, Eichenbaum, and Evans (1994a, b), and Bernanke and Mihov (1995). The great appeal of using VARs for studying monetary policy transmission is that they appear to be able to identify the effects of policy without a complete structural model of the economy.

Indeed, only a bare minimum of structural identifying assumptions are maintained for the monetary VAR analyses. Of these assumptions, the most important are those that allow endogenous monetary policy actions to be distinguished from exogenous ones. Endogenous (or reactive) policy responds to developments in the economy; exogenous (or autonomous) policy consists of all other actions. As stressed by Christiano, Eichenbaum, and Evans (1994a), without a complete structural model of the economy, it is the response of variables to *exogenous* policy actions that must be examined in order to gauge the effects of monetary policy. This is because movements of the economy following an endogenous policy action may be due to the policy action itself or to the variable that spurred that action. Therefore, the separation of monetary policy actions into those that are endogenous and those that are exogenous is a crucial element in VAR analyses of the effects of monetary policy.

Since Bernanke and Blinder (1992), VARs have typically assumed that the federal funds rate is the instrument of monetary policy. Therefore, in a VAR, the dissection of exogenous from endogenous monetary policy is determined by an equation that regresses the funds rate on an information set that includes lags of the funds rate as well as lags and possibly contemporaneous values of the other variables in the VAR. The fitted values from

(°) I thank Larry Christiano, John Cochrane, Tim Cogley, Jim Hamilton, and Tom Sargent for comments on an earlier draft and Desiree Schaan for research assistance. The views expressed in this paper do not necessarily reflect those of the Federal Reserve Bank of San Francisco.

this regression are the endogenous monetary policy actions; the residuals are the exogenous policy actions.

The literature has provided only cursory examinations of VAR funds rate equations or their associated residuals; instead, the focus has been on impulse response functions. This is perhaps not surprising because most VAR equations do not have a clear structural interpretation. However, because the funds rate is under the control of the Federal Reserve as its operating instrument, there is a direct structural interpretation of a VAR funds rate equation as the Federal Reserve's reaction function and of its residuals as policy shocks. Such an interpretation is not new—it is, for example, explicitly maintained in many of the VAR studies cited above. In this paper, however, I will explore this interpretation in detail in order to determine whether the usual VAR representation of monetary policy makes sense.

Two questions are at the heart of my investigation: "Does a VAR funds rate equation correctly model reactive Fed policy?" and "Do its residuals plausibly represent monetary policy shocks?" After describing a typical VAR model in the next section, I consider each of these questions in turn.

In section 3, I examine whether the fitted values of VAR funds rate equations correctly model endogenous policy—that is, whether VAR funds rate equations make sense as representations of the Fed's reaction function in terms of functional form and information set. One benchmark for this evaluation is the large literature of non-VAR structural estimates of the Fed's reaction function. Although this literature certainly has not settled on the exact nature of the Fed's reaction function, it does provide insights into modeling Fed behavior. In addition, I examine the structural stability of the VAR reaction functions, and I contrast their information set with the Fed's own descriptive record of its policy actions. Based on these and other analyses, the Fed reaction functions estimated by the monetary VARs appear implausible in many respects.

Although the VAR misspecification problems described in section 3 appear to be very serious shortcomings, it is difficult to gauge their practical import. This is probably why VAR modelers have ignored these problems and have implicitly assumed that VARs provide an acceptable approximation in practice. Section 4 casts doubt on this assumption. In section 4, I consider whether the residuals from a monetary VAR's funds rate equation make sense. I focus on the interpretation of these residuals as unanticipated monetary policy shocks and examine them from the perspective of forward-looking financial markets. The futures market for federal funds rates provides very clear readings on expected future movements in the funds rate; thus, a measure of unanticipated policy shocks can be easily constructed. I find that the funds rate shocks from VARs have little in common with the financial market shocks. This low correlation provides a straightforward, intuitive measure of how important the misspecification problems in section 3 are *in practice*.

Indeed, the two investigations in sections 3 and 4 examine two sides of the same coin. Obviously, the VAR Fed reaction function cannot make sense unless the VAR monetary policy shocks make sense and vice versa. However, the dual nature of this exercise, which considers models and descriptions of systematic Fed policy as well as information in financial markets on policy surprises, provides a forceful cross-*in*validation of recent monetary VAR models.

2. The Characterization of Monetary Policy in a VAR

The VAR is a system of linear equations, one for each variable. In the reduced form, each equation writes one of the variables as a linear function of its own lagged values as well as lagged values of the other variables in the system. Of interest here is the federal funds rate equation, which is common to all of the monetary policy VARs cited in the introduction.

The reduced form of the funds rate equation can be written as

$$FFR_t = \sum_{s=1}^{L} \hat{A}_s X_{t-s} + \hat{u}_t^{VAR} \tag{1}$$

where FFR_t is the funds rate, X_t is an n-vector of variables (including the funds rate), and $\hat{A}_s$ is an n-vector of estimated coefficients. The linear function $\sum_{s=1}^{L} \hat{A}_s X_{t-s}$ can be considered a reduced-form reaction function for the Federal Reserve. It specifies predictable movements in the funds rate that are based on lagged information in X_t. The residuals $\hat{u}_t^{VAR}$ are the unanticipated monetary policy shocks or innovations in the VAR.

Of course, the residuals $\hat{u}_t^{VAR}$ may be correlated with the residuals (that is, the unanticipated shocks) of the other equations in the VAR. If this is the case, then assumptions must be made about the causal direction of this correlation in order to completely identify the monetary policy reaction function. For example, if it is assumed that the Fed sets the funds rate at time t based on commodity prices at time t, then contemporaneous commodity prices must be added to the regression to obtain the structural reaction function of the Fed.

With assumptions about Fed reactions to contemporaneous variables, the funds rate equation is:

$$FFR_t = \sum_{s=0}^{L} \hat{B}_s X_{1,t-s} + \sum_{s=1}^{L} \hat{C}_s X_{2,t-s} + \hat{e}_t^{VAR}, \tag{2}$$

where the vector of variables in X is split so that X_1 and X_2 are a p-vector and m-vector of variables (with $0 \leq p < n$, $0 < m \leq n$, and $p + m = n$).[1] X_1 contains those variables that are ordered causally prior to the funds rate, so their contemporaneous values enter equation (2) as well as their lags. X_2 contains those variables ordered after the funds rate (and, of course, the funds rate itself), so it contains only lagged values. The residuals $\hat{e}_t^{VAR}$ are the estimated exogenous monetary policy shocks (the orthogonalized innovations) in the VAR. The linear function in (2) is a structural Fed reaction function that specifies the

[1]This discussion is based on the most common type of identification scheme used in the monetary VARs, namely a Choleski decomposition. The "structural" identification alternatives, e.g. Bernanke and Mihov (1995), are also subject to all of the criticisms below.

predictable movements in the funds rate that are based on contemporaneous and lagged information in X_t.

Examples of equations (1) and (2) are given in table 1 at a monthly frequency, from a VAR in Christiano, Eichenbaum, and Evans (1994b), and in table 2 at a quarterly frequency, from a VAR in Christiano, Eichenbaum, and Evans (1994a).[2] These reaction functions are typical of those estimated in the VAR literature.[3] The first column of table 1 gives the monthly, reduced-form reaction function, which regresses the monthly average of the daily federal funds rate (*FFR*) on twelve lags of itself as well as on twelve lags each of the log of nonfarm payroll employment (*EMP*), the log of the implicit price deflator for consumption expenditures (*PCE*), the smoothed change in an index of commodity prices (*PCOM*), minus the log of nonborrowed reserves (*NBRD*), the log of total reserves (*TR*), and the log of M1 (*M1*). The second column gives the structural form assuming that the Fed reacts to employment (*EMP*) and prices (*PCE* and *PCOM*) in month t in setting the funds rate during that month; thus, column 2 adds the contemporaneous values of those three regressors to the reaction function.

Similarly, the first column of table 2 gives a reduced-form reaction function at a quarterly frequency that regresses the quarterly average of the federal funds rate (*FFR*) on four lags of itself as well as on four lags each of the log of real GDP (Y), the log of the GDP deflator (P), the quarterly average of the smoothed monthly change in an index of commodity prices (*PCOM*), minus the log of nonborrowed reserves (*NBRD*), and the log of total reserves (*TR*). For the quarterly structural form, the benchmark identification scheme assumes that the Fed reacts contemporaneously to output (Y) and prices (P and *PCOM*) in

[2] I have updated their sample to include a few years of recent data.

[3] Thus, the deficiencies that I catalog below plague all recent monetary VARs and are not specific to Christiano, Eichenbaum, and Evans (1994a, b), which are among the most careful of VAR analyses.

setting the funds rate; thus, column 2 adds the contemporaneous values of those three regressors to the reaction function.

Figure 1 plots the residuals from the equations in table 1. It is interesting to note how little difference there is between the unanticipated shocks and the exogenous shocks—the correlation $\hat{u}_t^{VAR}$ and $\hat{e}_t^{VAR}$ is 0.98 over the sample. That is, the transformation from VAR innovations to VAR orthogonalized innovations is very minor. Similarly, in figure 2, which plots the quarterly residuals from table 2, the correlation between $\hat{u}_t^{VAR}$ and $\hat{e}_t^{VAR}$ at this frequency is 0.92.

3. Do VAR Interest Rate Equations Make Sense?

In papers that estimate VARs of any type, very little attention is paid to the individual equations; indeed, it is extremely rare to even report the estimated coefficients of the equations as in tables 1 and 2. This reflects the fact that most equations in a VAR have no clear structural interpretation even in their "structural" form. In contrast, the interest rate equation in a monetary VAR does have a clear structural interpretation. Because the Fed directly controls the level of the funds rate, the funds rate equation represents the Fed's reaction function.[4] [5] This interpretation of the funds rate equation is explicit, for example, in Christiano, Eichenbaum, and Evans (1994a), who call their estimated funds rate equation the "monetary authority's rule for setting [the policy instrument]", and in Bernanke and Blinder (1992, p. 991), who call it an estimated "policy reaction function."

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[4]There are two qualifications to note. First, the Fed does allow transitory reserve market pressures to affect the daily funds rate somewhat; that is, there is not a complete peg of rates, but close to it. Second, during the postwar period, the Fed has varied the importance it has placed on the funds rate as an operating instrument. See Rudebusch (1995) for details.

[5]Note that this interpretation is not valid for the previous vintage of monetary VARs, which used broad measures of money to model monetary policy rather than the funds rate. Movements in the broad monetary aggregates, even on a quarterly basis, were not completely determined by the Fed.

As a structural reaction function, the VAR's funds rate equation can be directly examined econometrically for structural stability as well as compared to the large number of non-VAR structural Fed reaction functions that have been estimated and to other descriptions of Fed behavior. Such an analysis highlights several shortcomings of the VAR reaction function: (1) its time-invariant, linear structure, (2) its restricted information set, (3) its use of final, revised data, and (4) its long distributed lags. These problems are each described below in turn.

3.1. A Time-Invariant, Linear Structure

The typical VAR reaction function, as illustrated in tables 1 and 2, imposes a simple constant linear structure on several decades of Fed behavior. In contrast, the temporal instability of empirical Fed reaction functions is now taken for granted in the non-VAR literature. Recent estimated non-VAR structural reaction functions are either limited to very short samples (as in Hakkio and Sellon (1994)) or explicitly account for different structural regions (as in McNees (1992a)). Even so, there have not been great successes in modeling Fed behavior.[6] For example, McNees (1992a) compares his latest estimates of a Fed reaction function to the one previously estimated in McNees (1986) and states: "The number of modifications to the original specification required to make it track the past six years serve as a clear illustration that policy reaction functions can be fragile." (p. 11)

To even a casual observer of the Fed, such instability is not surprising. Over time, the members of the Federal Open Market Committee (FOMC) change, and because of the new attitudes and abilities, there are changes in the Fed's response to a given economic

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[6]Khoury (1990) surveys 42 empirical reaction functions and finds little consistency in the significance of various regressors, in part, because of the differing sample periods used. He states: "One who [examines] just one of these reaction functions may feel convinced that one has learned how the Fed responds to economic conditions, but that seeming knowledge disappears as one reads a large number of these studies." (p. 28)

environment.[7] There are also changes in the structure of the economy that necessitate changes in the reaction function; thus, for example, a given movement in M1 today may have a different implication for the economy, and hence for the Fed, than it did in the 1980's.

These structural changes suggest that simple time-invariant linear monetary VARs are misspecified.[8] Indeed, the monthly and quarterly structural reaction functions in tables 1 and 2 are very fragile. Tests of the stability of their coefficients across various sub-periods overwhelmingly indicate structural instability. For example, simple Chow tests reject the null of structural stability at *every* single sample breakpoint date from 1975 through 1980 for all of the reaction functions, and most of these rejections were at significance levels well below the 1 percent critical value.[9] Finally, it appears that these statistical rejections are also significant in economic terms; for example, Balke and Emery (1994a, b) and Pagan and Robertson (1995) calculate very different impulse responses for the same VAR estimated over different sub-samples.

3.2. The Scope of the Information Set

There has been much debate in the literature about which variables should be included

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[7] As Alan Blinder (1985) presciently put it: "Policymakers come and go—at the Fed, in the White House, and on Capitol Hill—bringing with them different preferences." (p.687)

[8] This is consistent with the conclusions of Brunner (1994) and McCarthy (1995). Also note that Bernanke and Mihov (1995) allow for time variation in the contemporaneous variable responses in their VAR (structural) reaction function to account for changes in the importance of the funds rate as the instrument of policy; however, they impose a time-invariant structure on all lagged variables. Thus, their policy innovations are still obtained from a structure that is largely assumed to be stable and linear.

[9] Such instability is perhaps not surprising given the small sample size (relative to the number of parameters) and the multicollinearity of the regressors. Still, it makes structural interpretation of the equation or of the residuals very hazardous.

in a monetary VAR.[10] For example, Christiano, Eichenbaum and Evans (1994a, b) argue that commodity prices were a crucial input for monetary policy and must be included in a properly specified VAR, while others have disagreed. There are two quite different sources that can illuminate the range of variables important for Fed decisions.

First, there is the long list of regressors that have been used in various non-VAR empirical structural reaction functions. For example, some of the reaction functions in Khoary's (1990) survey include as significant determinants of policy such non-VAR variables as the foreign trade deficit, the stance of fiscal policy, and measures of political pressure.

Second, there is much untapped evidence from official records about which variables the Fed itself considered to be important factors in the determination of monetary policy. For example, during the mid-1980's, the FOMC's official policy operating directives issued to the Federal Reserve Bank of New York (the FOMC's trading agent) identified, *in their order of importance*, the key variables that were being monitored for possible changes in policy (see Heller (1988)). In 1987, according to the directives, the FOMC focused quite closely on the value of the dollar, at first, and then, later in the year, on the value of the stock market and general financial liquidity. These financial market influences in the policy calculation were fairly obvious at the time, yet they are generally excluded from the VARs. An even richer information set is found in the verbatim transcripts of the FOMC meetings.[11] For example, at the November 1, 1988 FOMC meeting, the policy discussion

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[10] This debate has not considered the statistical significance of the variables; indeed, most of the regressors in tables 1 and 2 are insignificant even at the 10 percent level. Of course, multicollinearity among various lags of the same variable will reduce these individual significance levels. Still, it is noteworthy that exclusion tests can eliminate all of the lags of about half of the variables in these tables.

[11] Because policy directives are released publicly after about six weeks, they may be strategic instruments of communication (perhaps "cheap talk") as well as revelations about policy determinants. In contrast, recent transcripts were never intended to be public and were released (in early 1994) only under political pressure.

considered, in part, recent data on labor costs, housing starts, inventory-to-sales ratios, durable goods orders, as well as reports on various regional shocks. Again, these are all variables unlikely to be found in a typical monetary VAR.

Overall, the long list of possible regressors that have been used in various non-VAR structural reaction functions and the assortment of variables deemed important in actual Fed policy discussions suggest that the information set of typical monetary VARs is too restrictive. The limited VARs that have been estimated thus far appear inadequate to model a Fed that "looks at everything".[12]

3.3. Use of Final, Revised Data

With all of the attention given to the number and ordering of the variables in VARs, it is surprising that little is made of the fact that the monetary VARs actually use far too much information on the variables they do include. The VARs are estimated using final, revised data that were, of course, unavailable to the FOMC at the time of its decisions. Policymakers used initial releases and preliminary data, not final estimates.[13]

To see the potential importance of this issue, assume that the final estimate of output in quarter t, Y_t^F, is only available with a one-quarter lag (that is, in period $t+1$). A preliminary estimate is available in quarter t as Y_t^P. The revision from the preliminary to final estimate, w_t, is defined by

$$Y_t^F = Y_t^P + w_t. \qquad (3)$$

[12]For an analysis of the consequences of such a misspecification in a general VAR, see Braun and Mittnik (1993).

[13]As an example of how important this distinction can be in another context, see Diebold and Rudebusch (1991). For non-VAR structural reaction function studies that confront this issue, see McNees (1986, 1992a). For a careful formal analysis, see Maravall and Pierce (1986).

Now, consider a simple quarterly reaction function in which the Fed responds to the preliminary estimate of the current quarter's output, Y_t^P, the final estimate of last quarter's output, Y_{t-1}^F, and last quarter's funds rate (which is measured without error):

$$FFR_t = \alpha\, Y_t^P + \beta Y_{t-1}^F + \delta FFR_{t-1} + e_t. \tag{4}$$

A bivariate output-funds rate VAR with one lag and with output ordered first will correctly model the form of this reaction function. However, if the econometrician uses the final estimates of the data, the estimated VAR structural funds rate equation is

$$FFR_t = \hat{\alpha}\, Y_t^F + \hat{\beta} Y_{t-1}^F + \hat{\delta} FFR_{t-1} + \hat{e}_t^{\,VAR}. \tag{5}$$

Then, even assuming that the revision w_t has good properties (no correlation with Y_t^P, for example), the classic results from the errors-in-variables model suggest that all of the estimated coefficients in (5) will be biased.

However, in practice, it is not clear what properties the data revisions will have. Equation (5), as is typical of most VARs, assumes that an estimate of output is available for the contemporaneous period for setting the interest rate. This is never the case. For example, the *initial* estimate of a given quarter's GDP is released one month after that quarter's end and is unavailable as a contemporaneous input to interest rates. Thus, the Y_t^P in equation (4) must be a forecast, and the revision w_t is the difference between the *forecasted* value and the final estimate. It is hard to overestimate the magnitude of forecast uncertainty plaguing actual policy making.[14]

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[14]The transcripts of FOMC meetings are illuminating in this regard. For example, after summarizing the near-term outlook at the December 16, 1987 meeting, an FOMC officer states: "By depicting these two [forecast] scenarios, I certainly don't want to suggest that a wide range of other possibilities doesn't exist. However, I believe both scenarios are well within the range of plausible outcomes, and they point up what we perceive to be a dilemma for the Committee: namely, given the lags in the effect of policy action, an easing or tightening step might be appropriate now, but it isn't clear which."

In truth, the problem is even deeper. There are not only statistical revisions and forecast errors contained in w_t but definitional revisions as well. That is, the Fed reaction functions in VARs are often estimated using re-defined variables or variables that did not even exist during the historical period being modeled.[15] For example, in table 2, the Fed is modeled as reacting in the 1960's and 1970's to real GDP in 1987 dollars—a variable that did not exist before 1990.[16] Similarly, Bernanke and Blinder (1992) use an experimental version of the consumer price index that was not available until after the end of their estimation sample, while Bernanke and Mihov (1995) go even further and construct their own private monthly output and price variables to use as regressors in a historical Fed reaction function. It is hard to envision how these variables could have any role in the historical Fed policy information set.

3.4. Long Distributed Lags

There is one last feature of typical interest rate equations in VARs that suggests that they misrepresent endogenous policy. About half of the significant coefficients in tables 1 and 2 are for variables that are lagged four months or more. Such long lags are not found in the non-VAR estimated structural reaction functions. Taken literally, the VAR equations indicate that the Fed reacts systematically to old information. Such a reaction function would imply predictable variation in the funds rate at horizons of more than three months. This contradicts a large literature, surveyed in Rudebusch (1995), that has found essentially no information in the term structure for predicting short-term interest rates beyond a horizon of

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[15] See Diebold and Rudebusch (1991) for a discussion of definitional revisions. They find no predictive information in the index of leading indicators in "real-time" but significant information in the final, revised figures (after the index components had been re-selected).

[16] McNees (1992b) provides some discussion of how, for example, the amplitude of historical recessions depends on the base year used in calculating aggregate output.

about three months. This suggests that many of the significant coefficients in tables 1 and 2 are likely the spurious result of in-sample data fitting.

4. Do VAR Interest Rate Shocks Make Sense?

The flip side of the question as to whether VAR funds rate fitted values make sense is whether VAR funds rate shocks make sense. This section judges those shocks from the perspective of forward-looking financial markets. Unanticipated movements in the funds rate can be easily identified using financial market expectations for future rates. Financial markets, in forming these expectations (assuming rationality), will account for a time-varying or nonlinear structure for the Fed reaction function, will incorporate all the informational variables relevant to the Fed, and will use only the contemporaneous, real-time data available to the Fed. That is, the criticisms of VAR reaction functions leveled in the previous section cannot be readily applied to market-derived definitions of systematic or unanticipated Fed policy actions. Accordingly, if the above criticisms are important, there should be a large divergence between VAR shocks (which would be based on a faulty structure) and market-based shocks.

The focus of this section is primarily on judging the $\hat{u}_t^{VAR}$ rather than the $\hat{e}_t^{VAR}$. Although they are not as prominent in the VAR literature, the $\hat{u}_t^{VAR}$ are arguably as important as the $\hat{e}_t^{VAR}$. From figures 1 and 2, it appears that the latter are simply a modestly orthogonalized version of the former. In any case, it is hard to imagine that one could get the unanticipated shocks wrong (the $\hat{u}_t^{VAR}$), but still get the exogenous unanticipated shocks right (the $\hat{e}_t^{VAR}$). Also, as the discussion in section 2 makes clear, the measurement of the $\hat{u}_t^{VAR}$, unlike the $\hat{e}_t^{VAR}$, does not depend on the particular VAR identification scheme used. Thus, any criticisms of the $\hat{u}_t^{VAR}$ are robust to whether the funds rate is ordered first or last or whether a structural VAR identification scheme is used instead (as in Bernanke and Mihov (1995)).

4.1 Construction of Shocks from Financial Market Data

Unanticipated shocks to the funds rate could be constructed from various forward-looking financial market series, including Treasury bill rates or quotes on Eurodollar futures. I use rates from federal funds futures (FFF) contracts because they provide expectations about the funds rate that are relatively unclouded by time-varying term premia or non-federal-funds-market idiosyncratic movements. Most importantly, unlike any other series, these futures contracts are bets about the monthly average of the daily funds rate, which is precisely the interest rate series that enters most VARs.[17] The disadvantage of using FFF rates is that the underlying contracts were first traded in late 1988, so I will be able to compare the financial market surprises to only the last six and a half years of VAR innovations. Based on figures 1 and 2, this sample period does not appear to be atypical.

As evidence of the clear, unbiased nature of the FFF rates, it is instructive to run the usual forecast evaluation regression of actual on expected. Let $FFF1_{t-1}$ be the FFF market's one-month-ahead expected funds rate as of the end of period t-1. The regression of the actual funds rate on this expected rate (with standard errors in parentheses) yields:

$$FFR_t = \underset{(.0454)}{-.00505} + \underset{(.0068)}{.9976}FFF1_{t-1}; \quad R^2 = .996; \quad 1988{:}10\text{-}1995{:}3.$$

There is no significant bias, the slope coefficient is insignificantly different from one, and the residuals are serially uncorrelated (for example, the Durbin-Watson statistic equals 2.01).[18]

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[17]Quarterly VARs typically use the quarterly average of the daily funds rate. See Carlson, McIntire, and Thomson (1995) for a comprehensive discussion of the FFF market.

[18] If FFR and FFF1 are integrated, this regression tests whether their cointegrating factor is one, a necessary but not sufficient condition for efficient forecasts. For this case, the evidence of no residual serial correlation is crucial, a fact also supported below in figure 3, where the forecast error, $\hat{u}_t^{FFF} \equiv FFR_t - FFF1_{t-1}$, is shown and appears to be white noise. In addition, similar results to this regression and the following two, are obtained by regressing the *change* in the funds rate on the anticipated *change* in the funds rate.

Based on this regression, I construct the FFF market one-month-ahead unanticipated policy shocks simply as $\hat{u}_t^{FFF} \equiv FFR_t - FFF1_{t-1}$.[19]

Likewise, $FFF2_{t-2}$ and $FFF3_{t-3}$, the two-month- and three-month-ahead forecasts of FFR_t (also measured at the end of the month), are unbiased:

$$FFR_t = \underset{(.0754)}{-.0811} + \underset{(.0165)}{1.0031} FFF2_{t-2}; \quad R^2 = .989; \quad 1988{:}11\text{-}1995{:}3,$$

$$FFR_t = \underset{(.1158)}{-.1339} + \underset{(.0301)}{1.0026} FFF3_{t-3}; \quad R^2 = .975; \quad 1988{:}12\text{-}1995{:}3.$$

Thus, the one-*quarter*-ahead *anticipated* rate can be constructed as the average of the one-month-, two-month-, and three-month-ahead expected rates all measured as of the end of the previous quarter. Accordingly, I construct one-quarter-ahead *unanticipated* policy shocks at a quarterly frequency from the monthly data as

$$\hat{u}_q^{FFF} \equiv (FFR_t + FFR_{t+1} + FFR_{t+2} - FFF1_{t-1} - FFF2_{t-1} - FFF3_{t-1})/3$$

where quarter q contains months t, $t+1$, and $t+2$.

Finally, I also made an attempt to construct *exogenous* policy shocks, $\hat{e}_t^{FFF}$, from the monthly $\hat{u}_t^{FFF}$. Recall that the $\hat{u}_t^{FFF}$ are surprises relative to information through the end of month t-1 but may reflect endogenous policy responses to news about the economy that arrives during month t. I construct $\hat{e}_t^{FFF}$ by regressing the $\hat{u}_t^{FFF}$ on the month-t news about nonfarm payroll employment, which is probably the most important single monthly indicator of economic activity. This news, $EMPNEWS_t$, is defined as the difference between the initial estimate of the change in nonfarm payroll employment from month t-2 to t-1, which is

[19]The result that short-term interest rate futures are efficiently priced has general support in the literature. For example, Krueger and Kuttner (1995) conclude that the FFF market ". . . does efficiently incorporate virtually all publicly available information on the likely direction of future funds rate movements."

released close to the start of month t, and the median expectation of that change, which is from a Money Market Services survey taken near the end of period t-1.[20]

There is some anecdotal evidence that the payroll employment numbers were, at times, a key factor in determining the Fed's policy actions.[21] Indeed, eight of the 43 changes in the Fed's funds target rate during my sample occurred on release dates for the employment data.[22] However, the linear regression of the policy innovation on employment news yields fairly modest results (with a p-value of 0.07 on the significance of $EMPNEWS_t$):

$$\hat{u}_t^{FFF} = \underset{(.017)}{-.014} + \underset{(.00015)}{.00028} * EMPNEWS_t + \hat{e}_t^{FFF}; \qquad R^2 = .044; \quad 1988{:}10\text{-}1995{:}3.$$

The size of the coefficient is also small in economic terms: The maximum observation (in absolute value) of *EMPNEWS* is 320 (in thousands of workers), which translates into a change in the funds rate of just under 10 basis points. Still, the $\hat{e}_t^{FFF}$ go part of the way to orthogonalizing the $\hat{u}_t^{FFF}$.

Attempts at further orthogonalizing the $\hat{u}_t^{FFF}$ with news on other variables (such as the consumer price index or retail sales) were not fruitful. This inability to model a systematic response by the Fed is consistent with the results described in section 3.[23] Also, I was

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[20] I thank Athanasious Orphanides for supplying these data.

[21] For example, on December 7, 1991, the New York Times (Quint (1991)) stated: "The Federal Reserve eased monetary policy another notch yesterday, pushing down short-term rates in response to a much larger-than-expected decline of 241,000 jobs on corporate payrolls in November." Also see Cook and Korn (1991).

[22] These dates (based in part on Rudebusch (1995)) are July 7, 1989, December 7, 1990, February 1, 1991, March 8, 1991, December 6, 1991, July 2, 1992, September 4, 1992, and February 4, 1994.

[23] It may also reflect two inadequacies in the measure of news. First, surprises to the market may not be surprises to the Fed. Second, my data set contains only initial release surprises, so informative revisions to earlier months are not accounted for.

unable to make any attempt to model $\hat{e}_t^{FFF}$ at a quarterly frequency because I lacked the requisite two-month and three-month-ahead forecasts of economic variables.

4.2 Comparison of Financial Market and VAR Shocks

How well do the VAR shocks and the futures market shocks match? At a monthly frequency, figure 3 displays the innovations $\hat{u}_t^{FFF}$ and $\hat{u}_t^{VAR}$, and figure 4 displays the exogenous shocks $\hat{e}_t^{FFF}$ and $\hat{e}_t^{VAR}$. There is little apparent fit. Most notably, in early 1989 and again during 1991, the VAR shocks indicate large unanticipated and large exogenous policy tightenings that were not present in the futures markets. There is also an obvious difference in the sizes of the shocks. Standard errors for the shocks (calculated from 1988:10 to 1995:3) are given in parentheses in the figures. The VAR shocks, which are almost twice as volatile as the FFF shocks, give a much greater role to unanticipated movements in monetary policy than do futures markets.[24]

As shown in figure 5, at a quarterly frequency, the story is much the same (recall that no $\hat{e}_t^{FFF}$ could be constructed at this frequency). There are wide divergences between the VAR and FFF shocks, particularly at the beginning of 1989 and 1991. Also, the VAR shocks imply much more vigorous policy instrument adjustments by the Fed.

To provide some formal measures of fit, I regressed the VAR shocks on the associated FFF shocks. At a monthly frequency, these regressions yielded

$$\hat{u}_t^{VAR} = \underset{(.03)}{.05} + \underset{(.20)}{.56}\hat{u}_t^{FFF}; \qquad R^2 = .09; \qquad 1988{:}10\text{-}1995{:}3,$$

$$\hat{e}_t^{VAR} = \underset{(.03)}{.05} + \underset{(.22)}{.58}\hat{e}_t^{FFF}; \qquad R^2 = .09; \qquad 1988{:}10\text{-}1995{:}3.$$

[24]The story is the same in mean absolute terms. For example, the mean absolute value of $\hat{u}_t^{FFF}$ is 0.11 and of $\hat{u}_t^{VAR}$ is 0.22.

At a quarterly frequency, this regression is

$$\hat{u}_t^{VAR} = \underset{(.08)}{.13} + \underset{(.36)}{.87}\hat{u}_t^{FFF}; \qquad R^2 = .20; \qquad 1988{:}Q4\text{-}1995{:}Q1.$$

The statistic of note is the very low R^2 of these regressions. Assuming the FFF markets accurately measure policy shocks, then movements in these "true" shocks account for only about 10 to 20 percent of the variation in the VAR shocks. That is, most of the variation in VAR funds rate residuals appears unrelated to financial market perceptions of monetary policy shocks.

Finally, I should stress that these results are not specific to my particular VAR specification. I also examined the funds rate shocks from a monthly VAR in Bernanke and Mihov (1995) (their model B shocks). These alternate VAR shocks also displayed a low correlation with the financial market shocks ($R^2 = .07$) as well as surprisingly little correlation with the original VAR shocks ($R^2 = .12$).

5. Conclusion

In VAR analyses, there is little direct justification for the funds rate equations and shocks that are estimated. Typically, the main argument advanced by authors in favor of their VAR equations and shocks is that "good results" are obtained—in the sense that the associated responses of output, prices, and other variables to the supposed monetary shocks have shapes that accord with the authors' priors. However, such an argument is fairly weak, especially because the impulse responses appear sensitive to variations in the choice of the sample period, lag length, and the variables included.[25] Indeed, the VARs' estimated

[25]See, for example, Balke and Emery (1994a, b) and Pagan and Robertson (1995).

impulse responses will be only as good as the VARs' measures of exogenous shocks,[26] and, from the evidence above, these measures do not appear to be very good.

Just as seriously, how can all of the shocks from the different estimated VARs make sense simultaneously? Each paper listed in the first paragraph estimates a different VAR with a different set of variables in X_t and a different definition of the monetary shocks. Indeed, some authors, such as Christiano, Eichenbaum, and Evans (1994a), estimate many different VARs (one for each variable investigated) and implicitly use many different definitions of a monetary policy shock in a single paper. The message of this paper is that the monetary reaction functions and shocks must be taken seriously as constructs in their own right.

In this paper, I have presented evidence from outside the VAR framework in order to give an independent judgement of the adequacy of VAR analyses of the effects of monetary policy. The specifications of such VARs appear to be severely deficient. The VAR reaction functions mis-characterize the Fed's information set and exhibit fragile coefficient estimates; furthermore, their associated unanticipated monetary shocks are essentially uncorrelated with financial market surprises. Accordingly, it would be surprising if VARs could provide even approximately correct answers to structural questions about the monetary transmission mechanism.

One could attempt to correct for the obvious misspecification problems by adding omitted policy variables, using only the data available historically at each point in time, allowing for structural shifts, and shortening the lag lengths. This appears to be a daunting task (especially with respect to incorporating the real-time data set) and weakens the

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[26]Indeed, the n-period impulse response of a variable to a monetary shock can be calculated as the sum of the first n coefficients of a regression of the variable on lagged exogenous shocks.

atheoretical appeal of VARs noted in the first paragraph of the introduction. Indeed, it perhaps suggests that more effort should be put into structural modeling.

Finally, on a positive note, this paper introduces a potentially rich source of information with which to validate certain models. Models that maintain a structural interpretation of a residual as an interest rate surprise (or alternatively, say, an exchange rate surprise) can be assessed in terms of goodness of fit by comparing the estimated surprises to actual financial market surprises. This technique may have further productive application.

Table 1

Estimated Coefficients from VAR Interest Rate Equations
Monthly Data (1960:1 to 1995:3)

Variable	Reduced Form	Structural Form	Variable	Reduced Form	Structural Form
EMP{0}	...	0.357 *	FFR{5}	0.082	0.081
PCE{0}	...	-0.175	FFR{6}	0.117	0.102
PCOM{0}	...	0.663 *	FFR{7}	-0.225 *	-0.227
			FFR{8}	0.202 *	0.210
EMP{1}	0.303 *	-0.100	FFR{9}	0.080	0.084 *
EMP{2}	-0.211	-0.222	FFR{10}	-0.034	-0.057 *
EMP{3}	-0.035	0.006	FFR{11}	-0.143	-0.123
EMP{4}	0.135	0.105	FFR{12}	0.127 *	0.129
EMP{5}	-0.091	-0.004	NBRD{1}	0.053 *	0.051
EMP{6}	-0.215	-0.229	NBRD{2}	-0.096 *	-0.092 *
EMP{7}	0.170	0.130	NBRD{3}	0.020	0.028 *
EMP{8}	0.106	0.142	NBRD{4}	0.010	-0.001 *
EMP{9}	0.008	-0.028	NBRD{5}	0.037	0.040
EMP{10}	-0.056	-0.010	NBRD{6}	-0.060 *	-0.056
EMP{11}	-0.245	-0.276	NBRD{7}	0.001	0.005
EMP{12}	0.108	0.123	NBRD{8}	0.032	0.024 *
PCE{1}	0.028	0.204	NBRD{9}	-0.014	-0.003
PCE{2}	0.190	0.197	NBRD{10}	0.002	-0.010
PCE{3}	-0.080	-0.128	NBRD{11}	-0.027	-0.016
PCE{4}	0.013	0.068	NBRD{12}	0.024	0.022
PCE{5}	-0.075	-0.042	TR{1}	-0.042	-0.024
PCE{6}	-0.013	-0.078	TR{2}	0.006	0.010
PCE{7}	0.006	0.016	TR{3}	-0.020	-0.009
PCE{8}	-0.190	-0.205	TR{4}	0.085	0.055
PCE{9}	-0.031	-0.016	TR{5}	-0.019	-0.008
PCE{10}	0.340 *	0.384 *	TR{6}	-0.003	0.020
PCE{11}	-0.247	-0.286	TR{7}	-0.051	-0.054
PCE{12}	0.056	0.076	TR{8}	0.051	0.045
PCOM{1}	0.537 *	-0.741	TR{9}	-0.023	-0.021
PCOM{2}	-0.546	0.250	TR{10}	-0.053	-0.060
PCOM{3}	-0.148	-0.181	TR{11}	0.046	0.069
PCOM{4}	0.299	0.138	TR{12}	0.015	0.005
PCOM{5}	0.434	0.494	M1{1}	0.403 *	0.379
PCOM{6}	-1.213 *	-1.193 *	M1{2}	-0.301 *	-0.334
PCOM{7}	0.680	0.636	M1{3}	-0.109	-0.068 *
PCOM{8}	0.608	0.599	M1{4}	-0.113	-0.130 *
PCOM{9}	-0.738	-0.684	M1{5}	0.125	0.157
PCOM{10}	0.475	0.475	M1{6}	0.072	0.020
PCOM{11}	-0.605	-0.545	M1{7}	-0.303 *	-0.283
PCOM{12}	0.398	0.336	M1{8}	0.337 *	0.329
FFR{1}	1.243 *	1.259 *	M1{9}	-0.015	0.000 *
FFR{2}	-0.313 *	-0.334 *	M1{10}	-0.025	-0.037 *
FFR{3}	0.087	0.075	M1{11}	-0.193	-0.187
FFR{4}	-0.190 *	-0.160 *	M1{12}	0.124	0.117

Note: The numbers in brackets indicate the number of months that the variable is lagged. Starred coefficients are significant at the 10 percent level.

Table 2
Estimated Coefficients from VAR Interest Rate Equations
Quarterly Data (1960:Q1 to 1995:Q1)

Variable	Reduced Form	Structural Form
Y{0}	...	0.250 *
P{0}	...	0.044
PCOM{0}	...	0.817 *
Y{1}	0.262 *	-0.074
Y{2}	-0.205	-0.142
Y{3}	0.051	0.115
Y{4}	-0.111	-0.157
P{1}	0.289	0.101
P{2}	0.173	0.393
P{3}	-0.781 *	-0.979 *
P{4}	0.321	0.438 *
PCOM{1}	0.355	-0.772 *
PCOM{2}	0.035	0.698 *
PCOM{3}	0.009	-0.302
PCOM{4}	0.146	0.361
FFR{1}	0.991 *	1.075 *
FFR{2}	-0.339 *	-0.330 *
FFR{3}	0.389 *	0.363 *
FFR{4}	-0.094	-0.081
NBRD{1}	-0.013	-0.022
NBRD{2}	-0.039	-0.025
NBRD{3}	-0.003	-0.020
NBRD{4}	0.019	0.033
TR{1}	0.054	0.032
TR{2}	-0.143	-0.093
TR{3}	0.045	-0.004
TR{4}	0.008	0.037

Note: The numbers in brackets indicate the number of quarters that the variable is lagged. Starred coefficients are significant at the 10 percent level.

Figure 1
Monthly VAR Shocks

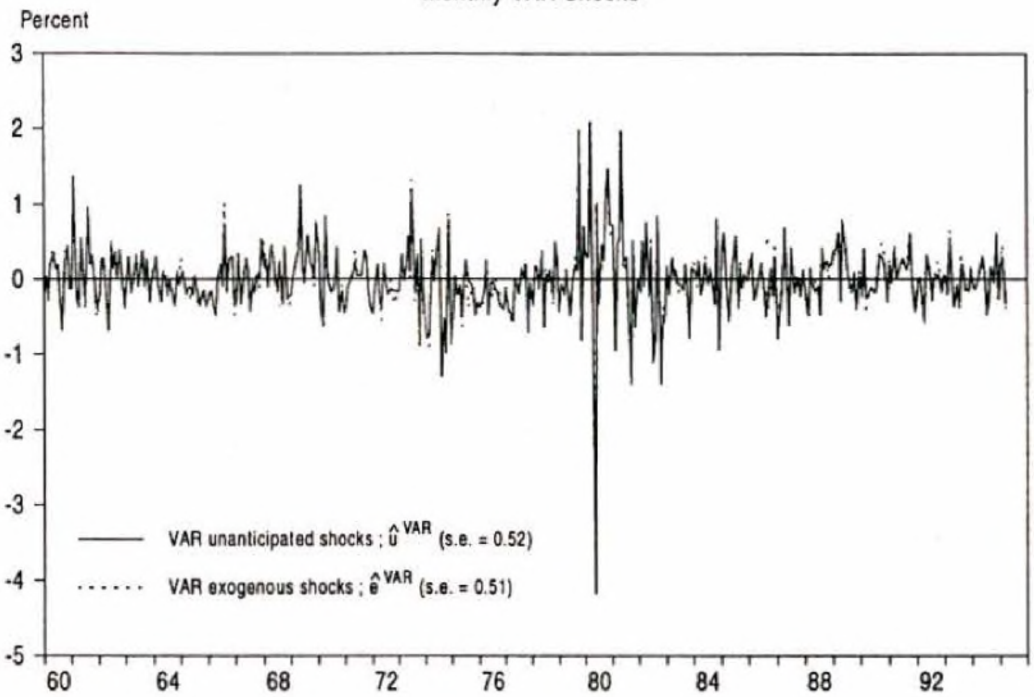


Figure 2
Quarterly VAR Shocks

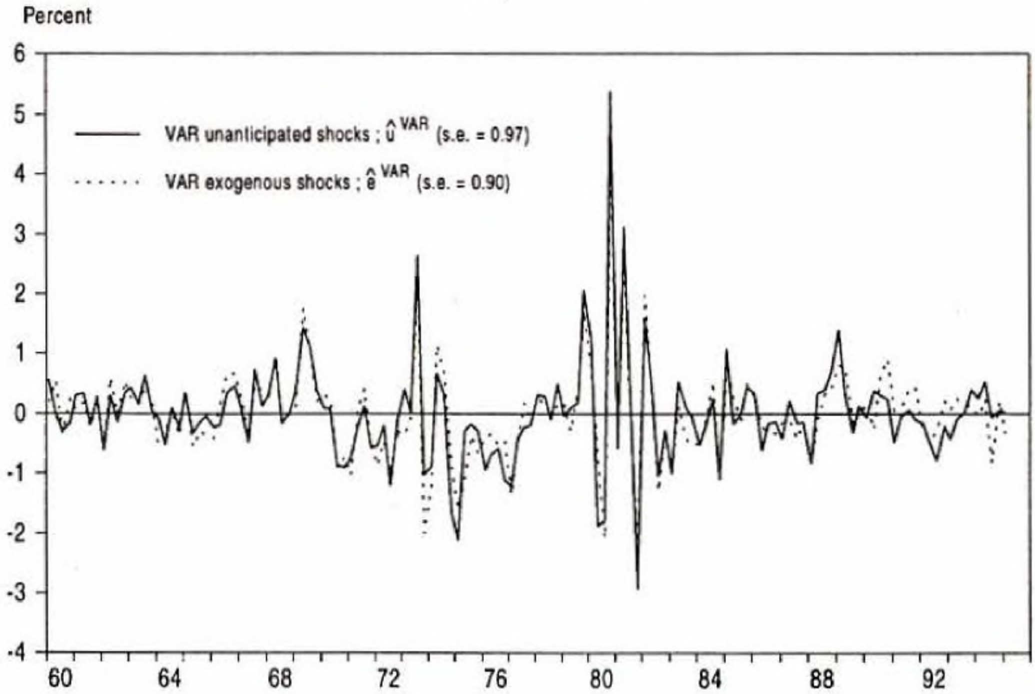


Figure 3
Monthly VAR and Futures Market Unanticipated Shocks

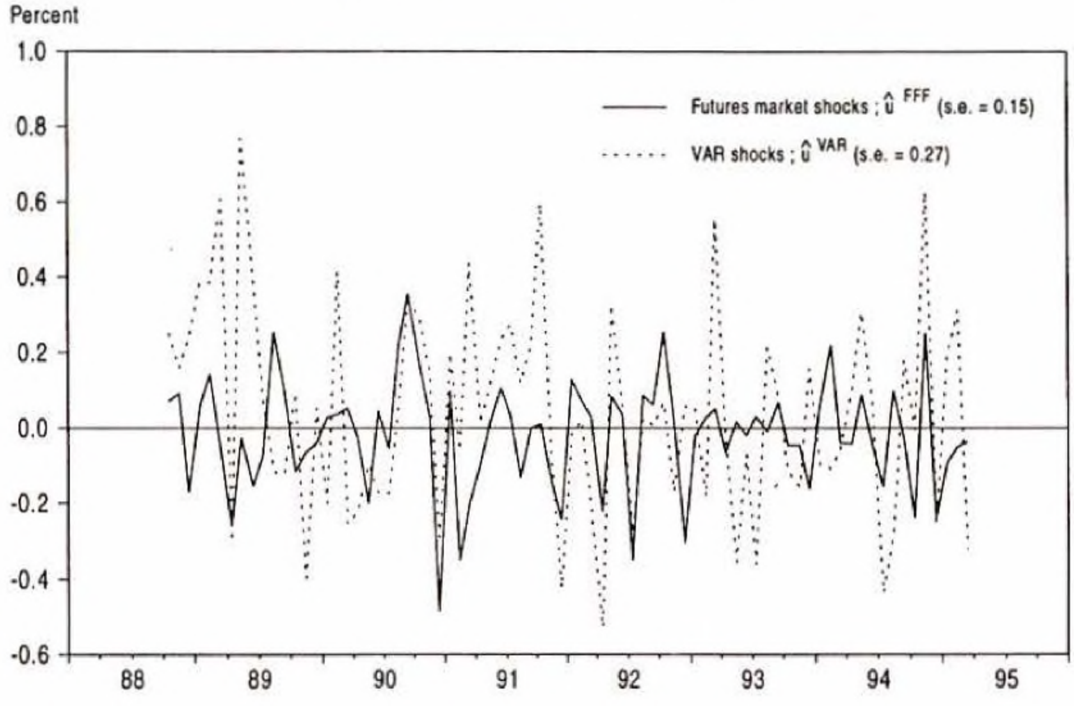


Figure 4
Monthly VAR and Futures Market Exogenous Shocks

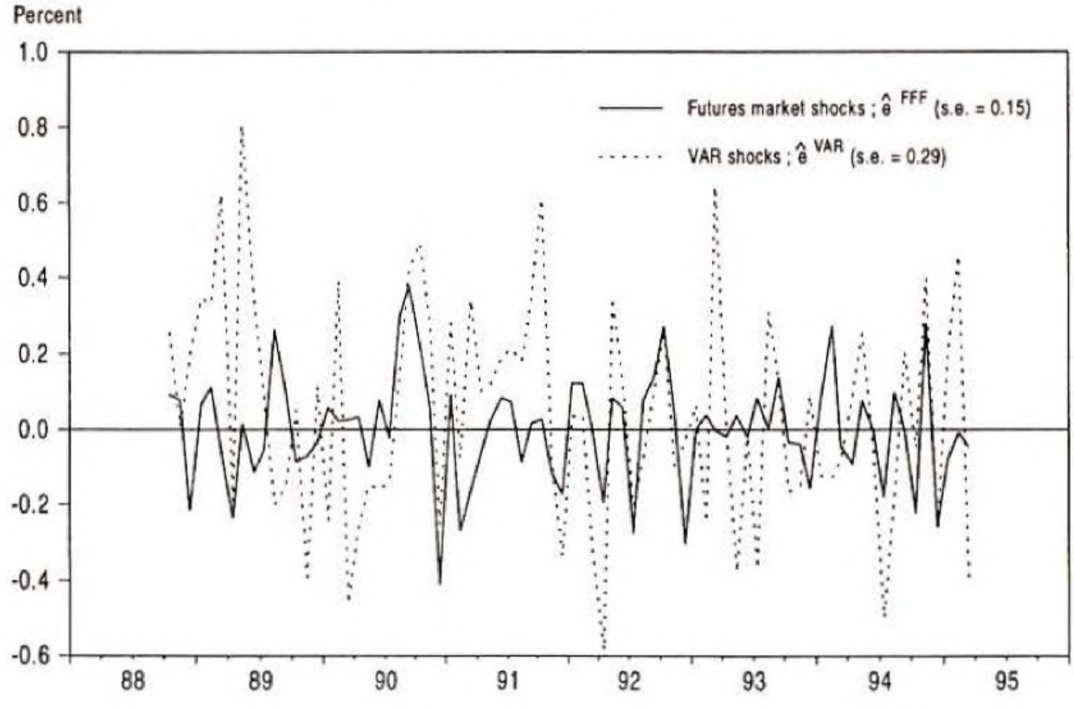
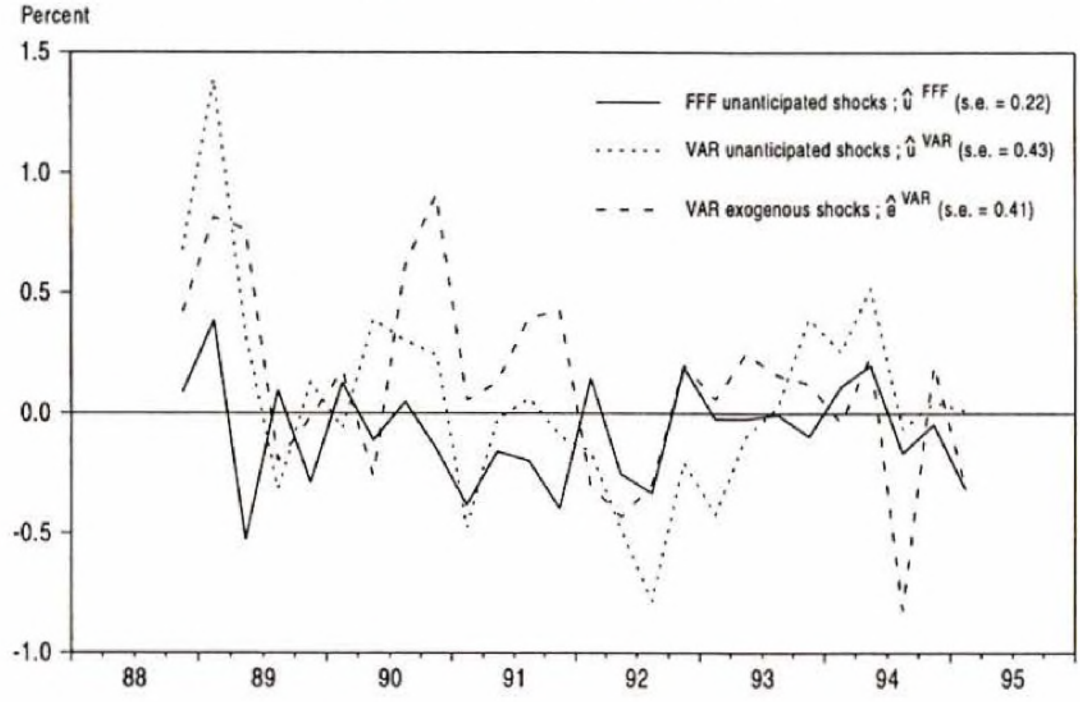


Figure 5
Quarterly VAR and Futures Market Shocks



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