The Effects of Monetary Policy Shocks: Comparing Contemporaneous Versus Long-Run Identifying Restrictions

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I. Introduction

Vector autoregressive (VAR) models have been widely used in recent years to analyze the effects of monetary policy shocks. However, estimates of the macroeconomic effects of monetary policy often differ across studies with regard to both timing and magnitude. The studies generating these estimates frequently differ in terms of the variables comprising the model, the sample period for estimation, and the method of identifying policy shocks; see, for example, Christiano, Eichenbaum, and Evans (1994; 1996; 1998), Gordon and Leeper (1994), Lastrapes and Selgin (1995), Pagan and Robertson (1995; 1998), and Leeper, Sims, and Zha (1996).

Certainly a critical element in the estimation of the effects of policy shocks is the identification of these policy shocks, i.e. the determination of exogenous shocks to monetary policy. Two methods have been widely used in the VAR literature to identify structural shocks to monetary policy. One general approach employs restrictions on the contemporaneous relations among the variables of the vector autoregressive model, while the second general approach imposes restrictions on the long-run relations among the variables. Although economic and institutional arguments can be used to rationalize each identification scheme, there is no consensus as to which approach to identifying shocks is preferred, and the weaknesses of both approaches have been discussed in the literature.[1] Keating (1992), Lastrapes and Selgin (1995), and McCarthy (1995) consider limitations of the use of contemporaneous identifying restrictions. Faust and Leeper (1997) discuss potential drawbacks of imposing long-run restrictions.

[1] Lastrapes (1998) suggests a Bayesian approach to dealing with uncertainty about the appropriate identification scheme. The framework for his analysis is the Gordon and Leeper (1994) model.

The aim of this study is to examine the implications of contemporaneous versus long-run identification schemes for estimating the effects of monetary policy shocks within the VAR model used by Christiano, Eichenbaum, and Evans (hereafter CEE) (1994; 1996; 1998) and Bernanke and Mihov (hereafter BM) (1998) over a particular sample period. Holding constant the variables in the VAR model and the sample period allows one to clearly observe the effect of the identification scheme in estimating the timing and magnitude of the effects of monetary policy actions. The model employed comprises output, the price level, commodity prices, and three reserves market variables—total reserves, nonborrowed reserves, and the federal funds rate. The focus upon the reserves market is important since it allows a more thorough consideration of how policy actions are implemented than does a model that includes only a reserve aggregate or the federal funds rate as the policy variable. Following BM (1998), monthly data are used in estimating the model; use of monthly data reduces problems that may arise with temporal aggregation (see Christiano and Eichenbaum (1987)). The effects of monetary policy shocks for different identification schemes are evaluated by computing impulse response functions.

The approach in this paper is similar in spirit to Keating (1992) and Lastrapes (1998). However, these studies focused upon the effects of **money supply** shocks while the focus of the current study is upon **monetary policy** shocks. It is generally thought that, since money supply shocks typically confound policy actions and non-policy events, they are not a good measure of monetary policy shocks. For example, consider a textbook model of the money supply process in which the money supply equals the product of a money multiplier and a reserve aggregate like nonborrowed reserves. The money multiplier is affected by portfolio decisions of the nonbank public as reflected in changes in the currency/checkable deposit ratio and, depending upon the definition of money considered and whether reserves are imposed on time deposits, the time deposit/checkable deposit ratio. The money multiplier is also affected by bank behavior as embodied in the ratio of excess reserves to checkable deposits, by reserve requirements set by the central bank, and, in some formulations, by the discount rate set by the central bank. A change in either the money multiplier or the reserve aggregate will alter the money supply, and, since changes in the money multiplier and reserve aggregates frequently occur in the same period, changes in the money supply will often reflect the behavior of the central bank, banks, and the nonbank public. Fackler and McMillin (1998) demonstrated the importance of separating money supply shocks into reserve aggregate shocks and money multiplier shocks within the context of a VAR model that used long-run restrictions to identify structural shocks to the money multiplier, a reserve aggregate, and money demand, as well as structural shocks to aggregate supply and the IS curve. They found differences in the timing and magnitude of the effects of the money multiplier and reserve aggregate shocks on macro variables. This suggests that considering just money supply shocks may yield a distorted picture of the effects of monetary policy actions.

Although BM (1998) and CEE (1998) compared the effects of alternative monetary policy shocks identified using contemporaneous restrictions within a common model and sample period, no comparison was made with monetary policy shocks identified using long-run restrictions. In their study of alternative approaches to estimating the liquidity effect, Pagan and Robertson (1995) explicitly considered the CEE model, but, within this specific framework, they did not consider the Strongin, Bernanke-Mihov, Bernanke-

Blinder, or long-run restrictions identification schemes. They impose CEE-type and Strongin-type restrictions within other models that comprise a subset of the CEE model variables, but don't consider long-run restrictions schemes or the Bernanke-Blinder or Bernanke-Mihov schemes within these models. They also compare estimates of the impact liquidity effect for money supply shocks within a four-variable model that includes money, price, output, and an interest rate for a long-run restrictions scheme, a scheme that blends long-run and contemporaneous restrictions, and a scheme that uses only contemporaneous identifying restrictions.

Pagan and Robertson (1998) compared estimates of the liquidity effect of a shock to a reserve or monetary aggregate within three different VAR models. One model used only contemporaneous restrictions to identify a shock to total reserves, one model used only long-run restrictions to identify a shock to either the monetary base, M1, or M2, and the third used a blend of contemporaneous and long-run restrictions to identify a money supply (M1) shock. The variables in each model differ, and the same sample period is not used for all models.

Although these previous studies have provided valuable information about estimating the macro effects of either the money supply or monetary policy, it seems important to compare the effects of contemporaneous versus long-run restrictions within a model that contains the major reserve market variables over a common sample period, something not done in previous studies. Section II of the paper discusses the model and the alternative identification schemes in more detail. Section III presents the impulse response functions while Section IV provides a brief summary and conclusion.

II. Model Specification and Identification of Monetary Policy Shocks

As noted earlier, the model consists of output, the price level, a commodity price index, total reserves, nonborrowed reserves, and the federal funds rate. The commodity price index is included in light of the "price puzzle" often generated in VAR models that don't include a variable that proxies for information about future inflation. The reserves market variables are the ones generally considered critical in specifying a model of this market.

The model is estimated using monthly data for the period 1962:1-1996:12. Data from 1962:1-1964:12 are used as presample data, and estimation is done for 1965:1-1996:12. The three year gap between the beginning of the data and the start of the estimation period is necessitated by the manner in which the reserve variables are constructed. This is described momentarily. Following CEE (1994), a lag of 12 months is used in all VAR models. All data are from the DRI Basic Economics database, and the database name is enclosed in parentheses after the variable description. Following BM (1998), output is measured by the log of real gdp (gdpq (chain-weighted real gdp) interpolated from quarterly data).[2] The price level is measured by the log of the interpolated chain-weighted price index for gdp (gdpdfc). The commodity price index is

[2] The interpolation of real gdp and the chain-weighted price index for gdp is done using the distrib.src procedure in RATS. The random walk option is selected in this procedure. The distrib procedure ensures that the average of the three months' interpolated data for a quarter equals the quarterly figure.

To check robustness of results, the commonly used industrial production index is also considered along with the index of coincident indicators. Walsh and Wilcox (1995) argue that the index of coincident indicators is a more comprehensive and hence better measure of aggregate output than is industrial production alone since the index of coincident indicators is a weighted average of industrial production, nonagricultural employment, real income minus transfers, and real manufacturing and trade sales. When these alternative output measures were used, the log of the personal consumption deflator was used as the price variable. Since the results for industrial production and the index of coincident indicators were very similar to those in Figure 1, all subsequent analysis was done using real gdp.

the log of the Commodity Research Bureau's spot market price index for all commodities (psccom).

Total reserves (fmrra) are adjusted for reserve requirement changes, as are nonborrowed reserves (fmrnbc). The nonborrowed reserves measure includes extended credit; the series with only nonborrowed reserves exhibits a sharp drop at the time of the Continental Illinois crisis in 1984. Following BM (1998), both total reserves and nonborrowed reserves are normalized by a 36-month moving average of total reserves. They do this rather than take logs since they employ a linear model of the reserves market in their identification scheme. Since the BM scheme is considered in this paper, their method of constructing the reserves variables is used. The level of the federal funds rate (fyff) is employed.

As noted earlier, this study focuses upon the implications of using contemporaneous restrictions versus long-run restrictions to identify monetary policy shocks for the estimation of the effects of monetary policy on the macroeconomy. Four alternatives using contemporaneous restrictions are employed. Three rely solely upon the Choleski decomposition while the other uses the Choleski decomposition in conjunction with the estimation of a structural model of the reserves market.

The first identification scheme was suggested by CEE (1994; 1996) and employs the following order for the decomposition: output (y), price level (p), commodity price (cp), federal funds rate (ffr), nonborrowed reserves (nbr), and total reserves (tr). nbr are taken as the policy variable. Since all contemporaneous correlation between two variables is attributed to the variable higher in the ordering with the Choleski decomposition, this scheme implies that monetary policy actions affect y, p, and cp only with a lag. It also implies that the Federal Reserve responds to contemporaneous movements in these three variables; that is, the Federal Reserve's reaction function includes the contemporaneous values of these three variables as well as lagged values of these variables and lagged values of nbr, tr, and ffr. The assumption that monetary policy affects y and p only with a lag and that it has a contemporaneous effect upon a short-term market interest rate is uncontroversial; however, the assumption that monetary policy affects an auction market variable like cp only with a lag has been questioned (McCarthy (1995). McCarthy (1995) and Rudebusch (1998) have also criticized the assumption that the Federal Reserve responds to the current period values of y and p. They point out that the Fed is likely to have only noisy preliminary information about the current period values of these variables. Depending upon the nature of the revision to the preliminary estimates, the use of the current period value of revised data for y and p may have important effects upon the estimates of the structural monetary policy shocks and impulse response functions, although Sims (1998) questions the quantitative importance of this criticism. Thus, this method of identifying monetary policy shocks has some unappealing as well as appealing features.

The second identification scheme involving contemporaneous restrictions is in the spirit of Strongin (1995). It employs the Choleski decomposition with the ordering y, p, cp, tr, nbr, ffr. Strongin argues that shocks to nbr are mixtures of reserve demand shocks and policy shocks. He contends that under the policy procedure followed over the sample used here that the level of tr was determined primarily by Fed accommodation of the demand for reserves. Thus, in this view, shocks to tr reflect reserve demand shocks, and ordering tr before nbr purges nbr shocks of reserve demand effects. The contemporaneous causal link between nbr and tr is the reverse in the Strongin identification approach (hereafter STR) of what it was in the CEE approach. The critique of the CEE scheme carries over to STR as well.

The third procedure considered that uses contemporaneous restrictions is that of BM (1998). This procedure blends the Choleski decomposition with the estimation of a small structural model of the reserves market. The estimation of the reserves market model is done with VAR residuals for nbr, tr, and ffr that are orthogonalized with respect to y, p, and cp. Thus, as in CEE and STR, it is assumed that monetary policy actions affect the macro variables only with a lag and that policymakers respond to contemporaneous movements in y, p, and cp.

The structural model has the following specification.

(1) $e_{TR} = -\alpha e_{FFR} + \mu^d$ (total reserve demand)

(2) $e_{BR} = \beta e_{FFR} + \mu^b$ (borrowed reserve demand)

(3) $e_{NBR} = \varphi^d \mu^d + \varphi^b \mu^b + \mu^s$ (Federal Reserve reaction function)

where the e's represent the VAR residuals from the tr, nbr, and ffr equations orthogonalized with respect to y, p, and cp, and the μ's are structural shocks with μ^s (μ^d) (μ^b) representing the structural shock to monetary policy (total reserve demand) (borrowed reserve demand). Equilibrium is defined by equality between tr demand and tr supply. Conceptually, tr demand is assumed to depend negatively upon ffr while borrowed reserve demand is assumed to depend positively upon ffr.[3] The Fed is assumed to react to

[3] BM (1998) specify borrowed reserve demand to depend upon the gap between ffr and the discount rate, but in most of their empirical work they make the simplifying assumption that discount rate shocks are zero. This is consistent with the studies of CEE and Strongin who do not explicitly consider the discount rate.

contemporaneous shocks to both tr demand and borrowed reserve demand in determining the supply of nbr. As in CEE and STR, structural shocks to nbr are the measure of monetary policy shocks. Furthermore, BM note that a just-identified version of their model with $\alpha = 0$ performs well. Consequently, this assumption is employed in this paper as well; with $\alpha = 0$, shocks to tr (orthogonalized with respect to y, p and cp) are assumed to be shocks to tr demand, as in STR. The model is estimated with a two-step GMM procedure; specifically, a RATS procedure (measure.src provided by BM) is used to estimate the reserves market model and obtain μ^s.

Again, the critique of the CEE identification scheme with regard to cp and current period knowledge of y and p is applicable to the BM procedure. CEE (1998) present an additional criticism of BM based upon BM's assumption that there is no contemporaneous effect of nbr on borrowed reserves. Although they allow shocks to borrowed reserve demand to affect nbr, it is assumed by BM that nbr have no contemporaneous effects upon borrowed reserves. CEE argue, using as an example Goodfriend's (1983) model of borrowed reserves, that theory suggests an effect of nbr on borrowed reserves, and they present empirical evidence that nbr affects borrowed reserves contemporaneously.

Following Bernanke and Blinder (hereafter BB) (1992), the fourth scheme assumes ffr is the policy variable. A Choleski decomposition with the ordering y, p, cp, ffr, nbr, tr is used. As before, it is assumed that monetary policy actions have only a lagged effect upon y, p, and cp and that the Fed responds to current period movements in these variables.

The final method of identifying monetary policy shocks examined imposes restrictions on the long-run relations among the variables in the model. No restrictions are placed on the contemporaneous relations among the variables. This procedure (hereafter referred to as LR) was introduced by Blanchard and Quah (1989) and Shapiro and Watson (1988) to identify shocks to aggregate demand and supply and has been used recently by Lastrapes and Selgin (1995) to identify money supply shocks and by Fackler and McMillin (1998) to identify monetary policy shocks.[4]

The key restrictions used to identify monetary policy shocks in this approach are neutrality restrictions. Prior to implementing this procedure, the model is transformed in the following way. The model is specified as comprising y, the log of real commodity prices (cp – p), cp, nbr, tr, and ffr. We note that p no longer enters as a separate variable, but the effect of monetary policy on p can be determined in a straightforward way from the separate effects of monetary policy on the relative price of commodities and on cp. nbr are assumed to be the monetary policy variable.[5] All variables are first differenced prior to estimation, i.e. a unit root is imposed. With the model in first differences, a Choleski decomposition of the **long-run relations** allows one to easily impose neutrality restrictions. With the model in first differences, the moving average representation indicates the effect of shocks to the variables on the changes in the variables. The effect on the level of a variable at a particular point is the cumulative effect of the changes up to and including that point. The long-run effect of a shock on the level of a variable is simply the cumulative sum of the relevant part of the entire moving average representation. Since the

[4] The model used in Fackler and McMillin (1998) is a good bit different from the CEE and BM-type model used in this paper. However, the basic patterns of effects of a monetary policy shock on y and p are similar to those reported in this paper.

[5] With ffr as the monetary policy variable, applying long-run restrictions to identify the policy shock implies that the central bank can set the **level** of ffr at any desired value in the long-run. This assumption is more questionable than is the analogous assumption that the central bank can set nbr at a desired level in the long-run when nbr are the monetary policy variable.

Choleski decomposition attributes all of the correlation between two variables to the one higher in the ordering, one can impose neutrality restrictions by placing real variables prior to the monetary policy variable in a Choleski decomposition of the long-run relations among the variables. This is demonstrated in Keating (1999).

The first restriction used to identify the monetary policy shock is that shocks to monetary policy have no long-run effects on y. A second restriction is that shocks to monetary policy have no long-run effects on (cp-p), and a third is that monetary policy shocks have no long-run effects on the interest rate. The first and third restrictions are familar results from a sticky-wage/price aggregate demand-aggregate supply-type model with IS-LM underlying aggregate demand. A positive shock to nbr initially raises real money balances, shifting the LM curve and the aggregate demand curves right and raising y above the natural level. The interest rate falls initially. However, as p adjusts and y returns towards its initial level, real balances begin to fall and the interest rate begins to return to its initial level. In long-run equilibrium, real balances are back at their initial level as are y and the interest rate. p is permanently higher.

No restrictions are placed on the long-run effects of monetary policy shocks on tr, cp, or p. As noted earlier, the structural shock to monetary policy can be identified by a Choleski decomposition of the **long-run** relations among the variables, with y ordered first, the relative price of commodities ordered second, ffr ordered third, nbr ordered fourth, tr ordered fifth, and cp ordered last.[6] Since y, (cp-p), and ffr precede nbr in the ordering, it is assumed that shocks to these variables can influence nbr and hence monetary

[6] Since the focus of this paper is on monetary policy shocks, what is critical to the identification of monetary policy shocks is that nbr are ordered after y, (cp-p), and ffr and before tr and cp. Within the block of variables before nbr, the relative ordering is not critical for estimating the effects of a shock to nbr; the same is true for the block following nbr.

policy in the long-run. Placing tr and cp after nbr allows monetary policy to have long-run effects on these variables, but also assumes that shocks to these variables have no long-run effects on nbr. If one interprets tr shocks as shocks to tr demand, then ordering tr after nbr implies that the Fed doesn't accommodate shocks to tr demand in the long-run, even though it may well do so in the short and intermediate runs. An alternative ordering with tr preceding nbr has the unappealing implication that permanent shocks to nbr have no long-run effects on tr. Finally, the assumption that shocks to cp have no long-run effect on nbr in conjunction with a long-run effect of (cp-p) on nbr implies that shocks to p can have long-run effects on the monetary policy variable. Ordering cp after nbr is consistent with the view that the Fed looks at cp as an indicator of future movements in p, which is the price variable of ultimate interest to the Fed, and not as a variable of fundamental concern to the Fed. Other interpretations of the ordering are, no doubt, possible. For a discussion of the conditions under which long-run recursive structures like that employed here identify structural shocks, see Keating (1999).

One advantage of the use of LR is that no restrictions are placed on the contemporaneous relations among the variables. Thus, a restriction that monetary policy shocks have no contemporaneous effects on cp is not imposed, as was done in the schemes previously considered. However, Faust and Leeper (1997) note the problematic nature of imposing infinite horizon restrictions in a VAR estimated with data from a finite sample. They argue that the estimate of the long-run effect is uncertain and that uncertainty about the long-run effect is transmitted to impulse response functions since long-run restrictions are used to identify structural shocks. It is apparent that each approach to identifying monetary policy shocks has its weaknesses, and no consensus on the best approach has emerged. Consequently, it is of interest to compare the effects of monetary policy shocks identified using contemporaneous and long-run restrictions, holding constant the model variables, lag length, and sample period.

III. Empirical Results

A. Impulse Response Functions

The effects of monetary policy shocks are evaluated by computing impulse response functions. The impulse response functions (IRFs) present the effects of a one standard deviation shock to the monetary policy variable and represent the "average" effect of a monetary policy shock over the sample period. The IRFs for y, p, and ffr are presented in Figure 1. The first column of this figure presents the effects of a shock identified using the CEE procedure. The remaining columns present analogous results for the STR, BM, BB, and LR restrictions approaches, respectively. In each diagram, the solid line is the point estimate and the dotted lines represent a one standard deviation band around the point estimate. The confidence bands are derived from Monte Carlo simulations with 1000 draws. We note that the point estimates of the effects of a monetary policy shock vary somewhat in terms of magnitude, timing, and persistence, although the general pattern is similar for each variable. For y, we observe a hump-shaped pattern with y eventually returning essentially to its initial value for the CEE, STR, BM, and LR approaches. The BB model indicates a very persistent positive effect even after 48 months. All identification schemes indicate a permanent effect of monetary policy on p. A liquidity effect is present in all cases. ffr falls initially, but rebounds close to its initial value within a year and remains at the initial value thereafter for the BM, BB, and LR procedures. For the STR procedure, the lower bound of the confidence interval is close to zero and eventually includes zero. The pattern for the CEE identification is troublesome, however. After about 8 months, the confidence interval for ffr lies above zero for the remainder of the horizon reported.[7]

Although the general pattern of effects is similar across identification schemes, the magnitudes of the point estimates differ across schemes. Consequently, it is useful to determine whether these differences are substantial. This is done by first assuming that the LR approach is the appropriate way to identify shocks. The confidence bands for the LR approach are then plotted along with the point estimates from the other approaches. This provides information on whether the differences in magnitudes across schemes are substantial in the sense that the point estimates lie outside the confidence bands. Next it is assumed that a particular contemporaneous identifying restriction is appropriate. Confidence bands for this scheme are plotted along with the point estimates from the other schemes. This procedure could be repeated using the confidence bands from the other contemporaneous restrictions identification schemes, but doing this provides essentially no additional information. Consequently, the confidence bands for the BM procedure are plotted along with the point estimates of the other schemes.

Figure 2 plots the confidence bounds for the LR approach and the point estimates for the CEE, STR, BM, and BB approaches. For y and p, the point estimates of the approaches using contemporaneous restrictions lie within the LR confidence bands.

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[7] Figure 1 presents results only for y, p, and ffr since these variables have been the focus of attention in the literature estimating the effects of monetary policy shocks. The effects on the cp, nbr, and tr will be described briefly and figures are available on request. For all identification schemes, there is a long-lived positive effect on the commodity price level. For the procedures using contemporaneous restrictions, there are transitory positive effects on both tr and nbr with the level of these variables returning to the initial value in the long-run. For LR, a monetary policy shock has only a transitory effect on the change in nbr and tr but has a permanent positive effect on the level of both tr and nbr. This is not surprising since this identification scheme used restrictions on the long-run effects of policy shocks, and long-run effects on these variables were explicitly allowed for in the identification procedure.

However, for ffr, we observe that the point estimate for the CEE identification lies above the upper bounds of the confidence interval at horizons greater than a year. The point estimate for the STR identification essentially lies within the confidence bound while the point estimates for the BM and BB identifications lie below the lower bound for the first 6 months and within the bounds thereafter.

Figure 3 plots the confidence bounds for the BM procedure and the point estimates for the other procedures. In the case of y, we observe that for approximately 12 months, the point estimates from the CEE and STR procedures lie within the confidence bounds. The point estimates for CEE drop below the lower bound after approximately 15 months and remain below the lower bound after that. The point estimates for the STR procedure lie within the confidence bounds until approximately 32 months when they drop slightly below the lower bounds while the BB point estimates lie within or on the confidence intervals at all horizons. The point estimates for the LR approach lie above the upper bound for the first 6 months, but are within the bounds thereafter.

For p, the point estimates essentially lie within the confidence bounds, although there are some slight deviations above the upper bound for part of the horizon for the CEE identification procedure. There are some substantial differences for ffr, however. We observe that the point estimate for the CEE scheme lies entirely above the upper bound of the confidence interval. The point estimate for the STR procedure lies above the upper bound for approximately 6 months and is then close in value to the upper bound until about 13 months when it falls entirely within the bounds. The point estimate for the BB scheme lies on or within the bounds at all horizons. The point estimate for the LR scheme lies above the upper bound for about 8 months, but then lies within the bounds thereafter.

Clearly the BM and BB identification procedures indicate a stronger liquidity effect than do the other identification schemes.

B. Why Do the Magnitudes of the IRFs Differ?

Figure 3 suggests that the CEE procedure generates results for y and ffr that differ substantially from the other contemporaneous identification schemes. It is useful to explore why this occurs. Consider the following structural model:

(4) $y_t = A_0 y_t + A_1 y_{t-1} + \ldots + A_q y_{t-q} + \mu_t$ where y_t = vector of model variables, A_0 = coefficient matrix of contemporaneous effects, A_i, i = 1, … q = coefficient matrices for lagged effects of y, q = maximum lag, and μ_t = vector of structural shocks (which are assumed to be uncorrelated) with variance-covariance matrix Ω. Solving for y_t, we obtain:

(5) $y_t = B_1 y_{t-1} + \ldots + B_q y_{t-q} + e_t$ where $B_i = (I - A_0)^{-1} A_i$, and $e_t = (I - A_0)^{-1} \mu_t$. The moving average representation is

$y_t = (I - B_1 L - \ldots - B_q L^q)^{-1} e_t$ or $y_t = C(L) e_t$ where $C(L) = (I - B_1 L - \ldots - B_q L^q)^{-1}$.

In terms of structural shocks, we have $y_t = C(L)(I - A_0)^{-1} \mu_t$. C(L) is identical for all the contemporaneous identification schemes employed in this paper (except, of course, the order of the variables differs). It is different for the LR scheme since the model variables are transformed when this scheme is employed. Of course, both $(I - A_0)^{-1}$ and μ_t differ across identification schemes and is the only source of difference in the IRFs for the contemporaneous schemes.

Table 1, Part A presents the correlation coefficients for the structural monetary policy shocks (μ_t) generated by the different schemes. We note that the correlations are high between some policy shock measures (CEE-STR and BM-BB, for example) and low between others (CEE-BB, LR-STR, and LR-BB, for example). This has been noted by Rudebusch (1998) in his critique of VAR measures of policy shocks. Sims (1998) argues that as long as appropriate instruments are used to identify monetary policy shocks, qualitatively similar effects on macro variables may be obtained, even though the monetary policy shocks themselves may not be highly correlated across schemes.[8]

To obtain the effects of one standard deviation shocks, one can replace μ_t by $\Omega^{1/2}$ where $\Omega^{1/2}$ is a diagonal matrix of standard deviations of the structural shocks. $(I - A_0)^{-1}\Omega^{1/2}$ is generated by the Choleski decomposition of the variance-covariance matrix for the CEE, STR, and BB schemes. For the BM scheme, $(I\text{-}A_0)^{-1}\Omega^{1/2}$ is a "hybrid" matrix in which the GMM estimates of the reserves market structural parameters and variances replace the relevant elements of a regular Choleski decomposition. In the case of the LR scheme, $(I - A_0)^{-1}\Omega^{1/2}$ is a transformation of the Choleski decomposition based on the long-run restrictions for the LR scheme. These results are demonstrated in an appendix available on request.

Table 1, Part B presents the contemporaneous effects of a monetary policy shock in each of the identification schemes. This is the column of $(I - A_0)^{-1}\Omega^{1/2}$ corresponding to the monetary policy variable. The differences in the magnitudes of the effects are propagated forward through time by the moving average coefficients in C(L). In the CEE scheme, a one standard deviation shock to the monetary policy variable, nbr, is .0129. This shock induces a contemporaneous change in ffr of -.155 and in tr of .005. Since the CEE scheme assumes monetary policy affects y, p, and cp only with a lag, the entries for

[8] See Evans and Kuttner (1998) for an insightful discussion of Rudebusch's critique of VARs.

these variables are 0. We see that for the STR scheme the one standard deviation shock to nbr, .0105, is smaller than for CEE. tr are ordered before nbr in this scheme, and the contemporaneous correlation between tr and nbr (.6) is attributed to tr, so there is no contemporaneous effect on tr of a shock to nbr. The change in ffr, -.2469, is larger than for CEE. One interpretation of these relative effects in the spirit of Strongin is that the larger structural shock to nbr in the CEE scheme is contaminated by shocks to tr demand. When one controls for tr demand shocks, the structural shock to nbr is smaller but the contemporaneous effect on ffr is larger (since this shock now omits positive tr demand shocks which tend to raise ffr).

The standard deviation of structural shocks to nbr in the BM scheme is smaller than for CEE (two-thirds the size) or STR (80% the size). This is expected, of course, since the BM scheme purges nbr shocks of the effects of demand shocks to both tr and borrowed reserves. The contemporaneous decline in ffr is larger than for CEE or STR, again as expected. In the BB scheme, ffr is the policy variable. A one standard deviation shock to ffr is larger in absolute value than for the other schemes using contemporaneous restrictions, and the change in nbr is much smaller since ffr precedes nbr in the Choleski decomposition and hence ffr is given credit for all contemporaneous correlation between the two variables. Surprisingly there is a negative effect on tr for which there is no obvious explanation. This counterintuitive result raises some concern about the appropriateness of this identification scheme.

In the LR scheme there are no constraints on contemporaneous effects. A one standard deviation shock to the monetary policy variable, nbr, is .0101, approximately the same value as for STR. The change in ffr is -.2028, again approximately the same size as for the STR scheme. tr rise by .007, a larger value than for CEE. We also note there is a small contemporaneous positive movement in y. The sign of the contemporaneous effect on p and cp is puzzling since one would normally expect a positive sign. However, in the case of p, the contemporaneous effect is essentially zero.

From Figure 3, we see that the CEE scheme generates results for y that are substantially below those for the other schemes. To the extent that monetary policy effects on output are transmitted through a liquidity effect, the results for y are explicable in terms of the much weaker liquidity effect for the CEE scheme. As seen in Table 1, the initial decline in ffr for the CEE scheme is less that half the decline in ffr for the BM and BB schemes and is only about 60% of the decline for the STR scheme. Even though C(L) is the same for the four contemporaneous schemes, the effects of the smaller initial decline in ffr for CEE are carried forward, and the path of ffr is above the path of ffr for the other schemes. The initial effects on ffr in the STR scheme are weaker that in the BM or BB schemes, but after approximately a year and a half, the point estimate for ffr for the STR scheme begins to move away from the upper bound of the confidence interval. We note that, for the STR scheme, y moves toward the lower bound or is actually slightly below the lower bound after about 20 months. Thus the two contemporaneous schemes with the weakest liquidity effects also display the weakest effects on y. Furthermore, when the impact liquidity effect from the CEE scheme, -.155, is substituted for the impact effect on ffr in the other contemporaneous schemes, the point estimates for y drop below the lower bound of the BM confidence intervals.

We also note in Figure 3 that the initial effects on ffr for the LR scheme are weaker than for the BM scheme; they are similar in magnitude to those of the STR scheme. However, the effects on ffr quickly move within the confidence bounds and stay there. Even though the initial liquidity effect is weaker in the LR scheme than in BM, the initial effects on y are somewhat stronger. Recall that there is a positive contemporaneous effect of a monetary policy shock on y in the LR scheme. This apparently causes y to rise above the upper bounds on the BM confidence interval initially even though the liquidity effect is weaker than for BM.

Figure 3 is more suggestive of substantial differences across schemes than is Figure 2 which plots the relatively wide confidence bounds of the LR scheme. The only sustained departure from the confidence bounds in this figure is ffr for the CEE scheme; even though ffr is initially within the confidence bounds, it rises, and remains, above the upper bound after about a year. The point estimate of y for CEE remains within the confidence bounds at all horizons, although it drops toward the lower bound after 18 months.

C. Robustness of IRF Results

1. Nonborrowed Reserve Targeting

The estimates in Figures 1-3 assume that monetary policy was implemented in essentially the same way over the entire sample. As has been widely discussed (see Strongin (1996) or BM (1998)), there were several changes in operating regimes over the period considered here. Perhaps the most substantive changes were the switch in October 1979 from targeting short-term interest rates to targeting nonborrowed reserves and the return to a primary focus on short-term interest rates in October 1982. In order to deal with the possibility that inclusion of the October 1979-October 1982 period substantially affected the IRFs presented thus far, the following was done. A dummy variable that takes on the value of 1 over 1979:10-1982:10 and 0 in all other periods was created. The reserve market variables--tr, nbr, and ffr--were multiplied by this dummy variable. Lagged values (12) of these interaction dummy variables were then added to each equation of the VAR. This allows the reserves market variables to have effects that differ over the periods of focus on short-term interest rates from the period of focus on nonborrowed reserves. The VAR with the interaction dummy variables was estimated, and the coefficients on the dummy variables were then set to zero. The identification procedures were then applied and IRFs were computed. To conserve space, the figure for this exercise is not presented here but is available on request. With only a few minor exceptions in the case of ffr, the IRFs are within the confidence bounds from the initial estimates.

2. Extension of the Model

The basic model studied in this paper contains only one interest rate, ffr. At the suggestion of a referee, a long-term interest rate was added to the basic system. Since most discussions of the interest rate channel of the monetary transmission process focus upon long-term interest rates as the main determinant of interest-sensitive spending, it is important to consider what happens when a long-term interest rate is added to the system. Gordon and Leeper (1994), Pagan and Robertson (1995), and Edelberg and Marshall (1996) are among the relatively few studies to consider the effect of monetary policy shocks on long-term interest rates within VAR models. In this paper, the constant maturity 10-year Treasury bond yield (DRI basic series fygt10) (hereafter referred to as r10) is added to the model. Following Pagan and Robertson (1995) and Edelberg and Marshall (1996), r10 is added as the last variable in the ordering for the CEE, STR, and BB identification schemes, thereby implying that monetary policy affects r10 contemporaneously but does not respond to current period movements in r10.[9] For the BM scheme, r10 is assumed to respond contemporaneously to shocks to y, p, cp, tr demand shocks, borrowed reserve demand shocks and monetary policy shocks, but is assumed to have no contemporaneous effects on the other model variables. For the LR scheme, r10 is ordered before nbr and after ffr, i.e. the ordering is y, (cp-p), ffr, r10, nbr, tr, cp. This implies that monetary policy actions have no long-run effect upon either short-term or long-term interest rates (or y or (cp-p)), but these variables can have long-run effects upon nbr. The LR scheme does allow contemporaneous and intermediate term effects of nbr on r10, and, of course, contemporaneous as well as long-run effects of r10 on nbr are possible in the LR scheme.

Figure 4 presents results analogous to Figure 1 for the models with r10. The inclusion of r10 has essentially no impact on the magnitude and pattern of monetary policy effects on y, p, and ffr for all schemes, with the exception of ffr in the LR approach. There is no current period effect on ffr in this scheme. All schemes indicate r10 falls immediately following a monetary policy shock. For the approaches using contemporaneous restrictions, r10 quickly rebounds to its initial value after only a small decline. For CEE, the confidence bands lie above zero after about 6 months (similar to the case for ffr) while the confidence bands essentially span zero after 6 months for the STR, BM, and BB schemes. In contrast, the LR approach suggests a very long-lived decline in r10 that has no obvious explanation.

Figures for the model with r10 analogous to Figures 2 and 3 are available on request, but aren't presented in order to conserve space. For y, p, and ffr, these figures are

[9] In contrast, Gordon and Leeper (1994) allow a contemporaneous effect of a long-term rate on ffr.

very similar to Figures 2 and 3. For r10, only the BB point estimate lies anywhere within the LR confidence bands, and it lies near the upper bound for months 14-40. When the BM confidence intervals for r10 are plotted, the STR and BB point estimates lie within or on the confidence bands while the CEE point estimate lies above the upper bound and the LR point estimate lies below the lower bound.

Adding r10 thus reinforces the earlier conclusions about CEE relative to the other schemes that use contemporaneous restrictions. Adding r10 has the most impact for the LR approach. Although the effects of monetary policy shocks on y and p using the LR scheme are essentially the same as for the basic model, the LR scheme generates results for r10 that differ sharply from the other schemes and that are difficult to understand. It thus appears that the LR approach is much more sensitive to the extension of the basic model than are the contemporaneous approaches.

Part C of Table 1 presents the relevant entries of $(I-A_0)^{-1}\Omega^{1/2}$ for the model with r10. As might be expected from Figure 4, the biggest differences from the basic model occur for the LR approach. The one standard deviation shock to nbr is a good bit smaller than in the basic model, and the contemporaneous effect on ffr is much smaller as well. The effect on r10 is much larger than the effect on ffr. The results for the contemporaneous restrictions schemes are very similar in magnitude to those for the basic model, and the effects on r10 are much smaller than the effects for ffr.

IV. Summary and Conclusion

Many previous studies of the effects of monetary policy shocks in VAR models have used alternative methods of identifying these policy shocks and have employed different VAR models and different sample periods in the analysis. The use of alternative models and sample periods complicates isolating the effect of the identification scheme on the differing estimates of the effects of monetary policy shocks on the macroeconomy. Holding constant the VAR model and sample period, this study has compared the implications of four different procedures for identifying monetary policy shocks that use contemporaneous restrictions with a procedure that uses long-run restrictions. The four identification procedures employed that use contemporaneous restrictions are those of Christiano-Eichenbaum-Evans, Strongin, Bernanke-Mihov, and Bernanke-Blinder. The long-run restrictions approach is based upon that of Blanchard-Quah. The effects of monetary policy shocks identified using each procedure are evaluated by computing impulse response functions.

The impulse response functions for the basic model reveal that monetary policy shocks identified by all procedures considered have a similar pattern of effect on output, the price level, and the federal funds rate. However, the magnitude and timing differ to some degree. It appears that the contemporaneous identification schemes of Strongin, Bernanke-Mihov, Bernanke-Blinder and the long-run restrictions identification procedure generate impulse response functions of essentially the same magnitude for output and the price level. The Bernanke-Mihov and Bernanke-Blinder procedures do seem to generate somewhat stronger liquidity effects than do either the Strongin procedure or the long-run restrictions procedure. The results for the method of CEE differ more substantially from the others. The effects on output appear to peak sooner and die out more quickly than for the other contemporaneous identification schemes. The liquidity effect is weaker than for the Bernanke-Mihov or Bernanke-Blinder schemes and this appears to generate the difference in results from the other schemes. A troubling aspect of the Christiano-

Eichenbaum-Evans scheme is the observation that the confidence interval for lies entirely above zero after a year, unlike all the other procedures. Thus the results are quite similar for the Strongin, Bernanke-Mihov, Bernanke-Blinder and long-run restrictions procedures, and there is little basis for selecting one of these as the preferred procedure.[10]

When the basic model is extended to include a long-term interest rate, similar results for output and the price level are found for all schemes and similar results for the federal funds rate are found for the contemporaneous identification schemes. The contemporaneous identification schemes all indicate a small, short-lived drop in the long-term rate following an expansionary monetary policy shock. This change is smaller than for the federal funds rate, and the long-term rate returns to the initial level quicker than for the federal funds rate. However, the confidence interval for the Christiano-Eichenbaum-Evans scheme for the long-term interest rate lies entirely above zero after about six months, in contrast to the other schemes where the confidence intervals include zero after about six months. The results for the long-run restrictions scheme differ substantially for the interest rate variables. The liquidity effect on the federal funds rate is much smaller than in the basic model, and the effect on the long-term interest rate is much larger than for the contemporaneous identification schemes. Furthermore, the confidence interval for the long-term interest rate lies below zero for over two years, a very puzzling result. The results for the long-run restrictions procedure are thus much more sensitive to the addition of a long-term interest rate than are the other schemes.

[10] An alternative to choosing one of the identification procedures would be to use the Bayesian approach to combining the impulse response functions suggested by Lastrapes (1998).

When the results for both the basic model and the extended model are considered, it is difficult to choose between the Strongin and Bernanke-Mihov schemes as a preferred approach to identification of policy shocks. These schemes share the features that total reserve shocks are assumed to be shocks to total reserve demand and that there is one way contemporaneous causality from total reserve demand shocks to nonborrowed reserves shocks. Although the Bernanke-Blinder scheme produces similar impulse response functions for output, the price level, and interest rates to those for Strongin and Bernanke-Mihov, it generates the counterintuitive result that an expansionary monetary policy shock is associated with a contemporaneous decline in total reserves. The Christiano-Eichenbaum-Evans and long-run restrictions procedures have some undesirable features. The Christiano-Eichenbaum-Evans scheme suggests a long-run positive effect on both short- and long-term interest rates of a shock to the level of nonborrowed reserves. The long-run restrictions scheme results for the federal funds rate are sensitive to the addition of a long-term rate to the model, and a monetary policy shock generates a very long-lived negative effect on the long-term rate in this scheme.

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TABLE 1

A. Correlations Among Structural Shocks					
	CEE	STR	BM	BB	LR
CEE	1.0				
STR	.82	1.0			
BM	.68	.83	1.0		
BB	.33	.52	.90	1.0	
LR	.74	.35	.53	.41	1.0

B. $(I-A_0)^{-1}\Omega^{1/2}$: Basic Model					
	Identification Scheme				
Variable	CEE	STR	BM	BB	LR
y	0	0	0	0	.00016
p	0	0	0	0	-.00002
cp	0	0	0	0	-.0023
nbr	.0129	.0105	.0087	.0042	.0101
tr	.0053	0	0	-.0015	.0072
ffr	-.1550	-.2469	-.4282	-.4759	-.2028

C. $(I-A_0)^{-1}\Omega^{1/2}$: Extended Model					
	Identification Scheme				
Variable	CEE	STR	BM	BB	LR
y	0	0	0	0	.00015
p	0	0	0	0	-.00003
cp	0	0	0	0	-.0020
nbr	.0123	.0101	.0078	.0035	.0065
tr	.0049	0	0	-.0017	.0047
ffr	-.1292	-.2180	-.4109	-.4492	-.0663
r10	-.0485	-.0690	-.0544	-.0707	-.1999

Figure 1:Shock to Monetary Policy: Basic Model

Sample: 1965:1-1996:12

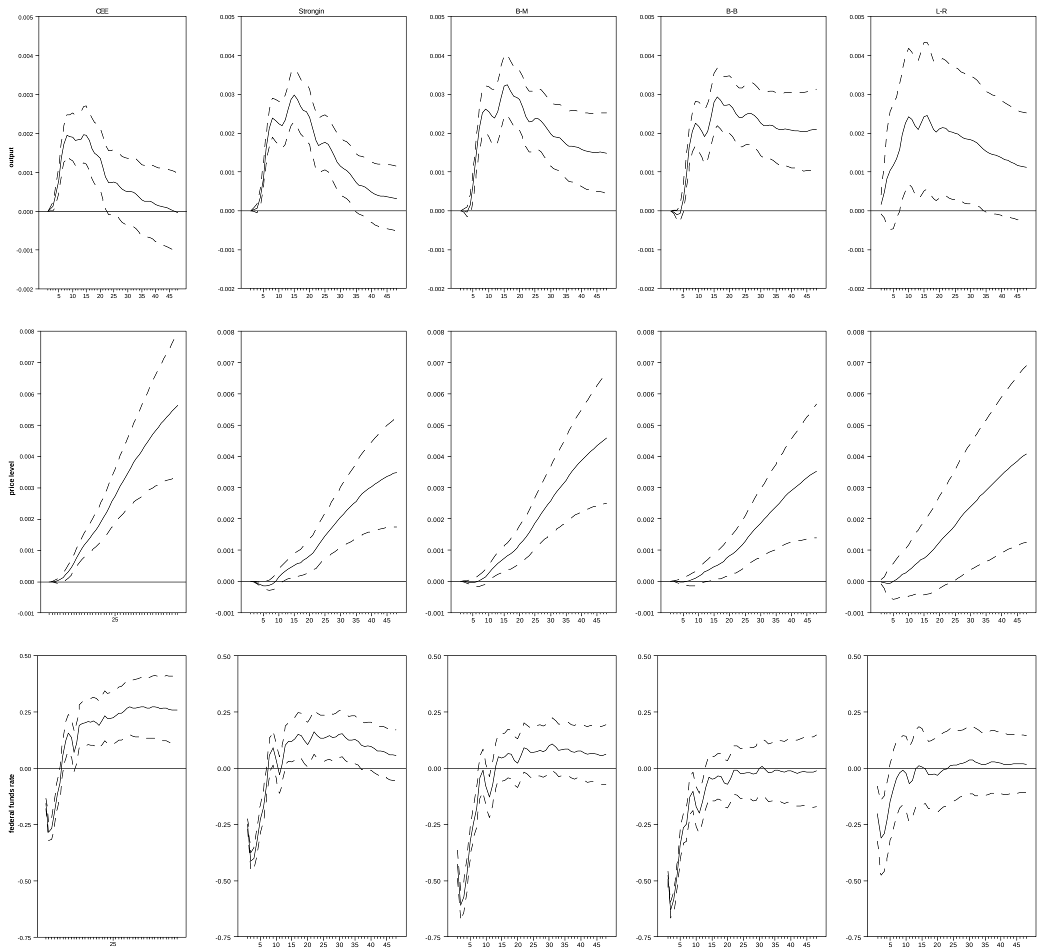

Figure 2: Long-Run Restrictions Confidence Intervals
Point Estimates from Other Identification Procedures

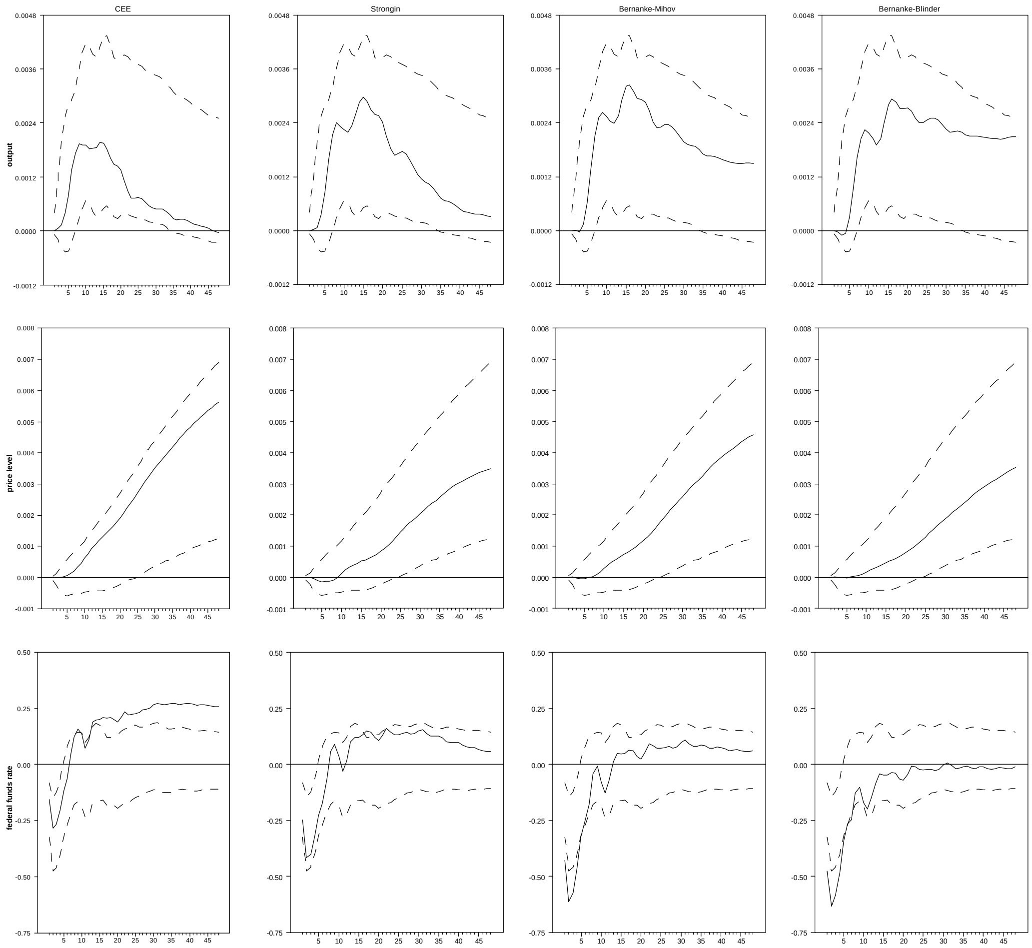

Figure 3: Bernanke-Mihov Restrictions Confidence Intervals
Point Estimates from Other Identification Procedures

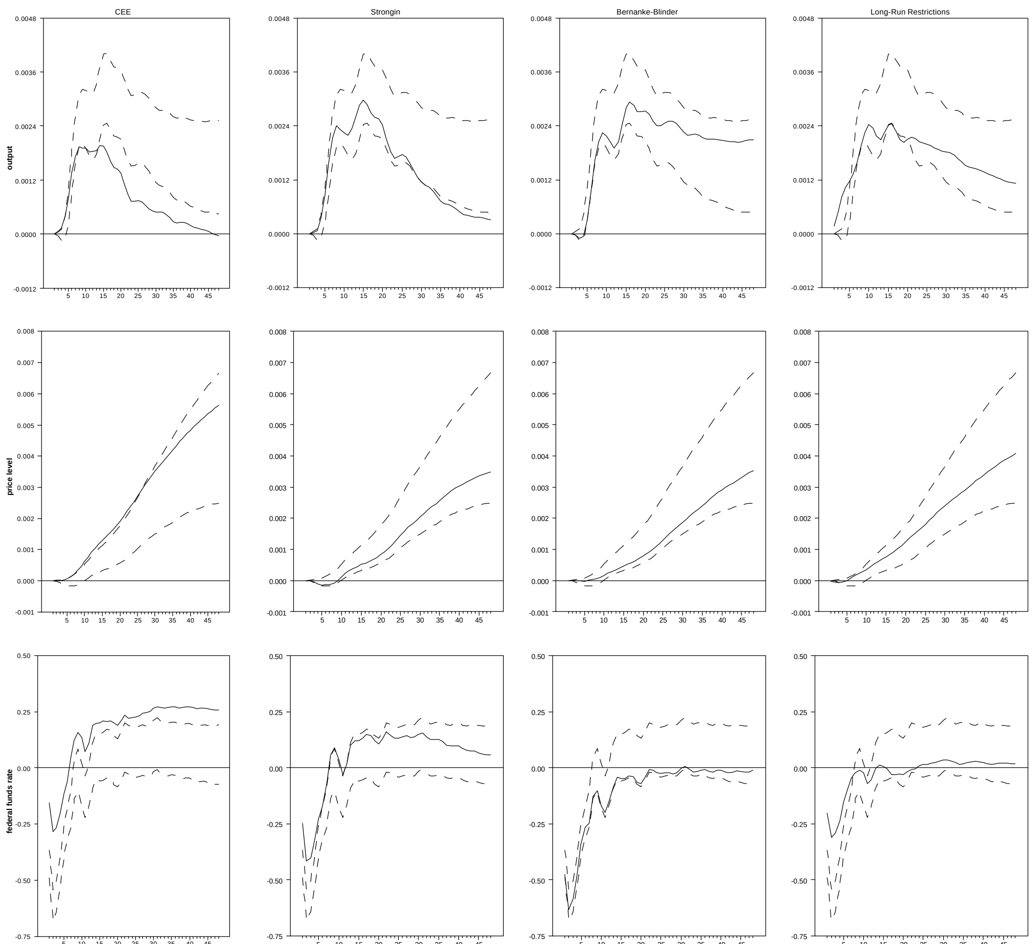

Figure 4:Shock to Monetary Policy: Extended Model

Sample: 1965:1-1996:12