

Econ 327 Project

**"Monetary Policy Shocks: What have We Learned and to What
End", by Lawrence Christiano, Martin Eichenbaum and Charles
Evans**

Marija Vukotic

Duke University

December 2005

Abstract

The main purpose of this paper is to replicate the results of CEE paper 'Monetary Policy Shocks: What Have We Learned and to What End?'. We chose this paper because it addresses very important and interesting fact: in order to asses any monetary policy model we must first answer the question what happens after an exogenous shock to monetary policy. Therefore, we must isolate monetary policy shocks in order to perform experiments in the data whose outcomes can be compared with the outcomes of the same experiments in models. Our results mostly coincide with the ones of the authors. Also, most of claims that authors make without explicitly showing them have been verified. Furthermore, some extensions have been added.

1 Introduction

The main question that this paper is concerned with is: What happens after an exogenous monetary policy shock? It is very important to answer this question in order to assess the empirical plausibility of the economic models concerned with the effects of monetary policy shocks. In fact, even though literature has not yet converged on identifying assumptions that should be used in order to answer this question, it converged on qualitative effects of exogenous monetary policy shocks which turn out to be robust to different identification assumptions.

This paper is organized as follows. Section 2 provides the description of data used. In Section 3 basic techniques used in this paper are elaborated. First, we explain which is the assumption that is used in the process of estimating impulse response functions as well as process itself. Second, we explain bootstrap procedure used in estimating confidence intervals. Other techniques used are explained in later sections, as they are mentioned. The most important part of the paper is section 4 which provides obtained results. First, using recursive-ness assumption we investigate the responses of different economic variables to three benchmark monetary policy shocks: federal funds shock, NBR shock and NBR/TR shock. Second, we perform several robustness checks which show that benchmark results are pretty robust to different changes considered. Third, we discuss well known phenomena in the literature: long run neutrality, liquidity effect and prize puzzle. Lastly, we discuss if our results are affected when recursiveness assumption is abandoned concentrating on Romer and Romer narrative

approach. It turns out that quantitative rather than qualitative results are affected. In last section we conclude by summarizing most important findings.

2 Data

Data used in the replication of the results are obtained directly from the authors. Hence, obtaining not exactly the same results cannot be justified by the possible difference in data used. Following series are used: real GDP (GDP_t), nonfarm payroll employment (EM_t), implicit GDP deflator (P_t), smoothed change in index of sensitive commodity prices ($PCOM_t$), federal funds rate (FF_t), total reserves (TR_t), non-borrowed reserves plus extended credit (NBR_t), and money aggregates M_1 , M_2 and M_0 . All series with the exception of federal funds rate have been logged.

3 Explanation of the Basic Techniques Used

3.1 VAR estimation

The fundamental tool in the literature that is very convenient for summarizing the first and second moment properties of the data is VAR (Vector autoregression). Consider the reduced form VAR with 4 lags, which is given by:

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \Phi_3 Y_{t-3} + \Phi_4 Y_{t-4} + u_t, \quad E(u_t u_t') = V \quad (1)$$

Consistent estimates of $\Phi_i's$ are obtained by running ordinary least squares equation by equation on (1). Variance-covariance matrix of error terms is estimated from the fitted residuals.

We partition Y_t , which is the vector of variables included in the analysis, in the following fashion: $Y_t = [Y_{1t} \ S_t \ Y_{2t}]'$. Here, vector Y_{1t} contains variables whose time t elements are contained in the information set of the Federal Bank. In fact, recursiveness assumption which will be explained latter, implies that these variables do not respond contemporaneously to a monetary policy shock. S_t represents a monetary policy instrument, while vector Y_{2t} contains other variables that are in the information set but respond contemporaneously to the monetary policy shock.

However, problem is that even if we know all $\Phi_i's$, the $u_t's$ and V it is still not possible to compute dynamic response of Y_t to the fundamental shocks in the economy, since there is no reason to presume that any element of u_t corresponds to a particular economic shock. Therefore, we assume that the relationship between fundamental economic shocks and innovations in the VAR is given by $A_0 u_t = \varepsilon_t$. Here, A_0 is an invertible square matrix and $E\varepsilon_t \varepsilon_t' = \Sigma_\varepsilon$, where Σ_ε is a positive definite matrix. Premultiplying (1) by A_0 we obtain following structural form VAR:

$$A_0 Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + A_3 Y_{t-3} + A_4 Y_{t-4} + \varepsilon_t \quad (2)$$

Now, A_i is a 4x4 matrix of coefficients and

$$\Phi_i = A_0^{-1}A_i, i = 1, 2, 3, 4 \text{ and } V = A_0^{-1}\Sigma_\varepsilon(A_0^{-1})' \quad (3)$$

3.2 Computing Impulse Response Functions (IRFs)

After estimating VAR in order to estimate dynamic effects of a fundamental economic shock we performed different VAR procedure than one in CEE still obtaining the same results. In fact, we rewrote a VAR(4) as a VAR(1), i.e. companion form:

$$\begin{bmatrix} Y_t \\ Y_{t-1} \\ Y_{t-2} \\ Y_{t-3} \end{bmatrix} = \begin{bmatrix} \Phi_1 & \Phi_2 & \Phi_3 & \Phi_4 \\ I_4 & 0 & 0 & 0 \\ 0 & I_4 & 0 & 0 \\ 0 & 0 & I_4 & 0 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ Y_{t-2} \\ Y_{t-3} \\ Y_{t-4} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

or

$$\Gamma_t = \Phi\Gamma_{t-1} + \nu_t \quad (5)$$

After defining selection matrix $S_{4 \times 16} = \begin{bmatrix} I_4 & 0 & 0 & 0 \end{bmatrix}$, matrix of impulse response functions k steps ahead was computed using the following formula:

$$C = [S\Phi^k S']A_0^{-1}, \quad (6)$$

While, as mentioned above, Φ_i 's can be estimated via ordinary least squares regressions, getting A_0^{-1} is not so easy. Imposing no restrictions on A_0^{-1} implies that there are in general many solutions for equation (6). Hence, in order to

obtain the unique solution we impose restrictions on both A_0 and Σ_ε . First, we assume that $\Sigma_\varepsilon = I$ i.e. shocks are uncorrelated and variance is normalized to be 1. Second, we assume that A_0 is lower triangular matrix. Indeed, by Cholesky factorization there exists unique representation $V = A_0^{-1}(A_0^{-1})'$. Later assumption is in fact recursiveness assumption which implies that monetary policy shocks are orthogonal to the information set of the monetary authority. This assumption justifies using the two-step procedure for estimating the dynamic response of a variable to a monetary policy shock, which can be replaced by the asymptotically equivalent above mentioned VAR based procedure.¹

3.3 Computing Confidence Intervals

Confidence intervals are computed using a bootstrap method. Let $U_{T \times nvar}$ denote the matrix of residuals from the estimated VAR, where each column corresponds to one variable in the VAR. First, we constructed 500 sets of new matrices of residuals $\tilde{U}_{T \times nvar}$. The i^{th} row of each new matrix of residuals was selected by randomly drawing from the set of fitted residuals matrix U . Second, for each new matrix \tilde{U} , using the original estimate of matrix Φ , we constructed a synthetic time series of Y_t . Then, we reestimated the VAR using constructed time series of Y_t and historical initial conditions. Finally, using new

¹In order to verify this result we performed two-step procedure which is reported in our MATLAB code. This procedure involves: first, estimating policy shock as a fitted residuals from the equation in which monetary policy instrument is regressed on elements of the information set; second, in order to estimate dynamic response of a variable to an exogenous monetary policy shock we regress the variable on current and lagged values of the estimated policy shocks, IRFs being the estimated coefficients. However, in this paper we will concentrate only on VAR based approach which is shown to provide a good summary of the second moment properties of the data, giving precise estimates of the impulse response functions.

matrix of coefficient estimates $\tilde{\Phi}$ we estimated impulse response functions for each 500 new series as described above, properly sorting them in order to get 95% confidence interval.

4 Results

4.1 Three Benchmark Identification Schemes

Three benchmark recursive identification schemes correspond to different specifications of S_t and Ω_t . These specifications are as follows:

1) Federal Fund Policy Shock: Element of S_t is a federal funds rate, while the elements of Ω_t are current and four lagged values of GDP_t , P_t , $PCOM_t$ as well as four lagged values of FF_t , NBR_t , TR_t and M_t which will be measured using different money aggregates.

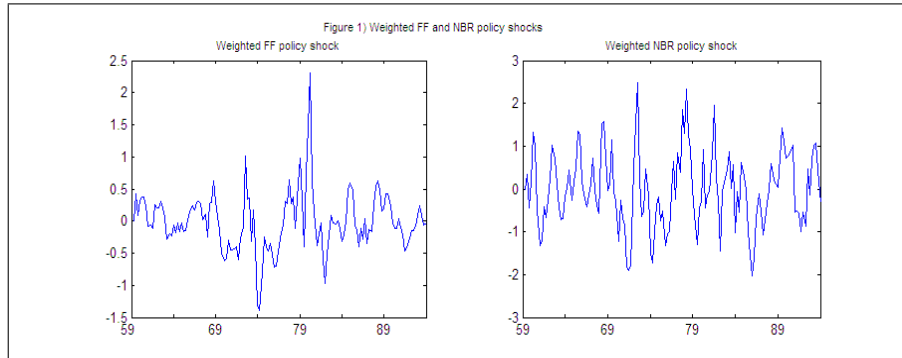
2) NBR Policy Shock²: Element of S_t is NBR_t , while the elements of Ω_t are the same as under the previous benchmark scheme.

3) NBR/TR Policy Shock: Element of S_t is NBR_t , while the elements of Ω_t are the same as in previous cases with a difference that current value of TR_t enters Ω_t .³

First, we discuss some basic properties of estimated time series of the FF and NBR policy shock. They are obtained using quarterly data over a sample

²Introducing this shock is based on the work of Christiano and Eichenbaum(1992).

³This shock was first proposed by Strongin who claimed that total reserves are interest inelastic in the short run and initially only the composition of total reserves is affected by the monetary policy shock. Therefore, current value of TR_t is considered as an element of the information set, capturing the above described fact.

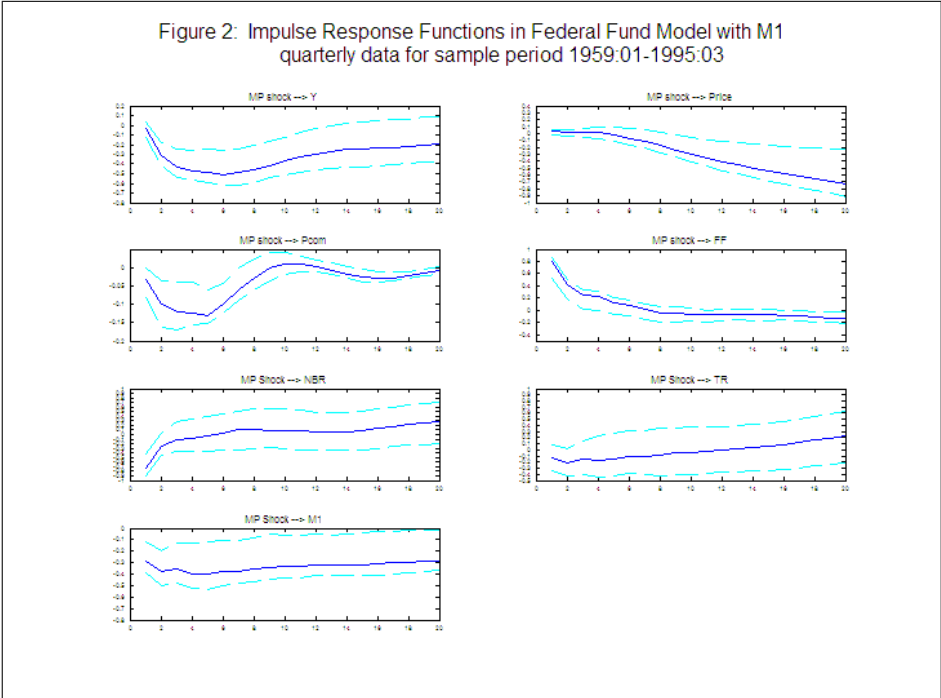


period 1959:01 - 1995:03. Figure 1 contains three-months weighted series of the two shock. Series are weighted since by construction, shocks are noisy. These two shocks are positively correlated, with the correlation coefficient being equal to 0.511. The estimated standard deviation of the FF policy shock is 0.778, while the estimated standard deviation of the NBR policy shock is 1.57.

Figure 2 displays the estimated impulse response functions to the contractionary benchmark FF policy shock described above. Again, quarterly data from 1959:01 until 1995:03 were used. Implementing NBR and NBR/TR shocks gives the same results.⁴ All three identification schemes were implemented using M_1 as a measure of money.⁵ The solid lines represent the point estimates of the IRFs, while dashed lines represent 95% confidence intervals for the IRFs.

⁴Refer to figures 2b and 2c after running the MATLAB code.

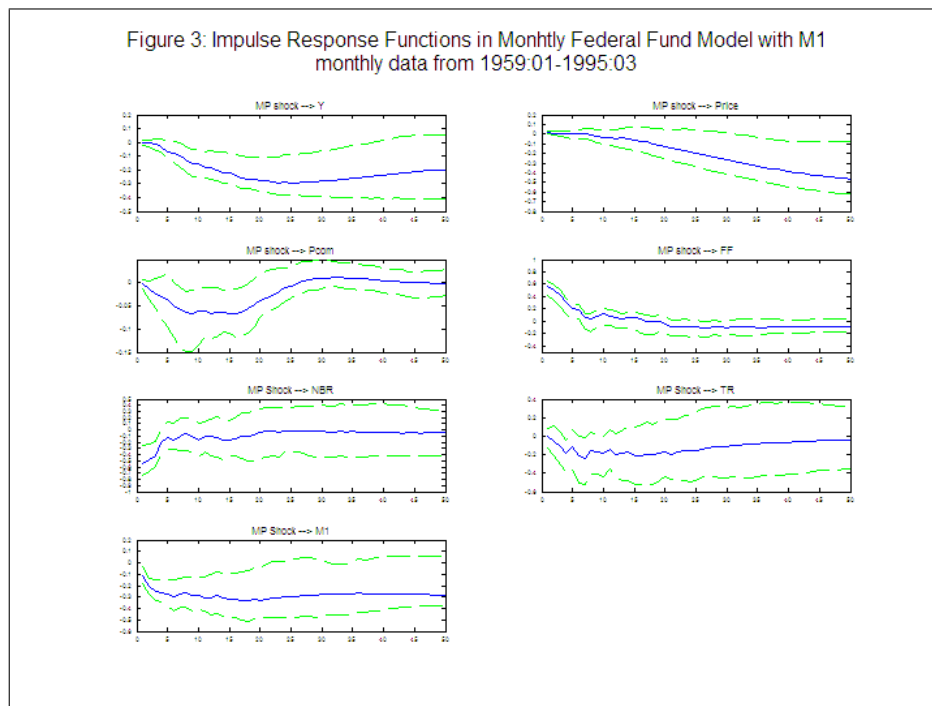
⁵In order to check the robustness of the results we also performed the analysis with M_2 and M_0 being used as a measures of money. The main finding is that results are robust to this change. However, we will not present these results here. In fact, figures 2d, 2e, 2f, 2g, 2h and 2i are available after running the provided MATLAB code.



Obtained results coincide with the results of the authors. First, after the contractionary FF policy shock there is a persistent rise in federal funds rate and persistent decline in non-borrowed reserves. This finding is consistent with the liquidity effect, well known phenomenon which asserts that in the short run changes in money supply induce changes in nominal interest rate of the opposite sign. Second, after a delay of two quarters output declines, having a "hamp shaped" response to a monetary policy shock with the maximum decline at one year after the shock. Third, total reserves fall by 0.2 percent. The response of M_1 is very similar to the response of total reserves. Fourth, GDP deflator and PCOM index decline.

In order to document the robustness of these results we perform the same

procedure using the monthly data rather than quarterly. In generating these results, as in CEE, we replace aggregate output with nonfarm payroll employment. Also, aggregate price level is measured by the implicit deflator for personal consumption expenditures. It is also worth noting that when using monthly data instead of using VAR(4) we used VAR(12). Even though authors do not mention this explicitly, our results when using 12 lags correspond to their results. Findings for FF benchmark analysis are shown in Figure 3.⁶ Again, we checked the robustness of the results by using also M_2 . Our results confirm that also when monthly data are used there is no significant effect on the qualitative results.⁷



⁶Implementing NBR and NBR/TR shocks led to the same results, which is documented in Figures 3b and 3c in our MATLAB code.

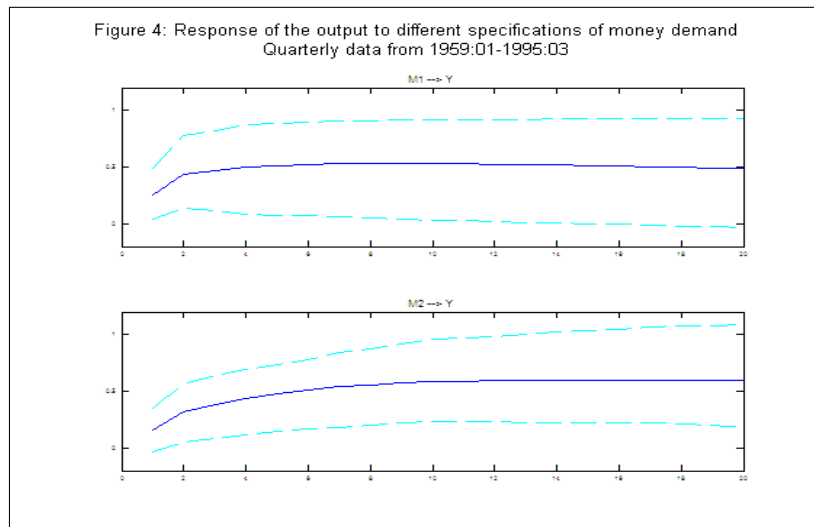
⁷These findings are documented in the tables 3d, 3e and 3f in our MATLAB code.

4.2 Robustness of the Benchmark Analysis

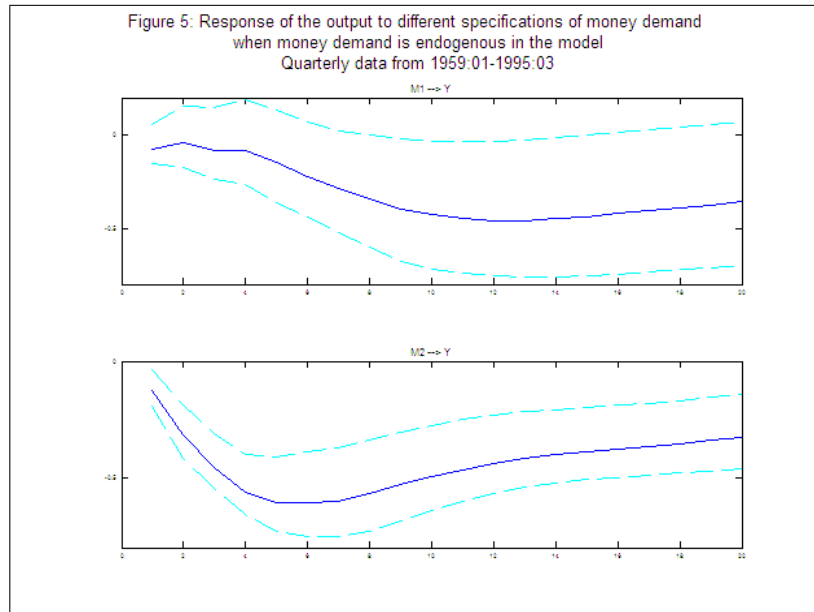
4.2.1 Long run neutrality: Does Ordering Matter?

As we mentioned above, our findings are consistent with the presence of a strong liquidity effect. Although CEE do not mention long run neutrality of money we thought that it might be interesting to make a small extension.⁸ This is due to the fact that liquidity effect and long run neutrality of money (LRN) are two widely accepted facts among the monetary policy makers. Here, we will present a small example that demonstrates the LRN puzzle. We use VAR with two variables: money and output which is measured by real GDP. The impulse response functions of money and GDP to two different specifications of money demand are shown in the Figure 4. It is obvious that after a monetary policy shock output does not return to zero. In particular, economy never returns to its equilibrium path, or does it very slowly which contradicts most theoretical models that claim that shock in the money supply does not have effect on the real variables.

⁸This discussion is inspired by Bernarke and Mihov (1998).



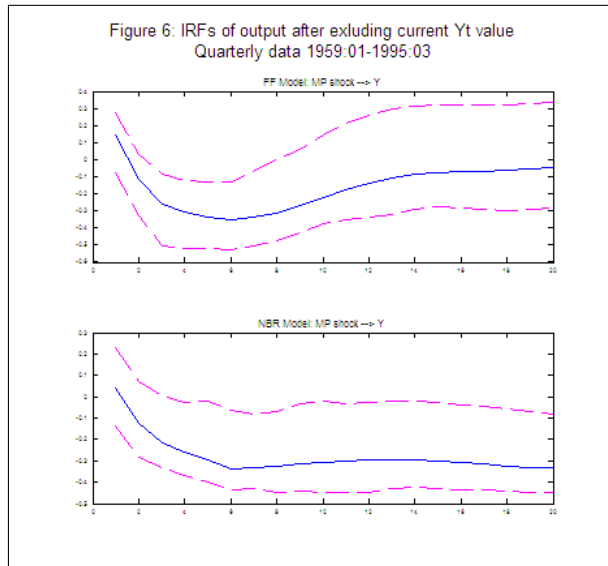
Now, we add more variables in the VAR and try to see if ordering of the variables in the VAR matter. We consider VAR model with real GDP, GDP price deflator, money and a federal funds rate. Impulse response functions of all the variables after a positive shock to money supply are reported in the Figure 5. As we can see, results are completely different than in the previous case: the direction of the short-run response of output is in the opposite direction than expected and federal funds rate rises instead of falling when expansionary monetary policy shock is introduced. The literature explains this results by the endogeneity of the money supply. That is, instead of experimenting with ordering we should think more carefully about the identification problems. In particular, endogeneity of money supply plays a central role in explaining the response of the output. This little experiment implicitly shows that ordering of the variables does not matter.



4.2.2 Excluding Current Output and Prices From Ω_t

One of the robustness checks imposed by CEE is to exclude the current output from the monetary authority information set. Since only output response differs if this specification is used as oppose to the benchmark specification, Figure 6 reports only response of the output.⁹ The difference is that under the changed specification output increases on impact. CEE argue that this result can be explained by the claim that this shock incorporates not just policy, but also non-policy disturbances.

⁹IRFs to FF and NBR shock of all other variables when output and prices are excluded are reported in figures 4a, 4b, 4c and 4d.



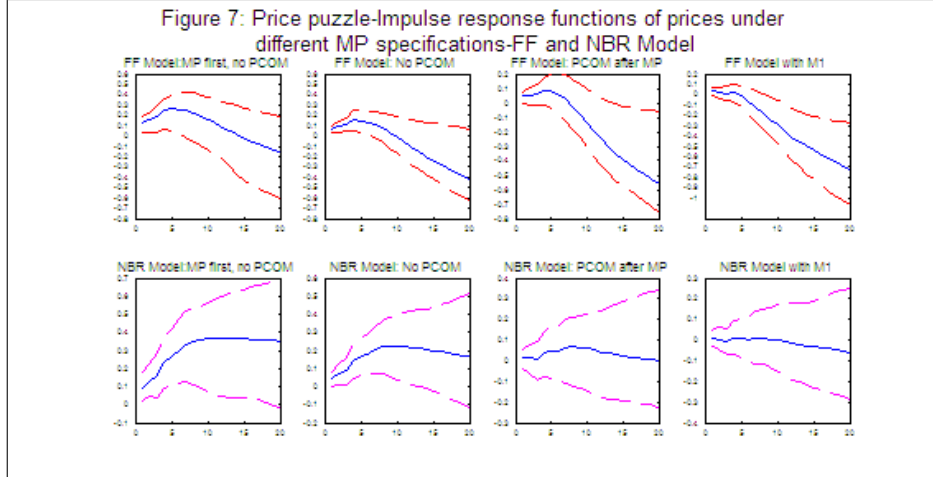
Obtained results under the specification in which current price is excluded from the information set of the monetary authority are in principle same as the results obtained under the benchmark analysis and we will not report it here.

Furthermore, we thought it might be useful to check the robustness of the results by adding a series of consumption.¹⁰ In fact, we assume that monetary authority observes both current and lagged values of consumption. The results we obtained when this little change is made are shown to be robust.¹¹ Furthermore, response of output and consumption is of the same qualitative characteristics.

4.2.3 The Price Puzzle

¹⁰This is the only series that is not obtained from the authors.

¹¹Again, due to the limited space, for the results refer to our MATLAB code.



Price puzzle is the well known puzzle in the literature. Namely, empirical results show that after a contractionary monetary policy shock there is a sustained rise in the price level, which is opposite to what the intuition would say. CEE(1996) and Sims and Zha (1995) "solve" the puzzle by including current and lagged values of the commodity prices in the information set. Therefore, Figure 7 reports the response of the price level to the eight different contractionary monetary policy shock measures. First row corresponds to the specification in which S_t is measured by FF_t , while the second row corresponds to the specification in which S_t is measured by NBR_t . It is obvious from the picture that adding price commodity index helps solving the puzzle, since price level goes down after the contractionary monetary policy shock. While CEE claim that price puzzle is less severe in case when NBR shock is used we got opposite result. That is, when FF shock is introduced price puzzle is less severe.

4.2.4 Equating Monetary Policy Instruments With M_0 , M_1 and M_2

The interesting question that we try to answer here is will our analysis change if instead of FF or NBR money aggregates are used as policy instruments. The main findings are that after introducing shock to M_0 or M_1 different results than ones when benchmark policy is used are obtained.¹² However, when M_2 shock is introduced results are pretty similar to those obtained under the benchmark analysis. Therefore, M based policy shocks measures provide mixed evidence about the robustness of our benchmark analysis.

4.2.5 Sample Period Sensitivity

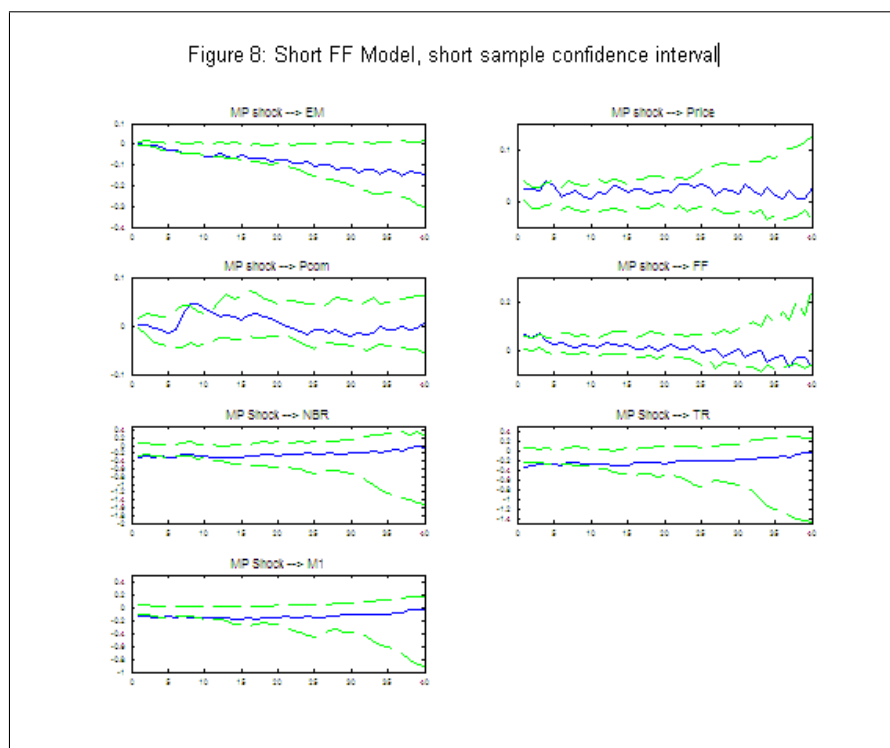
This part of the paper investigates subsample sensitivity. If there are different results obtained in different subsamples the question is whether this difference is due to the size of monetary policy shock or different dynamic response. First, we will concentrate on Rudebush sample period. Second, we will test if there were changes in the effects of monetary policy shocks among pre-Volcker and post-Volcker period. Finally, we will briefly discuss how much monetary policy shocks have contributed to the volatility of different economic variables.

Rudebush Subsample Period We test if there was a change in data generating mechanism for the Rudebush sample period.¹³ As in CEE, we constructed confidence intervals for the short sample under the null hypothesis that the true

¹²For this discussion refer to Figures 6a-6f in our MATLAB code.

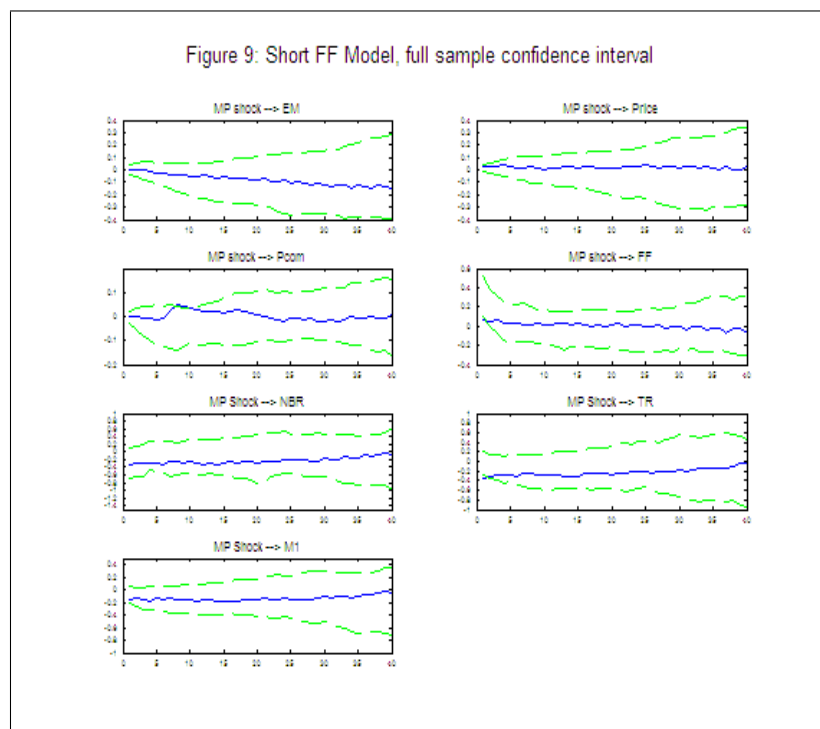
¹³Rudebush critique is explained in detail in the paper and in our opinion there is no need for concentrating on this part of the paper in details.

model is the one estimated using the data over the whole sample. This bootstrap procedure is slightly different from the one described above. In fact, this is a variant of the standard bootstrap procedure. The difference is that we generated data using the whole sample, but in each artificial series we estimated VAR(6) model using only artificial data over the Rudebush period.



Figures 8 and 9 report same short sample impulse response functions, but confidence intervals computed using short and full sample. One could see that the estimated impact effect of a one standard deviation policy shock on the federal funds rate lies outside the 95% confidence interval. Hence, we reject the null hypothesis that there was no change in the DGE in Rudebush period.

Figure 9: Short FF Model, full sample confidence interval



Pre-Volcker and Post-Volcker era Even though CEE investigate different subsamples, we thought it might be interesting to investigate if there is the difference in IRFs of the variables used in VAR in these two periods. This is due to the accepted fact that from the late 1960s through early 1980s, the US economy experienced high and volatile inflation along with several recessions as suggested . Furthermore, since the early 1980s, inflation has remained steadily low, while output growth has been relatively stable. Here, we try to test this fact. We present the impulse response of price level in these two periods.¹⁴ It is evident that price level volatility is higher in the pre-Volcker period.

Monetary Policy Shocks and Volatility Very interesting question that is considered in this section is how much have monetary policy shocks contributed to the volatility of various economic aggregates. The percentage of the variance of the k step ahead forecast error in variables used in VAR analysis after a benchmark FF shock are reported in Table that is available upon executing provided Matlab code. As authors, we showed that FF monetary policy shock had an important impact on the volatility of aggregate output. In fact, it accounts for 22.4%, 43.1% and 35% of the variance of the 4, 8 and 12 quarter ahead forecast error in variance in output, respectively. However, effects of NBR and NBR/TR shocks are significantly less important in explaining the variance of the forecast error of the output. Therefore, which monetary policy measure we use influences the inference about the importance of the monetary policy

¹⁴Refer to Figures 9a and 9b.

shock and one should be aware of this important fact.

4.3 Abandoning the Recursiveness Assumption

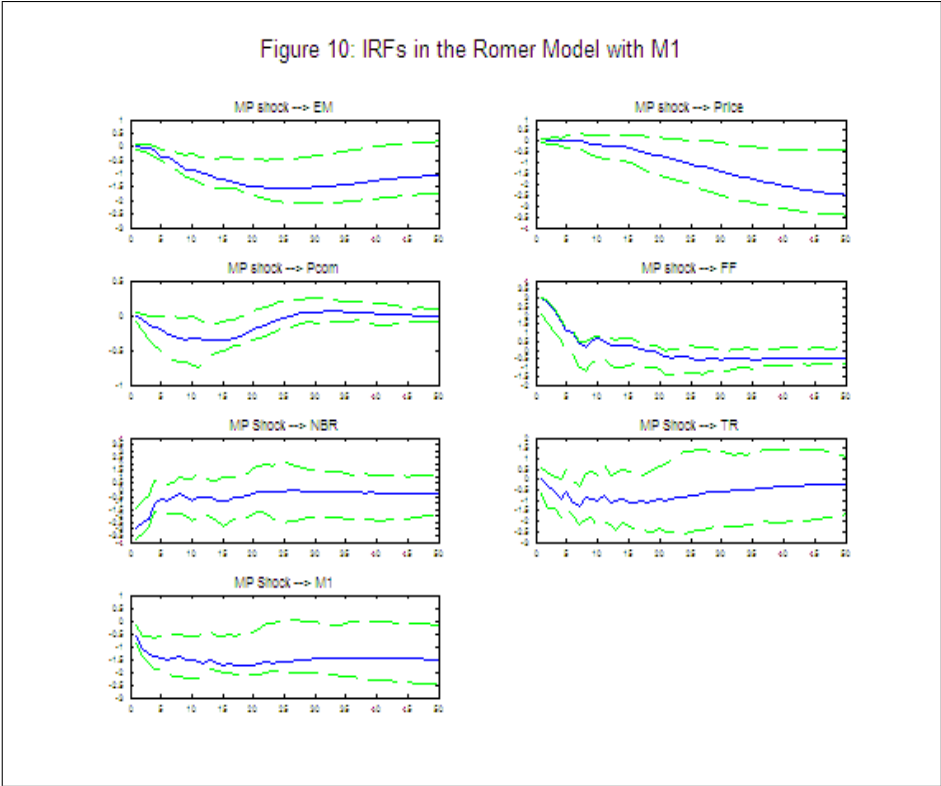
In the last part of the paper we will ask the question : What happens when recursiveness assumption is abandoned? Since, on one hand, we do not have data used in Sims and Zha procedure, and on the other hand, this procedure is rather complicated and beyond the scope of this paper, we decided to concentrate on Romer and Romer narrative approach.

Romer and Romer identify the monetary policy episodes based on the meetings of the Federal Reserve. They suggest the following episodes: December 1968, April 1974, August 1978 and October 1979. However CEE add two more episodes: February 1966 and August 1988. In order to estimate dynamic response of the variables in VAR to these episodes we generate dummy variable d_t that takes value 1 when episode took place and 0 otherwise. Then, we modify VAR by adding current and lagged value of this dummy variable, as follows:

$$Y_t = A(L)Y_{t-1} + B(L)d_t + u_t \quad (7)$$

Equation (7) is estimated using the OLS equation-by-equation procedure. Furthermore, in order to estimate the dynamic response to Romer and Romer episode rewrite the equation (7) as following:

$$Y_t = [I - A(L)L]^{-1}B(L)d_t + [I - A(L)L]^{-1}u_t \quad (8)$$



Hence, impulse response of Y_{t+k} to a Romer and Romer episode is given by the coefficient on L^k in the expansion $[I - A(L)L]^{-1}B(L)$. When obtaining the confidence intervals for IRFs we use the same bootstrap procedure as explained above accomodating the presence of d_t .

Results are pretty encouraging. That is, qualitative results when Romer and Romer approach is used are very similar to those when FF benchmark representation scheme is used. As shown in Figure 10 point estimates are different from ones obtained in our benchmark analysis, whereas shapes of impulse response functions of different variables are the same.

5 Conclusion

In this paper we tried to replicate the results of CEE paper "Monetary Policy Shocks: What Have We Learned and to What End?", which seeks to answer the question what happens after an exogenous shock to the monetary policy. After introducing our benchmark analysis which includes three monetary policy shocks we showed that obtained results are very robust to different changes we performed. Finally, we showed that even when recursiveness assumption is abandoned, qualitative effects of an exogenous monetary policy shock remain unchanged. This goes in favor of earlier mentioned fact that literature has converged on qualitative effects of monetary policy. However, discussion on different identifying assumptions is the ongoing one. In our opinion, this discussion is very needed since eventually it should lead to the agreement on what identifying assumption for studying effects of monetary policy shocks should be used.

References

- [1] Bernarke, Ben S. and Ilian Mihov (1998), 'The Liquidity Effect and Long-run Neutrality', *Carnegie-Rochester Conference Series on Public Policy* 149-194 North-Holland
- [2] Christiano Lawrence J., Martin Eichenbaum and Charles Evans (1998), 'Monetary Policy Shocks: What Have We Learned and To What End?',
- [3] Christiano Lawrence J. and Martin Eichenbaum (1995), 'Liquidity Effects, Monetary Policy and Business Cycle', (1995), *Journal of Money, Credit and Banking*, Vol. 27, No 4, pages 1113 - 1136.
- [4] Clarida, Richard, Jordi Gali, and Mark Gertler (2000), 'Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory', *The Quarterly Journal of Economics*, February 2000.
- [5] Eichenbaum, Martin (1992), 'Comments on Interpreting The Macroeconomic Time Series Facts: The Effects of Monetary Policy', *European Economic Review*, Vol. 36, No. 5, pages 1001 - 1011.
- [6] Romer, Christina D. and David H. Romer, 'Monetary Policy Matters', *Journal of Monetary Economics*, Vol. 34, pages 75 - 88.
- [7] Rudebush, Glen, (1995), 'Do Measures of Monetary Policy in VAR Make Sense?', manuscript, Federal Reserve Bank of San Francisco.
- [8] Sims, Christopher A. and Tao Zha (1995a), 'Error Bands for Impulse Responses', Working paper number 95-6, Federal Reserve Bank of Atlanta.