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Historical Decomposition of Aggregate Demand and Supply Shocks in a Small Macro Model

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We estimate and analyze the impact of multiple aggregate demand and aggregate supply shocks in a small macroeconomic model of the economy. The analysis serves two purposes. First, we assess the relative importance of the various shocks in explaining the path of output over the past three decades. Second, we conduct counterfactual policy experiments which show the effects of alternative policies on key macro variables. We find that using the monetary policy tool (reserves or the base) such that constant money growth occurs would have produced superior economic results.

1. Introduction

Fluctuations in macroeconomic activity are generally explained in terms of shocks to aggregate demand and supply. Many theoretical models suggest a role for both types of shocks. Demand shocks, including but not limited to policy innovations, are typically thought to have real effects in the short-to-medium run but not in the long run. Supply shocks, including resource and technology shocks, have effects in both the short and long runs. Most empirical studies find important effects of both aggregate demand and supply shocks.[1]

Although demand and supply shocks are important conceptually, in applied work the nature of the identified shocks has differed. Some studies identify only one generic shock to aggregate demand (e.g., Blanchard-Quah 1989), whereas others identify multiple shocks to aggregate demand (e.g., Shapiro and Watson 1988; Gali 1992; Ahmed 1993; Walsh 1993). Likewise, some of these studies identify only a single aggregate supply shock (e.g., Blanchard and Quah 1989; Gali 1992; Ahmed 1993; Walsh 1993), whereas Shapiro and Watson (1988) identify several supply shocks. King et al. (1991) identify three shocks: a balanced-growth shock (aggregate supply shock), an inflation shock (interpreted as a monetary policy shock) and a real interest rate shock. It is not clear how to classify the real interest rate shock because it could plausibly

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[1] Real business cycle models imply that aggregate supply shocks are a dominant factor in economic fluctuations, with little role for aggregate demand shocks over any horizon. Empirical results in King et al. (1991) find little evidence of an important role for monetary policy shocks, although their evidence doesn't support the view that a single productivity shock is the dominant factor in explaining cyclical fluctuations.

be interpreted either as an aggregate demand or supply shock or as a mixture of the two shocks.

Using a small macro model of the U.S. economy, we assess first the relative importance of shocks to both demand and supply over the past three decades, including shocks to monetary policy. This objective is achieved by applying the historical decomposition (HD) technique to an estimated vector autoregression (VAR). The demand and supply shocks are identified using the long-run restrictions approach of Blanchard and Quah (1989). Like Shapiro and Watson (1988), we identify multiple shocks to both aggregate demand and supply. On the supply side, we focus on productivity shocks and oil price shocks. On the demand side, we identify four aggregate shocks: an IS shock, a money demand shock, a money multiplier shock, and a shock to a reserve aggregate (interpreted as a monetary policy shock). This specification differs considerably from Shapiro and Watson (1988), who identify only generic IS and LM shocks, and from Gali (1992) and Walsh (1993), who do not distinguish between money multiplier shocks and reserve aggregate shocks but instead identify only a money supply shock. We show later that it is important to disaggregate money supply shocks into money multiplier shocks and reserve aggregate shocks because the timing and magnitude of the effects of these shocks on macroeconomic activity differ. Although Ahmed (1993) differentiates between money multiplier and monetary base shocks, he does so in a three-variable model that also includes output as an explanatory variable. Consequently, he is able to identify only one aggregate supply shock. Again, as we demonstrate later, it is important to distinguish between productivity shocks and oil price shocks because their effects on the macroeconomy differ substantially.

Second, we develop an extension of the HD technique that allows us to undertake "counterfactual" policy experiments. Using this technique, we show the effects of alternative monetary policy interventions for key macro variables such as output and inflation. The interventions we consider are, in the terminology of Leeper and Sims (1994), "normal policymaking" rather than "regime shifts." For example, these interventions can be viewed as alternative scenarios considered in the policy evaluation process undertaken by Federal Reserve officials in advance of Federal Open Market Committee (FOMC) meetings.

Finally, unlike the studies cited earlier, we use monthly rather than quarterly data to reduce problems that arise with temporal aggregation; see Christiano and Eichenbaum (1987) for a general discussion and Gamber and Joutz (1993) for a discussion related to the estimation technique employed here.

In section 2 we describe the historical decomposition methodology. The theoretical basis for the model to be estimated and the estimation procedure are discussed in section 3. The data are described in section 4, along with a preliminary data analysis. An overview of the estimated model is presented in section 5. Results of the historical decomposition technique are analyzed in section 6. A summary and conclusion is in section 7.

2. Historical Decompositions and Counterfactual Experiments

Derivation of Historical Decompositions

We use the historical decomposition technique (i) to describe the relative importance of historical demand and supply shocks and (ii) to evaluate the implications of alternative policy scenarios. Our application below imposes long-run identifying restrictions in the spirit of the

Blanchard–Quah identification technique. Similar derivations hold for short-run identifying schemes such as the Bernanke (1986) and Choleski approaches.

Start with a structural model:

$$y_t = A_0 y_t + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \mu_t \tag{1}$$

where A_i are the structural coefficients and the μ_t are the structural shocks. As is common with structural shocks, the elements of μ_t are assumed to be mutually orthogonal. Let $e_t = (I - A_0)^{-1}\mu_t$ represent the reduced-form shocks and $\mathbf{\Pi}_i$ the reduced-form coefficient matrices. Define $\mathbf{\Pi}(L) = (I - \mathbf{\Pi}_1 L - \ldots - \mathbf{\Pi}_p L^p)$. The moving average matrix is given by $\mathbf{C}(L) = [\mathbf{\Pi}(L)]^{-1}$, with $\mathbf{C}_0 = I$, so that the moving average representation (MAR) of Equation 1 is:

$$y_t = \mathbf{\Pi}(L)^{-1} e_t = \mathbf{C}(L) e_t = \sum_{s=0}^{\infty} C_s e_{t-s}. \tag{2}$$

The $\mathbf{C}_i$ are determined by the following recurrence relations:

$$\begin{aligned} \mathbf{C}_1 &= \mathbf{\Pi}_1 \mathbf{C}_0 \\ \mathbf{C}_2 &= \mathbf{\Pi}_1 \mathbf{C}_1 + \mathbf{\Pi}_2 \mathbf{C}_0 \\ &\vdots \\ c_j &= \mathbf{\Pi}_1 \mathbf{C}_{j-1} + \ldots + \mathbf{\Pi}_p \mathbf{C}_{j-p} \\ &\vdots \end{aligned}$$

Equation 2 is written in terms of the reduced-form shocks. It can be rewritten in terms of the structural shocks as

$$y_t = \sum_{s=0}^{\infty} [\mathbf{C}_s (I - A_0)^{-1}](I - A_0) e_{t-s} = \sum_{s=0}^{\infty} \mathbf{D}_s \mu_{t-s} \tag{3}$$

where $\mu_t = (I - A_0)e_t$ and where $\mathbf{D}_s = \mathbf{C}_s(I - A_0)^{-1}$. For a particular period $t + j$, Equation 3 may be written as:

$$y_{t+j} = \sum_{s=0}^{j-1} D_s \mu_{t+j-s} + \sum_{s=j}^{\infty} D_s \mu_{t+j-s}, \tag{4}$$

which represents the historical decomposition. This decomposition has two types of terms. The far right side term represents the expectation of y_{t+j} given information available at time t, the "base projection" of the vector $\mathbf{y}$. The first term on the right-hand side shows the difference between the actual series and the base projection due to the structural innovations in the variables subsequent to period t; that is, it shows that the gap between an actual series and its base projection is the sum of the (weighted) contributions of the structural innovations to the individual series in the analysis. Thus, the actual data at period $t + j$ are the sum of the base projection and the weighted structural innovations to the system variables. As indicated above, these structural innovations are assumed orthogonal to one another.

Counterfactual Simulation Methodology

We extend the historical decomposition technique to construct counterfactual (CF) paths for the variables in the system. The point of departure for understanding the CF experiments is

Equation 4, which shows that the base projection and the weighted shocks subsequent to the base projection sum to the data itself. We modify this in the following way: Given a base projection conditional on information at time t, suppose the shocks occurring after time t are selected to follow some other path. For example, suppose that we feed in shocks for the monetary aggregate that force it along a constant growth path. Combining these CF shocks with the effects of the other historical shocks and the base projection generates the path the data would have followed (i.e., the CF path) in the presence of these alternative shocks.[2] Because by construction the shocks to the different equations are orthogonal, selection of an alternative path for shocks to the monetary aggregate has no first-order implications for the shocks to the other variables.

Construction of the counterfactual shocks proceeds as follows: Equation 3 shows the historical decomposition in terms of model parameters and structural shocks, and Equation 4 shows the decomposition for a particular period $t + j$ in terms of the base projections conditional on information at time t and the contributions of shocks subsequent to t. Consider Equation 4 for $j = 1$:

$$\begin{aligned} y_{t+1} &= \mathbf{D}_0\mu_{t+1} + \sum_{s=1}^{\infty} \mathbf{D}_s\mu_{t+1-s} \\ &= \mathbf{D}_0\mu_{t+1} + \mathbf{BP}_t. \end{aligned}$$

Note that the ith equation in this system is:

$$y_{i,t+1} = d_{0,ii}\mu_{i,t+1} + \sum_{j\neq i} d_{0,ij}\mu_{j,t+1} + \mathbf{BP}_{1,i,t}$$

where $\mathbf{BP}_{k,i,t}$ is the k-period-ahead base projection for the ith equation at time t, and where $d_{k,ij}$ is the (i, j) element of matrix $\mathbf{D}_k$. Suppose we want to find the shock to this equation that will produce a predetermined value for $y_{i,t+1}$, denoted by $y^*_{i,t+1}$. To do so, solve the following equation for $\hat{\mu}_{t+1}$

$$y^*_{i,t+1} = d_{0,ii}\hat{\mu}_{i,t+1} + \sum_{j\neq i} d_{0,ij}\mu_{j,t+1} + \mathbf{BP}_{1,i,t}$$

the solution for which is

$$\hat{\mu}_{i,t+1} = (d_{0,ii})^{-1}\left[y^*_{i,t+1} - \mathbf{BP}_{1,i,t} - \sum_{j\neq i} d_{0,ij}\mu_{j,t+1}\right].$$

Proceeding in a similar manner, it can be shown that the structural residual needed to achieve a particular value for $y_{i,t+2}$, denoted by $y^*_{i,t+2}$, is:

$$\hat{\mu}_{i,t+2} = (d_{0,ii})^{-1}\left[y^*_{i,t+2} - \mathbf{BP}_{2,i,t} - \sum_{j\neq i} d_{0,ij}\mu_{j,t+2} - \sum_{j\neq i} d_{1,ij}\mu_{j,t+1} - d_{1,ii}\hat{\mu}_{i,t+1}\right].$$

[2] In slightly more technical terms, consider the element in the μ_{t+j-s} vector in the first right-side term of Equation 3 that corresponds to the monetary policy variable. This element can be replaced, for example, with a shock path that forces money to grow at a constant rate. The other elements continue to take on their "historic" (i.e., estimated) values.

Similar iterations produce a path of structural shocks that generate a path for $y_{i,t+j}$ that matches the desired path $y^*_{i,t+j}$, for $j = 1, \ldots, T$, where T is the planning horizon.[3]

This use of the counterfactual methodology is consistent with Sims (1982, 1987) and, more recently, Leeper and Sims (1994), who distinguish "regime shifts" from "normal policymaking." For example, consider a policy rule that might be embedded in an econometric model:

$$m = a(L)y + \mu$$

where m is, say, the growth rate of nonborrowed reserves, where y is an endogenous variable, $a(L)$ is a polynomial in the lag operator, and μ is a random structural shock orthogonal to the other shocks in the model. Regime shifts are represented by changes in the coefficients of $a(L)$. Normal policymaking is represented by imposition of a new "μ-path." This can be interpreted as the type of policy evaluation undertaken by the Federal Reserve in advance of FOMC meetings. Alternative scenarios might be presented at these meetings for, say, the growth path of nonborrowed reserves. These alternative μ-paths then generate what we call the CF paths for system variables.

Our reading of the policy literature, along with assessments in the financial press, suggests that most policy actions represent normal policymaking. Agents are likely aware of continuing debates about optimal policy both inside and outside the monetary authority. Although these debates are often presented in terms of regime shifts, sufficiently few shifts in policy regime occur in practice that agents may even discount announcements of regime shifts until the authority has pursued the new regime long enough to convince agents that a shift has indeed occurred; a long and continuous intervention period may be needed before agents begin to assign a high probability to a regime shift.

Even under normal policymaking, a CF path may impose conditions on the model outside the historical experience. This type of experiment would be subject to the Lucas critique. Consequently, in order to reduce concerns about the Lucas critique, we have typically considered CF paths "close" to the historical data, such as allowing nonborrowed reserves to grow at a constant rate equal to the historical average rate.

3. Theoretical Framework

The theoretical framework of the paper is a relatively simple aggregate demand–aggregate supply model with the IS–LM model underlying aggregate demand. This framework, common to many textbooks, has recently been employed in empirical analyses by Gali (1992) and Walsh (1993).

The demand side of the model consists of an IS function, a money demand function, and a money supply function in which the money supply is the product of a multiplier and nonborrowed reserves (or, alternatively, the monetary base). The money supply function differs from Gali or Walsh, each of whom examine only a generic money supply shock without dif-

[3] Note that the counterfactual methodology can also be used to assist in the type of short-run policy analysis undertaken prior to, say, FOMC meetings. Suppose the objective is to evaluate the effect on output of a particular target path for reserves. The policymaker can use the target path to compute the μ-path, which is the size of the policy interventions under "normal policymaking." The point estimate of the output path for this alternative policy is computed by assigning the other structural shocks their mean values of zero. Confidence bands around this alternative can then be constructed using bootstrapping techniques that sample from the historical distributions for the various structural shocks.

ferentiating between shocks to the multiplier and to nonborrowed reserves (or the monetary base). Conceptually, movements in nonborrowed reserves or the monetary base are dominated by open market operations, and movements in the money multiplier largely reflect the behavior of the public, including the effect on financial intermediation of changes in multiplier components such as the currency/deposit ratio. Recent empirical work consistent with the differentiation of money supply shocks into multiplier shocks and reserve aggregate shocks includes Manchester (1989), Plosser (1991), and Ahmed (1993). Robustness of the effects of monetary policy and the multiplier is assessed by substituting the monetary base and the M2/monetary base multiplier for the nonborrowed reserves measure.

The supply side of the model identifies two supply shocks: a relative oil price shock and a general aggregate supply shock that excludes the effects of changes in relative oil prices. The oil price shock is included based on Hamilton's (1983) demonstration of the importance of oil price movements in explaining macroeconomic activity in the U.S.[4]

The empirical framework is a VAR model that includes output, the interest rate, real money balances, nonborrowed reserves, the M2/nonborrowed reserves multiplier, and the relative price of oil.[5] Although the price level is not included as a separate variable, the effect of structural shocks on the price level can be inferred from the effects of these shocks on real and nominal money balances. Real money balances are included because we are interested in identifying money demand shocks. Because we can obtain the effects of shocks to nominal balances from the effects of these shocks to the money multiplier and the reserve aggregate, we can utilize information about the effects of the shocks on nominal and real balances to infer the effects of the shocks on the price level.[6]

The structural shocks are identified by imposing long-run restrictions, as in Blanchard and Quah (1989). We adopt this approach because the long-run restrictions used to identify the shocks are neutrality restrictions that have appeal beyond the specific structural model employed in this paper. Note that in the present setting, it is only in the short and medium runs for which substantive implications can be asserted because long-run results are constrained by the identifying restrictions.

Six restrictions are used to identify the structural shocks. (Hereinafter, for the sake of brevity, unless indicated otherwise, "shock" will refer to a structural shock.) The first restriction is that aggregate demand shocks—shocks to the IS curve, real money demand, the money

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[4] There is a large literature that corroborates Hamilton's finding. However, Hooker (1996a) recently reexamined the relationship between oil prices and economic activity. He found no Granger causality from his oil price measures to either real GNP or the unemployment rate in samples that included post-1973 data. However, using HDs based on a VAR estimated using data through 1985, he found that oil price shocks after the two major OPEC disruptions of the 1970s were important in explaining the movements in the unemployment rate.

[5] We do not explicitly attempt to measure inflationary expectations. However, the distinction between nominal and real interest rates and hence expectations of inflation likely are important elements for empirical macro models in the post-World War II period, in part because some functions (such as investment and consumption) depend on the real rate of interest and others (such as money demand) depend on the nominal rate of interest. In an effort to sidestep the thorny issue of measuring expected inflation, we include inflationary expectations only implicitly through the lagged values in the VAR. As shown by Keating (1991), and as summarized in our appendix (available on request), we can approximate the expected inflation rate with the actual rate when actual and expected inflation are cointegrated, which can hold under both rational and adaptive expectations schemes. When estimating the model using long-run identifying restrictions, it is plausible for such a condition to hold.

[6] Walsh (1993) has recently employed this approach.

multiplier, and nonborrowed reserves—have no long-run effects on output.[7] This restriction is consistent with an aggregate demand–aggregate supply model with a vertical long-run aggregate supply curve. Of course, the aggregate supply shocks can have long-run effects on output.

The second restriction is that shocks to real money demand have no effects on the nominal interest rate in the long run, and the third is that shocks to the money supply, generated either by shocks to the money multiplier or nonborrowed reserves, have no long-run effect on the level of nominal interest rates. Thus, shocks to money demand, the multiplier, or nonborrowed reserves shift LM and aggregate demand but not aggregate supply, altering the price level but not output in the long run.

The fourth restriction is that shocks to the money multiplier and nonborrowed reserves, which change the nominal money supply, have no effect on real money balances in the long run because changes in nominal money balances change the price level proportionately in the long run.

The fifth restriction, similar to that employed by Ahmed (1993) for the monetary base, requires a long-run effect of a shock to nonborrowed reserves on the money multiplier of zero. In the context of a nominal money supply function in which the money supply is the product of the money multiplier and nonborrowed reserves, this restriction means that a change in nonborrowed reserves leads to a proportionate increase in the nominal money supply in the long run.

The final restriction is that shocks to the IS curve, real money demand, the money multiplier, nonborrowed reserves, and the non-oil price aggregate supply shocks have no long-run effect on the relative price of oil. This restriction is consistent with the relative price of oil being determined in world oil markets.

These six restrictions imply a recursive long-run model. Thus the structural shocks can be identified by a Choleski decomposition of the long-run relations among the variables, with relative oil prices ordered first, followed by output, the interest rate, real money balances, the money multiplier, and nonborrowed reserves.[8] Formal demonstration of the recursive nature of the model is available on request.

Of course, virtually all identifying restrictions are subject to criticism. First, it may be that a VAR is the incorrect framework. Second, even if the imposed Blanchard–Quah long-run restrictions are "correct," there still remain an infinite number of paths, generated by various demand and supply shocks, which the economy could follow to satisfy these restrictions. More

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[7] The generic IS shock represents the net effects of shocks to fiscal policy, consumption, investment, and net exports. It is difficult to consider fiscal shocks separately because fiscal variables like government purchases and tax rates are not available monthly. A detailed analysis of these various shocks is beyond the scope of this paper.

[8] The classification of the money multiplier shock as an aggregate demand shock is somewhat problematic because some, like Plosser (1991), consider shocks to the money multiplier to be real shocks to financial intermediation that have implications for aggregate supply. We note that shocks to the money multiplier affect the nominal supply of money, and, in the spirit of the IS–LM model, we prefer to classify these shocks as aggregate demand shocks. However, we do examine the effects on output and the price level when the money multiplier is considered to be a real shock with the potential to have long-run effects on output. Compared to the ordering discussed in the text, this involves ordering the money multiplier before output. When this is done, shocks to the money multiplier have no lasting effects on output, a result consistent with our interpretation of money multiplier shocks as aggregate demand shocks.

One might argue that IS shocks raise the interest rate and hence lower private investment so that it is possible for IS shocks to alter output in the long run. We explicitly consider this alternative which, in terms of the ordering discussed in the text, involves placing the interest rate before output. Although this ordering allows the IS shock to potentially alter output in the long run, it also restricts non-oil price shocks from altering the interest rate in the long run. The effects of the IS shock on output suggest that these shocks have no lasting effect on output.

generally, because the long-run constraints are for an infinite horizon while only a finite amount of data is available, estimating a model with long-run restrictions and then attempting to infer short-run (finite horizon) structural conclusions can be problematic. Similarly, the dynamics implicit in short-run-identifying restrictions, as in the Choleski or Bernanke approaches, are also likely to be wrong. Third, following Blanchard and Quah (1989), Faust and Leeper (1994) also considered the conditions under which one shock correctly aggregates two or more underlying shocks. This issue is important in VAR analyses because of the small size of these models. Faust and Leeper argued that the aggregation of multiple shocks into one shock is appropriate only if the underlying shocks affect the variable of interest in precisely the same fashion. Although we can never "prove" that our disaggregation is indeed the appropriate one, nonetheless it is in the spirit of this second point that we consider separate oil price and non-oil price productivity shocks rather than a single supply shock and separate money demand, money multiplier, and nonborrowed reserves shocks rather than a single monetary shock; for an analogous strategy in another context, see Rogers (1995).

4. Data Description and Preliminary Data Analysis

The model is estimated using monthly data for the period 1959(1)–1993(12). Data from 1959(1)–1960(12) are used as presample data, and the model is estimated over the period 1961(1)–1993(12).[9] All data are from Citibase. The variables, with their Citibase names in parentheses, are: output = industrial production (ip), interest rate = 6-month commercial paper rate (fycp), real money balances = nominal M2 (fm2) deflated by the consumer price index (punew), nonborrowed reserves = nonborrowed reserves plus extended credit adjusted for reserve requirements (fmrnbc), money multiplier for nonborrowed reserves = nominal M2 divided by nonborrowed reserves, and relative oil prices = producer price index for crude oil (pw561) divided by the consumer price index. The robustness of the basic results to alternative measures of the interest rate and the reserve aggregate (and hence the money multiplier) was checked. The additional interest rates examined include the federal funds rate (fyff), the 3-month Treasury bill rate (fygm3), and the BAA corporate bond rate (fybaac). The alternative reserve aggregates employed include the monetary base (St. Louis Fed adjusted monetary base [fmbase]) and nonborrowed reserves, not adjusted for reserve requirements (fzmrnb). Money multiplier measures were defined for these reserve aggregates by dividing nominal M2 by the aggregate. The interest rate data are not seasonally adjusted. Other data are seasonally adjusted at the source with the exception of the producer price index for crude oil and nonborrowed reserves not adjusted for reserve requirements, which were seasonally adjusted using the SAS version of X11.

Prior to estimation of the VAR model, the data were checked for unit roots and cointegration. Augmented Dickey–Fuller τ_τ and τ_μ tests for unit roots were computed for the period 1960(4)–1993(12) and indicated the presence of a unit root in all variables. Johansen (1988)

[9] The sample employed here spans periods in which targeting short-term interest rates was a primary focus of monetary policy (the periods before October 1979 and after October 1982) and in which nonborrowed reserves targeting was a primary focus of policy (the October 1979–October 1982 period). In light of this, a dummy variable for the October 1979–October 1982 period was added to each equation of the system. Likelihood ratio tests of the significance of these variables indicated they were not significantly different from zero. Hence, these variables were not included in the systems whose results are reported in the text.

tests for cointegration were performed, but no evidence of cointegration was found. To conserve space, details of these tests are not presented, but are available on request. In light of these test results, the model was estimated using the first difference of the log of industrial production, real money balances, nonborrowed reserves, the money multiplier, and the relative price of oil. The first difference of the level of the interest rate was employed. Finally, based on the results of Mork (1989), Dotsey and Reid (1992), and Mory (1993), who find that only increases in the relative price of oil have macro effects, only positive values of the first difference of the log of relative oil prices were used in the estimation of the VAR.[10]

5. Macroeconomic Effects of Structural Shocks

Before using historical decompositions to analyze the relative importance of the various demand and supply shocks for movements in output, the price level, and the interest rate, we briefly assess whether the impulse response functions (IRFs) are consistent with the basic theory underlying the aggregate demand–aggregate supply model. Detailed presentations of the IRFs are included in the appendix, which includes the IRFs plotted over a 48-month horizon, along with confidence bands constructed from 1000 Monte Carlo draws. In the summary below, "significance" is inferred from the confidence bands in the usual manner.

Because we are interested in the effects of the shocks on the levels (log-levels for output and price) of these variables and the system is estimated in first difference form, we present cumulative IRFs. These cumulative IRFs merely sum the regular IRFs, thereby providing an estimate of the log-level (or level in the case of the interest rate) of the variables. As indicated earlier, the price level is not a separate variable in the system estimated above. However, it is used to deflate M2 in order to obtain real money balances, and the effect of the shocks on the price level can be inferred by adding the IRFs for the money multiplier and nonborrowed reserves (which gives an estimate of the effect of the shock on M2) and subtracting the IRF for real money balances from this.

The IRFs show the following:

(i) Positive shocks to the relative price of oil lead to a significant decline in industrial production, an immediate and significant rise in the price level, and a short-term rise in the interest rate. These patterns are basically consistent with our model; a leftward shift in aggregate supply should reduce output, the price level should rise, and the rise in the price level should lower real balances, increasing the interest rate.

(ii) Positive non-oil-price aggregate supply shocks lead to significant increases in output and declines in both the price level and the interest rate. These results are consistent with a rightward shift in aggregate supply, which along with raising output, will lower the price level and reduce the interest rate in the long run. The interest rate decline is the result of the increase in the real money supply.

The two points above suggest that accounting for at least two types of supply shocks is

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[10] Hamilton (1996) recently suggested using an alternative measure of oil price increases—the net oil price increase. This measure equals the percentage change in the current period's oil price if the current period value exceeds the previous year's maximum value and zero if this condition is not met. This measure is prompted by the observation that many of the oil price increases after 1986 followed even larger oil price decreases. Hooker (1996b) questioned the theoretical relevance of this measure. Based on Hooker's HD results, and given the controversy over Hamilton's suggested new measure, we decided to continue to use the oil price measure described in the text.

important. These alternative shocks theoretically have markedly different implications, and our model is consistent with the theory of how these different shocks affect key macroeconomic variables. Failure to distinguish oil price shocks from other supply shocks would likely bias the results.

(iii) IS shocks raise aggregate demand and significantly raise output for about two years, after which output returns to its initial level. Both the price level and the interest rate remain significantly above their initial values after 48 months. These findings are consistent with a model with a vertical long-run but positively sloped short-run AS curve—the short-run slope due to wage stickiness or expectational errors. Such a model predicts a transitory effect on output and a long-lived effect on both the price level and the interest rate.

(iv) Positive shocks to real money demand significantly lower output in the short run but not in the long run. There is no significant effect on either the price level or the interest rate over a 48-month horizon. We had expected the price level to fall in both the short and long runs, consistent with a rise in liquidity preference. We had also expected the interest rate to rise in the short run but return to its initial value in the long run.

(v) Positive shocks to both the money multiplier and nonborrowed reserves have significant though transitory positive effects on output, significant temporary negative effects on the interest rate, and permanent effects on the price level. There is no evidence of the price puzzle. Although the patterns of effects are qualitatively similar, shocks to the money multiplier have a quicker effect on output, the price level, and the interest rate than do nonborrowed reserve shocks, and the effects die out quicker for the multiplier shocks. The observed differences in timing have a reasonable explanation. Specifically, because nonborrowed reserves are adjusted for changes in reserve requirements, money multiplier shocks reflect changes in public and bank portfolio behavior. These changes are, no doubt, coordinated with spending decisions, especially for consumers. If this is the case, we might expect the effects of money multiplier shocks to be felt more quickly than nonborrowed reserves shocks, which affect spending by first affecting interest rates. There may well be substantial lags between the change in the interest rate and a change in spending and output as consumers and firms alter previous spending plans in light of the change in the interest rate. Analogous to our conclusion on the importance of accounting for various sources of supply shocks, these results confirm the importance of separating money supply shocks into multiplier and reserve aggregate shocks.

To check for robustness, a system was estimated in which the monetary base (adjusted for reserve requirement changes) was substituted for nonborrowed reserves, with the money multiplier redefined accordingly. The patterns and timing of effects are quite similar to the basic system. The effects of money multiplier shocks on output are somewhat longer lasting than in the nonborrowed reserves system, as are the effects of monetary base shocks. For both the nonborrowed reserves and monetary base systems, the monetary aggregate is adjusted for reserve requirement changes. Because Plosser (1991) has argued that reserve requirement changes are a real shock (a tax on deposits) rather than a monetary shock, we also considered a model in which nonborrowed reserves are not adjusted for reserve requirement changes. In this system, changes in reserve requirements will be reflected in changes in the money multiplier. The results for this system are comparable to the basic system.[11]

[11] We also checked the robustness of the basic results with three other interest rates: the federal funds rate, the three-month Treasury bill rate, and the BAA corporate bond rate. Three separate systems were estimated in which one of these alternatives was substituted for the commercial paper rate. All other variables remained the same as in the basic

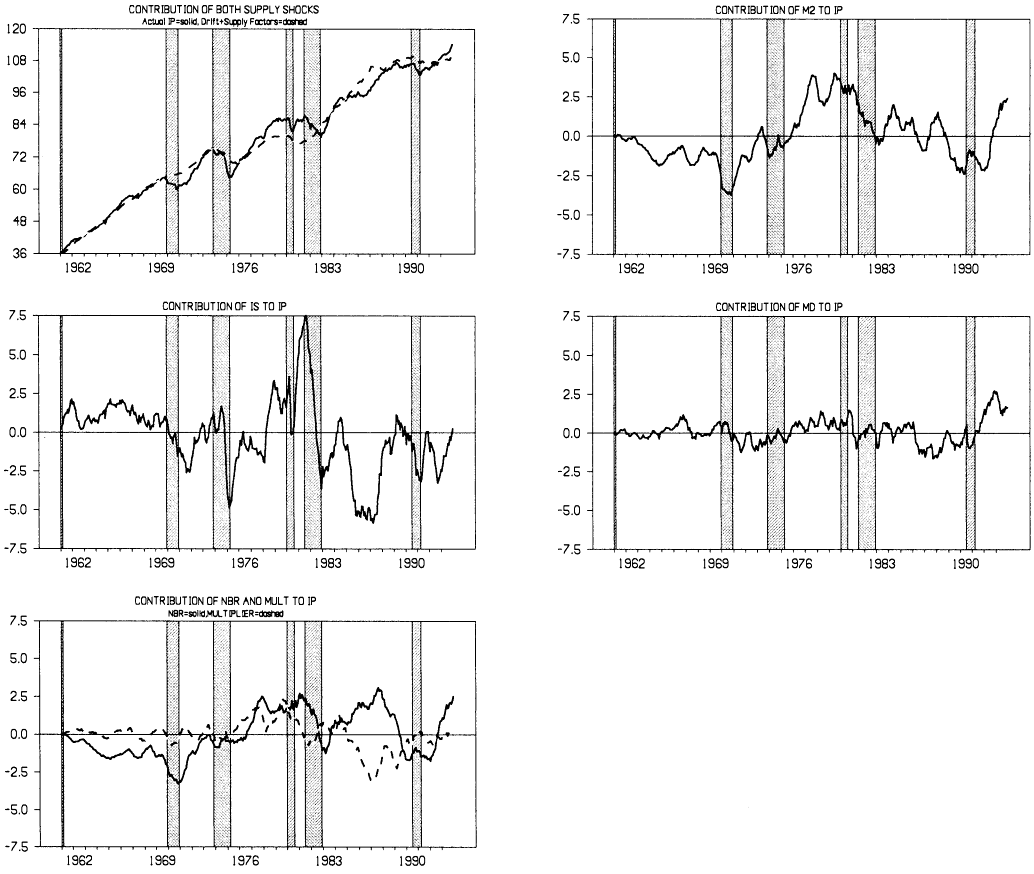

Figure 1. Historical Decomposition of Output

6. Historical Decompositions and Counterfactual Simulations

Historical Decompositions

As discussed earlier, the HD allows us to quantify the relative importance of specific shocks to each variable. For example, the HD allows us to determine the relative importance for industrial production (IP), either in a particular month or over some longer time period, of a shock to the monetary policy aggregate.

The HD of output is done for 1962(1)–1993(12) and is contained in Figure 1. In the upper left-hand panel of the figure, we plot actual IP and the "drift" in output, which is the sum of the base projection and the supply shocks (the shocks to the relative price of oil and the shocks in the IP equation itself). The next three panels show the contributions to the deviations between actual and drift IP of shocks to M2, the IS curve, and money demand (MD). Notice that the vertical scales on these panels are identical, so that we can investigate not only the expansionary

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system. The results correspond to those of the basic system quite closely for the two short-term rates. The same is true for the BAA system with the exception of the money multiplier and nonborrowed reserves shocks, where shocks to these variables had longer lived effects on output and the interest rate than in the basic system, although the pattern of effects is similar. However, the basic pattern of the IRFs was similar to the basic system. Thus we reach the same qualitative conclusions regardless of the interest rate measure.

and recessionary implications of a given shock, but also the relative importance of these various shocks. A variety of features stand out.

First, comparing across these three panels, notice that shocks to money demand play a relatively small role across time in accounting for the gap between actual and drift output; instability in money demand contributes relatively little to real outcomes. However, an exception to this is the 1990s; positive shocks to velocity exerted an expansionary effect comparable in magnitude to monetary policy actions. Second, notice that IS shocks tend to be a bit more important than money supply shocks in determining output deviations. Third, shocks to nonborrowed reserves contributed to the recession of 1969 and the recession ending in November 1982, but had little effect on the recessions in the mid-1970s and in 1980. Monetary policy, as characterized by nonborrowed reserves, also appears to have had an expansionary effect on the economy in the late 1970s, the 1983–1989 period, and again in 1992 and 1993. Fourth, IS shocks appear important in the recessions in the mid-1970s and the 1980s. Note that these shocks do not appear to enhance the "Reagan expansion" that followed the 1982 recession. These points are broadly consistent with Walsh (1993).

Two other features of the figure deserve comment. First, the expansion of the 1980s, being the longest peacetime expansion in a century and a half, is of added interest because traditional demand-side factors do not contribute much to output over this period. Nonborrowed reserves, while modestly expansionary in 1983 and 1984, do not appear to have a strong effect on this expansion until the middle of 1985. Furthermore, the contribution of reserves to output falls beginning in 1987 and restrains output beginning in 1988. Money demand or "velocity" shocks appeared to play only a negligible role, and IS shocks were not consistently stimulative until the end of the expansion. Rather, consistent with the labeling of the Reagan policy as "supply side," the expansion appears to result from the supply shocks in the model. Second, notice that the components of M2, nonborrowed reserves, and the multiplier often tend to offset one another, especially in the expansion during the 1980s. This raises the possibility that policy actions are aimed in part at offsetting deviations in private sector behavior that influence the multiplier.

Finally, we note that the expansion that began in 1991 was initially fueled by positive supply shocks. Although supply factors began to retard the expansion beginning in 1992, velocity shocks counteracted the supply shocks in this period. Because there were no major increases in the relative price of oil in this period, the contractionary effect of supply shocks may reflect the effects of tax rate increases and negative productivity shocks stemming from increased regulation and speculation over the nature of health care mandates. IS shocks were a drag on the expansion since its beginning; this may reflect the demand side effects of higher tax rates and lower defense spending. Shocks to nonborrowed reserves initially acted to slow the expansion, but began to contribute positively to the expansion in 1992 and 1993.

The expansionary effects of nonborrowed reserves shocks are of approximately the same magnitude as those of the velocity shocks of this period. Multiplier shocks appear to be of little importance in the expansion. Positive aggregate demand shocks provided the main expansionary thrust in 1992 and 1993, more than offsetting the retarding effects of aggregate supply shocks.

Counterfactual Simulations

We have experimented with a variety of monetary policy rules of the "x-percent" growth variety, including a rule proposed by McCallum (1990) that allows for deviations from the x-percent growth rate depending on velocity changes and the deviation of output from its target.

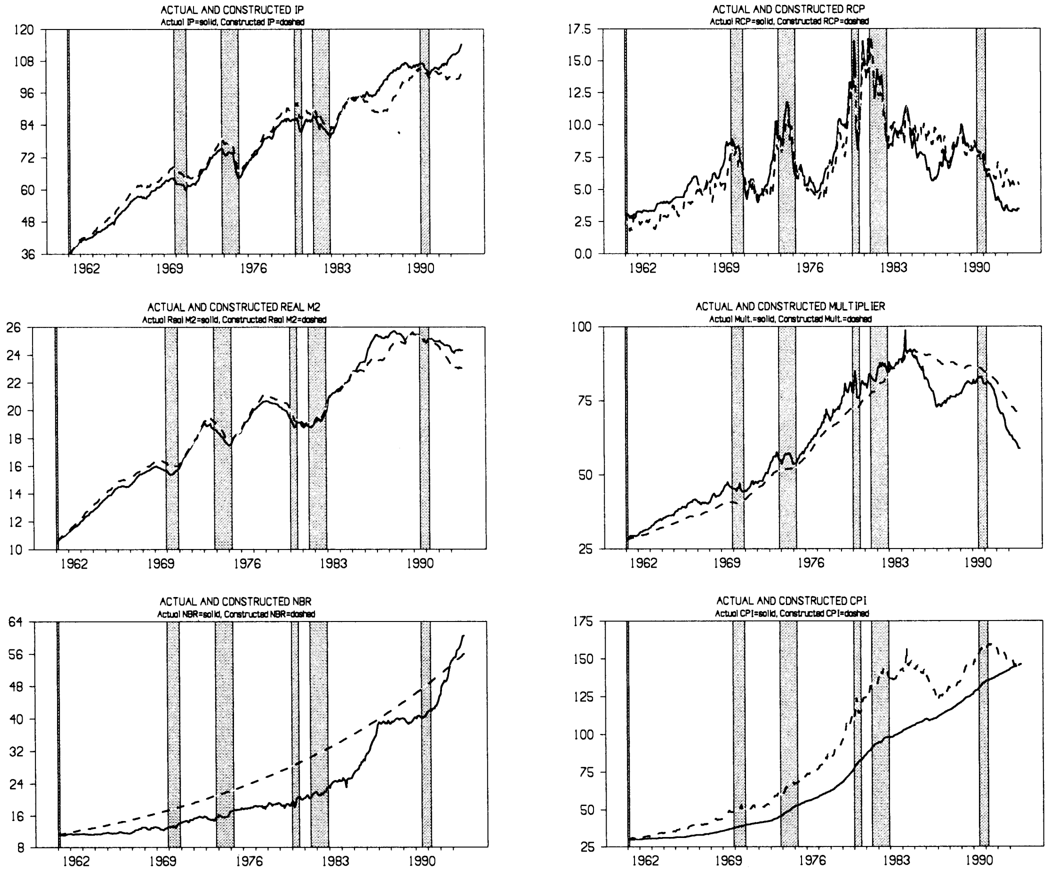

Figure 2. Actual and Counterfactual Paths for System Variables: Constant Reserve Growth

We conduct an analysis of how the economy would have responded over the past three decades to a constant growth rate rule for the monetary aggregate (the base or nonborrowed reserves). Thus, the CFs focus on the long-run implications and desirability of constant-growth policy rules.

We start with an analysis in which we allow nonborrowed reserves (NBR) to grow at an annual rate of 5%, a rate approximately equal to the historical rate. Figure 2 shows the counterfactual paths for the system variables (the dashed lines) along with the actual paths; below, we refer to the counterfactual path for variable X as CF X. As is evident, the counterfactual growth in the reserve aggregate is initially at a higher rate than the path actually followed, with predictable consequences. First, the CF price level is generally higher. Second, the relatively rapid growth in CF NBR results in a lower path for the interest rate, at least into the early part of the 1980s, and a higher path for industrial production. Note that when actual NBR begins to catch up with CF NBR in the mid- to late 1980s. The relative expansion of actual NBR produces an actual output path above the CF counterpart and a relatively low interest rate.

Although the display in Figure 2 conveys much of interest about how a CF path that is "close" to the actual path would have altered economic outcomes, a more formal evaluation of the CF paths for output and inflation relative to the actual paths is to compute the root mean squared error (RMSE) for CF industrial production around a target growth path. We adopt a deterministic trend as the target path for two reasons. First, our reading of the policy process is that Fed policymakers formulate policy in terms of trend growth. For example, in recent months the Fed has signalled to the financial markets that it views GDP growth in excess of 2.5% (which is the long-run deterministic trend) as inflationary. Note that we do not take a position on the issue of whether output in fact follows a deterministic or a stochastic trend. Rather, the Fed's public pronouncements seem to suggest that output movements around a deterministic trend serve as a useful yardstick for judging whether policy should be tightened or loosened. Second, McCallum (1990) evaluated alternative policies in the same fashion, so our use of a deterministic trend target helps facilitate comparisons of our proposed counterfactual policies with his preferred policy rules.

Consistent with using a deterministic trend as a policy yardstick, we regress the log of industrial production on a constant and a time trend and use the fitted values as the target path for output. This regression implied a target path of industrial production growth of about 3.5% per year. The RMSE of the level of actual IP around this target was 4.74, which serves as the benchmark RMSE for IP for the NBR system. The actual monthly inflation rate was 0.00402, an annual rate of 4.94%. Assuming that the inflation rate is stationary, monthly inflation of 0.00402, or an annual inflation rate of 4.94%, serves as our benchmark RMSE. For the experiment presented in Figure 2, the RMSE for CF IP was 7.40. In addition, the average CF monthly inflation rate is 0.00396, an annual rate of 4.87%. An interesting implication of the results in Figure 2 on constant NBR growth at the actual average rate is that the policy actually employed dominates the x-percent rule. In particular, the RMSE of actual output was smaller, and virtually the same inflation rate was observed. A similar conclusion holds with regard to an x-percent rule applied to the model which substitutes the monetary base for NBR; in this alternative, for steady 7% growth in the base, the RMSE for CF IP was 5.30 and monthly inflation was 0.00405.

Although the experiments summarized above control for a policy aggregate (NBR or the base), they do not control the money supply per se. In particular, fluctuations in the monetary multiplier may allow market participants to either offset or reinforce the actions of policymakers, frustrating the ability of these policymakers to control output or inflation. Our second set of experiments assumes that policymakers aim at x-percent growth in M2 rather than in the reserve aggregate. In particular, the policymaker in the next experiment uses NBR to offset/reinforce historical money multiplier movements in order to force M2 growth to occur at a constant rate. Recall that the HD analysis suggested that such a policy may have been pursued in the 1980s.

Figure 3 shows the actual and CF paths for the system variables for the model in which the policy aggregate, NBR, is used to target nominal M2 growth. In an effort to keep the counterfactual experiments "close" to historical experience, the NBR path is chosen such that M2 growth each month is equal to its long-run historical average monthly growth rate (an annual rate of 7.65%). Two features of this experiment stand out in Figure 3. First, the CF price level is generally below the actual price level, so that the inflation rate was relatively constrained in the experiment. Second, there is little obvious cost in output, especially when compared with results in Figure 2, where the CF output path tended to be much more volatile. The computed RMSEs support these observations. In particular, the RMSE of CF IP in this experiment is 4.06, below that of the benchmark RMSE for IP. Further, the average monthly CF inflation rate, 0.00393, is also below the historical average. Similar results occur when the monetary base replaces NBR in the model. The RMSE of CF IP for the monetary base system would have been 4.04, and average monthly inflation would have been 0.00384.

It is interesting to note that a marginally more conservative x-percent rule for M2, using

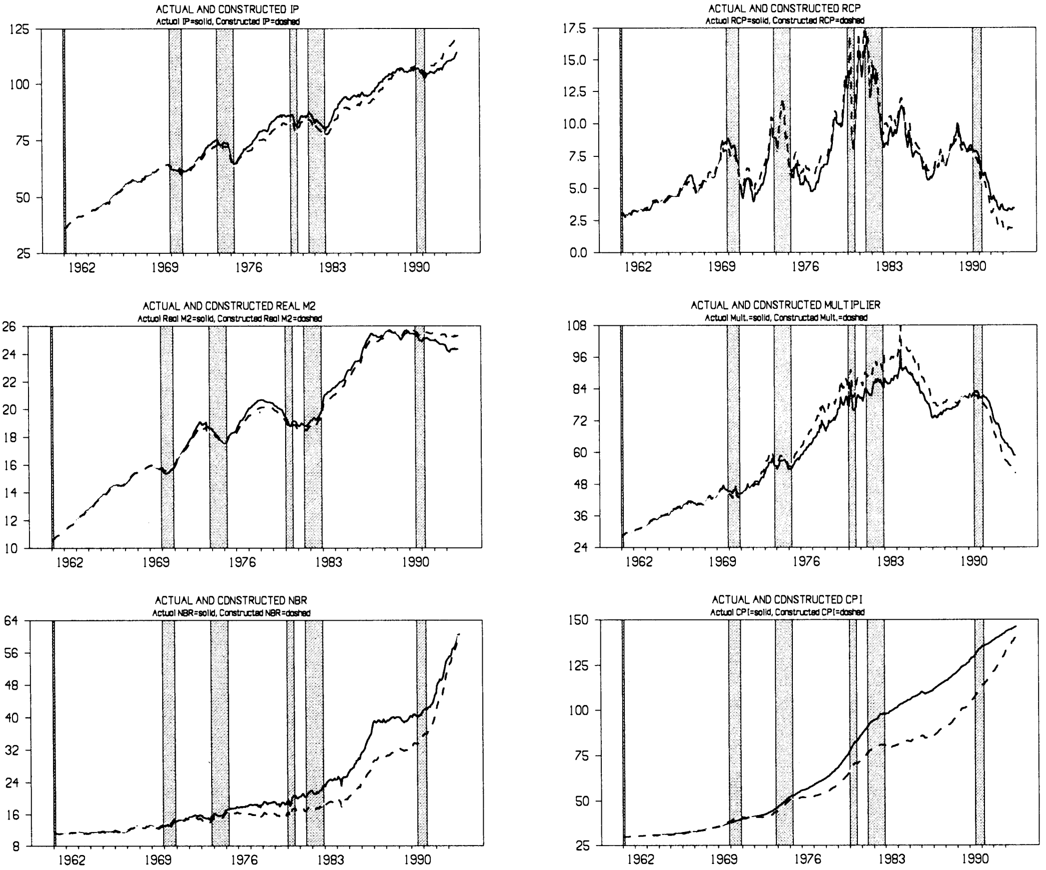

Figure 3. Actual and Counterfactual Paths for System Variables: Constant Money Supply Growth

either NBR or the base as the policy tool, would still have dominated actual policy. Specifically, using NBR (monetary base) to set M2 growth to 7% would have produced an RMSE for CF IP of 4.49 (4.29) and produced average monthly inflation of 0.00344 (0.00335). Tightening M2 growth to 5%, using either policy aggregate, would have produced RMSEs in the neighborhood of 6.80 and inflation rates of less than 0.00200. Thus, more restrictive money growth would have made further progress against inflation but would have worsened achievement of our IP objective. In fact, unlike a target M2 growth rate of 7%, a target of 5% tends to produce a level of CF IP consistently below the actual level.

In a very different context, McCallum (1990) uses a variant of the x-percent rule which adjusts the monetary aggregate for changes in velocity and for deviations of output from target. With monthly data, our version of the McCallum rule is:

$$\Delta A = x_A - (1/48)\lambda_1(\mathrm{IP}_{t-1} - A_{t-1} - \mathrm{IP}_{t-49} + A_{t-49}) + \lambda_2(\mathrm{IP}^*_{t-1} - \mathrm{IP}_{t-1})$$

where A = NBR or the monetary base, x is the x-percent rule used for the policy aggregate, and IP* is the target for IP. Note that an important difference between our rule and McCallum's is that we employ real output (IP) whereas he used nominal output (nominal GNP).[12]

[12] Our approach also differs from McCallum's in that we work explicitly in a VAR context, though his model, also

We have experimented with several values for λ_1 and λ_2, focusing most of our attention on the latter (as did McCallum). Our results showed that we could never dominate actual policy using this rule, coming closest for NBR when $\lambda_1 = 1.0$ and $\lambda_2 = 0.05$. With these settings, we produced an RMSE for CF IP of 5.69 compared with a benchmark RMSE for actual IP of 3.42 (which is different from the experiments above because we lost four years of data in order to incorporate the drift in velocity). This experiment did a bit better than actual policy for the inflation rate, with a monthly CF inflation rate of 0.00417 compared with an actual of 0.00444.

We note in passing that, in our various experiments, we have attempted to select counterfactual paths that are close to actual policy. As indicated, the rationale for this decision was to replicate normal policymaking rather than to investigate regime shifts; alternatively, our decision may be interpreted as an attempt to avoid the difficult issues related to the famous Lucas critique. It is certainly possible that larger deviations from the actual path than those considered here may produce superior results and/or that a careful analysis of regime changes may lead to improved policy rules. Such experiments, however, lie beyond the more modest goals of this paper.

7. Summary and Conclusion

This paper has examined the macroeconomic effects of shocks to aggregate demand and supply within the context of a six-variable vector autoregressive model, the theoretical counterpart of which is a relatively simple aggregate demand–aggregate supply model with the IS–LM model underlying aggregate demand. The structural shocks are identified using the long-run restrictions approach of Blanchard and Quah (1989).

Impulse response functions indicate the empirical shocks have effects consistent with those predicted by theory. The IRFs suggest it is important to distinguish between shocks to the relative price of oil and non-oil price aggregate supply shocks rather than treat all supply shocks as having effects that are similar in magnitude and timing, which is implicitly assumed when only a generic aggregate supply shock is identified. The IRFs also suggest distinguishing between shocks to the money multiplier and a reserve or base aggregate when evaluating monetary policy effects. The differing effects of IS shocks, money demand shocks, and monetary shocks on the macro variables with regard to magnitude, timing, and permanence of effects warn against identifying only a generic aggregate demand shock.

The historical decompositions do not suggest a monocausal explanation of cyclical fluctuations. The contributions of the various demand and supply shocks differ substantially across recessions and expansions. Neither an extreme real business cycle view that focuses primary attention on aggregate supply shocks nor an extreme monetary view that focuses primary attention on monetary actions is supported by the historical decomposition.

Counterfactual simulations indicate that constant growth rate rules in the neighborhood of historical policies could have produced superior economic outcomes. The key results suggest that rather than pursuing constant growth in a reserve aggregate or the monetary base, however, the objective of policy should be to smooth growth of the money stock; the policy aggregate

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reduced-form in nature, could be interpreted as a VAR with selected coefficients constrained to zero. Both approaches combine historical shocks of the nonpolicy variables with counterfactual policy equation shocks to assess alternative policies.

should be used to offset nonpolicy shocks to the money multiplier. Otherwise, multiplier variations introduce fluctuations into variables such as output and inflation.

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