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Abstract

Macroeconomic shocks such as oil price increases induce a systematic (endogenous) response of monetary policy. We develop a VAR-based technique for decomposing the total economic effects of a given exogenous shock into the portion attributable directly to the shock and the part arising from the policy response to the shock. Although the standard errors are large, in our application, we find that a substantial part of the recessionary impact of an oil price shock results from the endogenous tightening of monetary policy rather than from the increase in oil prices per se.

JEL: E3, E5

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The principal objective of this article is to increase our understanding of the role of monetary policy in postwar U.S. business cycles. We take as our starting point two common findings in the recent vector autoregression (VAR)-based literature on monetary policy (see, e.g., Leeper, Sims, and Zha (1996)): First, identified shocks to monetary policy explain relatively little of the overall variation in output (typically less than twenty per cent). Second, most of the observed movement in the instruments of monetary policy, such as the federal funds rate or nonborrowed reserves, is endogenous; that is, changes in Federal Reserve policy are largely explained by macroeconomic conditions, as we might expect given the Fed's commitment to macroeconomic stabilization. These two findings obviously do not support the view that erratic and unpredictable fluctuations in Federal Reserve policies are a primary cause of postwar U.S. business cycles; but, on the other hand, neither do they rule out the possibility that systematic and predictable monetary policies---the Fed's policy rule---affect the course of the economy in an important way. Put more positively, if one takes the VAR evidence on monetary policy seriously (as we do), then any case for an important role of monetary policy in the business cycle rests on arguing that the choice of monetary policy rule (the "reaction function") has significant macroeconomic effects.

Using time series evidence to uncover the effects of monetary policy rules on the economy is, however, a daunting task. It is not possible to infer the effects of changes in policy rules from a standard identified VAR system, since this approach typically provides little or no structural interpretation of the coefficients that make up the lag structure of the model. Large-scale econometric models, such as the MPS model, are designed for analyzing alternative policies; but criticisms of the identifying assumptions of these models have been the subject of a number of important papers, notably Lucas (1976) and Sims (1980).

Particularly relevant to the present paper is Sims's point that the many over-identifying restrictions of large-scale models may be both theoretically and empirically suspect, often implying specifications that do not match the basic time series properties of the data particularly well. Recent progress in the development of dynamic stochastic general equilibrium models overcomes much of the objection to the traditional approach raised by Lucas, but the ability of these models to fit the time series data - particularly, the relationships among money, interest rates, output, and prices - seems if anything worse than that of traditional large-scale models.

In this article we take some modest (but, we hope, informative) first steps toward sorting out the effects of systematic monetary policy on the economy, within a framework designed to accommodate the time-series facts about the U.S. economy in a flexible manner. Our strategy involves adding a little bit of structure to an identified VAR. Specifically, we assume that monetary policy works its effects on the economy through the medium of the term structure of open-market interest rates; and that, given the term structure, the policy instrument (in our application, the federal funds rate) has no independent effect on the economy. In combination with the expectations theory of the term structure, this assumption allows us to summarize the effects of alternative expected future monetary policies in terms of their effects on the current short and long interest rates, which in turn help determine the evolution of the economy. By comparing (for example) the historical behavior of the economy with its behavior under an hypothesized alternative policy reaction function, we are able to obtain a rough measure of the importance of the systematic component of monetary policy. Our approach is similar in spirit to a methodology due to Sims and Zha (1995), which however does not attempt to sort out the effects of anticipated and partially unanticipated policy changes, as we discuss later. While our proposed methodology is crude, and certainly not invulnerable to the Lucas critique, we believe that it represents a common-sense approach to the problem of measuring the effects of anticipated policy, given currently available tools.

To be able to perform comparisons between historical and alternative, hypothesized responses of monetary policy to economic disturbances, we need to select some interesting set of macroeconomic shocks to which policy is likely to respond. Our primary focus here is on oil price shocks, for two reasons.[1] First, periods dominated by oil price shocks are reasonably easy to identify empirically, and the case for exogeneity of at least the major oil price shocks is strong (although, as we will discuss, there is also substantial controversy about how these shocks and their economic effects should be modeled). Second, in the view of many economists, oil price shocks are perhaps the leading alternative to monetary policy as the key factor in postwar U.S. recessions: Increases in oil prices preceded the recessions of 1973-75, 1980-82, and 1990-91, and Hamilton (1983) presents evidence that oil price increases led declines in output prior to 1972 as well. Further, a leading criticism of the neo-monetarist claim that monetary policy has been a major cause of economic downturns is that this conclusion may confound the effects of monetary tightening and previous increases in oil prices, as discussed below.

The rest of the article is organized as follows. We first document that essentially all U.S. recessions of the past thirty years have been preceded by both oil price increases and a tightening of monetary policy, which raises the question of how much of the ensuing economic declines can be attributed to each factor. Discussion of this

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[1] Hooker (1996b) also studies the effects of oil price shocks and their interaction with monetary policy in a VAR framework. However, he does not explicitly attempt to decompose the effect of oil price shocks on

identification problem requires a digression into the parallel VAR-based literature on the effects of oil price shocks; a main conclusion here is that it is surprisingly difficult to find an indicator of oil price shocks that produces the expected responses of macroeconomic and policy variables in a VAR setting. After comparing alternative indicators, we choose as our principal measure of oil price shocks the "net oil price increase" variable proposed by Hamilton (1996a, 1996b).

We next introduce our identification strategy, which summarizes the effects of an anticipated change in monetary policy in terms of its impact on the current term structure of interest rate (specifically, the three-month and ten-year government rates). We show that our approach provides reasonable results for the analysis of shocks to monetary policy and to oil prices; and, in particular, we find that the endogenous monetary policy response can account for a very substantial portion (in some cases, nearly all) of the depressing effects of oil price shocks on the real economy. This result is reinforced by a more disaggregated analysis, which compares the effects of oil price and monetary policy shocks on components of GDP. Looking more specifically at individual recessionary episodes associated with oil price shocks, we find that both monetary policy and other, non-money, non-oil disturbances played important roles in these downturns; but that oil shocks per se were not a major source of these downturns. Overall, these findings help resolve the long-standing puzzle of the apparently disproportionate effect of oil price increases on the economy. We also show that our method produces reasonable results when applied to the analysis of monetary policy reactions to other types of shocks, such as shocks to output and to commodity prices.

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the economy into a part due the change in oil prices itself and a part due to the policy reaction.

After presenting the basic results, we look in more detail at their robustness and stability. Regarding robustness, we find that the broad conclusion that endogenous monetary policy is an important component of the aggregate impact of oil price shocks holds across a variety of specifications, although the exact proportion of the effect due to monetary policy is sometimes hard to pin down statistically. We also find evidence of sub-sample instability in our estimated system: However, to some extent this instability helps us strengthen our main conclusions about the role of endogenous monetary policy, in that the total effect of oil price shocks on the economy on output is found to be strongest during the Volcker era - when the monetary response to inflationary shocks was also the strongest - than in the pre-Volcker era.

Our analysis uses interpolated monthly data on GDP and its components. Appendix A documents the construction of these data, and Appendix B describes all the data used in this article.

Is It Monetary Policy or Is It Oil? The Basic Identification Problem

The idea that monetary policy is a major source of real fluctuations in the economy is, of course, an old one, with much of its continuing appeal reflecting the ongoing influence of Friedman and Schwartz's (1963) seminal book. Obtaining credible measurements of monetary policy's contribution to business cycles has proved difficult, however. As we discussed in the introduction, in recent years numerous authors have addressed the issue of measuring monetary policy's effects by means of the VAR methodology, introduced into economics by Sims (1980).[2] Roughly speaking, this approach identifies unanticipated

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[2] Recent applications of this methodology to the study of the effects of monetary policy include Bernanke and Blinder (1992), Christiano, Eichenbaum, and Evans (1994), Sims (1992), Strongin (1995), Bernanke and Mihov (1995), Sims and Zha (1995), and Leeper, Sims, and Zha (1996).

innovations to monetary policy with the unforecasted shock to some policy indicator, such as the federal funds rate or the rate of growth of nonborrowed reserves. Using the estimated VAR system, one can trace out the dynamic responses of output, prices, and other macroeconomic variables to this innovation, thereby obtaining quantitative estimates of how monetary policy innovations affect the economy. As Cochrane (1996) notes, this approach has "finally succeeded in obtaining empirical estimates of the effects of monetary policy that accord with our priors", for example, in finding that a positive innovation to monetary policy is followed by increases in output, prices, and money, and by a decline in the short-term nominal interest rate. In addition, despite ongoing debates about precisely how the policy innovation should be identified, the estimated responses of key macro variables to a policy shock are reasonably similar across a variety of studies, and suggest that monetary policy shocks can have significant (and persistent) real effects.

The VAR literature has focused on unanticipated policy shocks not because they are quantitatively very important - the conclusion of this literature is, indeed, that policy shocks are too small to account for much of the overall variation in output and other variables - but because of the argument that cause and effect can be cleanly disentangled only for the case of exogenous, or random, changes in policy. However, to reiterate a point made above, looking only at unanticipated policy changes begs the question of how systematic, or endogenous monetary policy changes affect the economy.[3]

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[3] Cochrane (1996) has emphasized that identification of the effects of even unanticipated policy changes may hinge on the anticipated-unanticipated distinction, since an innovation to policy typically also changes the anticipated future path of policy. The analyst thus faces the conundrum of determining how much of the economy's response to a policy shock is due to the shock per se, and how much is due to the change in policy anticipations engendered by the shock. Our focus here is different from that of Cochrane in that we emphasize the effects of

Earlier work on the effects of monetary policy often did not make the distinction between anticipated and unanticipated policy changes[4] (for example, Anderson and Jordan (1968)). These studies frequently found a very large role for monetary policy in cyclical fluctuations. An important recent example of this genre is the article by Romer and Romer (1989): Following the "narrative approach" of Friedman and Schwartz (1963), Romer and Romer used Federal Reserve records to identify a series of dates at which, in response to high inflation, the Fed changed policy in a sharply contractionary direction. The "Romer dates" correspond, we would guess, to policy changes which had both an unanticipated component (because they were large, or decisive) and a portion that was anticipated (because they were explicitly responses to inflation); indeed, Shapiro (1994) showed that the Romer dates are largely forecastable. Romer and Romer found that the dates they identified were typically followed by large declines in real activity, and they concluded that monetary policy plays an important role in fluctuations.

But, as several critiques of Romer and Romer (1989) and the earlier work on anticipated monetary policy have pointed out, studies which blur the distinction between anticipated and unanticipated policies suffer from precisely the identification problem that the VAR literature has attempted to avoid; namely, that it is not obvious how to distinguish the effects of anticipated policies from the effects of the shocks to which the policies are responding. This concern is not merely methodological carping but has potentially great practical importance in the postwar U.S. context, since a number of the most important tightenings of U.S. monetary policy have followed on the heels of major

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non-policy shocks, such as oil shocks, on anticipated monetary policy; but our methods could also be used to address the specific issue raised by Cochrane.

increases in the price of imported oil (Dotsey and Reid, 1992; Hoover and Perez, 1994).

This point is illustrated in Figure 1, which shows the historical behavior of the federal funds rate (here taken to be an indicator of monetary policy) in the top panel, and the log-level of the nominal price of oil in the bottom panel. NBER recessions are indicated by shaded areas. Also indicated (by stars) in the top panel are the five Romer dates that fall within our sample period. In the bottom panel, in analogy to the Romer dates, the triangles indicate seven dates at which there were major disruptions to the oil market, as determined by Hoover and Perez (1994).[5]

The top panel of Figure 1, taken alone, appears to support the neo-monetarist case that tight money is the cause of recessions: Each of the first four recessions in the figure was immediately preceded by sharp increases in the federal funds rate, and the 1990 recession followed a monetary tightening that ended in late 1989. Peaks in the federal funds rate also tend to coincide with the Romer dates. However, the bottom panel of Figure 1 shows why laying the blame for postwar recessions at the door of the Federal Reserve would be premature: As was first emphasized in an influential paper by Hamilton (1983), nearly all of the postwar U.S. recessions have also followed upon increases in the nominal price of oil, which in turn have been associated with monetary tightenings. Further, many of these oil price shocks were arguably exogenous, reflecting a variety of developments both in the Middle East and in the domestic industry, as indicated by the Hoover-Perez dates. Thus we have the general identification problem cast in a

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[4] Or, for that matter, between changes in the money stock induced by policy and changes induced by other factors.

[5] The Hoover-Perez dates, which were introduced in their critique of the Romer and Romer approach, are in turn based on a chronology due to Hamilton (1983). We have added August 1990, the month of the invasion of Kuwait by Iraq, to the six dates given by Hoover and Perez.

specific form: What portion of the last five U.S. recessions, and of aggregate output and price fluctuations in general, was due to oil price shocks per se, and what portion was due to the Federal Reserve's response to those shocks? To answer this question we need a means of measuring the effects of anticipated or systematic monetary policies.[6]

Measuring Oil Price Shocks and their Effects

We propose to identify the importance of the monetary policy feedback rule in a modified VAR framework. In order to do that, however, we first need to find an appropriate indicator of oil price shocks to incorporate into our VAR systems. This is a more difficult task than it may appear at first. The most natural indicator would seem to be changes in the nominal oil price; and indeed, in an article which helped to initiate the literature on the effects of oil price shocks, Hamilton (1983) showed that increases in the nominal price of oil Granger-cause downturns in economic activity.[7] However, the arrival of new data has shown this simple measure to have a rather unstable relationship with macroeconomic outcomes, leading successive researchers to employ increasingly complicated specifications of the "true" relationship between oil and the economy (see, e.g., Mork, 1989; Lee, Ni, and Ratti, 1995; Hamilton, 1996a; Hooker, 1996a, 1996b). In particular, Hamilton (1996a) argues that the correct measure of oil shocks depends very much upon the precise mechanism by which changes in the price of oil are supposed to affect the economy, a question for which many answers have been proposed but on which there is little

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[6] In this paper we take as given that anticipated as well as unanticipated monetary policies influence the real economy, owing to the existence of various nominal rigidities. In this regard, our objective is to provide an estimate the real impact of the systematic component of monetary policy, as opposed to testing the null hypothesis that this component is neutral.

agreement.[8] For our purposes, the exact channels through which oil affects the economy are not crucial. What matters is that we can identify an exogenous movement in the price of oil that has a significant and a priori plausible reduced-form impact on the economy.

Figure 2 illustrates the effects of some alternative measures of oil price shocks on selected variables, as indicated by estimated impulse response functions (IRFs). Each IRF is based on a five-variable VAR which includes, in this order: (1) the log of real GDP; (2) the log of the GDP deflator; (3) the log of an index of spot commodity prices; (4) an indicator of the state of the oil market; and (5) (the level of) the federal funds rate. Data are monthly, the VAR was estimated using a constant and seven lags (as determined by AIC), and the sample period is 1965-1995.[9] Only the impulse responses of real GDP, the GDP deflator, and the federal funds rate are shown, in each case over a 48-month horizon and for an oil price shock normalized to correspond to a 1% increase in the current nominal oil price. Dashed lines correspond to one-standard-error bands. As is standard in the VAR literature on the effects of monetary policy, the index of commodity prices is added to the VAR to control for information that the Fed may have about future

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[7] To the surprise of many, Hamilton showed that the close relationship between oil price increases and recessions appears to have existed even prior to the major OPEC shocks of the 1970s.

[8] Possibilities discussed by Hamilton (1996a) include aggregate supply effects operating through costs of production and the indirect effects of wage rigidity; aggregate demand effects; effects arising from the interaction of uncertainty about future energy prices and the irreversibility of investment; and asymmetric sectoral impacts that force costly reallocations of resources.

[9] The appendix describes the construction of monthly data for GDP and the GDP deflator. The log of real GDP was detrended with a cubic spline with three equally spaced knot points, with equality of the level and first two derivatives at the knot points imposed. The resulting estimated trend component was essentially piecewise linear with a break in the early 1970s reflecting the productivity slowdown. Other data were from CITIBASE (see Appendix B for description). The CITIBASE labels for the series are: FYFF (federal funds rate), PSCCOM (commodity price index), and PW561 (nominal oil price index, PPI for crude oil and products). We focus here on full-sample results, leaving a discussion of possible sub-sample instabilities until later.

inflation which is not captured by the other variables in the system;[10] the federal funds rate is included as an indicator of monetary policy.[11] The ordering of the oil indicator after the macro variables imposes the reasonable assumption that oil price shocks do not significantly affect the economy within the month. Similarly, ordering the funds rate last follows the conventional assumption that monetary policy operates with at least a one-month lag. The results are not sensitive to these ordering assumptions, as we document below in the context of a larger system.

We report results for four alternative indicators of the state of the oil market, one a slight variation of the original Hamilton (1983) indicator, the other three more exotic indicators that have been developed in ongoing attempts to identify a stable relationship between oil price shocks and the economy:

(1) *Log of the nominal PPI for crude oil and products*, or the nominal oil price for short. Hamilton (1983) employed the log-difference of the nominal oil price, which given the presence of freely estimated lag parameters is nearly equivalent to using the log-level. Given the other variables included in the VAR, this indicator is also essentially the same as that used by Rotemberg and Woodford (1996).

(2) *Hoover-Perez*. These are the oil shock dates of Hoover and Perez (1994), referred to in the discussion of Figure 1, plus August 1990. To scale these dates by relative importance, we have multiplied

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[10] The inclusion of the commodity price index was suggested by Sims (1992), as a way of eliminating the so-called "price puzzle" in monetary policy VARs. In the present context it is important to note that, for most of its history, the commodity price index appears to have excluded oil and other energy prices (a bit of uncertainty remains because of poor documentation of the series). Since 1987 an oil price has been included in the index. As we report below, however, there is little evidence that the inclusion of oil in the index in the latter period has any substantive effect on our results.

[11] Results from Bernanke and Blinder (1992), Bernanke and Mihov (1995), and Friedman and Kuttner (1996) suggest that it is reasonable to use the

the Hoover-Perez dummy variables by the change in the nominal price of oil in the surrounding three months.

(3) *Mork*. After the sharp oil price declines of 1985-86 failed to lead to an economic boom, Mork (1989) argued that the effects of positive and negative oil price shocks on the economy need not be symmetric. Empirically, he provided evidence that only positive changes in the relative price of oil have important effects on output. Accordingly, we employ an indicator in the VARs that equals the log-difference of the relative price of oil when that change is positive; and is zero, otherwise.[12]

(4) *Hamilton*. In response to the breakdown of the relationship between output and simpler measures of oil price shocks, Hamilton (1996a, 1996b) has proposed a more complicated measure of oil price changes, called the "net oil price increase". The net oil price increase distinguishes between oil price increases that establish new highs relative to recent experience and increases that simply reverse recent decreases. Specifically, in the context of monthly data, Hamilton's measure equals the maximum of (a) zero and (b) the difference between the log-level of the crude oil price for the current month and the maximum value of the logged crude oil price achieved in the previous twelve months. Hamilton (1996b) provides some evidence for the usefulness of this variable using semi-non-parametric methods, and

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funds rate as a policy indicator, except possibly during the 1979-82 reserves-targeting period.

[12] We measure the relative price of oil as the PPI for crude oil divided by the GDP deflator. Mork (1989) argued that the PPI for crude oil was a distorted measure of the marginal cost of oil during certain periods marked by domestic price controls; he therefore chose to measure oil prices by refiner acquisition cost (RAC) instead, for the period for which those data are available. For simplicity, and because we feel that there are also problems with RAC as a measure of the marginal cost of crude, we stick with the crude-oil PPI in this study.

Hooker (1996b) also finds it to perform well, in the sense of having a relatively stable relationship with macroeconomic variables.[13]

We can now turn to Figure 2. The deficiencies of the simplest measure of the state of the oil market, the nominal price of crude oil, are apparent. In particular, for the 1965-1995 sample we employ here, a shock to the nominal price of oil is followed by a <u>rise</u> in output for the first year or so, and by a slight short-run <u>decline</u> in the price level. Both of these results (which have been verified in the recent literature on oil price shocks) are anomalous, relative to the conventional wisdom about the effects of oil price shocks on the economy. As indicated in footnote 13, other simple measures (such as the relative price of oil) give similarly unsatisfactory results.

The three more complex indicators (Hoover-Perez, Mork, and Hamilton) produce "better-looking" IRFs, in that output falls and prices rise following an oil price shock, as expected, although generally neither response is statistically significant. The point estimates of the effect of an oil price shock on output suggest a modest impact from an economic perspective: For example, for the case of the Hamilton indicator, the sum of the impulse response coefficients for output over the first 48 months is -0.538, implying that a 1% (transitory) shock to oil prices leads to a cumulative loss of about half a percent of a month's real GDP, or 0.045% of a year's real GDP, over four years. As will be touched on below, more economically and statistically

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[13] We also experimented with VARs including the log-difference of the nominal price of oil (the indicator used by Hamilton, 1983); the log of the real price of oil (the nominal oil price divided by the GDP deflator); the log-difference of the real price of oil; and the log of the nominal price of oil weighted by the share of energy costs in GDP (suggested by William Nordhaus at the conference). As the results obtained were very similar to those found using the log nominal price of oil, we do not report them here. There are yet additional indicators of oil price shocks in the literature, such as those proposed by Ferderer (1996) and Lee, Ni, and Ratti (1995), which focus on the volatility of oil prices rather than the level; for simplicity we ignore these second-

significant effects of oil price shocks are estimated when 1) the latter part of the sample, which contains the somewhat anomalous 1990 episode, is omitted; and 2) when the VAR system is augmented with short-term and long-term market interest rates. Figure 2 also shows that, for all four indicators of the oil market, a positive innovation to oil prices is followed by a rise in the funds rate (tighter monetary policy), as expected, and the response is generally statistically significant. This response of the funds rate illustrates the generic identification problem: Without further structure, it is not possible to disentangle how much of the decline of output is the direct result of the increase in oil prices, as opposed to the ensuing tightening of monetary policy.

This brief exercise also demonstrates a main result of the recent literature on the macroeconomic effects of oil prices, that finding a measure of oil price shocks that "works" in a VAR context is not straightforward. It is also true, as we will discuss later, that the estimated impacts of these measures on output and prices can be quite unstable over different samples. For present purposes, however, based on the evidence of the literature and our own analysis (including Figure 2), we choose the Hamilton "net oil price increase" measure of oil price shocks for use in our basic analyses.[14] As we discuss further below, we have checked the robustness of our exercises to the use of alternative oil-market indicators; we find in general that, when the oil-market indicator being used gives reasonable results in exercises like those shown in Figure 2, our alternative simulations perform reasonably as well.

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moment-based measures and concentrate on measures that are functions of the level of oil prices.

[14] In particular, Hooker (1996b) finds that the Hamilton measure is the most stable across sub-samples.

Measuring the Effects of Endogenous Monetary Policy

Figure 2 showed that, at least for some more complex (some might argue, data-mined) indicators of oil prices, an exogenous increase in the price of oil has the expected effects on the economy: Output falls, prices rise, and monetary policy tightens (presumably in response to the inflationary pressures from the oil shock). At least since Tobin (1980), however, it has been argued that oil (and energy) costs are too small relative to total production costs to account for the entire decline in output that, at least in some episodes, has followed increases in the price of oil.[15] A natural hypothesis, therefore, is that part of the recessionary impact of oil price increases arises from the subsequent monetary contraction.

Sims and Zha (1995) have attempted to provide rough estimates of the contribution of endogenous monetary policy changes in a VAR context.[16] Their approach is to "shut down" the policy response that would otherwise be implied by the VAR estimates, e.g., by setting the Federal funds rate (the monetary policy indicator) at its baseline level (the values it would have taken in the absence of the exogenous non-policy shock). The difference between the total effect of the exogenous non-policy shock on the system variables and the estimated effect when the policy response is shut down is then interpreted as a measure of the contribution of the endogenous policy response. As Sims and Zha correctly point out, this procedure is equivalent to combining the initial non-policy shock with a series of policy innovations just sufficient to offset the endogenous policy response. Implicitly, then, in the Sims-Zha exercise people in the economy are repeatedly

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[15] See also Darby (1982), Kim and Loungani (1992), and Rotemberg and Woodford (1996). The latter argue that monopolistically competitive market structure, which leads to changing markups over the business cycle, can in principle explain the strong effect of oil price shocks.

"surprised" by the failure of policy to respond to the non-policy shock in its accustomed way. Sims and Zha argue, not unreasonably, that it would take some time for people to learn that policy was not going to respond in its usual way; so that, for deviations of policy from its historical pattern that are neither too large nor too protracted, their estimates of the policy effects may be acceptable approximations. This justification is similar to the one that Sims has given in previous articles, e.g., Sims (1986), for conducting policy analyses in a VAR setting, despite the issues raised by the Lucas critique.

Rather than ignoring the Lucas critique altogether, however, one might try to accommodate it partially in the VAR context, by acknowledging that Lucas's argument may be more important for some markets than for others. In particular, the evidence for the relevance of the Lucas critique seems much stronger for financial markets (e.g., in the determination of the term structure of interest rates) than in labor and product markets (Blanchard, 1984), which has led some economic forecasters and policy analysts to propose and estimate models with rational expectations in the financial market only (e.g., Taylor, 1993). In that spirit, we modify the Sims-Zha procedure for measuring the effects of endogenous policy by assuming that interest-rate expectations are formed rationally (and in particular, that financial markets anticipate alternative policy paths); but we assume that the other equations of the VAR system are invariant to the contemplated policy change. The latter assumption can be rationalized by assuming either that expectations of monetary policy enter the true structural equations for output, prices, etc., only through the term structure of interest rates; or, if other policy-related expectations enter into those structural equations, that (for policy changes that are not too large)

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[16] Counterfactual simulations in a VAR context have also been performed by West (1993) and Kim (1995). Neither paper distinguishes anticipated

these respond more sluggishly than financial-market expectations, as proposed by Sims (1986). Although our method is obviously neither fully structural nor immune to the Lucas critique, we think it provides an interesting alternative to the Sims-Zha approach.

More specifically, we consider small VAR systems that include standard macroeconomic variables, short-term and long-term interest rates, and the federal funds rate (as an indicator of monetary policy). We make the following assumptions:

First, we assume that the federal funds rate does not <u>directly</u> affect macroeconomic variables such as output and prices, a reasonable assumption since the funds rate applies to a very limited set of transactions (overnight borrowings of commercial bank reserves). Hence the funds rate is excluded from the equations in the system determining those variables. However, the funds rate is allowed to affect macroeconomic variables indirectly, through its effect on short-term and long-term interest rates, which in turn are allowed to enter every equation determining a macroeconomic variable. Note that the assumption that monetary policy works strictly through interest rates is a conservative one, as it neglects other possible channels (such as the exchange rate channel and the "credit channel"); in this sense, our estimates should represent a lower bound on the contribution of endogenous monetary policy.

Second, following many previous authors, we assume that the macroeconomic variables in the system are Wold causally prior to all interest rates. That is, in the monthly data that we will be using, we assume that interest rates respond to contemporaneous developments in the economy but that changes in interest rates do not affect "slow-moving" variables such as output and prices within the month. This is a

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from unanticipated movements in policy.

plausible assumption given the existence of planning and production lags.[17]

Third, we assume that the funds rate is Wold causally prior to the other market interest rates, that is, the covariation between innovations in the funds rate and in other interest rates is caused by the influence of monetary policy changes on interest rates, rather than by the response of the policy-makers to market rates within the month. This is a strong assumption, although it appears to give fairly reasonable results when viewed from the context of the expectations theory of the term structure. The assumption may be justified if the term premium contains no information about the economy that is not also contained in the other variables seen by the Fed. Below we briefly discuss an alternative ordering assumption, which allows for considerable reaction by the Fed to current market interest rate movements.

Formally, let Y_t denote a set of macro variables, including the price of oil, at date t. Similarly, let $R_t = (R_t^s, R_t^l)$ represent the set of market interest rates, specifically the three-month Treasury bill rate (the "short rate", R_t^s) and the ten-year Treasury bond rate (the "long" rate, R_t^l). Finally, the scalar FF_t is the federal funds rate. Under the assumptions above, the (restricted) VAR system is written

$$(1) \quad Y_t = \sum_{i=1}^{p} (\pi_{yy,i} Y_{t-i} + \pi_{yr,i} R_{t-i}) + G_{yy} \varepsilon_{y,t}$$

$$(2) \quad FF_t = \sum_{i=1}^{p} (\pi_{fy,i} Y_{t-i} + \pi_{fr,i} R_{t-i} + \pi_{ff,i} FF_{t-i}) + \varepsilon_{ff,t} + G_{fy} \varepsilon_{y,t} + G_{fr} \varepsilon_{r,t}$$

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[17] As Sims has pointed out, however, the assumption is less plausible for the commodity price index, which is included in the non-policy block as an information variable.

$$(3)\quad R_t = \sum_{i=1}^{p} (\pi_{ry,i} Y_{t-i} + \pi_{rr,i} R_{t-i} + \pi_{rf,i} FF_{t-i}) + \varepsilon_{r,t} + G_{ry}\varepsilon_{y,t} + G_{rf}\varepsilon_{ff,t}$$

where the π's and G's are matrices of coefficients of the appropriate dimensions, and the ε's are vectors of orthogonal error terms. The exclusion of FF_{t-i} from eq. (1) follows from the first assumption above, that the funds rate does not directly affect macroeconomic variables; and the exclusion of $\varepsilon_{r,t}$ and $\varepsilon_{ff,t}$ from eq. (1) is implied by our second assumption, that innovations to interest rates do not affect the non-policy variables within the period.

In order to apply the expectations theory to identify a relationship between the funds rate and the market interest rates, and to implement our policy experiments, it will be useful to decompose the market rates into two parts: a part reflecting expectations of future values of the nominal funds rate, and a term premium. We define the following variables:

$$(4)\quad \overline{R}_t^s = E_t\left(\sum_{i=0}^{ns-1} \omega_{s,i} FF_{t+i}\right)$$

$$(5)\quad \overline{R}_t^l = E_t\left(\sum_{i=0}^{nl-1} \omega_{l,i} FF_{t+i}\right)$$

$$(6)\quad S_t^s = R_t^s - \overline{R}_t^s$$

$$(7)\quad S_t^l = R_t^l - \overline{R}_t^l$$

where $ns =$ 3 months, and $nl =$ 120 months, are the terms of the short-term and long-term rates, respectively, and the weights ω are defined by $\omega_{s,i} = \beta^i \Big/ \sum_{j=0}^{ns-1} \beta^j$ and $\omega_{ll,i} = \beta^i \Big/ \sum_{j=0}^{nl-1} \beta^j$. We set the monthly discount factor β

= 0.997, so that β^{12} = 0.96. The $\overline{R}$ variables defined in eqs. (4) and (5) are the "expectations-based" components of the short and long market interest rates, and the residual S terms in eqs. (6) and (7) are time-varying term-cum-risk premia associated with rates at the two maturities. Note that the time series of the two components of short and long interest rates are easily calculated from current and lagged values of Y, FF, and R using the estimated π parameters in eqs. (1)-(3). In particular, finding the estimated expectations components of short and long rates is purely a forecasting exercise and does not require structural identifying assumptions.

With these definitions, it is useful to rewrite the model of eqs. (1)-(3) as

$$(8) \quad Y_t = \sum_{i=1}^{p} (\pi_{yy,i} Y_{t-i} + \pi_{yr,i} (\overline{R}_{t-i} + S_{t-i}) + G_{yy} \varepsilon_{y,t}$$

$$(9) \quad FF_t = \sum_{i=1}^{p} (\pi_{fy,i} Y_{t-i} + \pi_{fs,i} R_{t-i} + \pi_{ff,i} FF_{t-i}) + \varepsilon_{ff,t} + G_{fy} \varepsilon_{y,t} + G_{fs} \varepsilon_{s,t}$$

$$(10) \quad S_t = \sum_{i=1}^{p} (\lambda_{sy,i} Y_{t-i} + \lambda_{ss,i} R_{t-i} + \lambda_{sf,i} FF_{t-i}) + \varepsilon_{s,t} + G_{sy} \varepsilon_{y,t} + G_{sf} \varepsilon_{ff,t}$$

Equation (8) is identical to eq. (1), except that the two market interest rates have been broken up into their expectational and term premium components. Equations (9) and (10) correspond to eqs. (2) and (3), with the interest rates R being replaced by the corresponding term premia S. Since the difference between R and S is the expectational component of interest rates, which is constructed as a projection on current and lagged values of observable variables, eqs. (9) and (10) are equivalent to eqs. (2) and (3); in particular, the coefficients in eqs. (9) and (10) are simply combinations of the coefficients in eqs. (2) and

(3) and the projection coefficients of the federal funds rate on current and lagged variables.

We work with the system of equations (8)-(10) because it simplifies the imposition of some alternative identifying restrictions. Our main identifying assumption, discussed above, is that the federal funds rate is Wold causally prior to the other interest rates in the model; this corresponds to the assumption that $G_{fs} = 0$ in eq. (9). However, an alternative assumption, which allows for two-way causality between the funds rate and market rates, is that shocks to the federal funds rate affect other interest rates contemporaneously only through their impact on expectations of the future funds rate (i.e., funds rate shocks do not affect term premia contemporaneously); this corresponds to the restriction $G_{sf} = 0$ in eq. (10). Note that this alternative assumption allows the funds rate to respond to innovations in term premia. In both cases we assume that G_{yy} is lower-triangular (with ones on the diagonal), as in conventional VAR analyses employing the Choleski decomposition. In most of our applications, our "macro block" consists of real GDP, the GDP deflator, the commodity price index, and Hamilton's net oil price increase variable, in that order; as we show below, our results are robust to the placement of the oil-market indicator.

To illustrate how we carry out policy experiments, consider the scenario of greatest interest to us in this paper, the case of a shock to the oil-price variable. The base case, which incorporates the effects of the endogenous of the policy response, is calculated in the conventional way by simulating the effects of an innovation to the oil-price variable using the system (8)-(10). Among the results of this exercise are the standard impulse response functions, showing the dynamic impact of an oil price shock on the variables of the system, including the policy variables.

To simulate the effects of an oil price shock under a counterfactual policy regime, we first specify an alternative path for the federal funds rate (more specifically, deviations from the baseline impulse response of the funds rate), in a manner analogous to the approach of Sims and Zha (1995). However, unlike Sims and Zha, we assume that financial markets understand and anticipate this alternative policy response. (In this respect, which assumes "maximum credibility" of the Fed's announced future policy, we are making the polar opposite assumption to that of Sims and Zha, who assume that market participants are purely backward-looking.) To incorporate this assumption into the simulation, we calculate the expectational component of interest rates, $\overline{R}_{t+i}, i = 0,1,\ldots$ that is consistent with the proposed future path for the federal funds rate. We then re-simulate the effects of the oil shock in the system (8)-(10), imposing values of $\overline{R}_t$ consistent with the assumed path of the funds rate, and also choosing values of $\varepsilon_{ff,t}$ such that the assumed future path of the funds rate is realized. Note that this method can be used to construct alternative impulse response functions based on full-sample or subsample estimates, or to simulate counterfactual economic behavior for specific episodes, such as the individual major oil price shocks. We will use it in both ways below.

Some Policy Experiments

With our methodology in hand, we are prepared to do a variety of policy experiments, using estimates from our sample period 1965:1-1995:12. The VAR is estimated using a constant and seven lags, as determined by AIC.

A Monetary Policy Shock

To check on the reasonableness of the basic estimated system, we begin with the conventional analysis of a monetary policy shock, modeled here as a 25-basis-point innovation to the federal funds rate. The effects of an innovation to the federal funds rate are traced out in a seven-variable system that includes output, the price level, the commodity price index, the Hamilton oil measure, the funds rate, and the short and long term premia (Figure 3). As described above, the values of the short and long term premia at each date are calculated by subtracting the "expectational component" of short and long rates (based on forecasts of future values of the funds rate) from the short and long rates themselves. In this base case analysis, equivalent results are obtained by directly including the short and long rates in the VAR (ordered after the funds rate), and the implied responses for short and long rates are included in the figure. In the data, there are large low-frequency movements in the long-rate term premium with trend increases of about one percentage point in both the 1970s and the 1980s. This trend variation was removed with a cubic spline (specified as described in footnote 9). As reported in the section on robustness below, leaving the long premium undetrended does not significantly affect the results.[18] Impulse response functions to the funds rate innovation in Figure 3 are shown with one-standard-error bands.

The results of this exercise will look quite familiar to those readers who know the recent VAR literature on the effects of monetary policy. The innovation to the funds rate (initially 25 basis points,

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[18] Fuhrer (1996) shows that the large movements in the long rate can be explained in a way consistent with the expectations hypothesis, if the market was making rate forecasts at each date based on a particular set of beliefs about how the Federal Reserve's objective function has varied over time. However, there is nothing in Fuhrer's analysis which

peaking at about 35 basis points) is largely transitory, mostly dying away in the first nine months. Output declines relatively quickly, reaching a trough at about 18-24 months, then gradually recovering. The price level responds sluggishly, but eventually declines, nearly two years after the policy innovation. Commodity prices also decline, and do so much more quickly than does the general price level.

The model's only exclusion restriction, that the funds rate does not belong in the "upper block" (which includes the oil indicator, output, prices, and commodity prices), conditional on the presence in the upper block of short-term and long-term interest rates, is marginally rejected: The p-values for the exclusion of the funds rate from the equations of the upper block are, respectively, 0.01 for the output equation, 0.06 for the price-level equation, 0.23 for the commodity price equation, and 0.18 for the oil equation. However, the effects of this exclusion do not seem to be economically very significant. For example, if we compare the effects of a funds-rate shock on output in the restricted, seven-variable system with the analogous effects in the conventional, unrestricted five-variable system (excluding the market interest rates), we obtain virtually identical results.

An interesting new feature of the seven-variable system is that it allows us to examine the responses of market interest rates to monetary policy innovations, and in particular to compare these responses to the predictions of the pure expectations hypothesis. Looking first at short-term (three-month) rates, we see that a 25-basis-point innovation to the funds rate implies about a 15-basis-point increase in the short rate, and that the two rates then decline synchronously. This seems quantitatively reasonable. To check the consistency of this response

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connects these hypothesized beliefs with the actual time series behavior of the funds rate.

with the expectations hypothesis, we can look at the behavior of the short-rate term premium, which by construction is the difference between the actual short-term rate and the short-term rate implied by the pure expectations hypothesis. The short term premium is significantly negative immediately following a funds rate innovation, implying that in the first month or two after an innovation to the funds rate, the short-term interest rate is estimated to respond less than would be predicted by the expectations hypothesis. However, the short term premium quickly becomes statistically and economically insignificant, suggesting that the expectations hypothesis is a reasonable description of the link between the funds rate and the short-term interest rate after the first month.

The long-term interest rate is a different story. As is shown in Figure 3, the long rate responds about five basis points on impact to a 25 basis point innovation in the funds rate, with the response remaining above zero for some three years, which again does not seem unreasonable. However, comparison of the responses of the long-term interest rate and the long term premium reveals that they are very close, the latter being slightly less than the former. The implication is that the expectations theory explains relatively little of the relationship between the funds rate and the 10-year government bond rate. This finding is not very surprising in retrospect, given the transitory nature of funds rate shocks compared to the duration of a 10-year bond. The estimated behavior of the long term premium is thus some evidence of "over-reaction" of long rates to short rates, a phenomenon which has been documented frequently in the term structure literature (although the degree of over-reaction found here appears smaller than that typically found in that literature).[19]

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[19] An alternative explanation for the long rate's over-reaction is that the policy shock is imperfectly identified. Note the slight "output

Simulations of the Effects of an Oil Price Shock

Given that our expanded model seems to perform reasonably for the case of an innovation to monetary policy, we can now turn to the exercise of greatest interest, which is to use the model to decompose the effects of an oil price shock into direct and indirect (through endogenous monetary policy) components. Figure 4 shows impulse responses following a shock to Hamilton's net oil price increase measure under three scenarios.

The first scenario, labeled "base", shows the impulse responses of the variables to a 1% innovation in the nominal price of oil in the seven-variable system. This is a normal VAR simulation, except that the funds rate does not enter directly into the equations for output, prices, commodity prices, and the oil indicator. This case is intended to show the effects on the economy of an oil price shock <u>including</u> the endogenous response of monetary policy, in contrast with the next two simulations, which involve alternative methods of "shutting off" the policy response.

The second scenario we have labeled "Sims-Zha" (with some abuse of terminology). In this scenario we simply fix the funds rate at its base values throughout the simulation, in the manner of Sims and Zha (1995). However, recall that here (unlike in the original Sims-Zha exercise) the funds rate does not enter directly into the block of macroeconomic variables. Rather, the funds rate exerts its macroeconomic effects only indirectly, through the short-term and long-term interest rates included in the system. Effectively, then, in this exercise we are allowing the change in the funds rate to have its effects through its unconstrained,

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puzzle", for example (output increases in the first few months after the policy shock). Possibly a better identification scheme would eliminate the over-reaction.

reduced-form impact on market interest rates (which are ordered after the funds rate).

The third scenario, labeled AP (for "anticipated policy") applies our own methodology described above. Here again we set the funds rate equal to its baseline values (that is, we shut off the response of monetary policy to the oil shock and the changes induced by the oil shock in output, prices, etc.) But in this case we let the two components of short-term and long-term interest rates be determined separately: 1) The "expectations component" of both interest rates is set to be consistent with the future path of the funds rate, as assumed in the scenario. 2) The term premia, short and long, are allowed to respond as estimated in the base model. (Below we also consider a case where the term premia are kept at their baseline values.) For the simple, constant-funds-rate case being examined here, the difference between what we have labeled the Sims-Zha and Anticipated Policy approaches are modest. Note however that the former could not distinguish between policies that differ only in expected future values of the funds rate, while in principle the latter approach could make that distinction.

The results of Figure 4 are reasonable, with all variables exhibiting the expected qualitative behavior. In particular, the absence of an endogenously restrictive monetary policy results in higher output and prices, as we would anticipate. Quantitatively, the effects are large, in that a non-responsive monetary policy suffices to eliminate most of the output effect of an oil price shock, particularly after the first 8-10 months. The conclusion that a substantial part of the real effects of oil price shocks is due to the monetary policy response helps explain why the effects of these shocks seems larger than can easily be explained in neoclassical (flexible-price) models.[20]

The AP simulation in Figure 4 results in modestly higher output and price responses than the Sims-Zha simulation. The differences in results between the two approaches occur largely because the AP simulation involves a negative short-run response in both the short and long term premia, and thus lower interest rates in the short run. Figure 5 repeats the AP simulation but with the response of the term premia shut off; that is, the funds rate is allowed to affect the macro variables only through its effects on the expectations component of market rates. This alternative simulation attributes somewhat less of the recession that follows an oil shock to the monetary policy response, but endogenous monetary policy still accounts for two-thirds to three-fourths of the total effect of the oil price shock on output.

For another exercise in counterfactual policy simulation, we examine the three episodes of major oil price shocks followed by recessions (OPEC I, OPEC II, and the Iraqi invasion of Kuwait). Figure 6 shows the results, focusing on the behavior of three key variables - output, the price level, and the funds rate - for three five-year periods surrounding the oil price shock episodes. Again three paths of each variable are shown in each panel. The line consisting of mixed dashes and dots shows the actual historical path of the variable. The solid line, marked "FF endogenous", shows the behavior of the system when 1) the oil variable is repeatedly shocked so that it traces out its actual historical path, 2) all other shocks in the system are set to zero, and 3) the funds rate is allowed to respond endogenously to changes in the oil variable and the induced changes in output, prices,

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[20] It should be emphasized that we are not arguing that the actual policies followed by the Fed in the face of oil shocks were necessarily sub-optimal; the usual output-inflation tradeoff is present in our simulations, and we have not attempted a welfare analysis.

and other variables. This scenario is intended to isolate the portion of each recession that resulted solely from the oil price shocks and the associated monetary policy response. Finally, the dashed line (marked "FF exogenous") describes the results of an exercise in which oil prices equal their historical values, all other shocks are shut off, and the nominal funds rate is arbitrarily fixed at a value close to its initial value in the period. (Term premia are allowed to respond to the oil price shock.) This last scenario eliminates the policy component of the oil price shock's effect, leaving only the direct effects of the change in oil prices on the economy.

Several observations can be made based on Figure 6. First, the 1974-75 decline in output is generally not well explained by the oil price shock. Examination of the pattern of shocks reveals that, instead, the major culprit was (non-oil) commodity prices. Commodity prices (not shown) rose very sharply prior to this recession and stimulated a sharp monetary policy response of their own, as can be seen by comparing the historical path of the funds rate with its path in the "FF endogenous" scenario, in which the commodity price shocks are set to zero. The "FF exogenous" scenario, in which the funds rate does not respond to either commodity price or oil price shocks, exhibits no recession at all, suggesting that endogenous monetary policy (responding to both oil price and commodity price shocks) did indeed play an important role in this episode.

The results for 1979-83 generally conform to the conventional wisdom. The decline in output through 1981 is well explained by the 1979 oil price shock and the response of monetary policy to that shock. After the beginning of 1982, the main source of output declines (according to this analysis) was the lagged effect of the autonomous tightening of monetary policy in late 1980 and 1981. Note that, if we exclude both the monetary policy reaction to the oil price shocks and the autonomous tightening of monetary policy by Fed Chairman Volcker (the "FF exogenous" scenario), the 1979-83 period exhibits only a modest slowdown, not a serious recession.

The experiment for 1988-92 similarly shows that shutting off the policy response to oil price shocks produces a higher path of output and prices than otherwise. Again, compare the solid line with the short-dashed line. One puzzle that does emerge is why the substantial easing of actual policy beginning in late 1990 did not move the actual path of output closer to the alternative policy scenario. Here, "special factors" such as credit problems may have been at work.

Oil, Money, and the Components of GDP

The application of our method for separating the direct effects of oil price shocks from the indirect effects operating through the monetary policy response comes to a rather strong conclusion: That the greatest portion of the impact of an oil price shock on the real economy is attributable to the central bank's response to the inflationary pressures engendered by the shock.

A check on the plausibility of this result, using a different identifying assumption and more disaggregated data, is provided by Figure 7. The figure is based on the same seven-variable VAR system employed above (real GDP, the GDP deflator, commodity prices, the Hamilton oil-market indicator, the funds rate, and short-term and long-term interest rates), with the funds rate excluded from the first four equations. To this system we added, one at a time and without feedback into the main system, eight components of GDP: consumption, producer durables expenditure, structures investment, inventory investment, residential investment, government purchases, exports, and imports.[21]

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[21] Except for consumption, which is available at the monthly frequency, monthly data for the GDP components were interpolated by state space

With these systems we conducted two experiments: First, we examined the impulse responses obtained when the Hamilton oil-price variable is shocked by 1%, with the federal funds rate allowed to respond endogenously. These responses are shown by the dashed lines in the figure. Second, we looked at the impulse responses to an exogenous federal funds rate shock whose maximum value is the same as the endogenous response of the funds rate in the first scenario (solid lines). We think of this exercise as a comparison of the total effect of an oil price shock (including the endogenous monetary response) with the effect of a monetary tightening of similar magnitude but not associated with an oil price shock. To the extent that the two responses are quantitatively similar, it seems reasonable to attribute most of the total effect of the oil price shock to the monetary policy response. Note however that we are using a different identification assumption here than above, i.e., we are implicitly assuming that the responses of the economy to endogenous and exogenous tightenings of monetary policy are the same.

The results of Figure 7 provide substantial support for the view that the monetary policy response is the dominant source of the real effects of an oil price shock. In particular, the response of output is virtually identical in the two scenarios, implying that it matters little for real economic outcomes whether a change in monetary policy of a given magnitude is preceded by an oil price shock or not. Very similar responses across the two experiments are also found at the disaggregated level, especially in equipment investment (PDE), inventory investment, and residential investment. Slightly greater effects for the scenario including the oil price shock are found for consumption and structures (although the latter difference is quantitatively small and

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methods; see Appendix A. Components are measured relative to the exponentiated trend of log real GDP, as calculated from the spline statistically insignificant). Government purchases responds more in the scenario that includes the oil price shock, for reasons that are not obvious.

The differences between the two scenarios are also instructive. The experiment which includes the initial oil price shock does show a substantial inflationary impact in the short run, which is some indication as to why the Fed responds so vigorously to such shocks. On the margin, the oil price shock also raises commodity prices and the long-term interest rate (presumably reflecting an increased risk premium), and it leads to increased real exports and decreased real imports (net of terms-of-trade effects). These responses are as expected.

Some Alternative Experiments

Although we have focused in this article on the role of systematic monetary policy in propagating oil price shocks, our methodology applies equally well to other sorts of driving shocks. As a further check on the plausibility of our method, we briefly consider two alternative cases: a shock to commodity prices and a shock to output.

A Commodity Price Shock

Figure 8 looks at the effects of a shock to the commodity price index in our original seven-variable system. As with the oil price shock studied in Figures 4 and 5, we consider three scenarios: First, in the base scenario we calculate the impulse responses resulting from a 1% innovation in commodity prices, allowing monetary policy (as represented by the federal funds rate) to respond in its normal way. Second, we examine the effects of shutting off the policy response using the Sims-Zha methodology described above. Finally, we shut off the

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regression described in footnote 9.

monetary policy response by means of our Anticipated Policy approach. For simplicity, in the AP simulation we set the responses of the term premia to zero (as we also did in Figure 5), so that both short-term and long-term nominal interest rates are effectively assumed not to respond to the shock to commodity prices.

Figure 8 shows that a 1% innovation in commodity prices has an ambiguous effect on output, with real GDP rising for the first year but declining thereafter. Prices rise unambiguously. One explanation for these results is that what we are labeling a positive shock to commodity prices is in fact a mixture of an adverse shock to aggregate supply and an expansionary shock to aggregate demand. The federal funds rate rises sharply in response to an increase in commodity prices, which we interpret as the Fed's response to the inflationary surge; other interest rates also rise. The oil price indicator responds very little in the short run to a commodity price innovation, which is reassuring in the sense that it confirms that the commodity and oil price variables are not excessively collinear.

Shutting down of the monetary policy response to the commodity price shock, by either the Sims-Zha or AP methods, leads to the expected response. Analogous to the case of oil price shocks, the recessionary impact of a commodity price shock is eliminated, and the inflationary impact is magnified, when monetary policy is not allowed to react. Although it may well be the case that the innovation in commodity prices is not a cleanly identified supply shock, neither is there any evidence that an increase in commodity prices depresses real activity in the absence of a monetary policy response.

An Output Shock

Figure 9 shows analogous results when the driving shock is a shock to output. Again we compute the impulse response functions for three cases: a base case in which monetary policy is allowed to respond in its normal way to the output shock, and two cases corresponding to the Sims-Zha and AP methods for shutting down the policy response. Also, again we assume no response of the term premia.

Admittedly, like a shock to commodity prices, an output shock does not have a clear a priori economic interpretation; it is an amalgam of various random factors affecting output, holding constant the other variables included in the system. However, based on Figure 9 it seems reasonable to interpret output shocks in this system as being dominated by aggregate demand fluctuations: A positive output shock is followed by increases in oil prices, commodity prices, and the general price level, as well as in all three interest rates.

Because the historical tendency of monetary policy is to "lean against the wind", when the normal policy response is shut off the effects of the aggregate demand shock (as we interpret the output shock) are all the greater. Figure 9 shows that, in the Sims-Zha and Anticipated Policy scenarios, the output effect of the shock is much more persistent and prices rise by more. Interest rates are lower, reflecting easier monetary policy. Note that, in this analysis, the Sims-Zha and AP approaches give almost identical results.

These experiments demonstrate that our methods for "shutting down" the response of monetary policy are applicable to, and give reasonable results for, shocks other than oil price shocks. It would be interesting to combine our methodology with identified VAR techniques that could give a sharper structural interpretation to innovations estimated in the "macro block" of the model.

Robustness and Stability

In this last portion of the paper we retain to our main theme, the role of systematic monetary policy in amplifying the real effects of oil price shocks, to consider the issues of robustness and stability of our results.

We did a variety of checks for robustness, some of which (such as the shutting down of the term premium response) have been alluded to already. To provide more systematic information, Table 1 reports some summary statistics from alternative specifications of our VAR system. We consider 1) three alternative oil-market indicators; 2) three alternative orderings of variables within the VAR; and 3) two alternative detrending assumptions. Results were also calculated for alternative measures of output (e.g., industrial production), alternative measures of the price level (e.g., the PCE deflator and the CPI), and alternative interest rate maturities. Since none of these variable substitutions had important effects on our findings, the latter results are omitted from the table to save space.

Briefly, line 1 of Table 1 reports results for the Hamilton oil indicator (our base specification), while lines 2 and 3 substitute the Mork and Hoover-Perez indicators, respectively (see Figure 2). Line 4 corresponds to an ordering of the federal funds after, rather than before the two open-market interest rates. Line 5 has the Hamilton oil-market indicator ordered first in the system, and line 6 orders the oil-market indicator third (after output and prices, but before the commodity price index). Line 7 is for a specification in which output and the long-rate term premium are not detrended, and line 8 reports results when all variables in the system are detrended by a cubic spline.

For each of the eight alternative specifications, Table 1 reports the effects on output and prices of a 1% oil price shock, under 1) a standard simulation, allowing for the endogenous response of policy to the oil price shock, 2) the "Sims-Zha" simulation, in which the funds rate is fixed at its baseline value, and 3) the "Anticipated Policy" simulation. Reported under the heading "Output" is the sum of the impulse response coefficients for output for the first 24 months after the oil price shock, which we employ as a measure of the output loss associated with the shock. Under the heading "Prices" we report the 24th impulse response coefficient for prices, divided by two, which can be interpreted as the increment in the annual average inflation rate over the first two years following the shock. Standard errors, calculated by Monte Carlo methods employing 500 draws per specification, are shown in parentheses. Also shown are the differences between the baseline (endogenous policy) specification and the results obtained under the Sims-Zha and Anticipated Policy assumptions, again with the associated standard errors.

The point estimates reported in Table 1 are consistent with what we saw earlier (in Figures 4 and 5, for example). In particular, for all specifications the baseline simulations show that an oil price shock depresses output and increases inflation, by magnitudes that are reasonably comparable across specifications. The Sims-Zha method of shutting off the monetary policy response tends to eliminate all or most of the negative effect of the oil price shock and, in almost all cases, increases the inflationary impact, as expected. The Anticipated Policy method of eliminating the policy response has even larger effects, fully eliminating the recessionary impact of the oil price shock in all cases. The standard errors for most entries in Table 1 are quite high[22], reflecting the fact that the standard error bands on the impulse response functions spread out rather quickly. However, the differences in the output responses between the baseline and alternative simulations

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[22] This is particularly the case for the AP simulations, which appears to reflect in part the uncertainty associated with the long-term interest rate forecasts required by this method.

are statistically significant in a number of cases, particularly when the policy response is shut down by the Sims-Zha method.[23]

In general, our results appear to be qualitatively robust, although not always precisely estimated. In particular, a view which ascribes most or even all of the real effects of an oil price shock to the endogenous monetary response does not seem inconsistent with the data.

Stability of the Results: The Role of a Changing Policy Response

A second important issue, besides robustness of the results, is subsample stability. We take this issue up here not only as a qualification of our results, but also because it appears that at least some of the observed instabilities of our system can be given an interesting economic interpretation. Indeed, as we will see, variations in the Federal Reserve's reaction function have something of the flavor of a "natural experiment", which may help improve the identification of the endogenous policy effect.

Some tests of the stability of the coefficients in our seven-variable base VAR, with lag lengths chosen by BIC, are reported in Table 2. For simplicity, the funds rate is allowed to enter all equations. Panel A gives asymptotic p-values for the hypothesis that the coefficients of the variable listed in the column heading, together with the regression constant term, are stable over the sample period in the equation given by the row heading. Thus, for example, Panel A shows that the hypothesis that the coefficients on the price level in the oil

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[23] We also considered alternative models estimated with twelve lags, rather than the seven chosen by AIC. In this case, the finding that shutting off the monetary policy response eliminates the effect of the oil shock obtains at short horizons but not at the 24-month horizon. The reason is that, with 12 lags, the funds rate is estimated to rise in response to an oil price shock, but then to fall quickly below trend. Our alternative policy, which assumes no response throughout, is thus

equation are stable over the entire sample can be rejected at the 0.016 confidence level. In a similar format, Panel B of Table 2 tests each set of coefficients for stability across the two halves of the sample. The latter tests are included because, unlike the tests of Panel A, they are robust to heteroskedasticity.

There is substantial evidence of instability in the VAR system. The equation for the price level is clearly quite unstable, with p-values near zero for most blocks of coefficients. Panel A of Table 2 also suggests that there is instability in the coefficients relating the funds rate and the short-term and long-term interest rates. However, stability of the output equation cannot be rejected.

Interestingly, it appears that at least some of the instability in the relationship between oil and the macroeconomy may be due to a changing policy response. Figure 10 illustrates this point. Each panel of the figure shows the responses to an oil price shock of output, prices, and the federal funds rate, as implied by systems estimated over the whole sample and over each of the three decades of the sample (1966-75, 1976-85, and 1986-95).

The full-sample estimates of the effects of an oil price shock are as we have seen above. Note, though, how the impulse responses vary over the subsamples (keeping in mind that ten-year subsamples are short ones for this purpose). In particular, the magnitude of the output response across different periods tends to be inversely related to that of the federal funds rate response: The sharpest decline in output occurs during the 1976-85 period, which is also the time of the strongest response of the funds rate. The aggressive response of monetary policy during this period presumably reflects the emphasis on inflation fighting during the Volcker regime, relative to the more

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not effectively easier than the baseline policy over the 24-month horizon.

accommodationist stance of the earlier period. The output response is weakest in the 1986-95 subsample, during which there is virtually no response in the funds rate. The atypical estimated behavior of the funds rate during the post-1986 sample is no doubt dominated by the one major oil shock episode of that period, the 1990 increase in oil prices, which was followed by an easing of monetary policy---the result, we suspect, of confounding factors, such as the weakening of balance sheets in the financial sector and the decline in consumer confidence that occurred at about the same time. In any case, the subsample evidence appears quite consistent with the view that the reduced-form impact of oil on the economy depends significantly on the monetary policy response.

Conclusion

This paper offers both a methodological and a substantive contribution. Methodologically, we have shown how to modify standard VAR systems to permit simulations of the economy under alternative endogenous policies. Since our focus here has been on quantifying the economic impact of historical feedback policies, the alternative policy we considered in this paper was very simple; a virtue of our approach is that it would not be difficult to extend the analysis to consider more interesting alternatives, such as "Taylor rules", for example. It would also be interesting to compare our results with those obtained from alternative (possibly more structural) methodologies.

Substantively, our results suggest that an important part of the effect of oil price shocks on the economy results not from the change in oil prices *per se*, but from the resulting tightening of monetary policy. This finding may help explain the apparently large effects of oil price changes found by Hamilton (1983) and many others.

Appendix A. Interpolation of Monthly NIPA Variables

In this paper we use interpolated monthly values of GDP, the components of GDP, and the GDP deflator. This appendix describes the interpolation process. The data and additional detailed estimation results are available on a distribution diskette from the authors.

We designate quarterly series by capital letters and monthly series by lower-case letters. Quarters are indexed by $T = 1, 2, \ldots, N$, and months by $t = 1, 2, \ldots, n$. Let Q_T be an (observed) quarterly variable which is to be interpolated, for example real GDP, and let S_T be a scaling variable such that $Y_T \equiv Q_T / S_T$ is non-trending. Similarly, let q_t be the (unobserved) monthly series corresponding to Q_T (e.g., monthly real GDP), and let s_t be a scaling variable such that $y_t \equiv q_t / s_t$ is non-trending. Q_T and q_t are related by the identity

$$Q_T = \tfrac{1}{3}\sum_{i=0}^{2} q_{3T-i}$$

and hence Y_T and y_t are related by the identity

$$Y_T = \tfrac{1}{3}\sum_{i=0}^{2} y_{3T-i}\left(s_{3T-i} / S_T \right)$$

Interpolation is by state space methods. Suppose that we have available a vector of (observable) interpolator variables at the monthly level, x_t, for example, industrial production is a monthly variable that provides information about within-quarter movements of real GDP.

We assume that the unobserved monthly variable y_t is related to the interpolator variables according to the "causal" or "transition" equation

$$y_t = x_t'\beta + u_t, \text{ where}$$

$$u_t = \rho u_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim N(0,\sigma^2).$$

In our application, all transition equations included a constant term. When one or more of the interpolators became available mid-sample, all interpolators (including the constant term) were interacted with dummy variables and the possibility of a shift in the value of σ^2 was allowed for.

Let z_t be a monthly "indicator" variable which equals $Y_{t/3}$ in the third month of each quarter and is zero otherwise. Then the "indicator" or "measurement" equations are given by

$$z_t = \tfrac{1}{3}\sum_{i=0}^{2} y_{t-i}\left({}^{S_{t-i}}\!/_{S_{3t}}\right), \quad t = 3, 6, 9, 12, \ldots, n$$

$$z_t = 0 \times y_t, \quad \text{otherwise}$$

The parameters β, ρ, and σ^2 were estimated by maximum likelihood assuming Gaussian errors. Conditional on the estimated parameters, let $y_{t/\tau} = E_\tau y_t$. The interpolated values, given the full information set, are thus given by

$$q_{t/n} = y_{t/n} s_t$$

This method is similar to that proposed by Chow and Lin (1971), although it allows for a more general treatment of the serial correlation in u_t.

To estimate the accuracy of the interpolation, we can use R^2 measures of fit. In levels the measure of fit is

$$R^2_{levels} = \text{var}(y^2_{t/n}) \Big/ \text{var}(y^2_t)$$

and in differences it is

$$R^2_{diffs} = \text{var}(\Delta y^2_{t/n}) \Big/ \text{var}(\Delta y^2_t)$$

Listed below are the quarterly series that were interpolated, the corresponding monthly interpolators, and the measures of fit (corresponding to the scaled values of the variables). Variables are listed by their CITIBASE mnemonics, which are defined in Appendix B. The scale variables used for real flow variables were personal consumption expenditures (GMCQ), at both the quarterly and monthly levels. The PCE deflator (GMDC), monthly and quarterly, was used as the scale variable in the interpolation of the GDP deflator.

Consumption data (disaggregated to durables, nondurables, and services) exist at a monthly frequency and thus did not have to be interpolated. Monthly GDP is calculated as the sum of the monthly GDP components (we ignore the slight deviations from that relationship caused by chain-weighting).

INTERPOLATORS AND GOODNESS OF FIT

Quarterly series interpolated (Q)	Monthly interpolators (z)	R^2_{levels}	R^2_{diffs}
GDPD	PWFSA PWFPSA PWIMSA PWCMSA	0.997	0.489
GIPDQ	IPE MSNDF ($t \geq 1968:1$) MSMAE ($t \geq 1968:1$)	0.999	0.775
GIRQ	IPIC MMCON CONFRC HSF	0.999	0.894
GISQ	IPIC MMCON CONIC CONCC	0.999	0.807
GVQ	Δ IVMFGQ Δ IVRRQ Δ IVWRQ	0.970	0.929
GGEQ	CONQC IPH FBO ($t \geq 1968:1$)	0.999	0.633
GEXQ	FSE602 FTE71 FTEF	0.999	0.919
GIMQ	FSM612 FTM333 FTM732	0.998	0.861

The R^2's suggest that the interpolators explain nearly all of the variability in the levels of the scaled series. With the exceptions of government consumption and the GDP deflator, they also explain nearly all of the implied month-to-month variation in the series.

Appendix B. List of data series used

CITIBASE mnemonic	Variable definition
Quarterly series	
GDPD	GDP deflator (92=100)
GEXQ	Exports of goods and services (92$)
GGEQ	Government consumption expenditures and gross investment (92$)
GIMQ	Imports of goods and ser vices (92$)
GIPDQ	Investment, producers' durables (92$)
GIRQ	Investment, residential (92$)
GISQ	Investment, nonresidential structures (92$)
GVQ	Change in business inventories, total (92$)
Monthly series	
CONCC	Construction put in place (commercial); 87$, SAAR
CONFRC	Construction put in place (private residential building); 87$, SAAR
CONIC	Construction put in place (industrial building); 87$, SAAR
CONCQ	Construction put in place (public); 87$, SAAR
FBO	Federal budget, net outlay, NSA; deflated by interpolated government purchases deflator, GDFGEC; seasonally adjusted by the authors, by means of a regression on monthly dummies
FSE602	Exports, excluding military aid shipments, SA, deflated by the PPI for finished goods, PWF
FSM612	General imports, SA, deflated by the PPI for finished goods, PWF
FTE71	U.S. merchandise exports, nonelectrical machinery, SA, deflated by the PPI for machinery and equipment, PWME
FTEF	U.S. merchandise exports, agricultural products, SA, deflated by the PPI for farm products, processed foods, and feeds, PWFPF
FTM333	U.S. merchandise imports, petroleum and petroleum products, SA, deflated by PPI for crude petroleum, PW561
FTM732	U.S. merchandise imports, automobiles and parts, SA, deflated by PPI for motor vehicles and equipment, PWAUTO
FYFF	Federal Funds Rats % Per Annum, NSA
FYGM3	Interest Rats, U.S. Treasury Bills, Seconday Market, 3 month, % PER ANN, NSA
FYGT5	Interest Rate: U.S. Treasury Constant Maturities, 5 Year, % Per Ann, NSA
FYGT10	Interest Rate: U.S. Treasury Constant Maturities, 10 Year, % Per Ann, NSA
GMCQ	Personal Consumption Expenditures (Chained), Total SAAR, Billions of $92
GMCDQ	Personal Consumption Expenditures (Chained), Durables

	SAAR, Billions of $92
GMCNQ	Personal Consumption Expenditures (Chained), NonDur. SAAR, Billions of $92
GMCSQ	Personal Consumption Expenditures (Chained), Services SAAR, Billions of $92
GMDC	Implicit Price Deflator, PCE (1987=100)
HSF	Housing starts, total, new private housing units, SAAR
IP	Industrial Production Index, Total 87=100, SA
IPE	Industrial production (business equipment); 87=100, SA
IPH	Industrial production (defense and space equipment); 87=100, SA
IPIC	Industrial production (construction supplies); 87=100, SA
IVMFGQ	Inventories, business, manufacturing, 92$, SA
IVRRQ	Manufacturing and trade inventories: retail trade, 92$, SA
IVWRQ	Manufacturing and trade inventories: merchant wholesalers, 92$, SA
MMCON	Manufacturing shipments (construction materials and supplies), SA, deflated by the PPI for materials and components for manufacturing, PWIMSM
MSMAE	Manufacturing shipments (machinery and equipment), SA, deflated by the PPI for machinery and equipment
MSNDF	Manufacturing shipments (capital goods industries, nondefense), SA, deflated by the PPI for capital equipment, PWFP
PSCCOM	Spot Market Price Index: BLS and CRB: All Commodities NSA (67=100)
PUNEW	CPI-U: All Items, SA (82-84=100)
PW561	PPI, Crude Petroleum, NSA(82=100)
PWFPSA	PPI, capital equipment, SA (82=100)
PWFSA	PPI, finished goods, SA (82=100)
PWIMSA	PPI, intermediate materials, supplies, and components, SA (82=100)
PWCMSA	PPI, crude materials, SA (82=100)

Table 1. Robustness of results to alternative specifications

Specification	Baseline		Sims-Zha		Anticipated policy	
	Output	Prices	Output	Prices	Output	Prices
Oil market indicator						
1. Hamilton	-0.308	0.009	0.133	0.013	0.179	0.016
	(0.334)	(0.014)	(0.361)	(0.015)	(0.565)	(0.022)
Differences			0.440	0.004	0.486	0.007
			(0.156)	(0.006)	(0.460)	(0.018)
2. Mork	-0.146	0.002	0.047	0.004	0.048	0.006
	(0.237)	(0.010)	(0.245)	(0.010)	(0.507)	(0.027)
Differences			0.193	0.002	0.194	0.004
			(0.065)	(0.003)	(0.449)	(0.026)
3. Hoover-Perez	-0.590	0.013	0.312	0.025	0.103	0.038
	(0.444)	(0.017)	(0.540)	(0.010)	(1.030)	(0.047)
Differences			0.901	0.012	0.693	0.025
			(0.355)	(0.013)	(0.920)	(0.045)
Ordering						
4. Fed funds last	-0.304	0.007	-0.079	0.009	0.237	0.015
	(0.356)	(0.015)	(0.371)	(0.015)	(0.682)	(0.024)
Differences			0.225	0.001	0.541	0.008
			(0.116)	(0.004)	(0.560)	(0.020)
5. Oil price first	-0.430	0.006	-0.111	0.009	0.012	0.011
	(0.391)	(0.015)	(0.407)	(0.015)	(0.463)	(0.017)
Differences			0.319	0.003	0.441	0.006
			(0.111)	(0.004)	(0.249)	(0.008)
6. Oil price third	-0.335	0.006	0.037	0.010	0.180	0.012
	(0.331)	(0.014)	(0.360)	(0.015)	(0.525)	(0.017)
Differences			0.373	0.004	0.515	0.006
			(0.145)	(0.006)	(0.404)	(0.011)
Detrending						
7. No detrending	-0.065	0.006	0.195	0.008	0.349	0.008
	(0.360)	(0.015)	(0.368)	(0.015)	(0.571)	(0.023)
Differences			0.260	0.001	0.414	0.002
			(0.076)	(0.003)	(0.439)	(0.018)
8. All variables detrended	-0.334	0.009	-0.034	0.000	0.330	-0.009
	(0.323)	(0.007)	(0.323)	(0.006)	(0.499)	(0.015)
Differences			0.300	-0.009	0.664	-0.018
			(0.099)	(0.002)	(0.458)	(0.014)

(Table 1 continued)

Notes: For eight different specifications (see text), and for the baseline, Sims-Zha, and Anticipated Policy assumptions regarding the response of monetary policy to an oil shock, the table shows the sum of impulse response coefficients over 24 months for output and the annualized inflation rate (the impulse response coefficient on month 24 divided by two), resulting from a 1% shock to oil prices. Standard errors are in parentheses. Also shown are the differences in output and inflation effects from the Sims-Zha and AP simulations, relative to the baseline simulation, with standard errors. Estimates and standard errors are constructed by Monte Carlo methods, with 500 draws employed for each simulation.

Table 2. Tests for Stability of the Coefficients in the VAR

A. Quandt Tests

Asymptotic p-values

	Regressor						
Equation	Oil	Output	Prices	PComm	Funds	RShort	RLong
Oil	0.000	0.004	0.016	0.004	0.188	0.267	0.461
Output	0.439	0.926	0.699	0.362	0.338	0.607	0.187
Prices	0.000	0.003	0.000	0.000	0.005	0.014	0.002
Pcomm	0.002	0.177	0.129	0.000	0.001	0.170	0.045
Funds	0.012	0.042	0.041	0.483	0.000	0.001	0.000
Rshort	0.152	0.132	0.017	0.092	0.128	0.072	0.000
Rlong	0.644	0.116	0.782	0.459	0.004	0.001	0.609

B. Chow Split-Sample Tests

Asymptotic p-values

	Regressor						
Equation	Oil	Output	Prices	PComm	Funds	RShort	RLong
Oil	0.882	0.651	0.233	0.422	0.259	0.181	0.667
Output	0.757	0.633	0.591	0.303	0.115	0.919	0.839
Prices	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Pcomm	0.004	0.131	0.080	0.127	0.109	0.018	0.007
Funds	0.814	0.159	0.125	0.123	0.048	0.099	0.030
Rshort	0.809	0.359	0.187	0.335	0.557	0.152	0.031
Rlong	0.254	0.215	0.388	0.658	0.507	0.002	0.581

Notes: The table shows asymptotic p-values for tests of the stability of the coefficients of the regressors shown in the column heading, together with the regression constant term, in the equation given by the row heading. The funds rate is allowed to enter all equations. Lag-lengths were chosen by BIC. First differences for all variables except Oil, which by construction is the difference of various oil prices. Panel A is based on Wald versions of the Quandt (1960) test over the middle 70% of the sample. The p-values are computed using the approximation due to Hansen (1997). Panel B is based on heteroskedasticity-robust Wald tests for breaks at the sample midpoint.

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Figure 1: NBER Recessions, The Federal Funds Rate, and Oil Prices

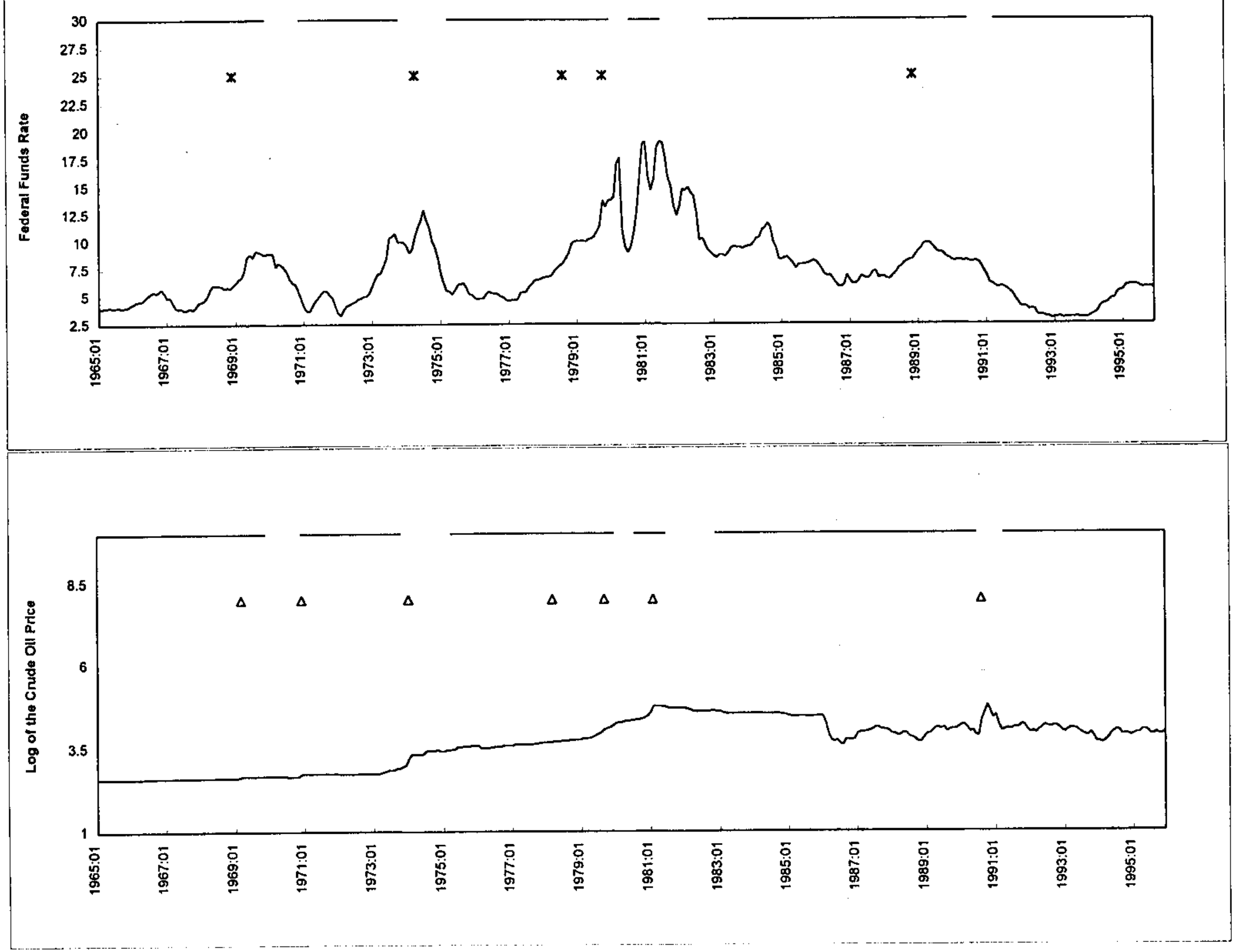


Figure 2: Response to a 1 Percent Oil Price Shock

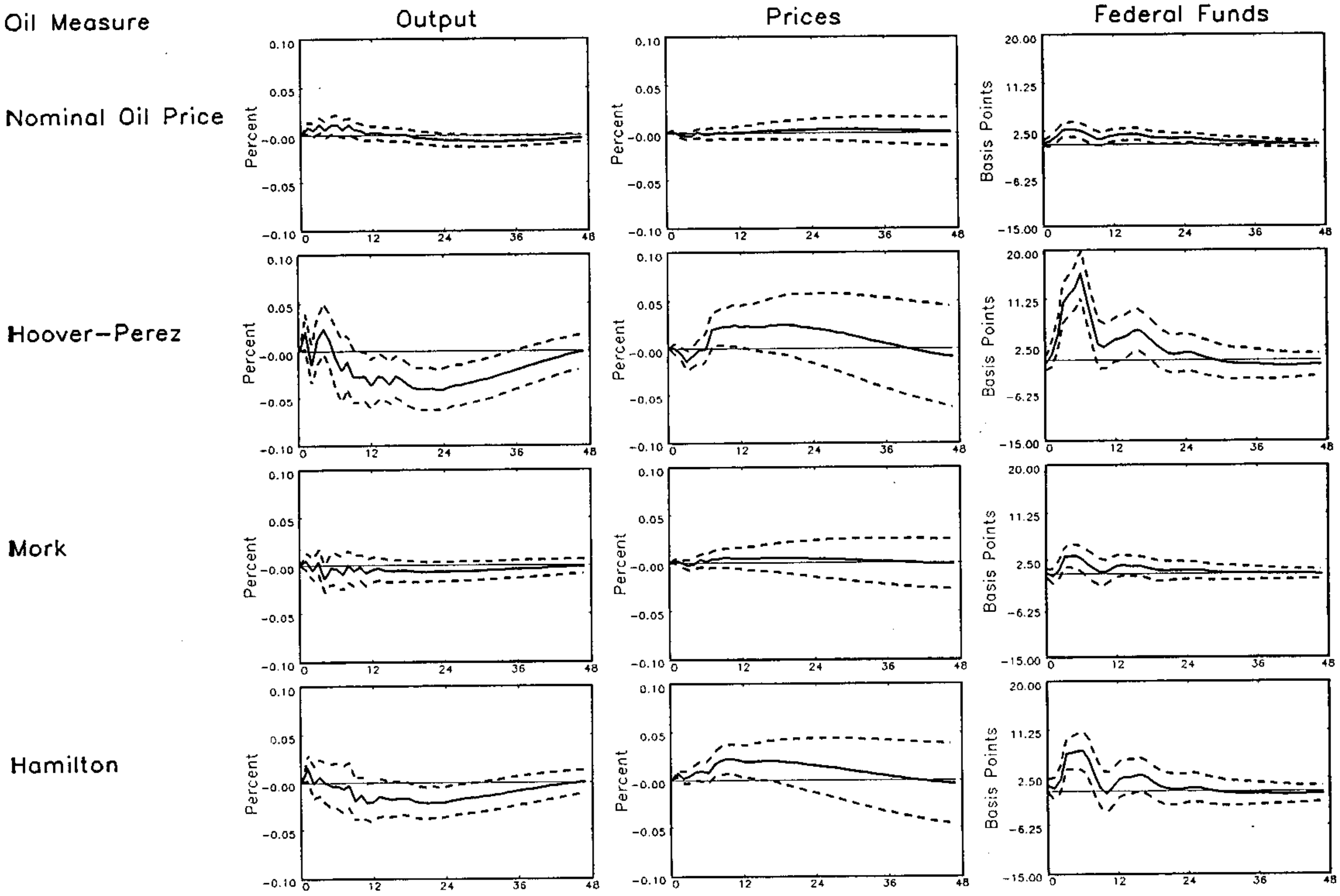


Figure 3: Responses to a Monetary Policy Shock in 7 Variable System

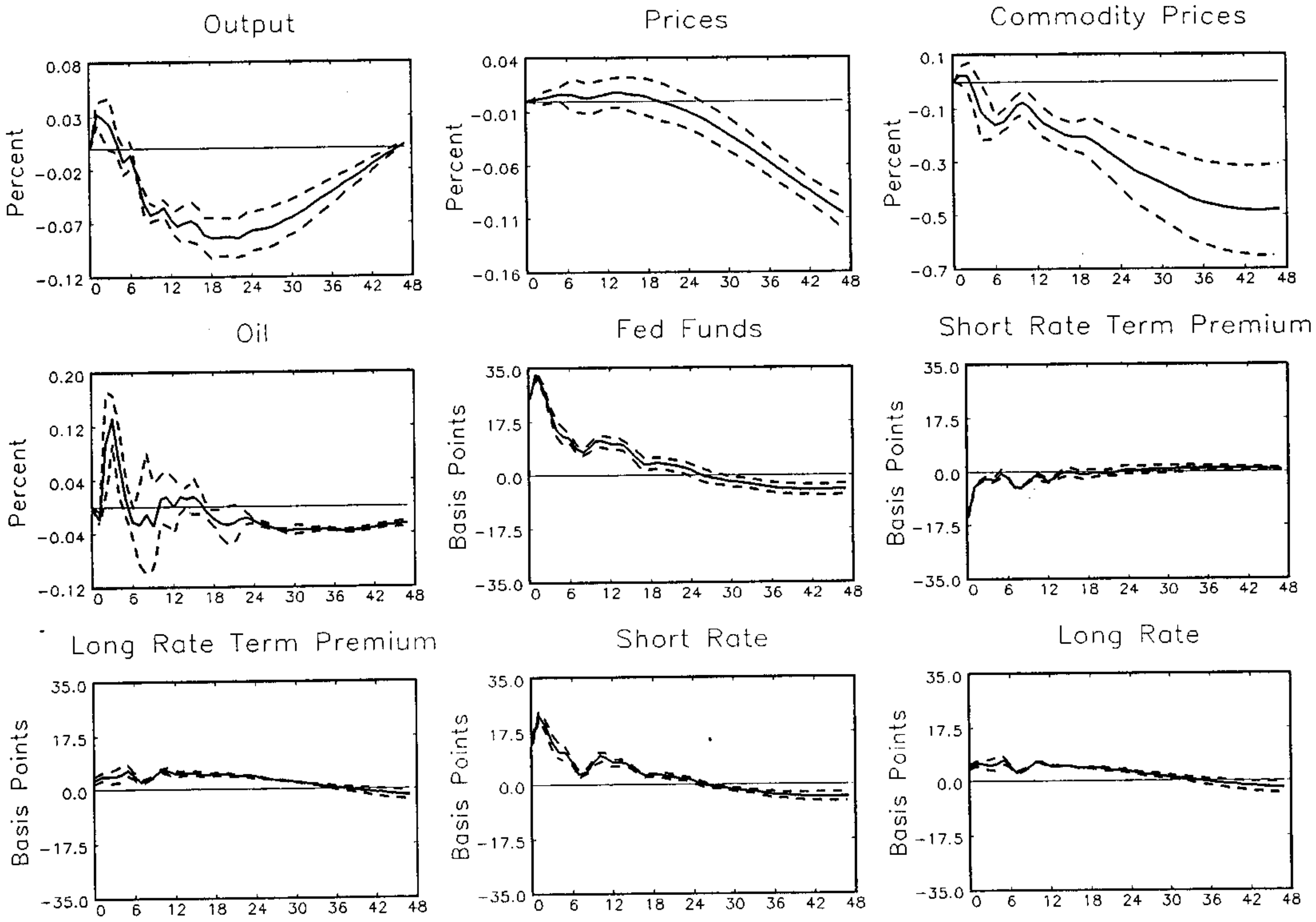


Figure 4: Responses to an Oil Shock (Hamilton) in 7 Variable Systems

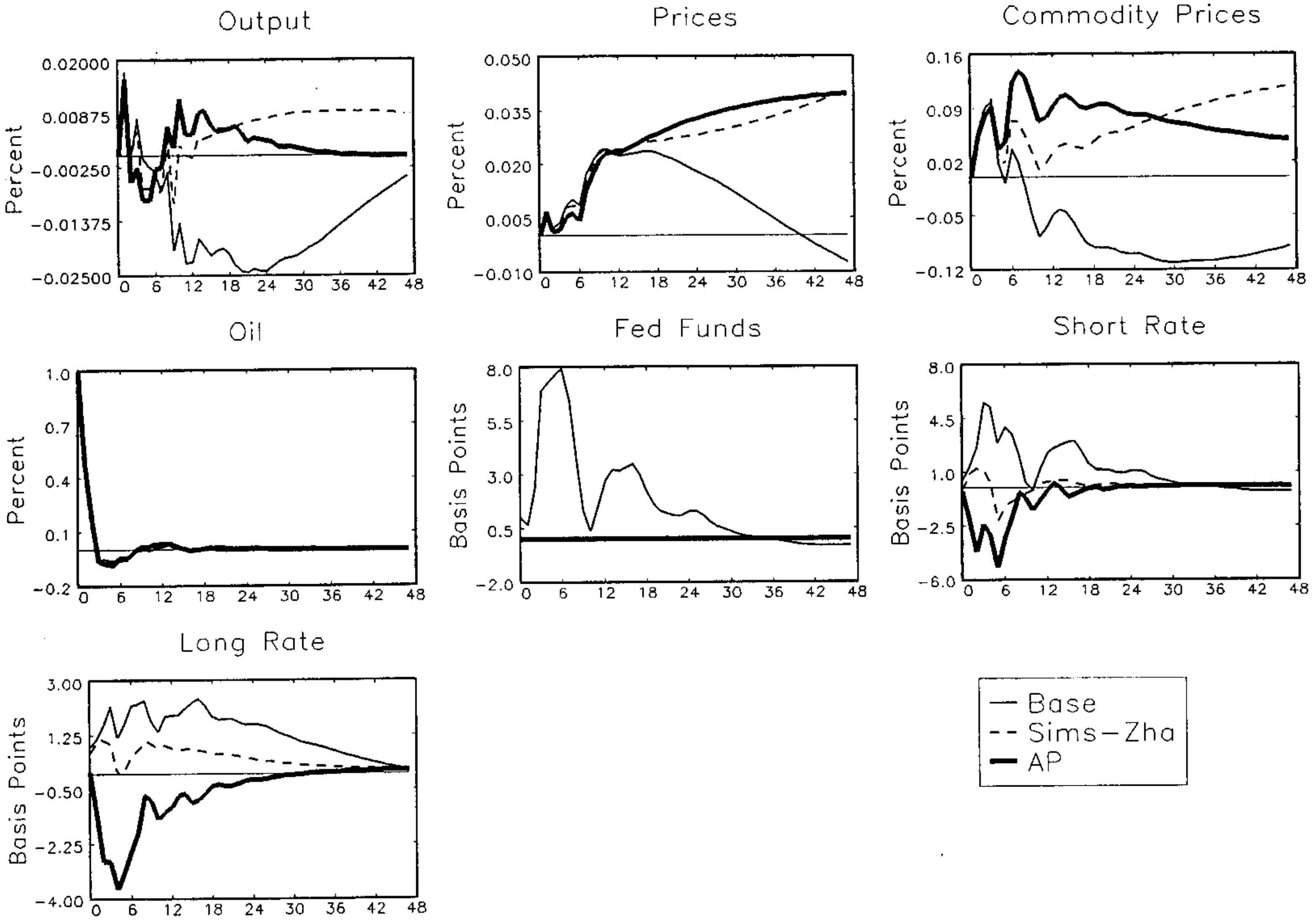
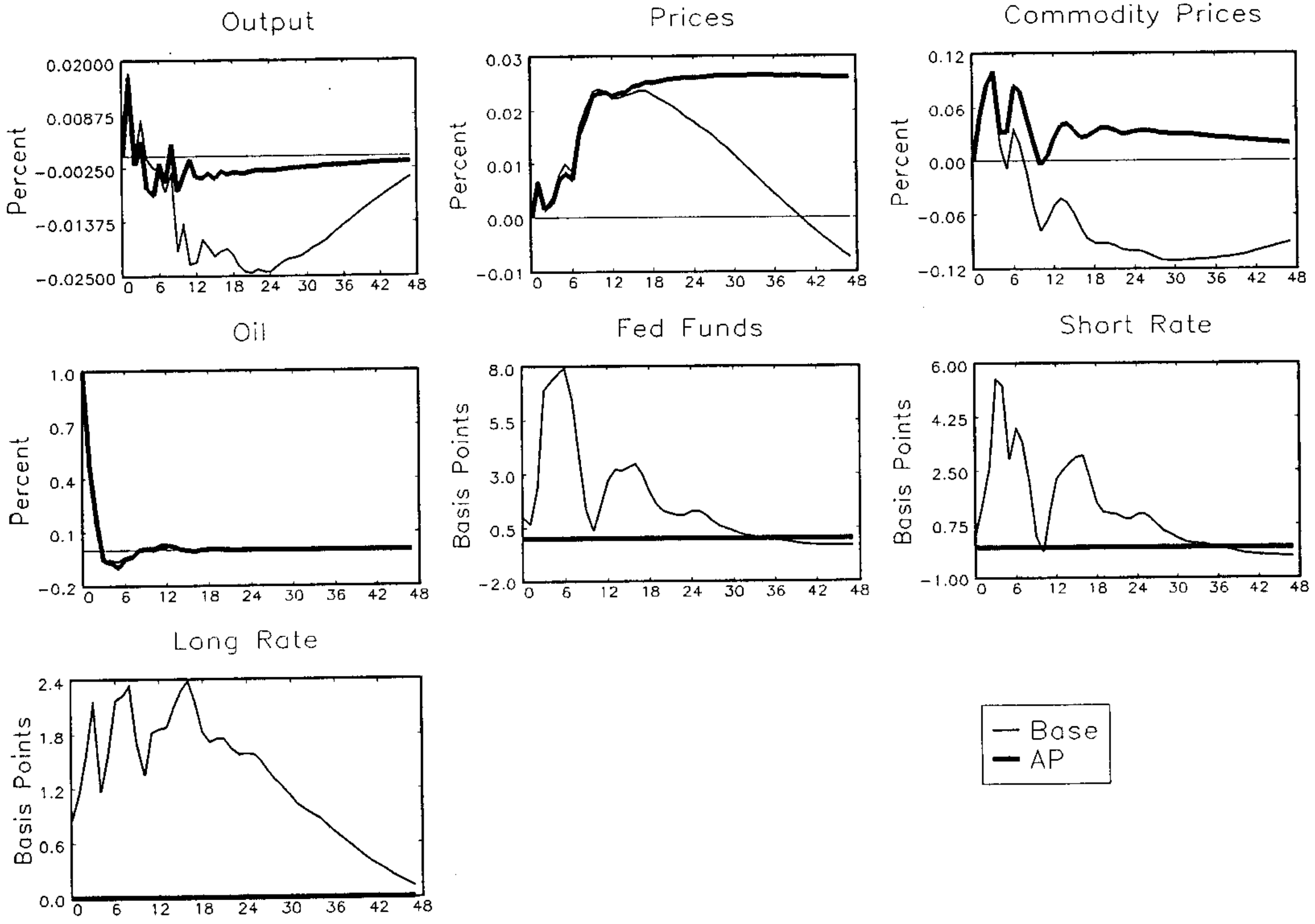


Figure 5: Responses to an Oil Shock (Hamilton) in 7 Variable Systems

No Term Premium Response


Output

Prices

Commodity Prices

Oil

Fed Funds

Short Rate

Long Rate

Figure 6: Simulations of Historical Oil Price Shocks

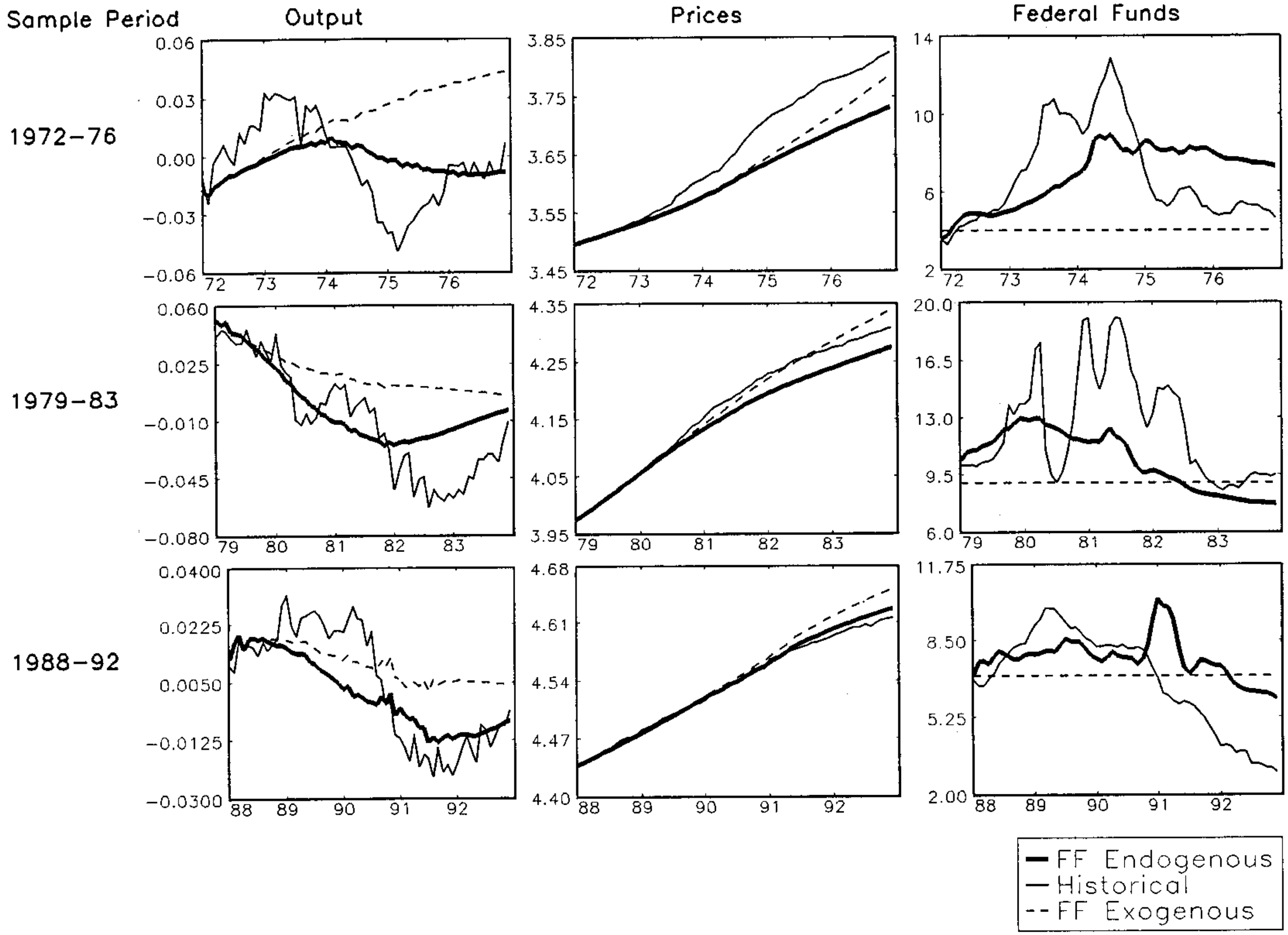


Figure 7: Sectoral Responses to Oil Price and Monetary Policy Shocks

Solid=Monetary Policy Shock; Dashes=Oil Price Shock

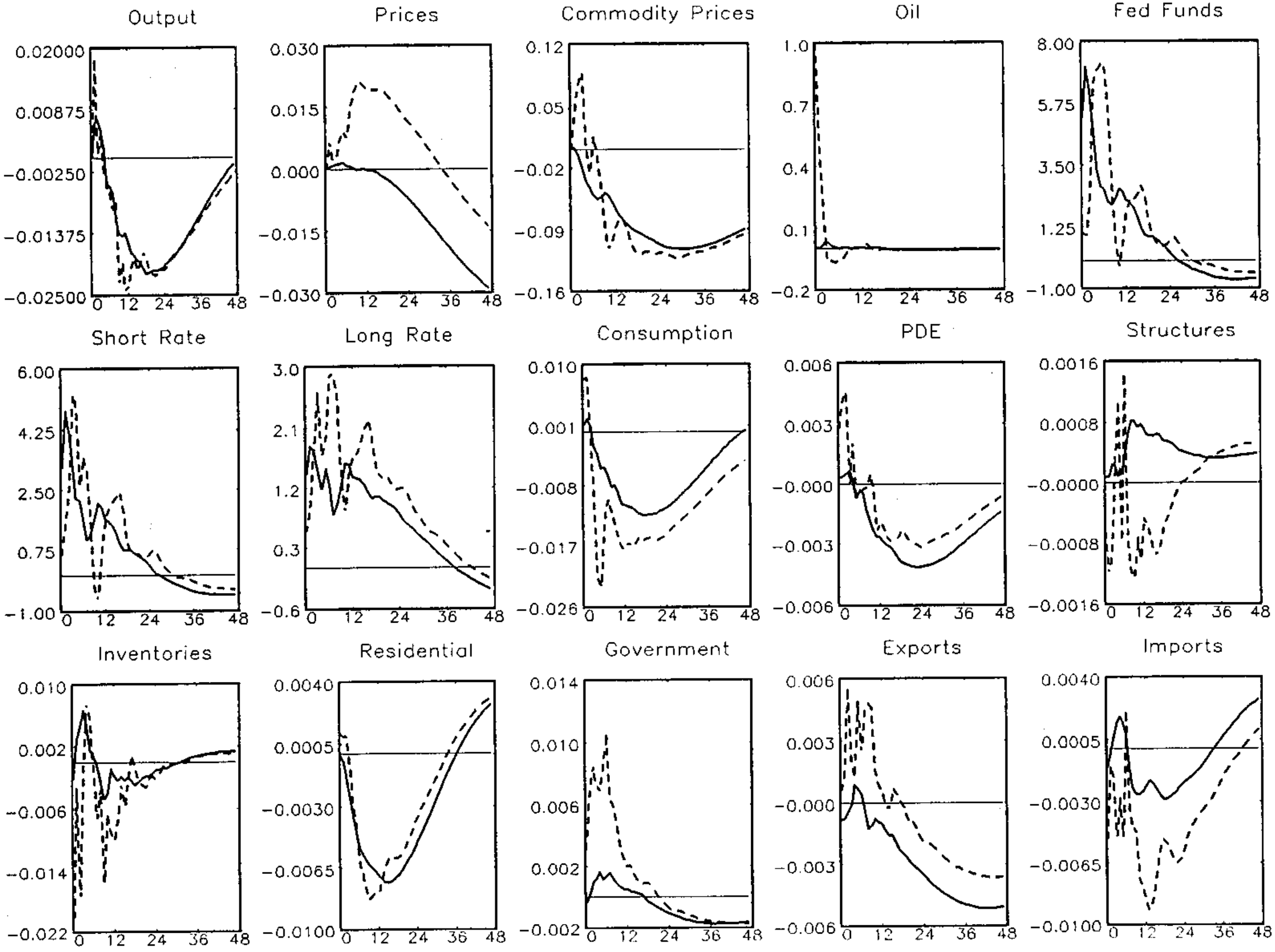


Figure 8: Responses to a Commodity Price Shock in 7 Variable Systems

No Term Premium Response

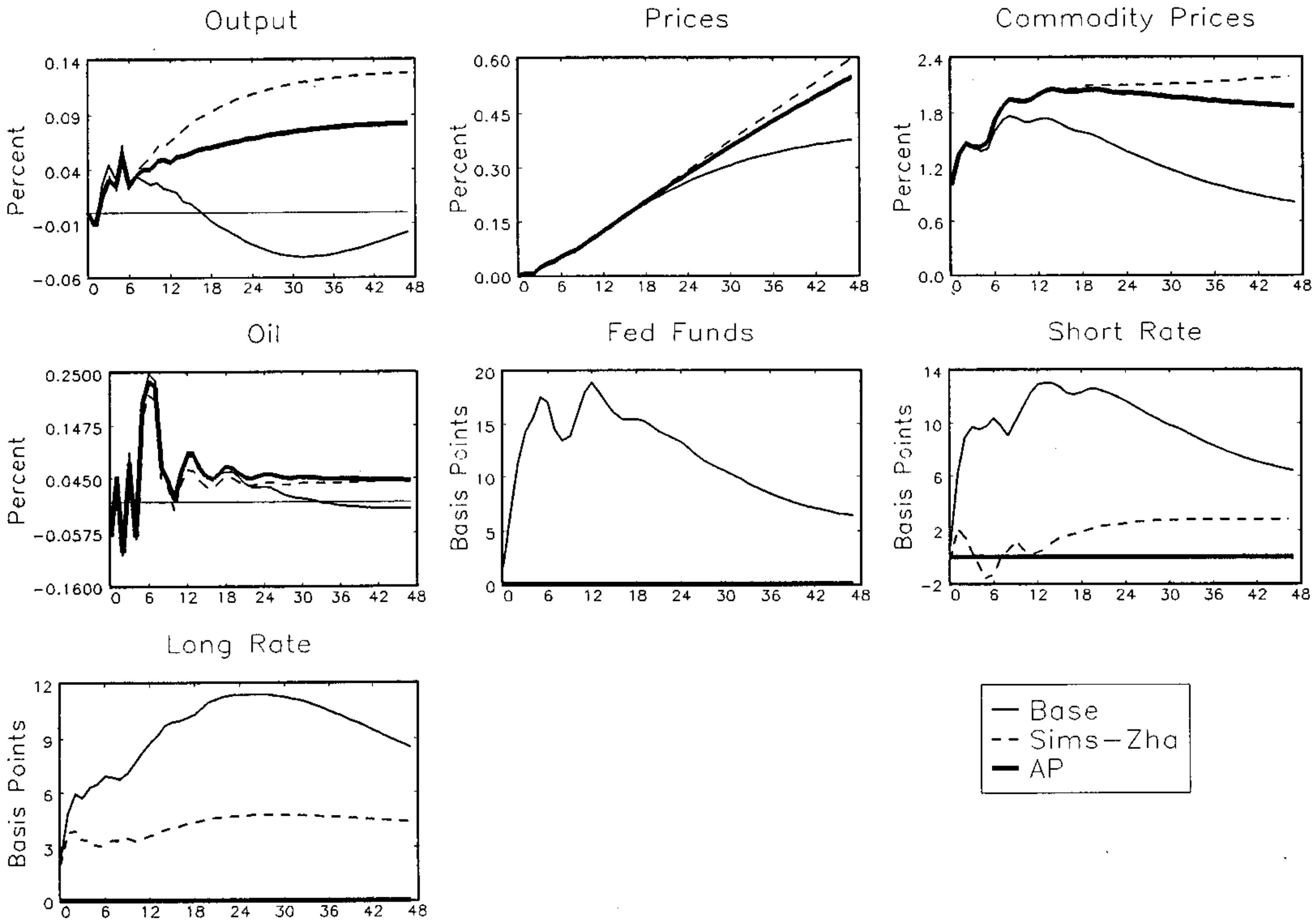


Figure 9: Responses to an Output Shock in 7 Variable Systems

No Term Premium Response

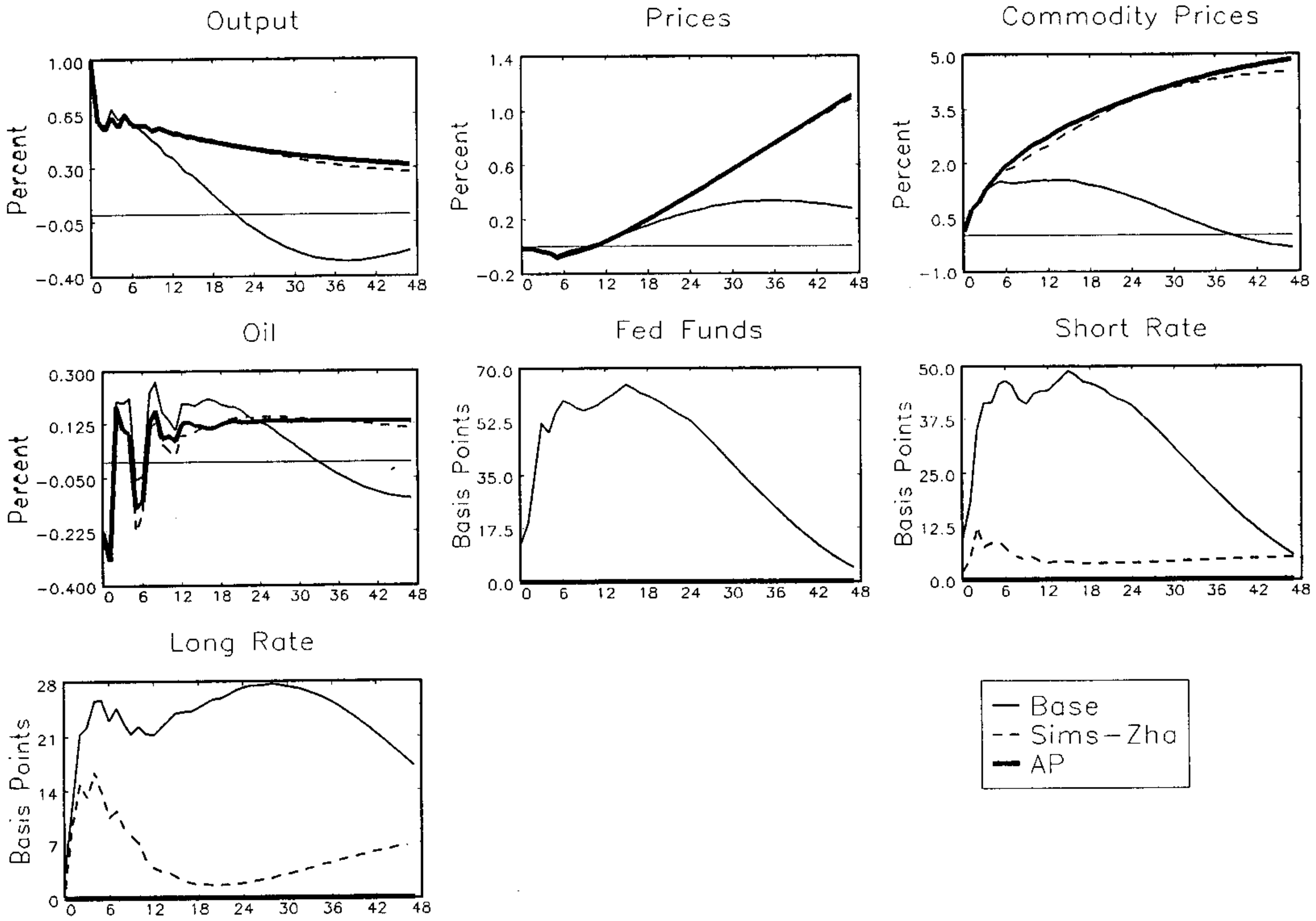
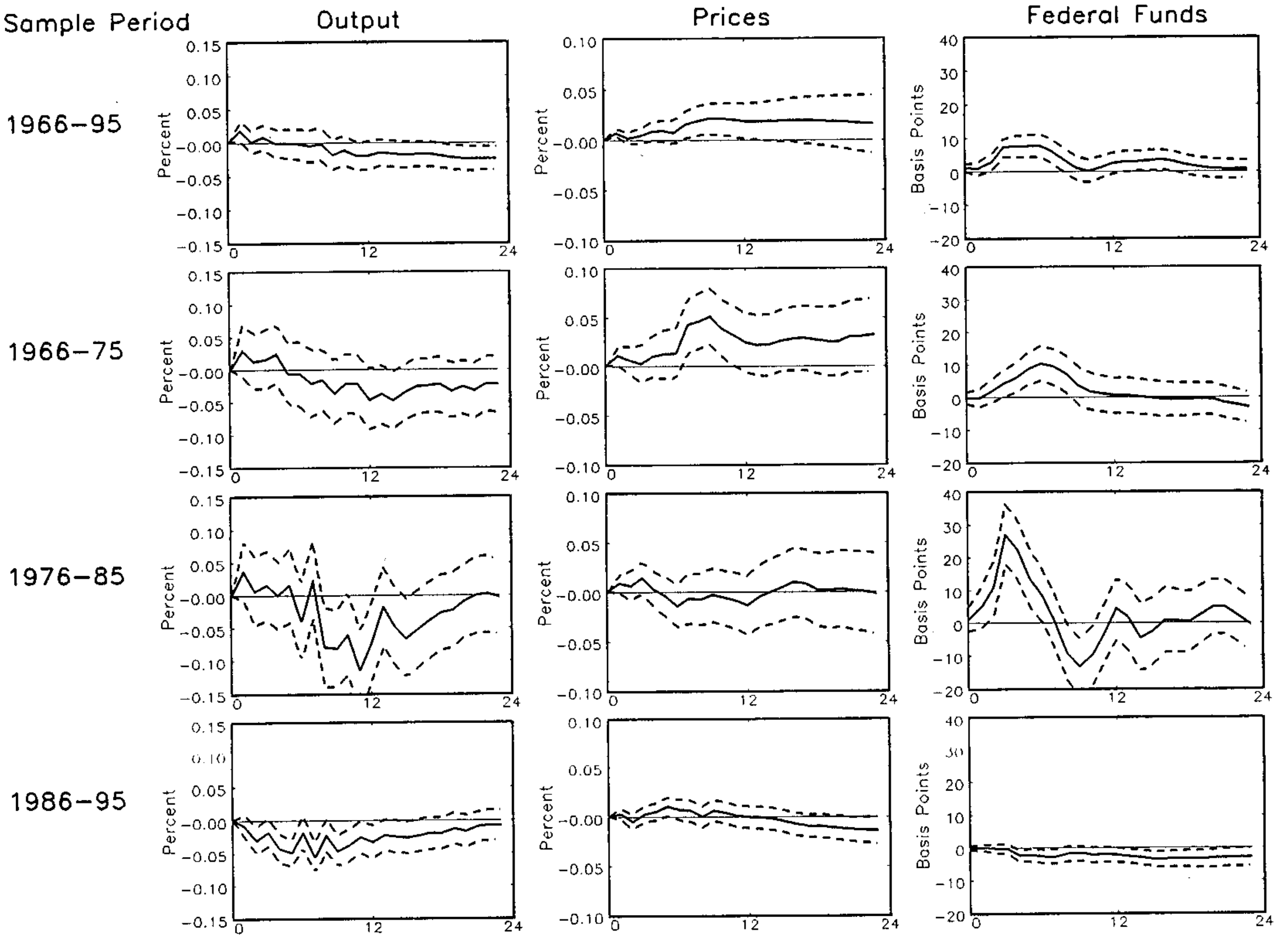


Figure 10: Response to a 1 Percent Oil Price Shock



Notes to figures:

Figure 1:

Source: See Appendix B for data. Shaded areas represent contractions as identified by the NBER business cycle dating committee. Stars (top panel) indicate Romer and Romer (1989) dates, triangles (bottom panel) indicate dates of oil-market disruptions as identified by Hoover and Perez (1994).

Figure 2:

Source: Based on authors' VARs, including real GDP, the GDP deflator, a commodity price index, one of the four indicators of oil-market conditions listed in the left-hand column, and the federal funds rate, for the sample period 1965-1995. See Appendix B for data descriptions. Solid lines show impulse response functions over a 48-month horizon, dashed lines show one-standard-error bands.

Figure 3:

Source: Based on authors' VARs, including real GDP, the GDP deflator, a commodity price index, the Hamilton oil-price indicator, the federal funds rate, and three-month and ten-year interest rates on government securities, for the sample period 1965-1995. See Appendix B for data descriptions. Solid lines show impulse response functions over a 48-month horizon, dashed lines show one-standard-error bands.

Figure 4:

Source: Based on authors' VARs for the sample period 1965-1995. See Appendix B for data descriptions. Solid lines show the base case, which includes the endogenous response of monetary policy to the oil price shock. The Sims-Zha and Anticipated Policy scenarios show the estimated effects of an oil price shock when the normal response of monetary policy is eliminated.

Figure 5:

See notes to Figure 4. The system compares the base case, in which the effects of the endogenous response of monetary policy to an oil price shock are included, to a hypothetical scenario in which monetary policy is anticipated not to react to the oil price shock. We assume no response of term premia as well as of the expectational components of short-term and long-term interest rates, so that effectively short-term and long-term nominal interest rates do not respond to the oil price shock.

Figure 6:

Source: Authors' calculations. For three historical episodes, the figure compares the actual behavior of output, prices, and the federal funds rate to scenarios in which (1) all shocks but oil price shocks are shut off, and monetary policy is allowed to respond endogenously ("FF endogenous"); and (2) all non-oil shocks are shut off, and the funds rate is set equal to a fixed, exogenous value ("FF endogenous").

Figure 7:

Source: Authors' calculations, using the basic 7-variable VAR with sectoral variables added one at a time and with no feedback. Dashed lines indicate impulse response functions for a 1% innovation to the Hamilton oil measure, with the endogenous monetary policy response included. Solid lines show impulse response functions for the case of an autonomous monetary policy innovation of comparable magnitude to the previous case, with no innovation to oil prices. The similarity of the responses for most real variables suggests that the marginal contribution of the oil price shock is small, for a given tightening of monetary policy.

Figure 8:

Source: Authors' calculations, using the basic 7-variable VAR. Solid lines show the base case, which includes the endogenous response of monetary policy to a 1% shock to commodity prices. The Sims-Zha and Anticipated Policy scenarios show the estimated effects of a shock to commodity prices when the normal response of monetary policy is eliminated.

Figure 9:

Source: Authors' calculations, using the basic 7-variable VAR. Solid lines show the base case, which includes the endogenous response of monetary policy to a 1% shock to output. The Sims-Zha and Anticipated Policy scenarios show the estimated effects of a shock to output when the normal response of monetary policy is eliminated.

Figure 10:

Source: Authors' calculations, using the basic 7-variable VAR. Solid lines show impulse response functions for output, prices, and the federal funds rate to a 1% oil price shock, for the whole sample and three decade-long subsamples. The dashed lines show the responses of output and prices to an oil shock, based on a system in which the output block is estimated over the relevant subsample; the interest rate block is estimated over the entire sample; and the monetary policy reaction is shut down by the Sims-Zha method.