# Oil Price Shocks and the U.S. Economy: Where Does the Asymmetry Originate?

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Rising oil prices appear to retard aggregate U.S. economic activity by more than falling oil prices stimulate it. Past research suggests adjustment costs and/or monetary policy may be possible explanations of the asymmetric response. This paper uses a quasi-vector autoregressive model of U.S. economy to examine from where the asymmetry might originate. The analysis uses counterfactual impulse response experiments to determine that monetary policy alone cannot account for the asymmetry. The robustness of short-lived asymmetry across the base case and counterfactuals is consistent with the adjustment-cost explanation.

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Rising oil prices appear to retard aggregate U.S. economic activity by more than falling oil prices stimulate it. Past research suggests adjustment costs and/or monetary policy may be possible explanations of the asymmetric response. This paper uses a quasi-vector autoregressive model of U.S. economy to examine from where the asymmetry might originate. The analysis uses counterfactual impulse response experiments to determine that monetary policy alone cannot account for the asymmetry. The robustness of short-lived asymmetry across the base case and counterfactuals is consistent with the adjustment-cost explanation.

## 1. Introduction

Rising oil prices appear to retard aggregate U.S. economic activity by more than falling oil prices stimulate it. All but one of the post World War II recessions have followed a sharp rise in oil prices. Yet, an acceleration of U.S. economic activity did not seem to follow the oil price declines that have occurred over the past two decades.

Over the past decade, a number of studies (Mork 1989, Mory 1993, Mork 1994, Lee et al. 1995, Hamilton 1996, Huntington 1998, Davis and Haltiwanger 1998, and Hamilton and Herrera 1999) have investigated and confirmed an asymmetric relationship between oil prices and aggregate economic activity. Although asymmetry is now fairly well accepted, few studies have attempted to determine through what channels oil price shocks travel to produce an asymmetric response in aggregate economic activity. One exception is Huntington (1998) who attributes the asymmetry to the relationship between crude oil and petroleum product prices.

Hamilton (1988) offers an explanation that asymmetry could be the result of adjustment costs to changing oil prices. Falling oil prices stimulate economic activity, and rising oil prices retard economic activity, but the costs of adjusting to changing oil prices also retard economic activity. Combining these elements, we see that rising oil prices would present two negative effects for economic activity. Falling oil prices would present both a negative and a positive effect which would tend to be offsetting. Empirical work by Loungani (1986), Davis (1987), Lee et al. (1995), Davis and Haltiwanger (1998), and Hamilton and Herrera (1999) supports but does not directly test Hamilton's explanation.

Another possibility is that monetary policy may account for the asymmetric response of aggregate economic activity. Bohi (1989, 1991) and Bernanke, Gertler and Watson (1997) argue that contractionary monetary policy accounts for the decline in aggregate economic activity following an oil price increase. Neither explore the asymmetry issue explicitly. Tatom (1988, 1993) argues that the apparent asymmetric response in U.S. economic activity to oil price shocks disappears when the stance of monetary policy or changes in the misery index (which combines unemployment and inflation rates) are taken into account.

In this paper, we examine asymmetry first with a bivariate time-series model, then with a multivariate model of U.S. economic activity. In the bivariate model, we find that GDP responds asymmetrically to oil price movements. With the multivariate model, we find that asymmetry is present not only in the GDP response, but also in the interest-rate response to oil price shocks. To analyze whether or not asymmetric monetary policy is the source of asymmetry, we perform several counterfactual experiments. We show asymmetry is transmitted through market interest rates to GDP, and monetary policy cannot be the sole source of asymmetry in the real economy.

## 2. A Bivariate Examination of Asymmetry

The measured effect of oil price movements on economic activity can be sensitive to the choice of the oil variable used in the analysis. Using nominal oil prices, Hamilton (1983) showed that oil price increases were associated with declines in output in the period 1948-1980. When the sample is extended to the 1980s or 90s, however, the oil-output relationship seems to break down (see Mork 1989 and Hooker 1996).

Researchers have tried many different oil-price specifications in an attempt to reestablish the oil-output relationship (Mork 1989, Ferderer 1996, Lee et al. 1995). In particular, Hamilton (1996 and 1999) proposes a "net oil price" variable which compares the price of oil each quarter with the maximum value observed during the preceding year. If the values for the current quarter exceeds the previous year's maximum, the percentage change over the previous year's maximum is the oil-price value. If the price of oil in quarter *t* is lower than it had been at some point during the previous year, the series is defined to be zero for date *t*. Hamilton found that the "net oil price" variable had a statistically significant and stable negative relationship with output.

As a first step in our analysis, we utilize bivariate tests to determine whether real output and the price level respond asymmetrically or symmetrically to oil price movements. In these tests, we utilize two representations of oil price movements. One representation is simply the first difference of (logged) oil prices ($\Delta$Poil). A second representation is the Hamilton net oil price described above (Hoil).[1] Taken together these two oil price series allow for either symmetry or asymmetry in the response to oil price shocks. This allowance may be particularly critical because Huntington (1998) finds that overall consumer prices may respond symmetrically to oil price changes.

The bivariate tests indicate that real U.S. GDP responds asymmetrically to oil price movements, but the U.S. GDP deflator responds symmetrically as illustrated in Table 1. Consistent with Hooker (1996), we find that changes in oil prices alone have no significant affect on real U.S. GDP, while the Hamilton net oil price taken alone is significant with greater than 95 percent confidence. The pattern doesn't change if both oil price variables are used on the right hand side of the GDP equation. The Hamilton oil price variable remains significant and the change in oil price variable remains insignificant.[2]

For the GDP deflator, the change in oil price variable by itself becomes highly significant. and the Hamilton net oil price taken alone also remains significant. When both oil price variables are used on the right hand side of the GDP deflator equation, changes in oil prices remain significant while Hamilton net oil price becomes insignificant.[3]

## 3. A Multivariate Examination of Asymmetry

### 3.1. Data and Model

To better understand the nature of the asymmetric relationship between oil prices and economic activity, we examine this relationship within the context of a multivariate time series model. We take as our point of departure the analysis of Bernanke, Gertler and Watson (hereafter BGW) who also used a multivariate model to assess the importance of oil price shocks on economic activity. BGW estimate a quasi-VAR with log output, log price level, a (log) commodity price index, the Hamilton oil price variable, the fed-funds rate, a short term interest rate (3 month t-bill) and a long term rate (10 year t-bond). They break their system into three sub-blocks of equations: a macro block, a policy block, and financial block. The macro block includes equations for output, aggregate price level, commodity prices, and oil price variable. Current and lagged values of the fed funds rate do not enter directly into the macro block and, hence, are absent from the output, price level, commodity price, and oil price equations while only lagged values of other the interest rate variables enter into the macro block equations. The contemporaneous causal ordering inside the macro block runs output, price level, commodity price, and finally oil prices. The policy block consists of an equation for the fed funds rate capturing the systematic response of monetary policy to the economic environment. This equation includes current and lagged values of all the variables in the macro block, but only lagged values of short and long term interest rates. Finally, the financial block consists of the short term and long term interest rate equations. These equations contain current and lagged values of the other variables including the fed funds rate and lagged values of the interest rates with the long rate equation also containing current values of the short term interest rate. Given this structure, BGW found that once one controls for the systematic response of monetary policy oil price increases have only small effects on output.

The original BGW specification is not entirely suitable for our examination of asymmetry and as a result we modify the BGW model in several ways. First, along with the Hamilton oil price variable, we include lags of the change in the (log) oil price in every equation. Unlike the original BGW specification, this allows for either a symmetric or asymmetric response to oil price changes (symmetric if coefficients on the Hamilton variable are zero). Second, we replace the Hamilton oil price as a dependent variable in the system with just the change in (log) oil price. Including the change in oil prices allows us to examine both positive and negative innovations. Furthermore, an innovation in the change in the price of oil is much easier to interpret than an innovation in a Hamilton oil price variable—it is not at all clear how to interpret a negative Hamilton innovation. Finally, we add an identity to the system that essentially defines the Hamilton oil price variable. The resulting model is a nonlinear system of equations with seven linear, estimated equations and one nonlinear identity. This system allows for nonlinear dynamics including asymmetric responses to oil price shocks.

Like BGW we use monthly data, spanning the period from January 1965 through December 1997. GDP is in constant 1987 dollars, with monthly GDP and GDP price deflator interpolated from quarterly data.[4] Our specification differs in that we use the raw values of log output and long-term interest rates rather than the spline detrended values used in BGW. The commodity price index is the spot market index for all commodities from the Commodity Research Bureau, used by BGW. The oil price is the Crude Oil PPI from Citibase. The federal funds rate, the three-month treasury bill rate and the ten-year treasury bond rate series are all from Citibase.

### 3.2 Nonlinear Impulse Response Analysis

One way to assess the degree to which asymmetry is present in the multivariate model is to conduct impulse response analysis. Because of the nonlinear nature of the model, impulse response functions (IRFs) must be calculated with care. Recall that an IRF is the change in conditional expectations, given an exogenous shock, $u_t$ and the current information set, $\Omega_{t-1}$, or:

$$E[Y_{t+k}|u_t, \Omega_{t-1}] - E[Y_{t+k}|\Omega_{t-1}].$$

In a linear VAR, the change in conditional expectation is a linear function of the underlying shock and does not depend on the initial conditions. In a nonlinear model, that is generally not the case.

Therefore, in order to calculate the conditional expectation, both with and without the exogenous shock, we simulate the model. This is done by drawing shocks for $u_{t+i}$ (from resampled empirical shocks) and simulating the model given the initial condition ($\Omega_{t-1}$) and the original shock $u_t$. We also simulate the model with for $-u_{t+i}$ so that we can eliminate any asymmetry that may arise just from sampling variation in the estimation of the conditional expectations. We repeat this 100 times and take the average over the simulations to get an estimate of the conditional expectation. This was done for 100 randomly drawn (from the actual sample) initial conditions, and the resulting IRFs were averaged.

Figures 1 and 2 plot the average (over initial conditions) IRFs for +/- 1 and 2 standard deviation shocks, respectively. From the Figures we see evidence of asymmetry; that is, positive and negative shocks are not mirror images of one another. However, the asymmetry is more evident in large (two standard deviation) shocks than in smaller shocks (one standard deviation shocks). The reason is that smaller shocks, even positive ones, are less likely to show up as affecting the Hamilton oil price variable. In addition, the degree of asymmetry is generally larger in the short run than in the long run. This is due, in part, to the fact that oil price shocks generally have only temporary effects on the Hamilton oil price variable; thus, the asymmetry originating in the oil-price impulses are relatively short-lived.

With respect to individual variables, we see that the output response is asymmetric for large changes in oil prices--both negative and positive shocks are associated with declines in output. Only after 10 periods does the output response become positive for large declines in the price of oil. Thus, oil price decreases do not have as large an expansionary effect on economic activity as oil price increases have a contractionary effect.

The responses of prices (both the GDP deflator and commodity price index) also appear to be asymmetric, albeit less so than output. Here, prices tend to respond more to a large oil price increase than they do to a large oil price decrease. Similarly, the fed-funds rate has a very asymmetric response to oil price shocks--the fed-funds rate rises much more in response to a large positive oil price shock than it does to a large negative oil price shock. In fact, the response is twice as large for a positive as for a negative oil price shock. Short-term interest rates also respond asymmetrically to oil price shocks, while long rates respond more symmetrically.

An alternative way to view whether the responses are asymmetric is to examine the sum of the responses to a positive and negative two standard deviation oil price shock. If the responses are symmetric, then this sum would be zero. To assess the precision with which the apparent asymmetry is estimated, we calculate the inner 90% percentile band for the distribution of the sum of responses.[5] The point estimates as well as the 5th and 95th percentiles of the sum of the responses are shown in Figure 3. Figure 3 illustrates the substantial asymmetry in the responses to oil price shocks in that the sum of the responses are frequently nonzero. For output, the price level, the fed funds rate, and the 3 month t-bill rate there are horizons in which the inner 90% percentile band does not include zero, suggesting that the evidence of asymmetry is not entirely the result of an imprecisely estimated parameter vector. This is despite that fact that impulse response functions for VARs are typically imprecisely estimated.[6]

## 4. Where Does the Asymmetry Originate?

The negative output response to negative oil shocks in the very short run is somewhat surprising, although Davis and Haltiwanger (1998) also found a slightly negative response of employment to negative oil price shocks. While there is little controversy that oil prices in principle can have a direct effect on economic activity as oil is an important input, it is not at all clear that this would imply an asymmetric effect. Perhaps, reallocation costs either across or within sectors might result in a negative response. For example, for putty-clay capital with energy intensity embodied in the vintage of capital a change in oil prices may have negative output consequences as firms adjust to new energy prices (see Atkeson and Kehoe 1999).

It is not only output, but also interest rates that respond asymmetrically to oil price shocks however. Judging from the reaction of the fed-funds rate, the Fed responds more vigorously to oil price increases than to decreases. The asymmetric response of the fed-funds rate then feeds through interest rates and results in the asymmetric response in output. In a traditional aggregate demand/supply model, increases in oil prices implies an unpleasant choice of policy responses by the Fed. It can accommodate an oil price increase by raising aggregate demand and lessen the negative effect on output but at the cost of higher prices, or it can reduce aggregate demand and lessen the price effect but at the cost of lower output. From the responses, it appears that the Fed is less willing to accommodate oil price increases than oil price declines.

In addition to fed-funds rate, the short-term interest rate response also suggests substantial asymmetry. One explanation is that the asymmetric response of short-term market rates is just a reflection of the asymmetric response of the fed-funds rate through the term structure. Alternatively, the interest rates may be reflecting the financial markets' expectations of the "real" effect of oil price changes. Thirdly, they may reflect increased financial stress brought about by oil price shock. For example, in the "financial accelerator" model of Bernanke and Gertler (1989), an adverse shock increases the likelihood of bankruptcy and default on loans, raising the costs of external finance, making it more difficult for firms to obtain loans from financial intermediaries. This results in a "flight to quality" with credit worthy firms being able to go to the commercial paper market while other firms would see the cost of external financing rise.

As a first pass at evaluating these alternative explanations of asymmetry, we test to determine whether it is possible to exclude the oil price variables from individual equations. Table 2 illustrates the results of the exclusion tests. For all the macro block variables (output, price level, commodity price index) neither the oil price nor the Hamilton oil price variable are statistically significant (this holds true if we included current values of the oil and Hamilton oil price variable into the regressions). On the other hand, the Hamilton oil price variable was significant in the fed-funds equation and the short-rate equation and was marginally significant in the long-rate equation. This suggests that the effect of oil prices on output is reflected primarily through interest rates, which are significant in the output equation.

### 4.1 Two Counter-Factual Experiments

BGW argue that the systematic response of monetary policy to oil price shocks is responsible for much of the response of output to oil price shocks. To determine the degree to which the systematic response of the Federal Reserve is responsible for the asymmetry, we conduct the same type of counter factual policy experiments as in BGW. Essentially, we shut down the response of the fed-funds rate to an oil price shock, so that the fed-funds rate is unchanged as a result of an oil price shock. By comparing these impulse responses with those of the baseline case, we get a sense of the Fed's contribution to the asymmetric response of output. We conduct two such counter-factual experiments. In the Sims-Zha experiment the fed-funds rate is held constant in the face of oil price shock, but no attempt is made to allow for the effect of expectations of future fed-funds rates on other interest rates. The second experiment assumes that the constant fed-funds rate is credibly embodied in the markets' expectations of future fed-funds rates and that this expectation affects current short and long-term rates through the term structure of interest rates (the anticipated policy) .[7]

Figures 4 and 5 illustrate the Sims-Zha and anticipated policy experiments with two-standard deviation positive and negative oil shocks. The output and short-term interest rate responses are clearly asymmetric in the Sims-Zha case, with a slightly asymmetric response in the commodity price variable. This suggests that oil price changes have an asymmetric effect even if the fed-funds rate is unchanged. Note also that decreases in the price of oil result in an initial decrease in output as in the base case but this is exacerbated if the fed-funds rate is kept at its original level (instead of falling as in the base case). Not letting the federal funds rate fall may be interpreted as tighter monetary policy than in the base case, leading to a contraction in output.

When we control for expectations of future fed-funds rates we continue to see asymmetric responses in both the macro and financial blocks. Although somewhat more muted, there is asymmetry in the responses of output, commodity price index and short-term interest rates. The long-rate response is also substantially asymmetric.

The fact that we see an asymmetric effect of oil even when we control for expectations of future fed-funds rate suggests that monetary policy is not solely responsible for these effects. Recall from the exclusion tests that oil appears to have no direct effect on the variables in the macro block. Even after controlling for the systematic response of the fed funds rate, we still see an asymmetric response in interest rates. This suggests that the term premia on the interest rates also responds asymmetrically. In fact, exclusion tests for estimated term premia support this fact as the oil price variables are significant for both the short and long-term premia (see Table 3).

**4.2 Commercial paper / t-bill spread and the flight to quality**

Because the effect of oil prices on output seems to be working through interest rates, we examine whether this result is robust for an alternative interest rates series. Specifically, we replace the long and short rates used in the BGW specification with the 6 month T-Bill and the spread between the 4-6 month commercial paper and the 6 month T-Bill (the CPBILL spread). That is, we replace the term-interest-rate relationship with a "quality" spread relationship. One advantage of examining commercial paper/ t-bill spread is that this variable has been argued to reflect "flight to quality" in financial markets (Bernanke, Gertler, and Gilchrist 1996).

When we repeat the exclusion tests with the "quality spread" we still find that oil variables are not significant in the macro block equations, but that interest rates, particularly the CPBILL spread, are significant, especially in the output equation (see Table 4). The current and lagged values of the Hamilton oil variable, however, have a significant effect on the quality spread as well as on the fed-funds rate.

The impulse responses from the CPBILL model exhibit strong asymmetry. As can be seen in Figure 6, the response of output to oil price shocks for the first 9 periods is nearly identical regardless of oil prices going up or down. At longer horizons, the responses become more symmetric. We see strong asymmetry for fed funds, 6-month t-bill, and the spread between commercial paper and t-bill rates. Large increases in the price of oil raise the quality spread more than decreases in the price of oil decrease the quality spread, by almost three times as much.

Figure 7 shows the sum of the responses to positive and negative oil shocks along with the inner 90% band of the distribution of responses. As can be seen, the point estimates of the sum for GDP, the short rates and the quality spread responses are often well outside the 90% band again suggesting that the estimated asymmetry is not entirely due to sampling variation.

Figure 8 and 9 show the base case and the two counter-factual experiments with the CPBILL model for a 2-standard deviation positive and negative oil price shock. The asymmetric response remains even after shutting down the fed-funds response. Shutting down the fed-funds rate response to an oil price increase (decrease) moderates the output response, while the interest-rate response is greater than in the base case. When we control for fed-funds rates, the response of the commercial paper/t-bill spread is still very asymmetric. Note also that the price responses are very similar regardless of whether the fed-funds rate is allowed to respond or not, especially in the short run suggesting a certain sluggishness of prices in response to movements in the fed funds rate. Overall, the character of the results when a quality spread is used in the analysis is similar to those using the BGW specification.

**5. Conclusions**

It is clear that negative and positive oil price shocks have asymmetric effects on output and interest rates. At first consideration, the strong asymmetry we find in output may seem puzzling, particularly the strikingly similar negative response of output to both positive and negative oil prices changes in the short run.[8] Mork (1994) and Davis and Haltiwanger (1998) found substantially similar results for the short run. Such findings are consistent with the explanation that oil price shocks necessitate costly adjustment (either inter-sectoral or intrasectoral as emphasized by Davis and Haltiwanger).

Our tests also show that oil prices affect interest rates asymmetrically before they affect output asymmetrically. BGW assert that the real effects of oil price shocks arise from the Fed's response to oil price shocks. This may be true to some extent, but we find that the asymmetry does not go away—and is in fact is enhanced—when either the fed-funds rate or the fed-funds rate and expectations of the fed-funds rate are shut down. Hence, monetary policy cannot be the sole cause of asymmetry on the real side.

The channel through which oil price shocks affect output in our model is through interest rates. One cautious interpretation of the asymmetry in the interest-rate response is that relatively fluid market rates move in anticipation of asymmetric real effects that will be realized later. Another interpretation is that interest rates are reflecting increased financial stress brought about by the oil price change, as in the "financial accelerator" models.

**Table 1. Bivariate Exclusion Tests**

| | Hoil | ΔPoil |
|---|---|---|
| GDP | 0.09 | 0.73 |
| GDP | | 0.56 |
| GDP | 0.04 | |
| Defl | 0.46 | 0.02 |
| Defl | | 0.001 |
| Defl | 0.06 | |

Note: The dependent variable is the variable in the first column on the left-hand side. The table represents significance values from joint F-tests testing whether the coefficients on all lags of the HOIL and ΔPOIL variables are zero.

**Table 2. Multivariate Exclusion Tests**

| | HOIL | ΔPOIL | HOIL & ΔPOIL |
|---|---|---|---|
| **GDP** | 0.82 | 0.66 | 0.80 |
| **Price Level** | 0.25 | 0.95 | 0.68 |
| **Commodity Price** | 0.27 | 0.67 | 0.57 |
| **ΔPOIL** | 0.21 | 0.00 | 0.00 |
| **Fed Funds Rate** | 0.01 | 0.92 | 0.06 |
| **Short Rate** | 0.02 | 0.49 | 0.16 |
| **Long Rate** | 0.17 | 0.96 | 0.26 |

Note: The dependent variable is the variable in the first column on the left-hand side. The table represents significance values from joint F-tests testing whether the coefficients on all lags of the HOIL and ΔPOIL variables are zero. Exclusion tests including the contemporaneous values of the oil variables were also done. The results are very similar to the above values.

**Table 3. Multivariate Exclusion Tests: Short and Long-Run Risk Premia Equations**

| | HOIL | ΔPOIL | HOIL & ΔPOIL |
|---|---|---|---|
| **Risk Premium (S)** | 0.00 | 0.01 | 0.00 |
| **Risk Premium (L)** | 0.00 | 0.40 | 0.00 |

The table represents significance values from joint F-tests testing whether the coefficients on all lags of the HOIL and ΔPOIL variables are zero. Exclusion tests including the contemporaneous values of the oil variables were also done. The results are very similar to the above values.

**Table 4. Multivariate Exclusion Tests- CPBILL Model**

| | Hoil | ΔPoil | Hoil & ΔPoil |
|---|---|---|---|
| **GDP** | 0.77 | 0.67 | 0.85 |
| **PriceLevel** | 0.40 | 0.95 | 0.80 |
| **PCom** | 0.15 | 0.50 | 0.37 |
| **ΔPoil** | 0.22 | 0.00 | 0.00 |
| **Fed Funds** | 0.2 | 0.92 | 0.11 |
| **T-bill** | 0.20 | 0.67 | 0.43 |
| **Spread** | 0.02 | 0.67 | 0.14 |

Note: The dependent variable is the variable in the first column on the left-hand side. The table represents significance values from joint F-tests testing whether the coefficients on all lags of the variables in the first row are zero. Exclusion tests including the contemporaneous values of the oil variables were also done. The results are very similar to the above values. Hoil is the Hamilton oil variable, T-bill is the 6-month treasury bill and the Spread is the spread between commercial-paper rate and the 6-month t-bill rate.

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**Notes**

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1. Our analysis uses monthly data including a monthly version of Hamilton's net oil price.

2. We found the persistence captured in the Hamilton variable to be of importance for U.S. GDP. For example, we also experimented with an oil variable defined as Upoil = Max $\{0, \Delta \text{Poil}\}$. Neither Poil, Upoil or Poil and Upoil combined had a significant effect on GDP.

3. Other specifications of the symmetry-asymmetry test yielded substantially similar results for the U.S. GDP Deflator.

4. We use a slightly different set of interpolators for GDP and the price deflator. Personal consumption expenditures, industrial production and total nonagricultural employment are used for interpolating GDP. The GDP price deflator is interpolated with the following producers' price indexes to make it monthly: PPI for capital equipment, PPI for finished goods, PPI for intermediate materials and the PPI for crude materials.

5. The distribution of the sum of responses is calculated by assuming a posterior distribution for the parameter vector that is a normal and whose mean and variance/covariance are that of the estimated parameter vector. We take the size of the shock to be a constant rather than a random variable. The distribution of responses are calculated by randomly drawing a parameter vector from its posterior distribution. We then calculate the average impulse response function over 100 different initial conditions (as described in the text) for the drawn parameter vector and the distribution of responses for 100 parameter vector draws. Calculating the distribution of the sum of responses requires a total of $4\text{x}10^6$ simulations of the nonlinear system of equations. The approach taken here is similar to one of methods Hamilton (1994) describes for calculating confidence intervals for impulse responses.

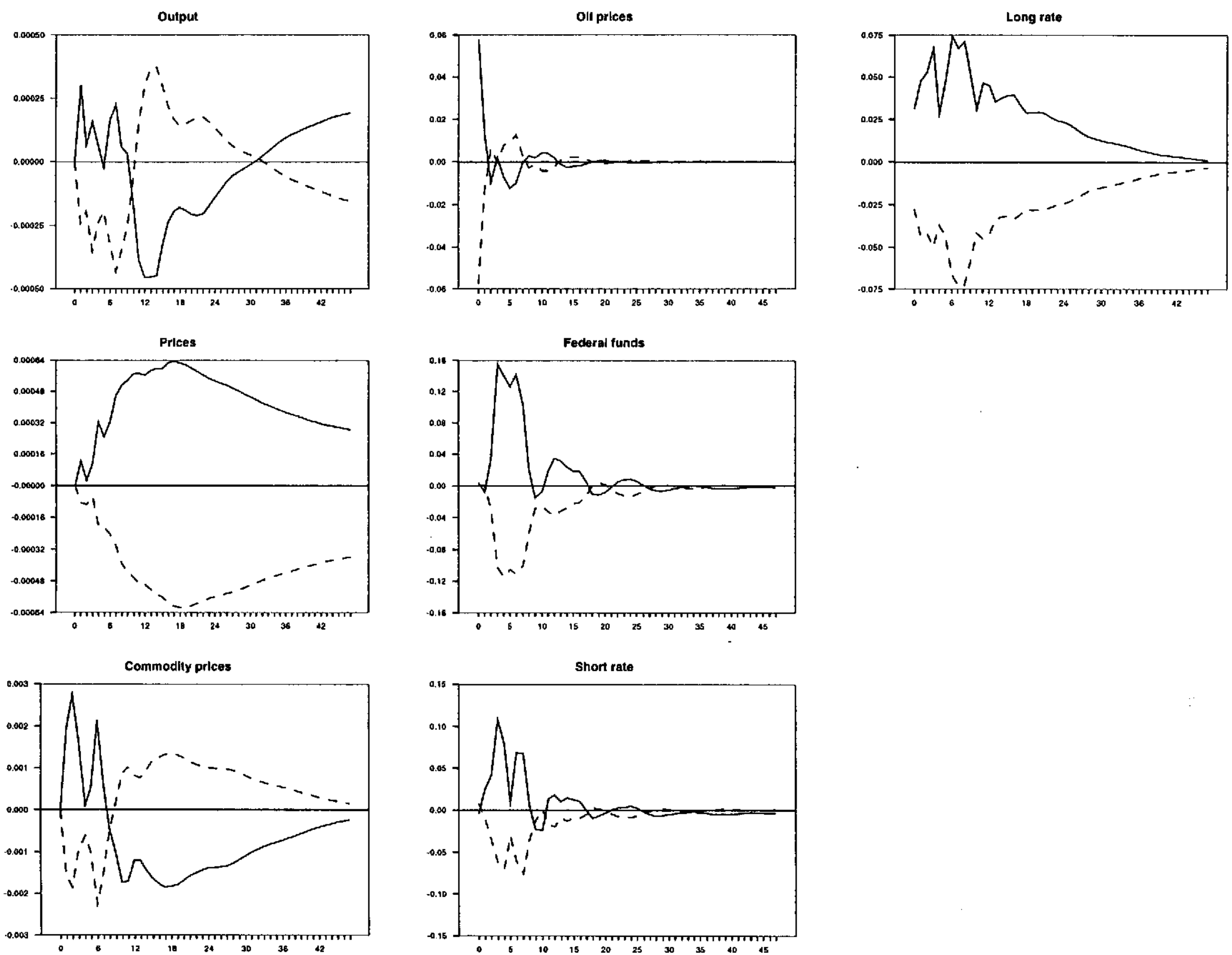
6. When we replace the Hamilton oil variable with the Upoil variable defined in note 2, the asymmetry is even more pronounced for GDP with zero being well outside the 90% band.

7. To control for the effect of expectations of future fed-funds rates on interest rates, we follow BGW by breaking up interest rates into an expectations component and a term premium. Expectations component is the average of current and future fed-funds rates while the term premium is just the difference between actual interest rate and the expectations component. Because of the nonlinear nature of the model, we must simulate the model in order to calculate

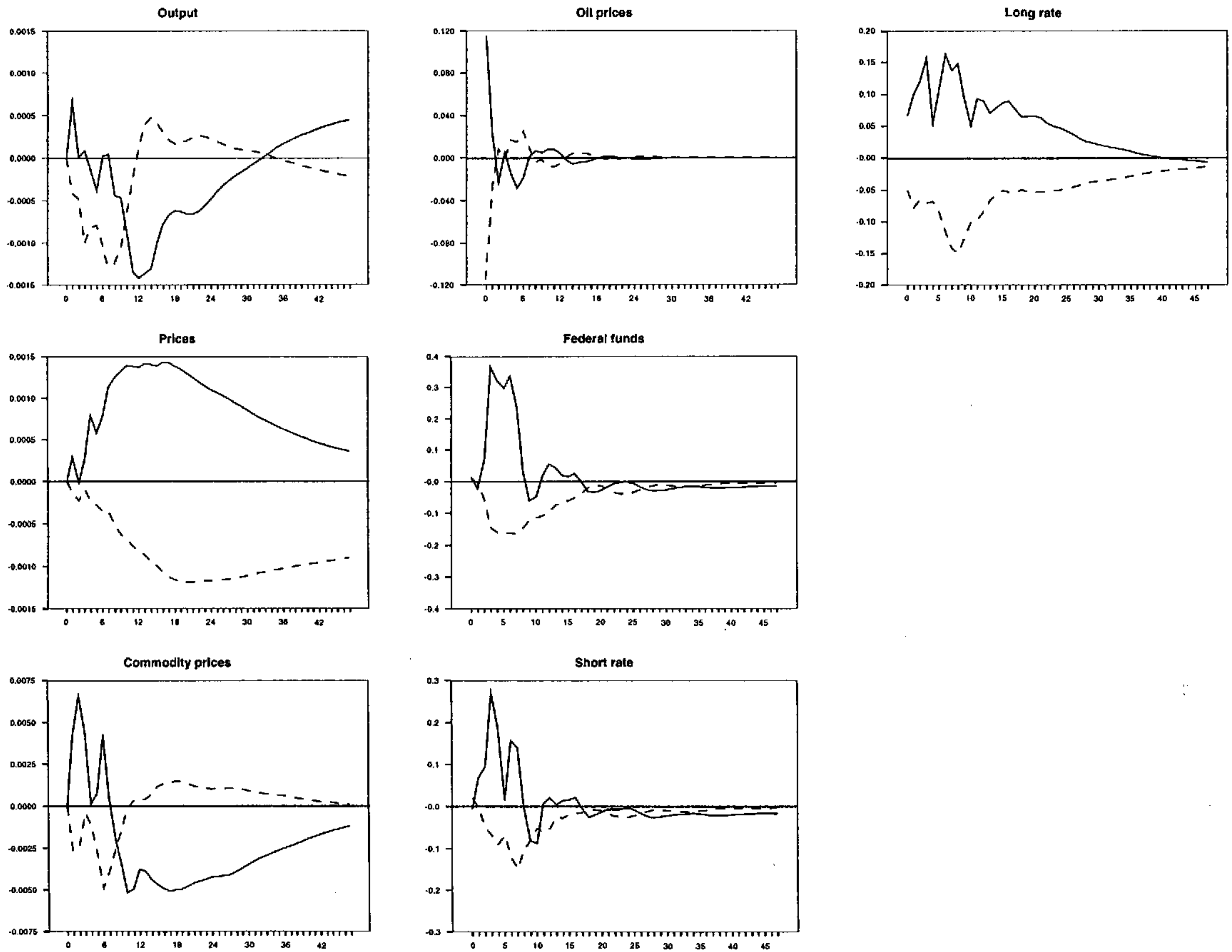
expectations of future fed-funds rates.

8. The asymmetry is also robust for the Sims-Zha and BGW counterfactuals.

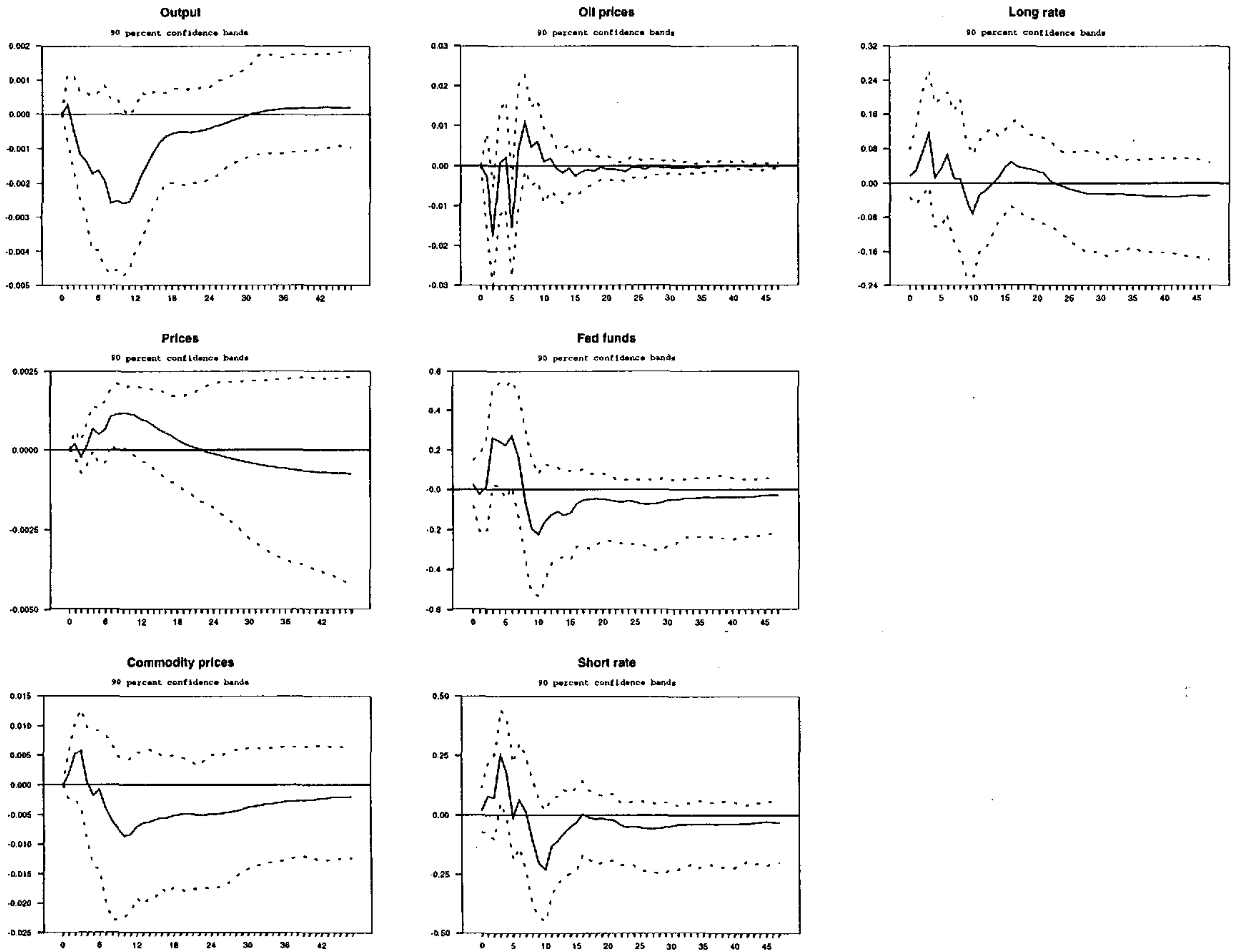
**Figure 1. Base Case Impulse Responses to +/- 1 Standard Deviation Oil Shock**



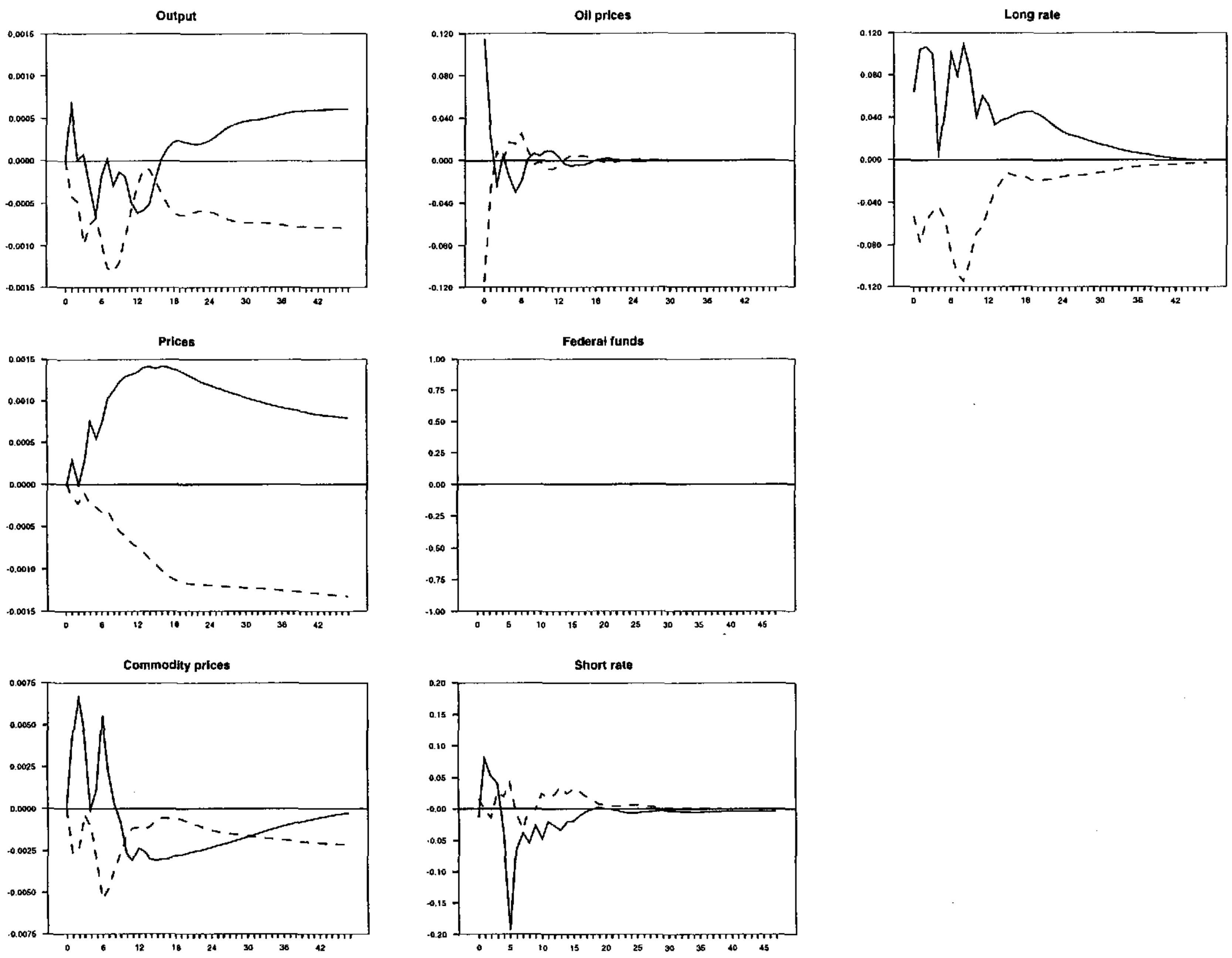
## Figure 2. Base Case Impulse Responses to +/- 2 Standard Deviation Oil Shock



## Figure 3. Sum of Responses to Positive and Negative Oil Price Shocks



## Figure 4. Sims-Zha Case Impulse Responses to +/- 2 Standard Deviation Oil Shock



## Figure 5. Anticipated Policy Case Impulse Responses to +/- 2 Standard Deviation Oil Shock

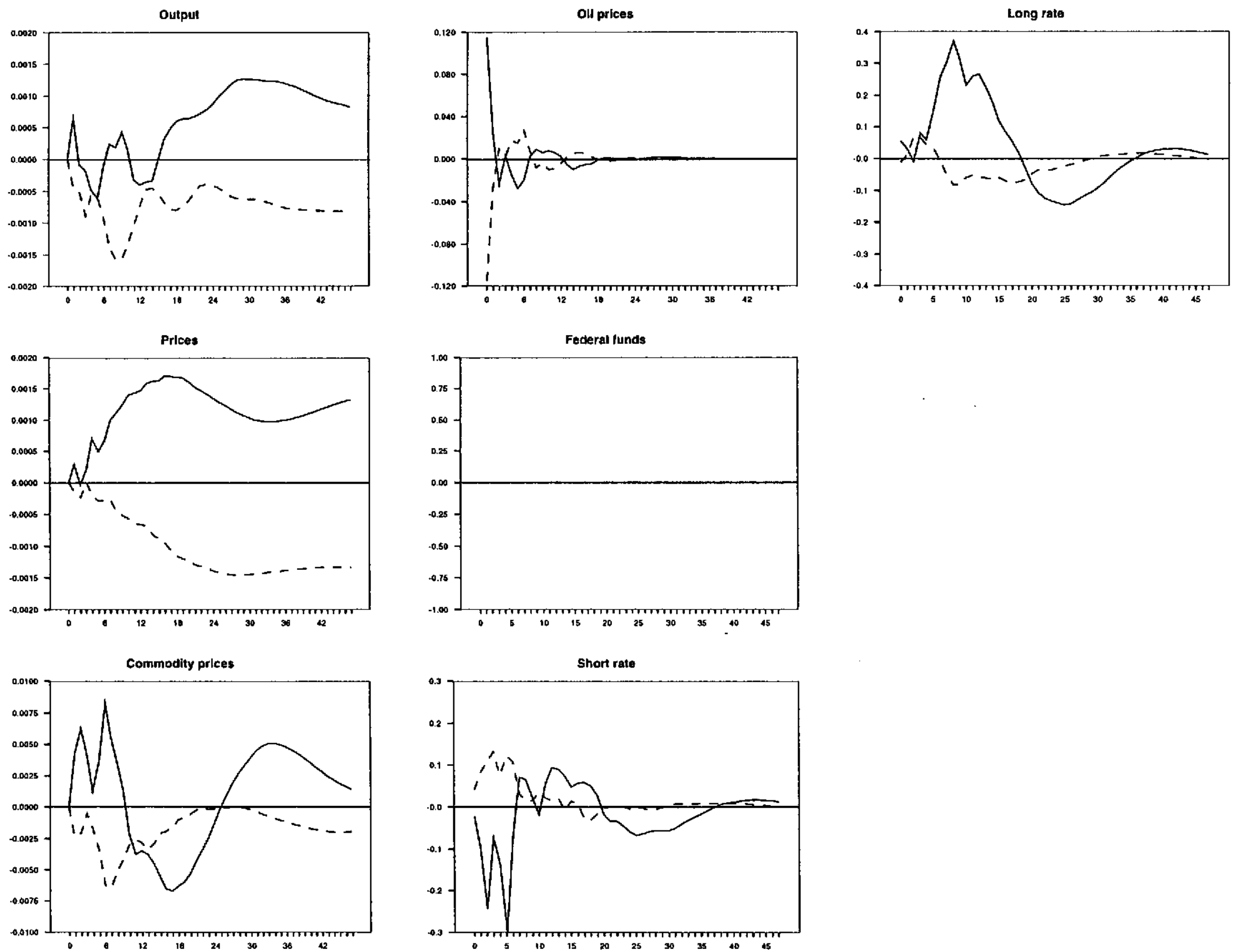
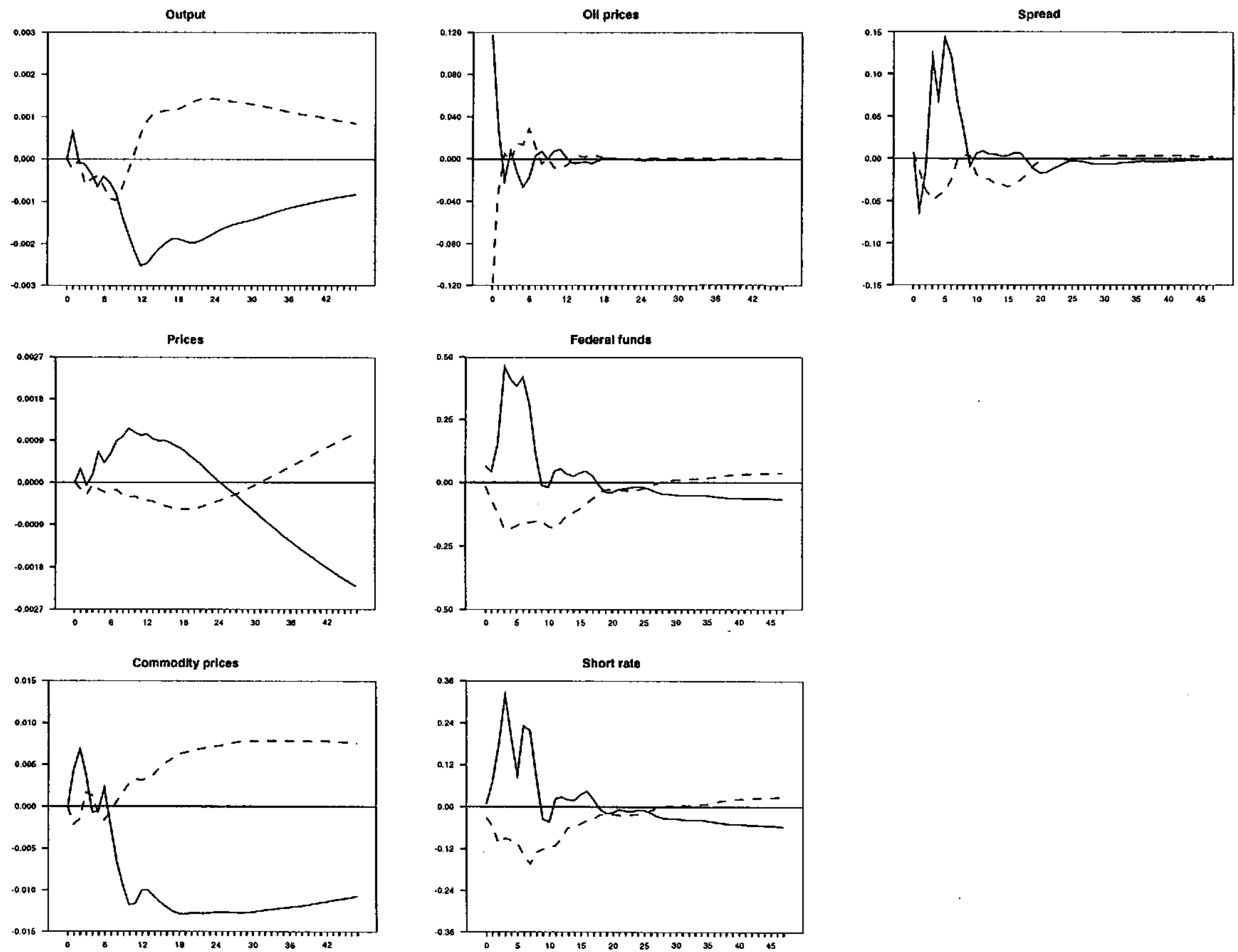
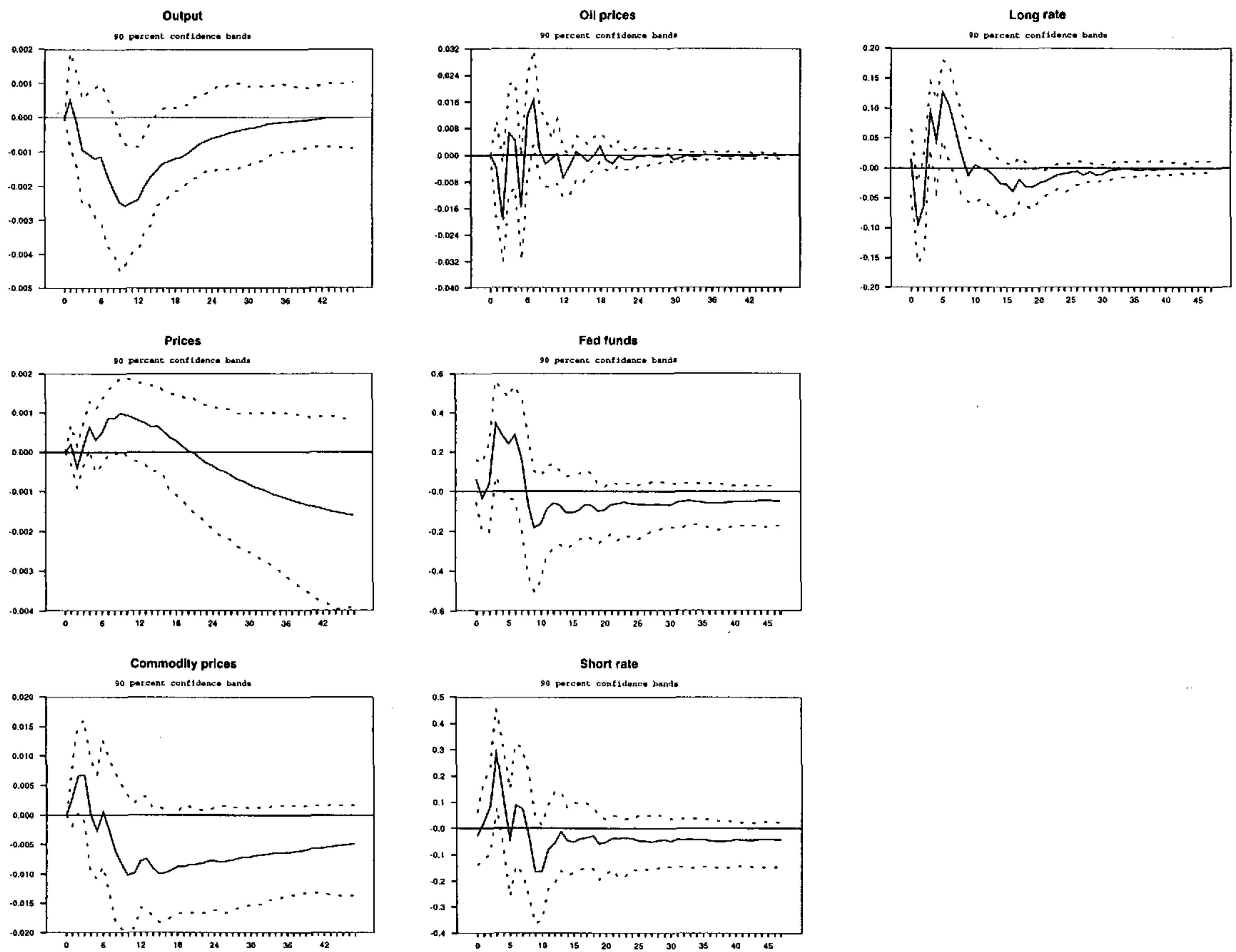


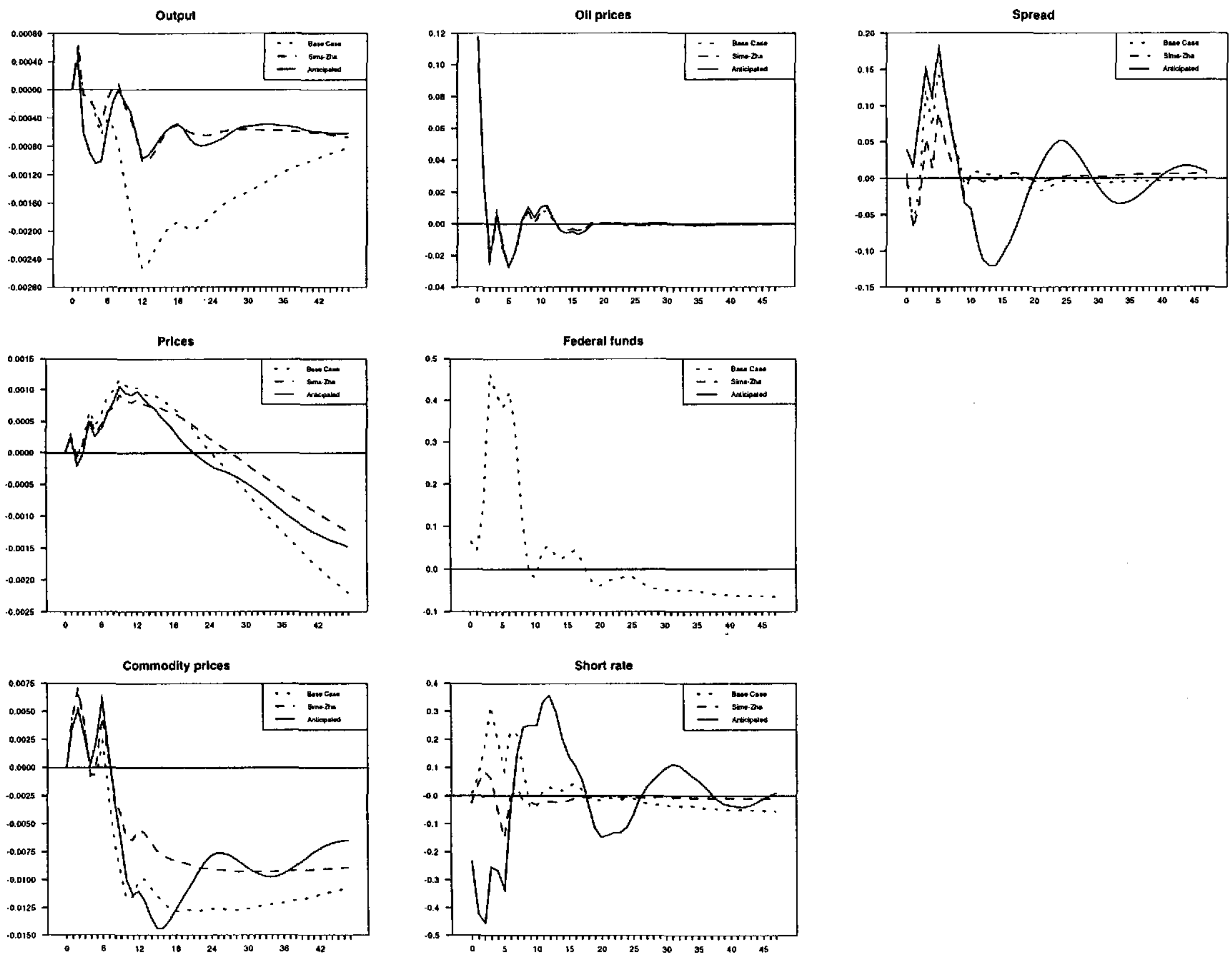
**Figure 6. CPBILL Model Base Case Impulse Responses to +/- 2 Standard Deviation Oil Shock**



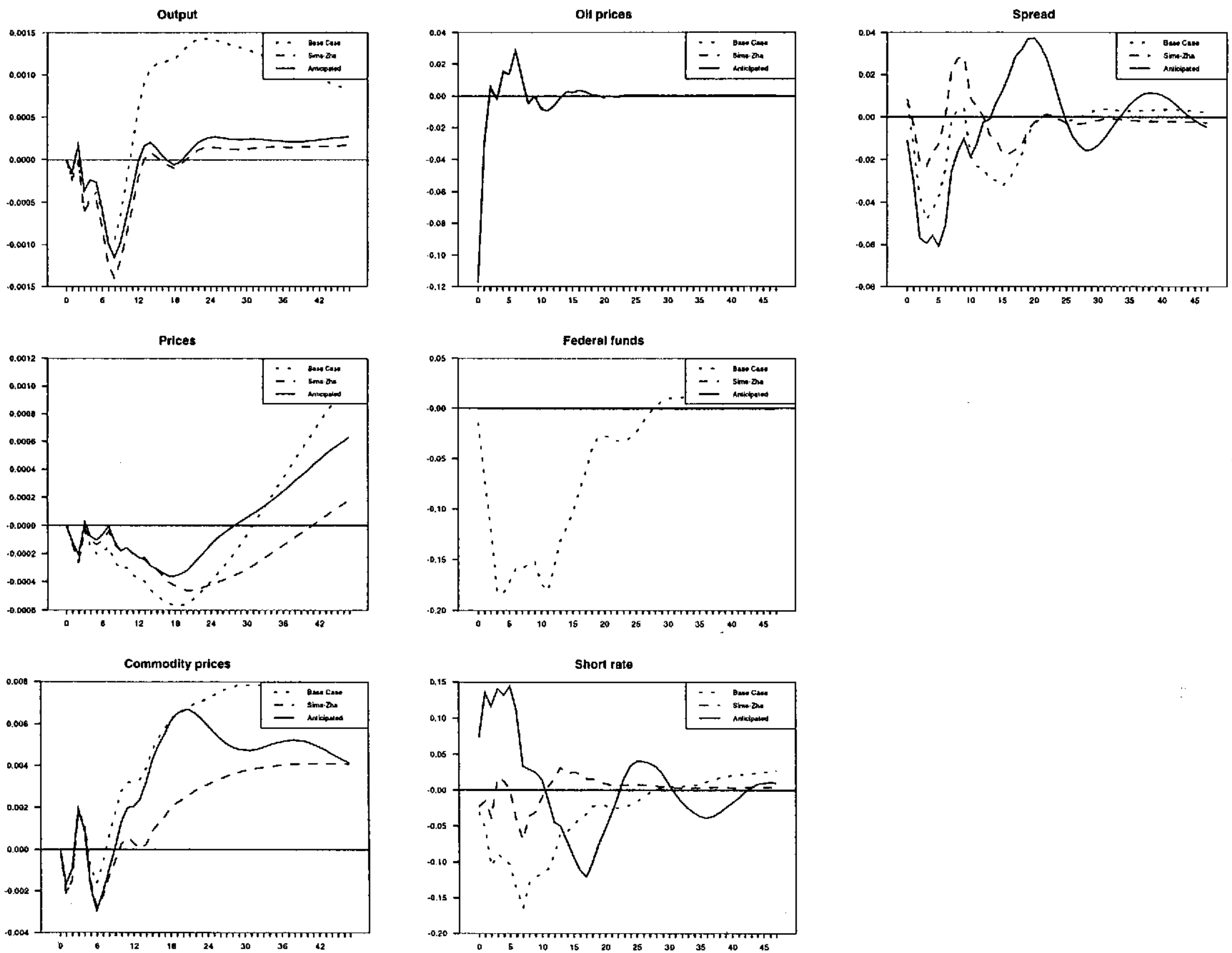
## Figure 7. CPBILL: Sum of Responses to Positive and Negative Oil Price Shocks



## Figure 8. CPBILL Model Counterfactual Impulse Responses to Positive Oil Price Shocks



# Figure 9. CPBILL Model Counterfactual Impulse Responses to Negative Oil Price Shocks



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