OIL PRICES AND INFLATION

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Abstract

This article uses impulse response functions based on a vector autoregressive model of the U.S. economy to analyze how oil price shocks move through major channels of the economy to affect inflation. The model represents the interactions between oil prices, real GDP, a monetary aggregate, short-term interest rates, the spread between long- and short-term interest rates, and the GDP deflator for the period 1970 through 1994. The responses of the model to monetary and interest rate shocks generally conform to economic theory. The analysis shows that oil price shocks have permanent effects on the price level and nominal GDP. These findings suggest that during the estimation period, monetary policy generally accommodated the inflationary pressure of oil price shocks.

JEL Classification: Q43 (Energy and the Macroeconomy)
E31 (Price Level, Inflation, Deflation)

Oil Prices and Inflation

Stephen P. A. Brown, David B. Oppedahl and Mine K. Yücel*

1. Introduction

Oil price shocks have major effects on output and inflation (Hamilton 1983, 1988; Tatom 1988; Mork 1989, 1994; Kahn and Hampton 1990; and Huntington 1995). In fact, oil price shocks have been an important source of economic fluctuation in the United States over the past three decades (Miller, Supel and Turner 1980; Kim and Loungani 1991; and Finn 1991). The preponderance of evidence suggests that rising oil prices contributed to falling output and increased inflation during the 1970s and early 1980s, and that falling oil prices boosted output and lessened inflation during the mid to late 1980s.

Although there are many estimates of how sensitive output and inflation are to changes in the price of oil, little research has been directed toward examining the rate at which oil price shocks are transmitted to inflation. Our work uses impulse response functions based on a vector autoregressive (VAR) model of the U.S. economy to analyze how oil price shocks move through major channels of the economy to affect inflation. The model represents the interactions between oil prices, real GDP, a monetary aggregate, short-term interest rates, the spread between long- and short-term interest rates, and the GDP deflator for the period 1970 through 1994.

Our approach adds to the existing research on the aggregate effects of oil price shocks in several additional ways. The 25-year time period we use for the analysis includes periods in which oil prices fell sharply, as well as periods in which prices were rising. We calculate confidence bands on the impulse response functions. In addition, we test the model's ability to represent aggregate economic activity. The tests indicate the model's responses to monetary and interest rate shocks generally conform to economic theory.

We use impulse response functions based on the model to examine the rate at which oil price shocks are transmitted to changes in inflation. Our analysis shows that past oil price increases have led to temporary a decline in real GDP, a transitory decline in the spread between long- and short-term interest rates, and transitory increases in short-term interest rates. The analysis also shows that oil price shocks have a permanent effect on the price level and nominal GDP.

2. Analytical Framework and Estimation

To analyze the effects of oil price changes on inflation, we constructed a vector autoregressive (VAR) model to represent the relationships between oil prices, aggregate economic activity and inflation. The model consists of six variables: the real price of oil, real gross domestic product (GDP), a monetary aggregate, a short-term interest rate, the spread between long- and short-term interest rates, and the GDP deflator.

2.1 *Model Specification*

The model is based in part on the monetary equation of exchange:

$$MV = PY \tag{1}$$

where M is the monetary aggregate; V is the velocity of the monetary aggregate; P is the aggregate price level; and Y is real GDP. Velocity is commonly represented as a function of interest rates because money demand is sensitive to the opportunity cost of holding money balances. With some money balances paying interest rates, we include both a short-term interest rate and a spread variable.

Because energy prices are incorporated into the calculation of the aggregate price level, changes in the real energy price can affect the aggregate price level directly. Nonetheless, this direct avenue cannot yield a permanent change in the aggregate price level. Under the monetary equation of exchange, a change in energy prices cannot have a permanent effect on the price level unless GDP, the monetary aggregate or velocity are altered.[1]

A change in real energy prices can have a permanent effect on the aggregate price level by altering real GDP. Higher energy prices reflect the increased scarcity of this productive input and reduce real GDP. Under a neutral monetary stance (defined here as one in which $M{\bullet}V$ or nominal GDP is held constant), a change in real GDP will affect the aggregate price level. A reduction in real GDP increases the aggregate price level by an equal percentage.

2.2 *Data*

For the analysis, the oil price variable is real composite refiner's acquisition cost and the monetary aggregate is represented by M2. The interest rate is the federal funds rate. The spread variable is the difference between rates on U.S. treasury bonds with a constant maturity of ten-years and U.S. treasury bills with a constant maturity of three months. Our measure of inflation is the implicit GDP deflator. GDP is in constant 1987 dollars. All the variables are endogenous. We use quarterly data from spanning the period from first quarter 1970 through fourth quarter 1994.[2]

We conducted sensitivity tests of the model by using alternate variables for the monetary aggregate, the short-term interest rate and the oil price. We used both bond-adjusted M2 and the Federal Reserve Bank of St. Louis' measure of the monetary base in place of M2, the rate of return on treasury bills of a three-month constant maturity in place of the federal funds rate and an aggregate energy price variable in place of oil prices. In addition, we considered the oil price as an exogenous variable. In all of these variants, we found the results to be substantially similar to those reported below.

2.3 *Model Specification*

As an initial step in our econometric work, we performed several diagnostic checks to assess the correct specification for the various series. We tested for stationarity using augmented Dickey-Fuller and Phillips-Perron tests, and concluded that we could not reject the hypothesis that all of the series were integrated of order of one. Thus, the first differences of the series were stationary.

There are two approaches in using of nonstationary data in a VAR model. One is to formulate an error-correction model in first differences with cointegrating terms. An alternative to the error-correction approach is to estimate the VAR in levels, without explicitly modeling the cointegrating relationships. Given the length of the data series and the number of variables, we selected a VAR model in log levels.

A case exists for examining the model in levels. The low power of cointegration tests and the resulting uncertainty about the number of cointegrating vectors conditions the test results from an error-correction model. Estimates from a levels model are not conditional upon the estimated number of cointegrating relationships and their estimated values. Although not all tests on a VAR model in levels have standard distributions, the tests presented in this paper do (Sims, Stock and Watson, 1990).

The lag length of the VAR model was determined by testing various lag lengths against the alternative of one less lag. The method of testing was the likelihood ratio test corrected for small samples using Sims' (1980) suggestion. The resulting lag length was five. Restricting the model to four lags was rejected by a likelihood ratio test of $X^2_{36}=52.98$ (p-value of 0.034) with a correction of 31. Also, testing for six lags versus five failed to reject the null hypothesis of five lags, because $X^2_{36}=36.51$ (p-value of 0.445) with a correction of 37. The tests are valid because the null hypothesis can be represented by restrictions on stationary variables, as is required for the use of standard distributions with the levels model (Campbell and Perron, 1991).

2.4 *Impulse Responses*

To examine the dynamics of monetary, interest rate, and oil price shocks to the U.S. economy and inflation, we calculated impulse response functions. The impulse response function traces over time the effects on a variable of a given shock to the innovations from an equation in the VAR system. The persistence of a shock tells us how fast the system adjusts back to equilibrium. The faster a shock dampens, the faster the adjustment. We analyzed the effects of a one-time oil price shock (based on the Choleski decomposition of the covariance matrix) and traced the effects of this shock on each of the variables.

We used the estimated coefficients of the VAR system of equations and Monte-Carlo integration with 1000 replications to compute confidence bands for the impulse response functions. The methodology follows Kloek and Van Dijk (1978) with the coefficient draws directly from the estimated posterior distribution of the coefficients. This methodology yields 80-percent confidence bands for the impulse response functions of the variables in the model. These bands can be used to distinguish where the impulse response functions differ significantly from zero.

2.5 *Variance Decomposition*

The VAR approach also enables one to calculate the variance decomposition of the system. The information provided by the impulse response functions and variance decompositions is the same, but presented in an alternate form. The forecast error variance is decomposed into the portion due to each of the innovation processes via a Choleski factorization.

3. Monetary and Interest Rate Shocks

To better understand the properties of the estimated VAR model and to see if it behaved in accordance to economic theory, we calculated impulse responses and confidence intervals for exogenous one-time shocks in the monetary aggregate and the short-term interest rate. Although these variables were conceived as endogenous--raising a question about the possibility of such exogenous shocks--the impulse responses can provide information about whether the model is useful in capturing aggregate economic behavior.

3.1 *Responses to a Monetary Shock*

As shown in figure 1, the impulse responses indicate that a monetary shock affects all variables significantly. The effects on many variables are persistent, but appear to depend on the persistence of the monetary shock itself. In response to its initial shock, M2 increases at an accelerating rate over a 60-quarter horizon. At four quarters, M2 is 2 percent higher than its pre-shock value; at eight quarters, it is 4 percent higher; at 20 quarters, it is 11 percent higher; and at 60 quarters, it is 43 percent higher.

Viewed over the medium-term, a shock to M2 appears to have transitory effects on real GDP--with a one-standard deviation increase in M2 leading to a slight increase in GDP in the short run. GDP increases 1.0 percent by the sixth quarter and the effect on GDP is insignificant after the 9th quarter. Viewed over the 60-quarter horizon, however, we find a significant stimulus to GDP after the 40th quarter, the apparent result of the continued increase in M2.

On the financial side of the market, a positive shock to M2 leads to a sharp increase in the federal funds rate for 13 quarters. The rate increases by 16 percent in four quarters, 47 percent in eight quarters, and by 65 percent in 13 quarters. After rising, the federal funds rate remains in a range 57 to 65 percent higher than its pre-shock value. The response of the federal funds rate to a monetary shock becomes insignificant at 29 quarters.

Long-term rates do not rise as much as short-term interest rates, consequently a positive M2 shock causes the interest-rate spread to decline by 11 percent in four quarters, 26 percent in 8 quarters, and 33 percent in 13 quarters. After falling for 13 quarters, the spread rises moderately for eight quarters and remains in a range 22 to 28 percent lower than its pre-shock value.

The shock to M2 leads to a continuing increase in the price level that becomes significant at eight quarters. At eight quarters, the GDP deflator is 1-percent higher than its pre-shock value; at 20 quarters, it is 7-percent higher; and at 60 quarters, it is 28-percent higher.

In the short term, a monetary surprise reduces the velocity of M2. Over an eight-quarter time horizon, nominal GDP increases by less than M2. At eight quarters, nominal GDP is only 1.8 percent higher than its pre-shock value, while M2 is 3.6-percent higher. Apparently, the 47-percent increase in nominal federal funds rates is not sufficient to prevent a drop in the velocity of M2.

Over the longer-term, however, the velocity of M2 is nearly constant. At 60 quarters, nominal GDP is 40 percent higher than its pre-shock value, while M2 is 43 percent higher. The unchanged velocity of M2 is consistent with a federal funds rate that is insignificantly different from its pre-shock value.

3.2 *Responses to an Interest Rate Shock*

As shown in figure 2, the impulse responses indicate that a shock to the federal funds rate leads to significant, but transitory changes in all other variables. In response to its initial shock of 8 percent, the federal funds rate rises sharply for 14 quarters, reaching a value 70-percent higher than its pre-shock value. After rising, the federal funds rate remains relatively constant in a range from 68 percent to 74 percent higher than its pre-shock value. The response of the federal funds rate to its initial shock becomes insignificant at 40 quarters.

As would be expected, a one-standard deviation increase in the federal funds rate leads to a small and transitory decrease in GDP. GDP declines 0.2 percent in four quarters and by a maximum of 5.9 percent in 20 quarters. After that, the impulse gradually weakens, becoming insignificant at 38 quarters.

On the financial side, a positive shock to the federal funds rate leads to declines in both M2 and the spread between short- and long-term interest rates. The effect on M2 is small and transitory. In response to the shock in the federal funds rate, M2 declines 1.2 percent in 4 quarters and by a maximum of 2.3 percent in ten quarters. After that, the impulse weakens, becoming insignificant at 14 quarters.

In contrast, the increase in the federal funds rate leads to a long-lived decline in the spread between long- and short-term interest rates, with the change in the spread significant at 60 quarters. The decline the in spread is substantially less than the increase in the federal funds rate, implying that the long-term rate also rises, but not as much as the short term rate. The spread falls by a maximum of 2.7 percent in 13 quarters. Its is relatively constant, thereafter, but the impulse becomes insignificant at quarter 38. The impulse barely reaches significance again at quarter 51 and remains significant through quarter 60.

A federal funds rate shock leads to a small, transitory increase in the GDP deflator. By quarter 12, the interest rate shock leads to a 2-percent increase in the GDP deflator. This increase in the GDP deflator is relatively small given the 67-percent increase in the federal funds rate that occurs over the same period. By quarter 13, the effect on the GDP deflator is no longer significant.

3.3 *The Price Puzzle*

The small, transitory impact of an interest rate shock on inflation is evidence of what has been termed "the price puzzle." (See Balke and Emery 1994.) Like much previous empirical research, we find the seemingly anomalous result that tighter monetary policy--as measured by an increase in the federal funds rate--leads to an increase in the price level. We do find, however, that including oil prices in the model quantitatively reduces the price puzzle.

Our findings are broadly consistent with those of Christiano, Eichenbaum and Evans (1994). They find that accounting for supply shocks by using an index of commodity prices resolves the price puzzle. An upward shock to commodity prices leads to both an increase in short-term interest rates and a higher price level. If supply shocks are omitted from the model, the co-movement of interest rates and the price level materialize as the price puzzle when a shock is applied to interest rates.

We find that an upward oil price shock leads to both an increase in the federal funds rate and a higher price level. In addition, introducing oil prices into our VAR model reduces the effects of interest rate shocks on the price level, but does not eliminate them. Using a real commodity price index in place of oil prices eliminates the price puzzle from our results. Oil prices were a major source of supply shocks during the estimation period, but not the only source.

4. Oil Price Shocks and Aggregate Economic Behavior

A variance decomposition shows that oil price shocks play an important role in the volatility of both the real and financial variables in our model (Table 1). In the first quarter, oil price shocks are an important source of volatility in the GDP deflator--accounting for 16.4 percent of the variance in forecast error. By the fourth quarter, oil price shocks are an important source of volatility to real GDP as well as the price level. By the eighth quarter, oil price shocks are an important source of volatility in real GDP, M2 and the price level. At 60 quarters, oil price shocks remain an important source of volatility for M2, and the deflator. Oil price shocks do not seem to be much of a source of volatility in either the federal funds rate or the spread between long- and short-term interest rates.

Combined, these findings suggest that oil price shocks have transitory effect on GDP, and permanent effects on M2 and the price level. The lack of response in the interest rate variables, suggests that monetary policy may play a role in the inflation that results from an oil price shock. An examination of the impulse response functions resulting from an oil price shock provides a clearer picture.

As shown in figure 3, the impulse responses indicate that an oil price shock affects all other variables in the model significantly. Some of the effects are transitory, some are long lived, and some are permanent. In response to its initial shock of 8 percent, oil prices rise for 33 quarters, reaching a value 95 percent higher than its initial value. Although the impulse weakens somewhat after reaching its peak, it remains significant throughout the 60-quarter time horizon.

4.1 *GDP Response*

Real GDP initially responds to a one-standard deviation shock in the real oil price with a barely significant uptick that lasts four quarters and reaches a maximum of 0.5 percent in the fourth quarter. The effect on GDP is insignificant in quarters five through ten, after which the impulse to GDP is negative. GDP falls a maximum of 3.0 percent below its pre-shock value by quarter 29. Thereafter, the impulse to GDP weakens, and it is no longer significant by quarter 34.

Our findings are similar to those of Hamilton (1983), Tatom (1988), Mork (1989 and 1994), and Huntington (1995) who find decreases in real gross national product after an oil price shock. Like Tatom, we find only temporary decline in output results from an oil price shock. If the maximum decline in GDP is normalized by the maximum increase in the price of oil, the resulting oil price elasticity of GDP is -0.045.[3] This elasticity is near the average of -0.05--and well within the range of estimates of -0.02 to -0.076--found in a 1987 Energy Modeling Forum study (Hickman et al. 1987).

4.2 *Interest Rates and Monetary Responses*

On the financial side, the oil-price shock leads to a transitory increase in short-term interest rates, a transitory decline in the spread between long- and short-term interest rates, and a delayed response in M2. The federal funds rate rises 13 percent above its pre-shock value by the fourth quarter, 27 percent by the eighth quarter, and 32 percent by the eleventh quarter. Impulses to the federal funds rate lose significance in the twelfth quarter.

The interest-rate spread falls 5 percent below its pre-shock value by the fourth quarter and 11 percent by the eighth quarter. The difference between the decline in the spread and the increase in the federal funds rate may be taken to imply that long-term rates also rise, but not as much as short-term rates. Impulses to the spread lose significance in the ninth quarter, implying no that is no difference between the response of long and short rates after two years.

The increase in oil prices yields a delayed response in M2. The oil price shock has no significant effect on M2 until quarter 41. After becoming significant, the M2 response increases steadily throughout the time horizon, with M2 rising 24 percent above its pre-shock value in quarter 60.

4.3 *Inflationary Response*

A shock to oil prices leads to a permanent increase in the price level. In addition, the price level rises throughout the 60-quarter time horizon.[4] During the first 11 quarters, the price level rises at an increasing rate. At four quarters, price level is 0.7 percent higher than its pre-shock value; at eight quarters, it is 2.5 percent higher; and at eleven quarters, it 4.2 percent higher.

After the eleventh quarter the impetus to inflation moderates. Nonetheless, the inflation persists and the price level rises throughout the 60-quarter time horizon and remains significant. At the end of the period, the price level is 22 percent higher than its pre-shock value. Estimated at the end of the 60-quarter period, the elasticity of the price level with respect to the real price of oil is 0.32.

4.4 *Inflation, GDP and Monetary Policy*

Throughout the 60-quarter time horizon, we find that an oil price shock yields a greater percentage increase of the GDP deflator than the percentage decline in real GDP. In other words, an oil price shock results in an expansion of nominal GDP, a finding that is inconsistent with a neutral monetary policy. The expansion of nominal GDP implies that accommodative monetary policy validates the inflationary impact of oil price shocks, which is consistent with Trehan's (1990) analysis.[5]

The response of real GDP and the price level are consistent with a supply-side response to an oil price shock. The shift in aggregate supply lowers output and increases prices. The Federal Reserve tries to offset the rise in prices by increasing the federal funds rate to slow the rate of money growth. In the medium term, however, the policy is neither strong enough or persistent enough to prevent a rise in nominal GDP, as the velocity of money increases. At 16 quarters after the oil price shock, M2 is unchanged from its pre-shock level, but nominal GDP is 4.7 percent higher than its pre-shock level. Over the longer run, velocity returns to its pre-shock levels, but the money supply is increased. At 60 quarters, M2 is 24 percent higher than its pre-shock value.

5. Summary and Conclusion

We use a VAR model of the U.S. economy to assess how oil price shocks move through major channels of the economy to affect inflation. The model represents the interactions between six variables: the real oil price, real GDP, M2, the federal funds rate, the spread between rates on U.S treasury bonds with a ten-year constant maturity and U.S. treasury bills with a three-month constant maturity, and the GDP deflator. Estimation used quarterly data from the period 1970 to 1994.

We use impulse responses to assess the model's ability to represent aggregate economic behavior. The responses to monetary and interest rate shocks generally conform to economic theory. Monetary shocks have persistent effects on real GDP and the price level, but appear to depend on a forecast that the shock to the monetary aggregate grows over time. Shocks to the federal funds rate have small and temporary effects on the price level. Omitting the oil price variable substantially increases the magnitude and duration of the effect on the price level, and replacing the oil price variable with a commodity price variable eliminates the effect.

We also use impulse responses to assess the channels through which oil prices affect aggregate economic activity. We find that a shock to real oil prices leads to transitory effects on real GDP, the federal funds rate, and the spread between long- and short-term interest rates. M2 shows a long delayed but permanent response to an oil price shock. The change in the price level is permanent and grows over time.

We find that an oil price increase results in an permanent expansion of nominal GDP, which is inconsistent with a neutral monetary stance. In the near to medium term, an increase in the velocity of M2 accounts for the increase in nominal GDP. Over the longer term, velocity is stable, but the money supply is increased. These findings suggest that during the estimation period, monetary policy generally accommodated the inflationary pressure of oil price shocks.

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Notes

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1. Although real oil prices are somewhat more volatile than real energy prices, changes in real oil prices may represent changes in energy prices. Yücel and Guo (1994) have shown that oil prices and other energy prices generally move together in the long run.

2. Data for all series are available for a longer span of time. We restricted the estimation period to one in which oil prices showed volatility.

3. The reported value is calculated on a constant elasticity basis.

4. Kahn and Hampton (1990) find an oil price shock is likely to lead to a persistent pick-up in the inflation rate because cost-of-living adjustment clauses and other contracts raise input prices and inflationary expectations are increased.

5. Darby (1982) notes that additional factors, such as the final breakdown of pegged exchange rates and the dismantling of price controls, may have augmented the inflationary effects of oil price shocks.

Figure 1
Monetary Shock with 80% Confidence Bands

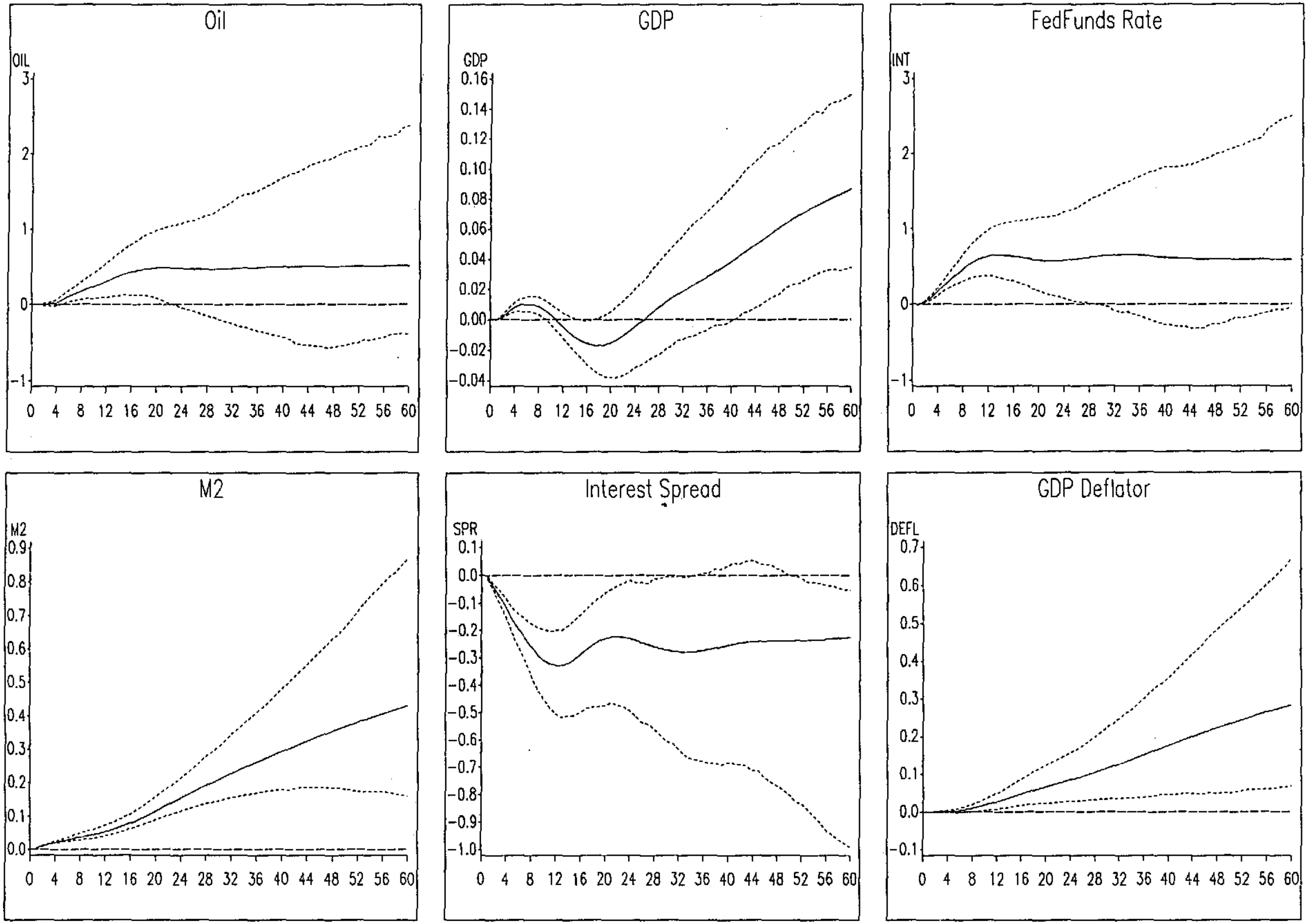


Figure 2
Federal Funds Shock with 80% Confidence Bands

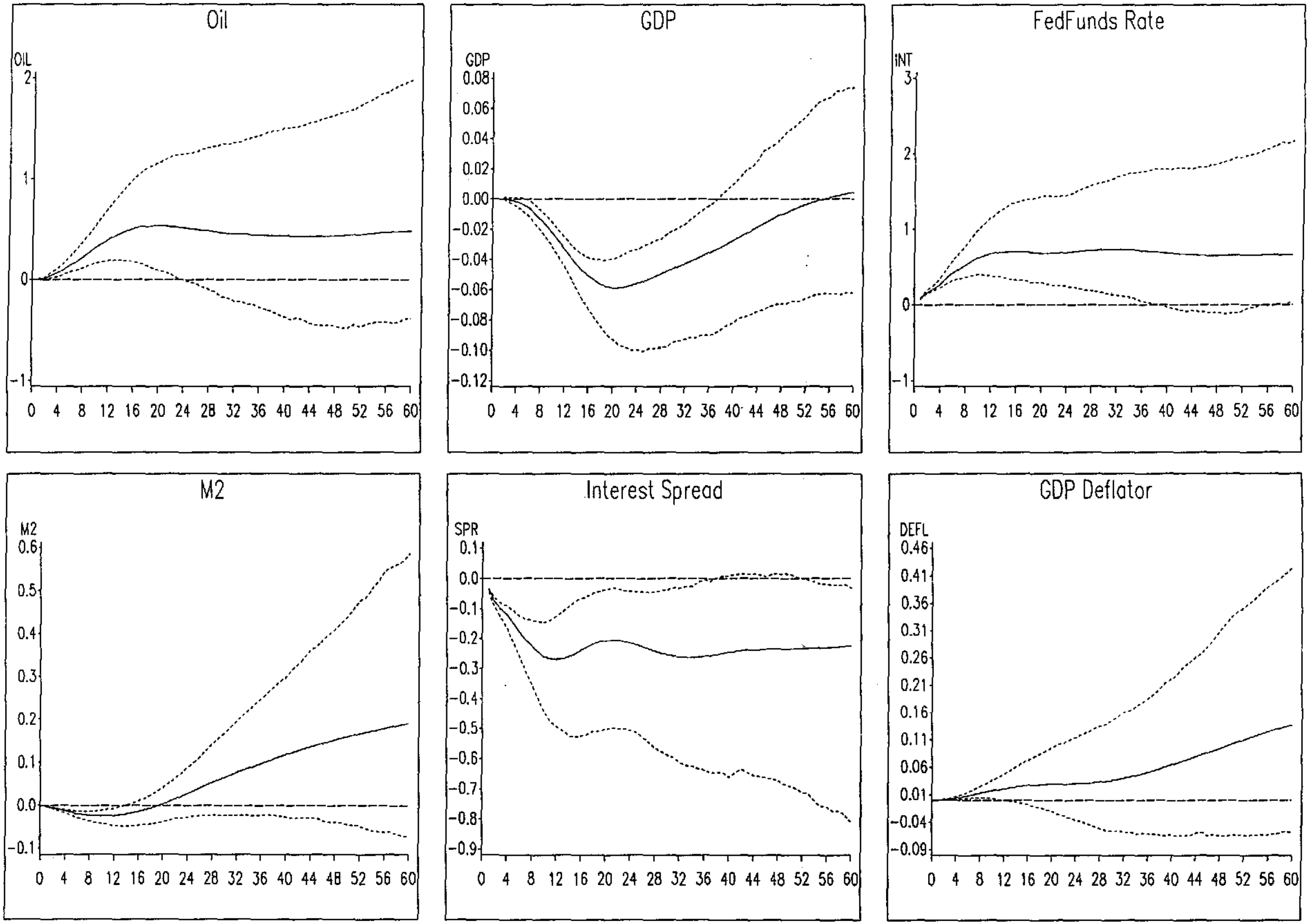
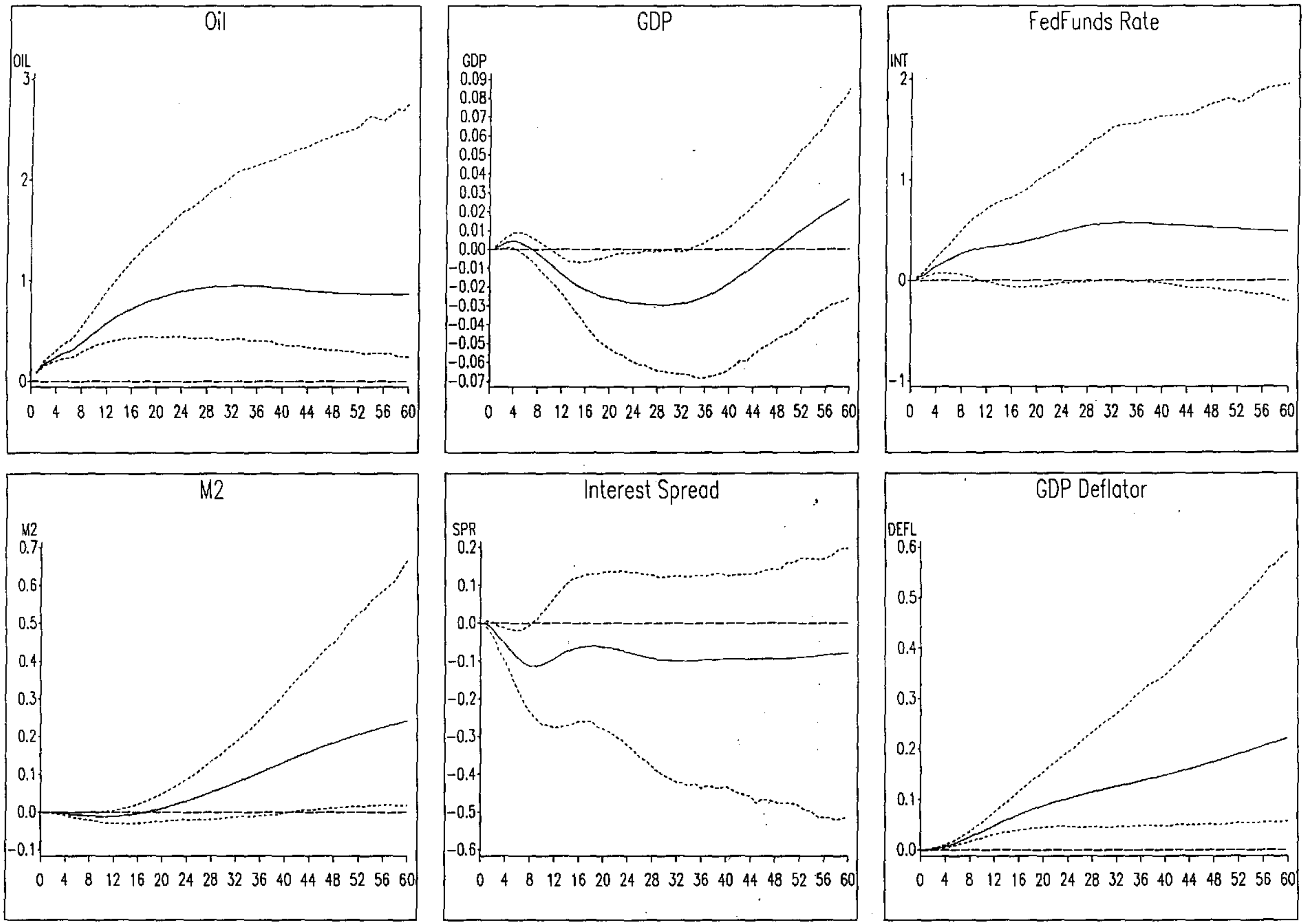


Table 1. Effect of Oil Price Shocks on Forecast Error Variance

	GDP	Fed Funds	M2	Spread	Deflator
1Q	2.6	1.8	0.0	0.1	16.4
4Q	10.5	7.8	5.6	4.0	25.6
8Q	13.2	5.6	14.1	3.7	27.3
20Q	10.3	4.4	8.8	5.5	24.3
32Q	8.6	4.9	7.0	5.7	24.5
60Q	8.6	5.5	12.3	6.0	24.0

Figure 3
Oil Price Shock with 80% Confidence Bands



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