Oil Shocks and the Macroeconomy: The Role of Price Variability

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In this paper we argue that an oil price change is likely to have greater impact on real GNP in an environment where oil prices have been stable, than in an environment where oil price movement has been frequent and erratic. An oil price shock variable reflecting both the unanticipated component and the time-varying conditional variance of oil price change (forecasts) is constructed and found to be highly significant in explaining economic growth across different sample periods, even when matched against various economic variables and other functions of oil price. We find that positive normalized shocks have a powerful effect on growth while negative normalized shocks do not.

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[*] An earlier version of this paper was presented at the world meeting of the IAEE in Stavanger, Norway, May 1994. The authors have benefited from comments by James Hamilton, Knut Mork, and Oystein Thogerson. The authors are with the Department of Economics, University of Missouri-Columbia, 118 Professional Building, Columbia, Missouri, 65211. USA.

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Introduction

In an influential paper, Hamilton (1983) found within a vector autoregression (VAR) framework that oil price change has a strong causal and negative correlation with real U.S.GNP growth from 1948 to 1980. Mork (1989) showed that when the sample period is extended to 1988:2 the correlation becomes only marginally significant, and more importantly that there is an asymmetry in effects: GNP growth has a definite negative correlation with oil price increases and a statistically insignificant correlation with oil price decreases.

Burbidge and Harrison (1984) using somewhat different data and methods also found significant impacts of oil and energy shocks on real activity for the U.S.[1] Using annual data, Mory (1993) showed that increases and decreases in real oil prices have asymmetric effects on output and other macrovariables variables from 1951 to 1990, and on personal income and earnings in most industries from 1959 to 1989. Darby (1982) made international comparisons of oil shock impacts within a VAR framework and found for the U.S. that the estimated oil shock effect was much reduced if price controls during the 1970s were taken into account. Hooker (1994) found the predictive power of oil shocks on macrovariables diminishes as the sample is further updated. These studies generally show that the effect of oil price increases and decreases have asymmetric effects on the economy and that the effects vary across time and countries.

As noted by Mork, until the oil price collapse in late 1985 the major oil shocks since 1948 were price increases. Since 1986:1 a pattern of large price increases and decreases is reflected in a substantial rise in the volatility of real oil price as illustrated in Table 1. Wide swings in real oil price during 1986 and 1987 have continued into the 1990s. For example, real oil price fell by 20 percent in 1990:2, rose by about 40 percent and 30 percent in 1990:3 and 1990:4 fell by 34 percent and 9 percent in 1991:1 and 1991:2. The real oil price in 1991:2 was almost back at the level one year earlier having almost doubled

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[1] They used monthly data in a VAR over 1962-82 to examine the impact of oil shocks in several OECD countries and found that the impact on Industrial Production was larger for the U.S. and U.K. than that for other countries.

during the interim. More recently a fall in the real oil price of about 13 percent in 1992:1 was followed by a rise of about 13 percent in 1992:2.

Our objective in this paper is to further explore the issue of causality of real oil price to the macroeconomy in the light of experience up to 1992. Unlike earlier periods, movements in real oil price and GNP during 1986:2-1987:3 and 1990:4-1992:3 have a positive correlation. This reversal in the relationship and large swings in real oil price provide an opportunity to further explore the relationship between oil price and GNP. A brief discussion of some results for different sample periods will help motivate the study.

Table 2 reports results for real GNP growth as the dependent variable in a vector autoregression (VAR) for three different sample periods. Results from a seven variable VAR show that real oil price change is significant at one percent during the period 1949:1-1986:1, but is not statistically significant for samples including more recent data. This result was noted by Mork for the period ending 1988:2. The seven variables are basically the same as those appearing in the seven variable system considered by Mork (1989): real GNP growth; GNP deflator inflation; 3-month Treasury bill rate; unemployment rate; wage inflation (average hourly earnings for production workers in manufacturing); import price inflation; and real oil price changes. As suggested in footnote 2, real oil price changes are calculated following Mork (1989). Data are from Citibase. Variables are in annual percentage terms. In summary, using Mork's model, we find similar results for the period considered by him, and further deterioration in the predictive power of oil price shocks for real GNP as the sample is further updated.

Results from an eight variable VAR show that real oil price increases are significant at 5 percent during 1949:1-1986:1 and 1949:1-1988:2 (the period considered by Mork), but not statistically significant at this level for the period 1949:1-1992:3.[2] In addition, formal tests of pairwise equality of coefficients for real oil price increases and decreases have p-values of 0.355 for 1949:1-1986:1, 0.042 for 1949:1-

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[2] The F values are different from those appearing in Table 1 in Mork (1989). This is probably due to several factors. While Mork's method is followed in that refiners acquisition cost for crude oil is used rather than the PPI (because of the price controls of the 1970s) when possible, monthly oil price data is averaged to obtain quarterly observations rather than using a single monthly observation during a three month period to represent a quarterly observation as in Mork. In addition, the import price variable is exclusive of movement in the price of oil imports. Mork noted the decline in statistical significance of real oil price change when the sample is extended to 1988:2. However, for his data, real oil price change was marginally significant at the 7% level. Also, Mork found the oil price increase variable to be somewhat more statistically significant for the period 1949:1-1988:2 than that reported here.

1988:2, 0.044 for 1949:1-1992:3. Thus the hypothesis of symmetry is not rejected for the early period, but is rejected at the 5 percent level for periods ending in 1988:2 and 1992:3.[3]

This paper claims that the real oil price has not lost predictive power for growth in real GNP if appropriate account is taken of oil shocks and the variability of real oil price movement. The basic idea is that an oil shock is likely to have greater impact in an environment where oil prices have been stable than in an environment where oil price movement has been frequent and erratic. The oil price shock variable proposed to be included in a VAR system reflects both the unanticipated component of real oil price movement and the time-varying conditional variance of oil price change forecasts. This variable can be thought of as being a measure of how different a given oil price movement is from the prior pattern.[4]

It is found that this variable is highly statistically significant in explaining GNP growth over different sample periods, even when matched in a VAR against other functions of real oil price.[5] These results are consistent with the view that the effect of a change in real oil price depends upon whether it is an unusual event rather than merely an adjustment in response to a change in the previous month. An asymmetry is found to exist between the effects of positive and negative normalized shocks in all sample periods. Positive normalized shocks in real oil price are strongly related to negative real growth. Negative normalized shocks are not statistically significant. A generalized autoregressive conditional heteroskedasticity (GARCH) model is utilized to construct the conditional variation of oil price changes used to normalize unexpected movements in real oil price. This model is presented in the second section. Empirical results on the causal relationship between oil prices and GNP growth are presented in the third section. The impulse responses of GNP growth and unemployment over multiple horizons to normalized oil price shocks are discussed in the fourth section. Concluding remarks are made in the last section.

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[3] The hypothesis of parameter stability for the asymmetric model for extension of the sample from 1986:1 to 1988:2 and from 1986:1 to 1992:3 cannot be rejected (p-values of Chow test are 0.466 and 0.852 for the two periods).

[4] The suggestion that the prior pattern of relative price change has real consequences is not new. It has been argued by Davis (1987) and Hamilton (1988b) that the predicted effects of a given change in real oil price (or relative material price) are quite different depending upon the previous pattern of oil price change.

[5] It should be emphasized that this outcome holds even for periods that exclude the mid and late 1980s and early 1990s.

THE MODEL OF PRICE VARIABILITY

A distinguishing feature of the model employed in this paper from earlier work is incorporation of an oil shock variable normalized by a measure of oil price variability. A univariate GARCH error process is used to compute the unexpected component and conditional variance of real oil price.[6] These variables are then used to augment the VAR system of Hamilton and Mork.

A univariate regression with error GARCH (*p,q*) error process in the quarterly rate of change in real oil price z_t, can be represented as

$$z_t = a_0 + \sum_{i=1}^{r} a_i z_{t-i} + \sum_{i=1}^{s} x_{t-i}\beta_i + e_t, \tag{1}$$

where $$e_t | I_{t-1} \sim N(0, h_t),$$

and $$h_t = \gamma_0 + \sum_{i=1}^{q} \gamma_i e_{t-1}^2 + \sum_{j=1}^{p} \gamma_{q+j} h_{t-j}. \tag{2}$$

$\{x_{t-j}: j \geq 1\}$ denotes an appropriately chosen vector contained in information set I_{t-1}, $t = 1, \ldots, T.$, β is a vector of coefficients. The conditional expectation $z_t, \hat{z}_t = E(z_t \mid I_{t-1})$, is assumed to be a linear projection on the conditioning information. The unexpected part of the rate of change in real oil price is defined as $e_t = z_t - \hat{z}_t$.

The metric e_t does not reflect changes in conditional variability over time. When the data generating process is described by equations (1) and (2) a measure of an unexpected oil shock that does reflect the magnitude and the variability of the forecast error e_t, might be defined as

$$e_t^* \equiv e_t / h_t^{1/2}. \tag{3}$$

It is the central hypothesis of this papers that e_t^* can be expected to have a more systematic causal relation to the real GNP than either z_t or e_t. The intuition is that a given unexpected rate of change in real oil price will have a smaller impact on real activity when conditional variances are large since much of the change in real oil price will be regarded as transitory. The variable e_t^* can be thought of as being a measure of how different a given oil price change is from the historical pattern.

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[6] See Engle (1982), Bollerslev (1986), Bollerslev, Engle, and Wooldrige (1988), and Bollerslev, Chou, and Kroner (1992), among others, for discussion of various ARCH and GARCH models.

When changes in real oil price are regarded as exogenous shocks (e.g., Granger prior with respect to macroeconomic variables) the choice of right hand variables of equation (1) would seem to be limited to lagged values of the dependent variable. A search over alternative specifications for x_{t-1}, including various lag lengths, and the three month T-bill rate, rate of change in the GNP deflator, and the unemployment rate as possible explanatory variables did not result in finding a variable with statistical significance at the 5 percent level in explaining z_t. When z_t is regressed on its own lags, lags one to four and lag eight are significant at the 5 percent level. Since the first four lags alone make the Ljung-Box Q statistic with 36 lags statistically insignificant, only the first four lags are included.

GARCH(1,1) was adopted as a parsimonious representation of the process of conditional variance of $\{e_t\}$ in equation (1) with $r = 4$ and $s = 0$.[7] Table 3 presents parameter estimates of equation (1). The GARCH(1,1) parameters are significant and have the correct sign.[8] The sum of $\hat{\gamma}_1$ and $\hat{\gamma}_2$ (2.405) indicates the conditional variance process is highly persistent, i.e., integrated GARCH with integration order higher than 1 (see Engle and Bollerslev (1986)).[9] It will be assumed that the usual asymptotic theories for integrated GARCH processes apply to the model.[10] An analysis of residuals does not suggest the presence of information unexploited by the model. The Ljung-Box Q test statistic with 36 lags yields 32.403 with marginal p-value 0.640 (based on a χ^2 distribution with 36 degrees of freedom). This model is used to generate e_t and e_t^*.

The normalized oil price shocks in real oil price e_t^* usually assumes smaller magnitudes after 1974 relative to magnitudes assumed before 1974. In terms of Hamilton's (1983) oil price episode classification, an analysis of oil price change in terms of rather than z_t raises the importance of the oil

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[7] Bollerslev, Chou, and Kroner (1992; p. 10 and p. 20) argue in favor of low-order GARCH modeling, and especially for GARCH(1,1).

[8] For the sample period 50:1-86:1 the coefficient on h_{t-1} is not significant although that of e_{t-1}^* is significant at the 5 percent level. For the sample period 50:1-88:2, both parameter estimates are significant. For all three sample periods, the parameter estimates of GARCH(1,1) indicate persistence in conditional variance of e. In the VAR results presented below a GARCH system is estimated for each sample period corresponding to the sample period over which each VAR is estimated. The VAR results do not substantively change if the model reported in Table 3 were used to generate e_t in all the VAR models.

[9] When three dummies for structural shifts in the dates used are included in GARCH(1,1), the sum of $\gamma_1 and \hat{\gamma}_2$ decreases to 1.30, and when an ARCH (4) is used the sum of the γ coefficients is reduced slightly. These alternative models of conditional variance of oil prices do not change the main results of the paper.

[10] See Nelson (1990), Bougerol and Picard (1992), and Lumsdaine (1991) for discussion of the asymptotic properties of integrated GARCH models. It has been noted by several researchers that persistence in the conditional variance process could be

price rises of 1952-53, of those during the Suez crisis, and of those in 1969 and 1979 relative to the oil price shock of 1973-74 and the price rises since early 1986. These observations reinforce the view that oil price shocks have always been important in the macroeconomy and are not solely a phenomena of the 1970s.[11]

THE EMPIRICAL RESULTS

The consequence of introducing surprises in the rate of change in real oil price change normalized by their conditional standard deviation, e_t^*, to various VAR systems is reported in Table 4.[12] It can be seen from the second line of Table 4 that normalized oil price shock is highly significant for all three sample periods while real oil price change is insignificant. The issue of asymmetric effects of normalized positive oil price shocks is explored in the remainder of Table 4. Two variables are defined for normalized shocks in oil price equal to either the positive or the negative values of and zero elsewhere. It can be seen from the exclusion tests for the nine and ten variable systems in Table 4 that positive normalized shocks are highly significant in all three sample periods. Negative normalized oil price shocks are not statistically significant in any of the VAR systems. In the presence of positive and negative normalized oil price shocks the variables oil price change and positive and negative oil price changes do not achieve statistical significance.[13]

Table 5 reports lag coefficients for various normalized oil price shock variables. Results for an eight variable VAR (the six macro variables, z_t, and e_t^*) appear in the upper part of the Table. The coefficients on the normalized shock variable are negative. Results when positive and negative oil price

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due to of the variance equation. Lamoureux and Lastrapes (1990) found a substantial decline in the persistence in stock return variance when intercept dummies are included (see also (1986)).

[11] An analysis of oil price change episodes in terms of unexpected oil price change (e_t) would lead to qualitative conclusions similar to that suggested by z_t. The correlation of e_t, and z_t, over 1949:3-1992:3 is 0.879, whereas the of with e, and z, are 0.696 and 0.608, respectively. It might be of interest to note that achieves its largest value in (slightly higher than the second highest value achieved in 1974:1).

[12] The effect of introducing unexpected oil price change (e_t) rather than e_t^* to the VAR system is reported at the bottom of Table 2. It can be seen that unexpected oil price change is not statistically significant. We also find that the predictive power of expected oil price change on GNP growth resembles that of the actual oil price change and is insignificant. The detailed results are not reported here.

[13] The results are robust to alternative models of conditional variance. When the last column of Table 4 is reproduced with obtained from a I) with three intercept dummies, the following F statistics are obtained. Eight variable system 3: 1.684 (z, real oil price change) and 5.073 (e^*). Nine variable system: 0.852(z) 9.447 (e^{*+}) *and 1.342*(e^*). Ten variable system: 0.852 (z), 0.567 (z^-), 7.878 (e^{*+}), and 1.647 (e^{*-}). The results obtained from an ARCH(4) are almost the same as above and are available upon request.

changes replace z_t and positive and negative normalized shocks replace e_t^* appear in the lower part of Table 5. The coefficients on positive normalized shocks are all negative. For all sample periods the hypothesis of pairwise equality of the coefficients on normalized unexpected oil price increases and decreases can be rejected at the one percent level, as can the hypothesis of parameter change as the sample is extended from 1986:1 to later periods.

The above results are robust for variation in lag length and model specification. For example, if the import inflation variable is omitted, the asymmetry observed by Mork disappears, whereas the normalized shock is still significant. For the whole sample period, in the seven variable VAR system 1 in Table 2, the F-statistic (p-value) of oil price increases becomes 1.574 (0.182) (oil price decreases becomes 0.957 (0.433)) when the import price variable is excluded. Following this exclusion for the seven variable VAR system 3 in Table 4, the F-statistic (p-value) for oil price change becomes 0.988(0.416) and for e^* becomes 4.991(0.001). Similarly, while increases in lag length change some results, normalized shocks remain significant.[14] Table 6 reports results of a VAR model including only GNP growth and oil price changes. Results are similar to those reported above for larger VAR systems. Normalized oil price shocks provide significant information for GNP growth in all periods, and positive normalized shocks are more important than negative normalized shocks in explaining GNP growth.

As an additional check of the robustness of the predictive power of the normalized oil price shock variable we pursued a suggestion by James Hamilton that the relationship between the impulse response of real GNP growth obtained from a nonparametric kernel estimate and e_t^* be examined. We let a nonparametric kernel estimator $\mu_{t+n}(y_t,..y_{t-L})$ of the conditional expectation, $E(y_{t+n}|y_t,..y_{t-L})$,

$$\mu_{t+n}(y_t,..,y_{t-L}) = \sum_{i=L,i\neq t}^{T-n} y_{i+n}k_{it},$$

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[14] For example, for the period ending 92:3, in the 8 variable VAR system 1 reported in Table 2 (not normalized variables) if lag is 6, F-statistic (p-value) for oil$^+$ is 1.107 (0.362), and oil$^-$ is 1.190 (0.316); if lag is 8, then oil$^+$ is 1.242 (0.282), and oil$^-$ is 1.021(0.425). In the 8 variable VAR system 3 reported in Table 4, if lag is 6, then the p-value for e^* is 2.601 (0.021), and if lag is 8 then it is 2.018 (0.052). In the 10 variable VAR in Table 4 with lag 6 e^{*+} is 3.112 (0.007) and e^{*-} is 0.993 (0.433), and with lag 8 e^{*+} is 2.305 (0.051) and e^{*-} is 0.696 (0.695).

where k_{it} are the Gaussian kernel weights given by Pagan and Hong (1991):

$$\kappa_{it} = \exp[-\textstyle\sum_{k=0}^{L}(y_{i-k} - y_{t-k})^2 /(2\psi_k^2)] / \sum_{j=L, j\neq t}^{T-n} \exp[-\sum_{k=0}^{L}(y_{j-k} - y_{t-k})^2 /(2\Psi_k^2)]$$

and the bandwidths ψ_k are set to be the sample standard deviations of y_{t-k} multiplied by $T^{1/(5+L)}$. The nonlinear impulse response (with L set to be 3) is defined as

$$\xi_{t+n}(y_t, \Delta) = \Delta^{-1}[\mu_{t+n}(y_t + \Delta, .., y_{t-L}) - \mu_{t+n}(y_t, .., y_{t-L})].$$

When regression equations were run with different forecasting horizons, n, with ξ_{t+n} as dependent variable and e^{*+} and e^{*-} as independent variables it was found that e^{*+} is significant for every n whereas e^{*-} is only marginally significant. (Other functions of oil price change were less significant if used in the same regression.) This is consistent with the strong statistical significance of positive normalized oil price shocks in predicting growth and the presence of asymmetry between positive and negative oil price shocks found in the VAR analysis. The nonparametric estimator of y uses no other information than the data in the real GNP series yet leads to results supportive of the VAR findings. It should be emphasized however, that experiments with alternative kernels suggested by a referee yielded statistically insignificant results. The details of the nonparametric models and results are available from the authors upon request.

Results consistent with those obtained above emerge when a variance decomposition metric is used as an alternative to F-statistics (see, for instance, Bernanke and Blinder (1992) for the pros and cons of the two metrics). The fractions of the variance of the forecasted GNP growth accounted for by nine elements (excluding the lags of growth itself) in the ten-variable VAR (in Table 4) at one-year horizon become 0.146 for the T-bill, 0.087 for oil price increases, and 0.253 for e^{*+}. The fraction attributable to e^{*+} is the largest among the nine variables despite the fact that e^{*+} and e^{*-} are placed last in the ordering of variables.[15]

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[15] At a two-year horizon, the T-bill becomes slightly more important than e^{*+} in terms of variance decomposition (e.g., 26.1 1% for the T-bill and 24.86% for e^{*+}). At horizons of 3, 4, 5, and 6 years, however, the variance accounted for by e^{*+} attains values close to 27% while that of the T-bill is about 23.6%.

IMPULSE RESPONSES OF OUTPUT AND UNEMPLOYMENT

The impact of e_t^* on GNP growth and unemployment over multiple horizons is investigated using orthogonalized impulse responses. The impulse responses are obtained form a moving average representation of a seven-variable VAR with variables placed in the following order: GNP growth, GNP deflator inflation, unemployment, the 3-month Treasury bill rate, real wage growth, import price inflation, and e_t^{*+}. The ordering of the VAR implicitly assumes that e^{*+} does not affect current GNP growth. The middle line in Figure 1 illustrates the response in GNP growth to a one-standard-error shock in e_t^{*+}. Five negative responses are followed by five positive responses, with the effect of the oil shock greatly diminished after ten quarters.[16]

In order to assess the significance of the impulse response, standard errors are also calculated from the variances of the posterior distribution of the orthogonalized impulse responses. One hundred random draws are made directly from the posterior distribution of the VAR coefficient. The solid lines above and below the line connecting the squares in Figure 1 represent plus and minus 2 standard errors obtained from the simulation. It turns out that only the impulse responses at horizons 3, 4, and 8 quarters are statistically significant. The sum of responses over 24 horizons is -0.65 which is (in absolute value) larger than one-half the largest negative impulse response obtained at the 4-quarter horizon. The negative sum suggests that there is a decline in the level of GNP over 24 horizons following an oil shock.

The results for the unemployment rate are somewhat stronger. Except for the first two small negative responses, Figure 2 shows persistent positive responses of unemployment to a shock in e_t^{*+}. The sum of 24 responses is 1.86 and five responses are statistically significant, i.e., those at the 4 through 8 quarter horizons. This indicates a cumulative loss in employment that is not offset at later dates by subsequent increase in the GNP growth rate during the second and third years following an oil price shock. While the impulse of GNP growth reaches a positive peak at the 8-quarter horizon, the response of unemployment at the 8-quarter horizon is significantly different from zero. This might indicate that the

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[16] This finding is consistent with that of Burbidge and Harrison (1984) in that the oil shock variable does not help improve forecasting macroeconomic variables beyond a 3-year horizon.

recovery in output after an oil shock is mainly accounted for by an increase in productivity. This explanation may be consistent with the finding of Blanchard (1989) that the variance of productivity innovation is three times larger than the variance of labor force participation innovation.

CONCLUSION

This paper has presented results on the causal relationship of normalized oil price shocks to real GNP growth. Results suggest that a real oil price surprise has a greater impact on real GNP (and unemployment) the more stable has been the real price of oil prior to the innovation. An asymmetry in effects was found to exist in that only positive normalized oil price shocks were statistically significant. This specification was stable over time, fitting observations before and after 1985, and results were similar whether or not other variables (including other functions of real oil price change) were included.

The results obtained in the paper are potentially explicable in the context of models containing multiple sectors and resource reallocation costs, or models capturing recent developments in the theory of investment as surveyed by Dixit (1992). A rise in real oil price that is large relative to recent volatility will result in reallocation of resources and the lowering of aggregate output (at least during the transition). During periods of high volatility in real oil price, since current oil price contains little information about future oil price, rational agents will be reluctant to reallocate resources in the presence of real costs of doing so.[17]

The asymmetric effect of change in real oil price follows from a sectorial shifts story since a fall in real oil price also results in resource reallocation with unemployment and output effects that mitigate positive macroeconomic effects. The asymmetry would be further reinforced given an "uncertainty" effect based on the new investment theory. In this framework the increased degree of uncertainty

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[17] In equilibrium business cycle models fluctuation in the real price of oil has been treated as exogenous and subject to positive serial correlation. The result has been negative and lagged effects of real oil price on output growth. See Finn (1992) and Kim and Loungani (1992) for real business cycle models incorporating oil and Davis (1987), Hamilton (1988a), and Loungani and Rogerson (1989) for work on business cycle models with real costs for reallocating resources. The results in this paper suggest that analysis of the impact of oil shocks in real business cycle theory might gain from allowing for the time varying nature of the second moments of parameters driving the model. In a paper with a somewhat different focus Loungani (1986) found that for the period 1947-82 oil price change was the major factor in explaining the dispersion of employment growth across industries and that it was associated with unemployment.

associated with higher volatility in real oil prices would result in investment being postponed. Hence, the positive macro effect of an oil price decline would also be somewhat offset by depressing effects of increased uncertainty.

It would also probably be appropriate to expand the search for explanations of the way in which oil affects economic activity to models containing rigidities. One of the strong results in the work conducted in this paper is the effect of e_t^* on the level of unemployment. These results are as robust as those for output growth but qualitatively opposite. For example, in the unemployment equation in a ten variable VAR an exclusion test for positive normalized oil price shocks has a p-value of 0.000 for 1950:3-1992:3, a p-value of 0.007 for 1950:3-1988:2, and a p-value of 0.011 for 1950:3-1986:1.[18] It is likely that a model in which real wage rigidity plays a significant role in the adjustment of the economy to changes in the real price of oil (and of other inputs) might be able to provide a satisfactory explanation of the results reported here.[19] Development of a formal model that explains the results presented here and further investigation of the effect of oil price shocks in other economies remains on the agenda for future work.

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[18] The lag on the positive shock variable for the period 1950:3-1992:3 in the unemployment equation in the 10 variable VAR are 0.0116(0.0444), 0.0025(0.0446), 0.1476(0.0438), and 0.1682(0.0432). Standard errors are in parenthesis. These results are consistent with arguments advanced by Mork and Hall (1980) concerning the effects of unexpected events in the presence of rigid wages. It is also worth noting that the unemployment variable in the GNP growth equation is statistically significant at the one percent level in all samples.

[19] The application of models containing rigidities is also in part suggested by the results of Kim and Loungani (1992). Within a conventional RBC model they found only a relatively small contribution of oil price shocks to an explanation for variability in output. The content of this section of the paper owes a great deal to suggestions made by Knut Mork, particularly on the need to examine models containing rigidities.

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Table 1. Summary Statistics of Changes in Real Oil

	50:1 – 86:1	50:1 – 92:3	73:1 – 79:3	86:1 – 92:3
Mean	1.1938	0.4241	16.7472	-8.0111
Std. Dev.	23.8877	35.7899	41.2152	75.2101
LM Test	26.2441	31.4915	4.4211	7.5542
(p-value)	(0.000)	(0.000)	(0.3520)	(0.1090)

Note: Std. Dev. denotes standard deviation of change in real oil price, z_t, defined as 400 times the log difference in the real price of oil. The Lagrange Multiplier (LM) test represents x^2 test statistics with four degrees of freedom for joint correlation tests of residuals of mean regression of z_t (marginal p-values are in parentheses). The null hypothesis of no serial correlation in residuals is rejected for the long sample periods, marginally accepted for 86:1-92:3, and accepted for 86:1-92:3, and accepted for 73:1-79:3.

Table 2. Exclusion Tests: Real GNP Growth Rate is the Dependent Variable

Variable	49:1 – 86:1	49:1 – 88:2	49:1 – 92:3
Seven Variable System			
Real Oil Price Change	3.439	0.998	0.797
	(0.010)	(0.411)	(0.529)
Eight Variable System 1			
Oil Price Increases	2.820	2.591	2.043
	(0.028)	(0.040)	(0.092)
Oil Price Decreases	1.128	1.525	1.079
	(0.347)	(0.199)	(0.369)
	49:4 – 86:1	49:4 – 88:2	49:4 – 92:3
Eight Variable System 2			
Real Oil Price Change	1.765	2.662	0.979
	(0.141)	(0.036)	(0.421)
Oil Price Shocks (*e*)	2.426	2.574	1.353
	(0.052)	(0.041)	(0.254)

Note: The exclusion tests are for joint hypothesis of zero coefficient on all four lags of each variable using F distributions with four degrees of freedom in the numerator and appropriate degrees of freedom in the denominator. Numbers in parentheses denote marginal p-values obtained from asymtotic t values. The six variables not appearing in the Table are basically the same as those in Mork (1989); real GNP growth; GNP deflator inflation; 3-month T-bill rate; unemployment rate; wage inflation; price inflation.

Table 3. Parameter Estimates of EQNS (1) & (2), Data from 1949:3 – 1992:3

Parameter	Estimate	Std. Error	p-value
α_0	-1.986	0.670	0.003
α_1	0.436	0.144	0.002
α_2	0.401	0.085	0.000
α_3	0.244	0.055	0.000
α_4	-0.238	0.066	0.000
γ_0	23.843	4.146	0.000
γ_1	2.208	0.385	0.000
γ_2	0.197	0.098	0.044

Table 4. Exclusion Tests: Real GNP Growth is Dependent Variable

Variable	50:3 – 86:1	50:3 – 88:2	50:3 – 92:3
Variable System 3			
Real Oil Price Change	1.709	2.186	1.096
	(0.153)	(0.075)	(0.361)
Normalized Oil Price Shock (e^*)	6.769	7.489	5.449
	(0.000)	(0.000)	(0.000)
Nine Variable System			
Real Oil Price Change	1.668	2.100	0.872
	(0.162)	(0.085)	(0.483)
Normalized Positive Oil Price	7.313	10.154	7.600
Shocks (e^{*+})	(0.000)	(0.000)	(0.000)
Normalized Negative Oil Price	1.468	1.123	1.483
Shocks (e^{*-})	(0.217)	(0.349)	(0.211)
Ten Variable System			
Real Oil Price Increases	1.230	1.740	0.432
	(0.303)	(0.146)	(0.785)
Real Oil Price Decreases	1.546	1.962	1.330
	(0.194)	(0.105)	(0.262)
Normalized Positive Oil Price	6.012	7.178	6.193
Shocks (e^{*+})	(0.000)	(0.000)	(0.000)
Normalized Negative Oil Price	1.382	1.261	1.562
Shocks (e^{*-})	(0.245)	(0.289)	(0.188)

Note: Refer to the note of Table 2. Numbers in parentheses denote p-values obtained from asymptotic t values.

Table 5. VAR Results for Real GNP Growth Rate, Independent Variable is Normalized Oil Price Shock

	Lag Coefficient				Exclusion Tests	
Time Period	1	2	3	4	F-statistic	p-value
<u>Eight Variable 3</u>						
*e**						
50:3 – 86:1	-1.306	-0.454	-0565	-2.005	6.769	0.000
	(0.459)	(0.401)	(0.397)	(0.430)		
50:3 – 88:2	-1.087	-0.515	-0.912	-1.909	7.489	0.000
	(0.423)	(0.392)	(0.384)	(0.403)		
50:3 – 92:3	-0.536	-0.003	-0.621	-1.738	5.449	0.000
	(0.381)	(0.380)	(0.370)	(0.377)		
<u>Ten Variable</u>						
50:3 – 96:1						
e^{*+}	-1.474	-0.786	-1.746	-2.106	6.012	0.000
	(0.584)	(0.606)	(0.594)	(0.629)		
e^{*}-	-1.021	-1.007	0.594	-1.395	1.382	0.245
	(1.148)	(0.992)	(0.944)	(0.928)		
50:3 – 88:3						
e^{*+}	-1.671	-0.639	-1.709	-2.319	7.178	0.000
	(0.556)	(0.558)	(0.548)	(0.598)		
e^{*-}	-0.875	0.250	(0.221)	-1.475	1.261	0.289
	(0.846)	(0.847)	(0.853)	(0.783)		
50:3 – 92:3						
e^{*+}	-1.219	-0.434	-1.528	-2.049	6.193	0.000
	(0.550)	(0.553)	(0.542)	(0.535)		
e^{*-}	0.538	0.536	0.160	-1.212	1.562	0.188
	(0.630)	(0.692)	(0.682)	(0.590)		

Note: Numbers in parentheses denote standard errors.

Table 6. Exclusion Tests in Systems that Consist of GNP Growth and Oil Prices Only: Real GNP Growth is Dependent Variable

Variable	50:3 - 86:1	50:3 – 88:2	50:3 – 92:3
Three Variable System (growth, Real Oil, *e**)			
Real Oil Price Change	1.649 (0.166)	1.908 (0.113)	0.791 (0.532)
Normalized Oil Price Shock (e^*)	6.509 (0.000)	7.661 (0.000)	4.448 (0.002)
Four Variable System (growth, Real Oil, e^{*+}, e^*-)			
Real Oil Price Change	1.869 (0.120)	2.068 (0.089)	0.872 (0.483)
Normalized Positive Oil Price Shocks (e^{*+})	5.517 (0.000)	8.351 (0.000)	7.660 (0.000)
Normalized Negative Oil Price Shocks (e^{*-})	2.335 (0.059)	1.426 (0.228)	1.483 (0.211)
Five Variable System (growth, Real Oil +, Real Oil-, e^{*+}, e^{*-})			
Real Oil Price Increases	1.212 (0.309)	2.025 (0.094)	0.564 (0.689)
Real Oil Price Decreases	2.860 (0.026)	1.895 (0.115)	0.909 (0.460)
Normalized Positive Oil Price Shocks (e^{*+})	3.958 (0.005)	5.691 (0.000)	4.317 (0.002)
Normalized Negative Oil Price Shocks (e^{*-})	3.144 (0.017)	2.252 (0.067)	1.980 (0.100)

Note: Refer to the note of Table 2. Numbers in parentheses denote p-values obtained from asymptotic t values.

Figure 1. Impulse Response of GNP Growth

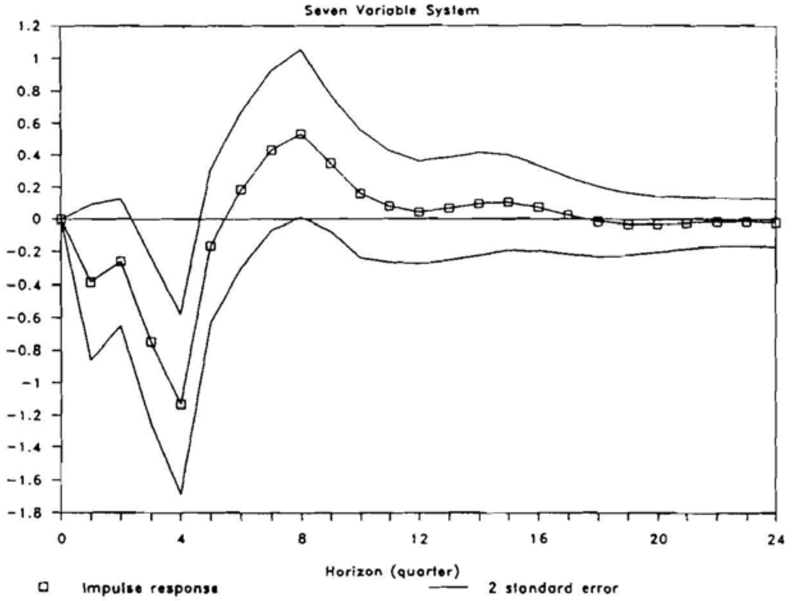

Figure 2. Impulse Response of Unemployment