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All but one of the U.S. recessions since World War II have been preceded, typically with a lag of around three-fourths of a year, by a dramatic increase in the price of crude petroleum. This does not mean that oil shocks caused these recessions. Evidence is presented, however, that even over the period 1948–72 this correlation is statistically significant and nonspurious, supporting the proposition that oil shocks were a contributing factor in at least some of the U.S. recessions prior to 1972. By extension, energy price increases may account for much of post-OPEC macroeconomic performance.

I. Introduction

The poor performance of the U.S. economy since 1973 is well documented:

1. The rate of growth of real GNP has fallen from an average of 4.0 percent during 1960–72 to 2.4 percent for 1973–81.
2. The 7.6 percent average inflation rate during 1973–81 was more than double the 3.1 percent realized for 1960–72.
3. The *average* unemployment rate over 1973–81 of 6.7 percent was higher than in any year between 1948 and 1972 with the single exception of the recession of 1958.

This paper is drawn from chap. 2 of my Ph.D. dissertation at the University of California, Berkeley. Earlier versions of this paper were presented at the NBER/NSF Time Series Conference in San Diego, March 13, 1981, and at the NBER Conference on Inflation and Business Fluctuations, April 30–May 1, 1982, Cambridge, Massachusetts. In addition to the helpful suggestions of my adviser, James Pierce, I am indebted to the many individuals whose comments and criticisms have helped sharpen the focus of this inquiry, including Allen Berger, Roger Craine, William Dickens, Charles Engel, Robert Engle, Marjorie Flavin, Richard Gilbert, Donald Nichols, Michael Riordan, Thomas Rothenberg, Christopher Sims, and the editors of this *Journal*.

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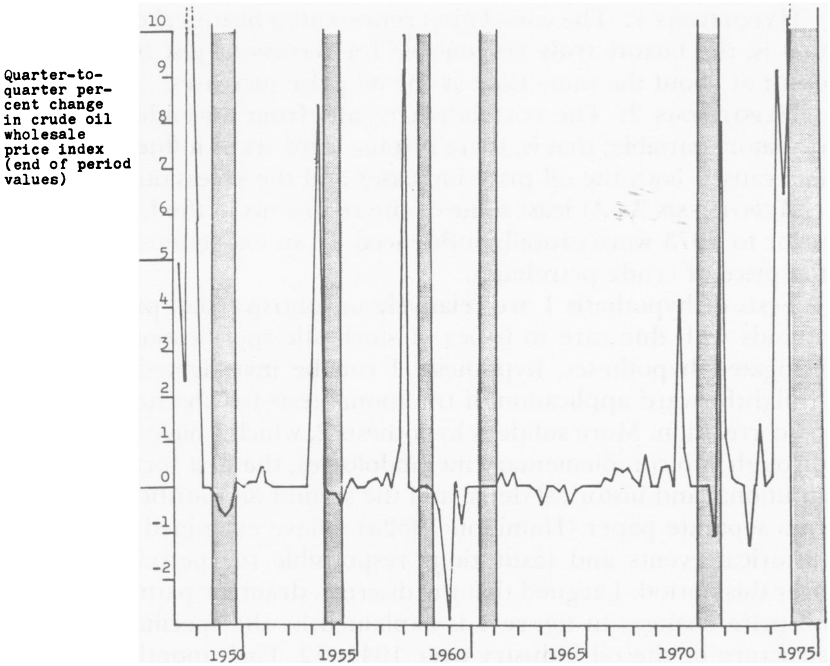

FIG. 1.—Changes in crude oil prices (solid lines) and U.S. recessions (shaded areas), 1947–75.

This decade of stagnating economic performance coincided with a period of rapidly rising energy prices and recurrent disruptions in petroleum supply, by the end of which the real price of energy had doubled its level of 1972. Not only has there been a secular correlation between energy and output over the last decade, there has been a cyclical correlation as well. Oil price increases and reports of heating oil shortages in early 1973 were followed by the onset of recession the subsequent winter. The sharp OPEC price increases of 1974 : 1 were likewise followed a year later by the dramatic output drop of 1975 : 1. And the gasoline shortages and price increases of 1979 : 2 in the wake of the Iranian revolution preceded the business cycle peak of 1980 : 1, just as the 1980 : 4–1981 : 1 oil price increases associated with the Iran-Iraq war and U.S. decontrol preceded the business cycle peak of 1981 : 3.

Figure 1 indicates that the cyclical tendency manifest over the last decade for oil price increases to be followed by recessions has in fact characterized every recession in the United States since World War II, with the single exception of the recession of 1960–61. The correlation has three possible explanations:

HYPOTHESIS 1: The correlation represents a historical coincidence; that is, the factors truly responsible for recessions just happened to occur at about the same time as the oil price increases.

HYPOTHESIS 2: The correlation results from an endogenous explanatory variable; that is, there is some third set of influences that in fact caused both the oil price increases and the recessions.

HYPOTHESIS 3: At least some of the recessions in the United States prior to 1973 were causally influenced by an exogenous increase in the price of crude petroleum.

Tests of hypothesis 1 are relatively uncontroversial; provided one attends with due care to issues of stochastic specification and data-instigated hypotheses, hypothesis 1 can be investigated through a straightforward application of traditional tests for absence of statistical correlation. More subtle is hypothesis 2, which I have investigated through two complementary methodologies, the first focusing on institutional and historical detail and the second on statistical evidence. In a separate paper (Hamilton 1982*a*) I have examined the specific historical events and institutions responsible for petroleum prices over this period. I argued that the discrete, dramatic pattern of crude oil price changes in figure 1 is explained by the specific regulatory structure of the oil industry over 1948–72. Each month the Texas Railroad Commission (TRC), and other state regulatory agencies like it, would forecast demand for petroleum for the subsequent month and would set allowable production levels for wells in the state to meet this demand. As a consequence, much of the cyclically endogenous component of petroleum demand showed up as a regulatory shift in quantities, not prices.[1] On the other hand, the TRC's sympathies were clearly with the producers it was meant to regulate, and the commission was generally unwilling or unable to accommodate sudden disruptions in supply, preferring instead to exploit these events to realize the dramatic price increases of figure 1.

The particular historical events behind such disruptions are summarized in table 1. I argued that this list of factors bears little resemblance to the usual enumeration of key business cycle developments, and in particular it seems difficult to claim economic endogeneity for events such as the Iranian nationalization in 1951–52, the Suez crisis of 1956–57, the secular decline in U.S. reserves toward the end of the

[1] This regulatory defense of posted petroleum prices also accounts for the close correspondence between domestic posted and transaction prices. According to Cassady (1954, p. 119), typically only 1 or 2 percent of total domestic crude would trade at premiums or discounts from posted prices and rarely more than 5 or 6 percent. This was not the case for internationally traded oil (see Adelman 1972; "What Price Crude Oil" 1969), whose price was not included in the Wholesale Price Index (WPI0561) on which my statistical results are based. See Hamilton (1982*a*) for further discussion.

TABLE 1

PRINCIPAL CAUSES OF CRUDE OIL PRICE INCREASES, 1947–81

Oil Price Episode	Principal Factors
1947–48	Previous investment in production and transportation capacity inadequate to meet postwar needs; decreased coal production resulting from shorter work week; European reconstruction
1952–53	Iranian nationalization; strikes by oil, coal, and steel workers; import posture of Texas Railroad Commission
1956–57	Suez crisis
1969	Secular decline in U.S. reserves; strikes by oil workers
1970	Rupture of trans-Arabian pipeline; Libyan production cutbacks; coal price increases (strikes by coal workers; increased coal exports; environmental legislation)
1973–74	Stagnating U.S. production; OPEC embargo
1978–79	Iranian revolution
1980–81	Iran-Iraq war; removal of U.S. price controls

SOURCE.—Hamilton (1982*a*).

1960s, the 1970 rupture of the trans-Arabian pipeline, the 1973–74 OPEC embargo, the 1979 Iranian revolution, and the 1980 Iran-Iraq war. My conclusion was that the regulatory environment thus acted to filter out many of the economically endogenous influences on petroleum demand and supply, with the result that the particular timing of changes in nominal crude oil prices reflects largely exogenous developments specific to the petroleum sector.

The second method by which I have sought to test for the endogeneity of crude oil prices is based on the suggestion of Granger (1969). The institutional perspective described above motivates the maintained null hypothesis of strict econometric exogeneity of crude oil prices. This hypothesis has the statistically refutable implication that no other series should "Granger-cause" oil prices. More loosely, I would further assert that if instead hypothesis 2 is true—that is, if some third set of variables in fact caused both the oil price increases and the recessions—then one should be able to identify unusual behavior in some of the key macro series in evidence *prior* to the oil price increases, which could have contributed significantly to the prediction of subsequent changes in oil prices.

A number of asymptotically equivalent tests have been proposed for assessing such a contribution to prediction. Monte Carlo studies by Geweke, Meese, and Dent (1979) and Nelson and Schwert (1979) suggest that the best approach may be to perform ordinary least squares on

$$z_t = a_0 + a_1 z_{t-1} + \ldots + a_q z_{t-q} + b_1 x_{t-1} + \ldots + b_q x_{t-q} + e_t \quad (1)$$

and test whether x is statistically informative about future z in the form of the restriction $b_1 = \ldots = b_q = 0$. For example, if z represents oil prices and x some other macro variable or set of macro variables suspected of causing oil prices, then I would regard failure to reject the null hypothesis H_o: $b_1 = \ldots = b_q = 0$ as failure to find evidence of unusual behavior in these macro variables prior to the oil price episode and thus as undermining the proposition that some third key influence was common to both the oil price increases and the subsequent recessions. On the other hand, if we perform a parallel test, letting z in equation (1) be the macro series and x oil prices, then I shall regard rejection of H_o as evidence against the assertion that the correlation between oil prices and real output is just a coincidence.

Limitations of such "causality" tests are well known. The finding "x does not Granger-cause z" is neither necessary nor sufficient for a least-squares regression of x on past x and past and present z to yield consistent estimates of the parameters, nor does the statistical assertion "x Granger-causes z" say anything about x forcing or producing z in the sense that we might normally use the word "cause."[2] I argue instead that the combined discovery that "oil is statistically informative about future x" and "x is not statistically informative about future oil," if found for a variety of scalar and vector candidates for x, would indicate that (1) the correlation between oil and macro variables is not just a coincidence, and (2) no evidence could be found that the oil price increases would have been predicted on the basis of what was happening in the macroeconomy up until that time. Such a finding, in conjunction with the historical analysis of the apparently exogenous causes of oil price increases, could then establish the case for seeking a causal interpretation of the pattern in figure 1.

II. The Role of Oil in a Simple Macroeconomic Model

As a starting point for this analysis, I examine the role of oil in a version of the six-variable system which Sims (1980*b*) presented as a compact approximation to macroeconomic reality. This system includes two output variables (real GNP and unemployment), three price variables (implicit price deflator for nonfarm business income, hourly compensation per worker, and import prices), and a single series M1 to represent the financial sector. My analysis also addresses two possible sources of nonstationarity. First, oil prices have obviously been determined under a radically different institutional regime since 1973 than before. Restricting the analysis to the period prior to 1973

[2] Jacobs, Leamer, and Ward 1979; Geweke 1980. Some of the obvious criticisms of such tests were anticipated by Sims (1972, 1977).

TABLE 2

BIVARIATE GRANGER-CAUSALITY TESTS FOR SIX VARIABLES IN SIMS'S (1980*b*) SYSTEM VERSUS CHANGES IN OIL PRICES

Null Hypothesis	$q = 4, T = 95$ (t = 1949:2–1972:4) $F(4,86)$	(p-value)	$q = 8, T = 91$ (t = 1950:2–1972:4) $F(8,74)$	(p-value)
Real GNP: $y_t = \log(GNP72_t/GNP72_{t-1})$:				
H_1: $y \nrightarrow o$	.58	(.68)	.71	(.68)
H_2: $o \nrightarrow y$	5.55	(.0005)	3.28	(.003)
Unemployment: $u_t = RUNS_t$:				
H_3: $u \nrightarrow o$	2.06	(.09)	1.48	(.18)
H_4: $o \nrightarrow u$	3.79	(.007)	3.08	(.005)
U.S. prices: $p_t = \log(PYNDOMNF_t/PYNDOMNF_{t-1})$:				
H_5: $p \nrightarrow o$	2.01	(.10)	1.54	(.16)
H_6: $o \nrightarrow p$	.40	(.81)	.31	(.96)
Wages: $w_t = \log(JRWSSNF_t/JRWSSNF_{t-1})$:				
H_7: $w \nrightarrow o$	1.92	(.11)	1.46	(.19)
H_8: $o \nrightarrow w$	1.28	(.28)	1.32	(.25)
Money: $m_t = \log(MONEYNS_t/MONEYNS_{t-4}) - \log(MONEYNS_{t-1}/MONEYNS_{t-5})$:				
H_9: $m \nrightarrow o$	.42	(.79)	.49	(.86)
H_{10}: $o \nrightarrow m$	1.10	(.36)	2.22	(.04)
Import prices: $p_t^m = \log(PM_t/PM_{t-1})$:				
H_{11}: $p^m \nrightarrow o$	.55	(.70)	3.21	(.003)
H_{12}: $o \nrightarrow p^m$	.22	(.93)	.26	(.98)
H_{13}: $p^m \nrightarrow y$	.92	(.46)	1.01	(.44)

avoids this source of nonstationarity[3] and also separates the data that suggested the hypothesis (i.e., post-OPEC experience) from those on which it is to be tested. A second source of nonstationarity is the secular time trend common to many macro series. This was generally treated by first-differencing, and where the autocorrelogram continued to exhibit symptoms of unit seasonal roots, a subsequent fourth difference was taken as well. Results for pre-1973 data of bivariate Granger-causality tests between oil price changes and detrended values of each of Sims's six variables are reported in table 2.[4]

[3] A structural shift in the univariate process for oil prices could change the reduced-form relation between output and oil prices even if the relation between innovations of the two series remained the same. Hence, tests of the null hypothesis that oil prices do not Granger-cause output may have limited power if the sample is nonstationary in this sense. It is also of course possible that OPEC today bases its decisions on U.S. output and prices in a manner which was not the case for oil prices over the period 1948–72, so that tests for other series which lead oil prices might well give different answers under the post-OPEC regime.

[4] Statistics for $x \nrightarrow z$ represent an F-test of $b_1 = \ldots = b_q = 0$ in an OLS estimation of

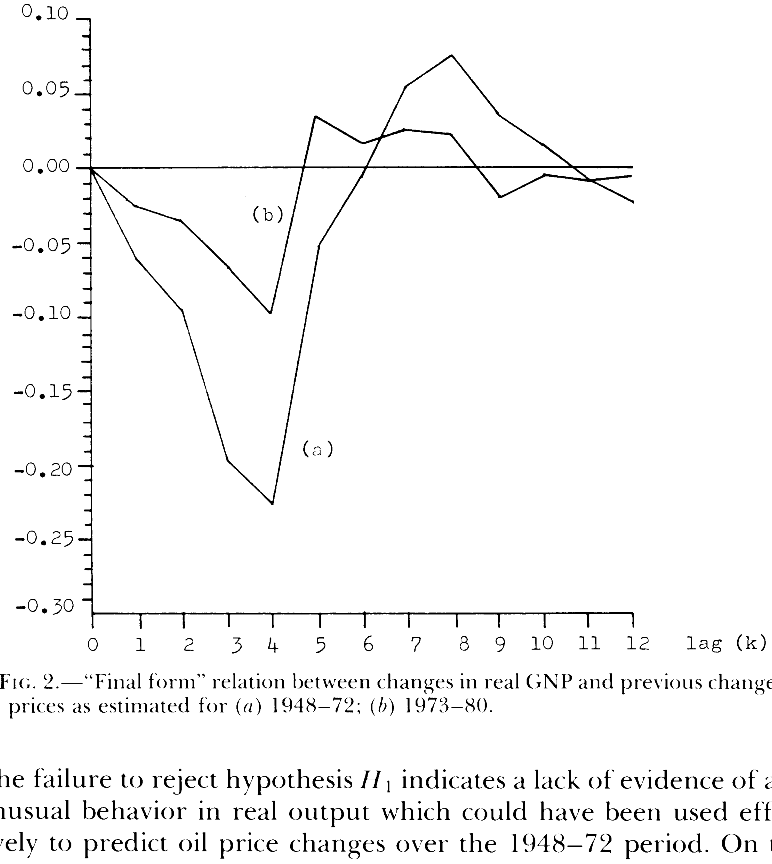

FIG. 2.—"Final form" relation between changes in real GNP and previous changes in oil prices as estimated for (*a*) 1948–72; (*b*) 1973–80.

The failure to reject hypothesis H_1 indicates a lack of evidence of any unusual behavior in real output which could have been used effectively to predict oil price changes over the 1948–72 period. On the other hand, the parallel hypothesis H_2 that oil price changes could not contribute to a prediction of future changes in real GNP can be easily rejected at the .001 level based on a four-lag regression and almost as solidly for an eight-lag regression. Inverting the autoregressive lag polynomial in the bivariate four-lag regression associated with H_2 produces an infinite distributed lag of y on past values of o alone, the coefficients of which are plotted in figure 2*a*: typically, an increase in oil prices was followed 3–4 quarters later by slower output growth, with a recovery beginning after 6–7 quarters.

Results for unemployment, the second output variable in Sims's system, are similar. Unemployment does a modestly better job at predicting oil prices than did real GNP, though the relation is not statisti-

eq. (1), with q = 4 and 8 and t running over bounds indicated in column headings. The variable o_t represents first-differenced logs of end-of-quarter values of monthly WPI0561, seasonally unadjusted. All data used in this analysis are published in Hamilton (1982*b*) and are available from the author on request.

cally significant at the .05 level.[5] The test for Granger causality running in the other direction, however, is again unambiguous; clear rejection of hypothesis H_4 at the .01 level casts serious doubt on the proposition that the correlation between oil price changes and future levels of unemployment represents a random coincidence.

Domestic prices (H_5) and wages (H_7) turn out to be no better predictors of oil prices than unemployment; the oil price series is clearly doing something substantially more than just mirroring the behavior of prices generally in the economy. It is also clear from hypothesis H_9 in table 2 that changes in the growth rate of M1, sometimes asserted to be a driving variable in the postwar economy, did not exhibit any unusual behavior prior to the oil price increases. On the other hand, the data warrant rejection based on the eight-lag test of hypothesis H_{10} that money growth rates were themselves unaffected by changes in oil prices. An increase in oil prices tended to be followed for the next year by slower than normal rates of growth of money and by faster than normal rates once the economy started to pull out of recession.

The only one of Sims's six variables to show up as individually statistically significant prior to oil prices is the change in import prices, and here only in the eight-lag regression (hypothesis H_{11} in table 2). Nor do the six variables collectively exhibit statistically unusual behavior in the year prior to the oil price increase (hypothesis H_1 in table 3). However, the F-test is close to the critical value, and in estimating 29 parameters, this latter test is not especially powerful. It might therefore be argued that import prices contributed to a prediction of oil prices in the eight-lag regression of hypothesis H_{11} in table 2 because import prices somehow captured better than the other five series the particular point in a business expansion at which excessive aggregate demand was soon to be manifest in an increase in oil prices. I have tried to test for this possibility using an approach pioneered by Barro (1977). As a first step I constructed a regression equation to predict import price changes according to previous values of each of the six variables in my version of Sims's system:

$$p_t^m = a_0 + \mathbf{x}_{t-1}'\mathbf{a}_1 + \mathbf{x}_{t-2}'\mathbf{a}_2 + \ldots + \mathbf{x}_{t-4}'\mathbf{a}_4 + e_t, \qquad (2)$$

[5] Note that use of the 5 percent level implies that for every 20 independent series tested, one will falsely appear to Granger-cause oil prices. For the large number of series examined in this paper this would seem to stack the odds against the finding of exogeneity. An alternative to classical hypothesis testing is to interpret the F-tests as a purely descriptive statistic of the usefulness of the variable in predicting oil prices. Specifying a critical value of 5 percent is equivalent to requiring the four parameters estimated for an added variable to increase the R^2 by .10 over a four-lag autoregression for oil prices.

TABLE 3

MULTIVARIATE GRANGER-CAUSALITY TESTS

H_1: $y, u, p, w, m, p^m \nrightarrow o$
t = 1949:2–1972:4, 4 lags each variable
$F(4,66)$ = 1.61, p = .065
H_2: $o \nrightarrow y$ given past y, u, p, w, m, p^m
t = 1949:2–1972:4, 4 lags each variable
$F(4,66)$ = 6.03, p = .0003
H_3: $o \nrightarrow u$ given past y, u, p, w, m, p^m
t = 1949:2–1972:4, 4 lags each variable
$F(4,66)$ = 3.99, p = .006
H_4: $o \nrightarrow y$ given past y, p^m
t = 1950:2–1972:4, 8 lags each variable
$F(8,66)$ = 3.45, p = .002
H_5: $o \nrightarrow y$ given past y, s
t = 1950:2–1972:4, 8 lags each variable
$F(8,66)$ = 3.18, p = .004
H_6: $o \nrightarrow y$ given past y, p^c
t = 1950:2–1972:4, 8 lags each variable
$F(8,66)$ = 3.34, p = .003
H_7: $o \nrightarrow y$ given past y, p^m, s, p^c
t = 1949:2–1972:4, 4 lags each variable
$F(4,74)$ = 3.39, p = .013

where $\mathbf{x}_t' = (y_t, u_t, p_t, w_t, m_t, p_t^m)$. I then interpreted the fitted values of this equation $\hat{p}_t^m$ as that component of import price changes which was most clearly endogenous with respect to the business cycle. The second step was to compare these fitted values $\hat{p}_t^m$ with the estimated residuals $p_t^m - \hat{p}_t^m$ in terms of their ability to explain future changes in oil prices:[6]

$$\begin{aligned} o_t = b_0 &+ b_1 o_{t-1} + b_2 o_{t-2} + \dots \\ &+ b_8 o_{t-8} + c_1 \hat{p}_{t-1}^m + \dots + c_8 \hat{p}_{t-8}^m \\ &+ d_1(p_{t-1}^m - \hat{p}_{t-1}^m) + \dots + d_8(p_{t-8}^m - \hat{p}_{t-8}^m) \\ &+ v_t. \end{aligned} \tag{3}$$

The null hypothesis that the influence of import prices on oil prices appears solely because import prices are proxying the state of the general economy was tested in the form of the restriction $d_1 = \dots = d_8 = 0$. This restriction was found to be inconsistent with OLS on equation (3) for t = 1952:2–1972:4, $F(8,58) = 2.41, p = .03$. On the

[6] In this and subsequent "anticipated-unanticipated" tests, the lags were chosen so as to give the strongest prediction of oil prices; hence, lag 8 was chosen in (3) in the light of hypothesis H_{11} in table 2.

other hand, the data fail to reject at the .05 level the null hypothesis that oil prices were influenced only by that part of import price changes which could not have been anticipated on the basis of the earlier state of U.S. prices and output; that is, the data admit the restriction $c_1 = \ldots = c_8 = 0, F(8,58) = 1.78, p = .10$. Moreover, even in a regression of output changes on four lags each of y, u, p, w, m, and p^m, lagged oil prices still enter statistically significantly in predictions of output (H_2 in table 3) and unemployment (H_3 in table 3) over this period. I thus conclude that to the extent that oil prices were correlated with previous changes in import prices, this correlation is not attributable to import prices acting as a proxy for the general state of output or prices in the U.S. economy as a whole.

Of course, the possibility remains that import prices were correlated with some other unspecified influences that were in fact true causes of the recessions. There are, however, several reasons for doubting this interpretation as well. (1) Import prices do not themselves Granger-cause output in either the four- or eight-lag regressions (H_{13} in table 2). (2) Those oil price increases anticipated on the basis of an eight-lag regression on past import and oil prices likewise fail to Granger-cause output, $F(4,74) = 1.11, p = .36$. (3) Rather, it is precisely those oil price increases which were unanticipated on the basis of previous import prices which account for the correlation between oil prices and output, $F(4,74) = 3.80, p = .007$. (4) Even with eight lags on import prices and output, lagged oil prices still contribute significantly to a prediction of output (H_4 in table 3). Thus, even though import prices are statistically informative about future oil prices over this period, this correlation is unable to account for that between oil prices and output.

The results of this investigation into the role of oil in Sims's macro model thus suggest that oil price increases over the period 1948–72 tended to be followed by reductions in real GNP growth that would not have been anticipated on the basis of the previous behavior of output, prices, or the money supply. Moreover, this statistical regularity is exceedingly unlikely to have resulted from random correlation between the series, and I have likewise been unable to find any indication that the correlation arises because oil prices were proxying some third macroeconomic influence that was in fact the true cause of the recessions. It is, of course, still possible that the particular series represented in Sims's system may not adequately represent the status of key macro variables. Accordingly, I examine in the next section a number of output, price, and financial variables not included in Sims's system for evidence of a common third factor behind oil prices and recessions during 1948–72.

III. Alternative Indicators of Output, Prices, and Finance

Output

Some may object to the regression of a real on a nominal magnitude. However, nominal GNP is no better a predictor of nominal oil prices than was real GNP (hypothesis 1 in table 4), whereas nominal oil prices still Granger-cause nominal GNP, $F(8,74) = 2.44$, $p = .02$. Note that, apart from the constant term, this latter regression is equivalent to a regression of real GNP on real oil prices.[7]

It is also conceivable that even though oil price increases do not seem to have been preceded by any unusual changes in the flow of output, there could be subtle differences in the composition of this flow between final sales and accumulation of inventories that were important in determining the future course of events. Hypothesis 2 in table 4, however, uncovers no evidence that changes in oil prices were preceded by any changes in the ratio of inventories to final sales. I further observe in hypothesis 3 that the Bureau of Economic Analysis (BEA) index of leading indicators likewise failed to be statistically informative about future oil prices over the 1948–72 period. Capacity utilization rates (hypothesis 4) would surely register an unusual status of aggregate demand, but as with all of the other output measures I have examined, this series contains no useful information about the timing of oil price shocks.

I suggested in table 1 that strikes by oil, coal, and perhaps steel workers were contributing factors in several of the oil price increases. A general increase in strike activity may in turn have reflected a critical state in the business cycle or may itself have played a role in the subsequent recessions. Hypothesis 5 in table 4 confirms that a statistically significant portion of the variance in oil price changes could be accounted for by the ratio of man-days idle due to strikes to total employment. However, the data reject the hypothesis that only those strikes anticipated on the basis of a regression on Sims's six variables are correlated with future oil prices, $F(4,74) = 3.31, p = .01$, whereas the data admit the hypothesis that only unanticipated strikes mattered, $F(4,74) = 1.64$, $p = .17$; thus strikes seem not to have been acting as proxy for the general state of the macroeconomy. Moreover, (1) those oil price increases anticipated on the basis of an eight-lag regression on past strikes and oil prices fail to Granger-cause output,

[7] I nevertheless regard H_2 in table 2 as the specification of interest, since (1) the institutional argument is that nominal, not real, oil prices track the historical petroleum shocks and are the exogenous variable belonging in a reduced-form regression, and (2) it is naive to assume that the expected change in the relative shadow price of oil equals the (possibly disequilibrium) market price divided by a contemporaneous price index (see Hamilton 1982*b*).

TABLE 4

MARGINAL SIGNIFICANCE LEVELS FOR REJECTION OF NULL HYPOTHESIS THAT x DOES NOT GRANGER-CAUSE OIL PRICES, FOR x ALTERNATIVE INDICATORS OF OUTPUT, PRICES, AND FINANCE, 1948–72

x	Filter for Stationarity	$F(4,86)$ p-value	$F(8,74)$ p-value
Output:			
1. Nominal GNP	$(1 - L)(1 - L^4)\log$	(.60)	(.50)
2. Inventories/sales	$(1 - L)$	(.58)	(.75)
3. BEA Index of Leading Indicators	$(1 - L)$	(.56)	(.61)
4. FRB Index of Capacity Utilization	1	(.27)	(.33)
5. Strikes	1	(.04)*	(.13)
Prices:			
6. Relative oil prices	1	(.13)	(.18)
7. Wholesale prices	$(1 - L)\log$	(.76)	(.88)
8. Nonferrous metals	$(1 - L)\log$	(.87)	(.45)
9. Iron and steel	$(1 - L)\log$	(.13)	(.12)
10. Farm products	$(1 - L)\log$	(.38)	(.55)
11. Lumber products	$(1 - L)\log$	(.90)	(.42)
12. Coal	$(1 - L)\log$	(.003)**	(.004)**
Finance:			
13. BAA Bond Yields	$(1 - L)$	(.10)	(.55)
14. Dow-Jones Industrial Average	$(1 - L)\log$	(.68)	(.44)

NOTE.—BEA = Bureau of Economic Analysis; FRB = Federal Reserve Board; BAA = a type of rating given to bonds that reflects a company's financial status.
* Statistically significant at 5 percent level.
** Statistically significant at 1 percent level.

$F(4,78) = 1.38$, $p = .25$. (2) By contrast, unanticipated oil prices are statistically informative about future output, $F(4,78) = 5.66$, $p = .005$. (3) Oil price increases are still statistically informative about future output even if lagged strikes are taken into account in the regression (H_5 in table 3). Again, an apparent cause of oil price increases has been found, but, as in the case of import prices, it appears to be a largely exogenous influence and is not amenable to a third-variable interpretation of the oil-output connection.

Prices

While one may argue that the proximate cause of the oil price increases of 1957 was the Texas Railroad Commission's refusal to raise production allowables in the wake of the Suez crisis, it still might be argued that the TRC's desire to see prices rise was in turn conditional on the modest inflation of 1954–56. I have sought evidence of an inflationary "catch-up" effect by regressing oil price changes on the (not detrended) ratio of the crude oil producer price index to that for commodities generally. Hypothesis 6 in table 4 shows that such a variable does a slightly worse job of predicting oil price changes than did simple changes in the implicit business income deflator. While a catch-up phenomenon was surely operative, it seems unable statistically to explain the particular timing of the oil price shocks or, thus, the regularity in the timing between these oil shocks and the subsequent recessions.

Despite the apparent absence of unusual aggregate demand conditions prior to the oil price increases, the concern remains that oil prices increase when economic booms confront inelastic commodity supplies; recessions, for reasons unrelated to the commodity price increases, might then follow booms. The main difficulty with this interpretation, however, is that one should see a pattern similar to that in figure 1 for a variety of price indexes; I am aware of no other series which displays parallel behavior. For example, neither the general wholesale price index, $F(4,86) = 0.47$, $p = .76$, nor that for nonferrous metals, $F(4,86) = 1.04$, $p = .39$, Granger-causes real GNP over this period, and a repetition of the test used to establish the exogeneity of oil prices would lead to the conclusion that increases in nonferrous metals prices could easily be predicted from previous changes in real GNP, $F(4,86) = 4.19$, $p = .004$. I have been unable to find any unusual behavior in the prices of nonferrous metals, iron and steel, farm products, or lumber products prior to the oil price increases (hypotheses 8–11 in table 4). The one price series which I have found to be strongly correlated with future oil price changes is that for coal, which finding again corroborates the historical conclusions of table 1.

I have repeated the anticipated-unanticipated decomposition for this coal-oil relationship. Coal prices again seem not to be proxying the general state of Sims's macroeconomy. On the other hand, both those oil price increases anticipated on the basis of coal prices, $F(4,78) = 3.29$, $p = .02$, and those unanticipated ($p = 6 \times 10^{-5}$) have a statistically significant correlation with future output. Part of the strength of the observed oil-output relation, then, may be attributable to the fact that crude oil price increases reflected broader increases in the relative price of energy generally. Still, coal prices are not by themselves statistically informative about future output, $F(4,86) = 1.42$, $p = .23$; $F(8,72) = 1.30$, $p = .26$; nor does the inclusion of coal prices in any way diminish the statistical contribution of oil prices (H_6 in table 3). Note further that even inclusion of all three of the economic variables associated with oil prices likewise cannot account for the statistical correlation between oil prices and output (H_7 in table 3), despite the fact that these three variables were selected specifically on the basis of their collinearity with oil price changes.

Financial Variables

Sims (1980*a*) has noticed a tendency for postwar recessions to be preceded by an increase in interest rates, which seems to have predated the decline in the rate of growth of the money supply known to be associated with the first stages of an economic downturn. I indeed found a positive correlation between oil price changes and the change in interest rates the previous period, though a test for statistical significance fails to reject the null hypothesis of no relation at the .05 level (hypothesis 13 in table 4), and the correlation is certainly not strong enough to explain the oil-GNP connection. Moreover, oil price increases tended to be followed by dramatic adjustments in the bond markets that would not have been anticipated on the basis of the earlier pattern developing in interest rates, $F(4,86) = 3.80$, $p = .007$. As final evidence against the assertion that some third influence both caused the oil price increases and contained the seeds of an incipient recession, I add the testimony of efficient markets: hypothesis 14 in table 4 shows that if recession was incipient prior to the oil shocks, it was news to Wall Street.

IV. Specification Analysis

Precisely because the visual appearance of figure 1 is so dramatic, oil price changes clearly cannot be presumed to follow a Gaussian process. This has implications both for the probability distribution assumed for regression residuals and for functional form.

The Distribution of Regression Residuals

My maintained hypothesis is that the variance of oil price changes was historically dominated by dramatic, exogenous events. In the regression used to test H_1 in table 2,

$$o_t = a_0 + a_1 o_{t-1} + \ldots + a_8 o_{t-8} + b_1 y_{t-1} + \ldots + b_8 y_{t-8} + e_t. \tag{4}$$

This corresponds to the joint assertion that $b_1 = \ldots = b_8 = 0$ and that e_t follows a highly leptokurtic probability distribution. Accordingly, an F-test could lead to rejection either because $\mathbf{b} \neq \mathbf{0}$ or because the small-sample properties of this test are poor when the e_t are nonnormal.[8] The Lomnicki (1961, p. 59) test for leptokurtosis compares the

[8] Even for normal errors, the F-test is only appropriate asymptotically. The assertion that ratios of sums of squares of highly leptokurtic residuals converge more slowly to the limiting distribution than if the true innovations were Gaussian remains an unproven conjecture of the author.

sample second and fourth moments about the mean (m_2 and m_4) with those expected for a normal distribution. For a white noise Gaussian process, the statistic $L = \sqrt{T}(m_4 m_2^{-2} - 3)/\sqrt{24}$ asymptotically approaches an $N(0, 1)$ distribution. For the residuals of regression 4, $L = 30.04$, and three of the 91 residuals are more than four standard deviations from zero—quite impossible events for a normal variate. Consequently, previously reported p-values associated with other series Granger-causing oil prices might be suspected of misstating the true probability.

By contrast, there is no particular reason to believe that the residuals from regressions in which oil price changes are the independent variable are similarly ill behaved. For example, in the regression associated with H_2 in table 2,

$$\begin{aligned} y_t = a_0 + a_1 y_{t-1} + \ldots + a_8 y_{t-8} \\ + b_1 o_{t-1} + \ldots + b_8 o_{t-8} + u_t, \end{aligned} \tag{5}$$

$L = 1.14$ and only two of these 91 residuals exceed two standard deviations. Thus the specification issue raised in connection with equation (4) seems not to apply to the tests for whether oil prices Granger-cause other macro series.

Geweke (1978, p. 169) suggested that one can exploit this asymmetry in choosing between the Granger (1969) and Sims (1972) versions of these tests. One can thus test for whether output Granger-causes oil prices through a regression in which the latter appears as the independent variable, namely,

$$\begin{aligned} y_t = a_0 + a_1 y_{t-1} + \ldots + a_8 y_{t-8} + b_0 o_t \\ + b_1 o_{t-1} + \ldots + b_8 o_{t-8} + c_1 o_{t+1} \\ + \ldots + c_s o_{t+s} + v_t, \end{aligned} \tag{6}$$

and testing the null hypothesis y does not Granger-cause o in the form of the restriction $c_1 = \ldots = c_s = 0$. Note that the residuals so restricted are essentially identical to the unrestricted residuals in (5), which were already seen to have been compatible with a Gaussian assumption.[9]

I have repeated the key tests for other series Granger-causing oil prices based on equation (6). None of Sims's six variables turn out to be statistically informative about future oil prices based on this specification for either $s = 4$ or $s = 8$, the strongest result coming for the four-lead test for wages predicting oil, $F(4,66) = 2.04$, $p = .10$. In

[9] On either (4) or (6), F-tests are apt to be a similar transformation of the conditional cross-correlation between y_t and o_{t+j} (see Theil 1971, pp. 173–74). Thus, the fact that (6) exists as a well-motivated test helps justify use of standard hypothesis tests on (4).

particular, the earlier finding that import prices were statistically informative about future oil prices cannot be reproduced under this alternative form of the test. On the other hand, the statistical influence of strike activity, $F(4,66) = 3.42$, $p = .01$, and coal prices, $F(4,66) = 5.23$, $p = .001$, on the crude oil price series is reconfirmed under the Sims-Geweke test. The conclusion that oil price increases over the period 1948–72 primarily reflected the influence of economically exogenous events thus appears to be robust with respect to the assumed distribution of regression residuals.

Functional Form and Structural Stability

It is well known that for a multivariate Gaussian process the expectation of one variable conditional on the values of the others is linear in the observed values. Alternatively, one often hopes to approximate an arbitrary function in a neighborhood of the sample mean by a linear relation. However, oil price changes are exceedingly leptokurtic, and the increases of 1974:1 were three times as large as anything observed during 1948–72. Consequently, extrapolation to post-1973 data of a linear relation between oil prices and output estimated over 1948–72 must be regarded with some caution, and indeed the postsample predictions of this relation turn out to be quite poor. An F-test documents a structural change among the nine coefficients of the relation

$$y_t = a_0 + a_1 y_{t-1} + \ldots + a_4 y_{t-4} + b_1 o_{t-1} + \ldots + b_4 o_{t-4} + u_t \tag{7}$$

between the sample periods t = 1949:2–1972:4 and t = 1973:1–1980:3, $F(9,108) = 2.43$, $p = .01$.[10]

Is it possible, then, that the regularity observed in (7) over the period 1948–72 represents a historical aberration which has no relation to events since then? Columns 1 and 2 in table 5 compare the coefficients in (7) estimated separately for t = 1949:2–1972:4 and t = 1973:1–1980:3, while figure 2 compares the final forms associated with each of these separate regressions. The dynamics of the relation in fact appear to be very similar over the two periods, with an increase in oil prices followed for 4 quarters by successively slower rates of growth of real GNP, and then a recovery after 6–7 quarters. Furthermore, the 1973–80 data in themselves warrant clear rejection of the null hypothesis that oil prices did not Granger-cause real GNP during the post-OPEC period (col. 2 in table 5). The impression, then,

[10] See Fisher (1970) for details of the tests invoked for structural change.

TABLE 5

REGRESSION COEFFICIENTS RELATING y_t TO o_t FOR INDICATED SAMPLE PERIODS, WITH F-TEST THAT COEFFICIENTS ON LAGGED o_t ARE ALL ZERO

	SAMPLE PERIOD*			
COEFFICIENT	1949:2–1972:4 (1)	1973:1–1980:3 (2)	1948:2–1972:4 (3)	1948:2–1980:3 (4)
Constant	.011	.023	.0088	.010
	(.0016)	(.0050)	(.0017)	(.0016)
y_{t-1}	.19	−.20	.30	.21
	(.097)	(.18)	(.10)	(.088)
y_{t-2}	.15	−.064	.10	.16
	(.097)	(.20)	(.11)	(.092)
y_{t-3}	−.049	−.088	−.098	−.081
	(.097)	(.20)	(.10)	(.092)
y_{t-4}	−.28	−.34	−.26	−.25
	(.092)	(.19)	(.10)	(.088)
o_{t-1}	−.061	−.023	−.041	.004
	(.056)	(.028)	(.061)	(.023)
o_{t-2}	−.082	−.038	.019	−.007
	(.056)	(.028)	(.036)	(.021)
o_{t-3}	−.170	−.078	−.057	−.050
	(.057)	(.030)	(.035)	(.021)
o_{t-4}	−.177	−.115	−.047	−.062
	(.059)	(.033)	(.035)	(.021)
F-statistic	$F(4,86)$ = 5.55	$F(4,22)$ = 5.71	$F(4,90)$ = 1.51	$F(4,121)$ = 5.28
p-value	.0005	.003	.21	.0007

NOTE.—y_t = quarterly changes in log of real GNP; o_t = quarterly changes in nominal end-of-period crude oil prices. SEs of coefficients are in parentheses.
* Bounds on t in regression 7.

is that the separate periods 1948–72 and 1973–80 are each characterized by a statistically significant relation between oil prices and real GNP and that, while this relation manifests similar dynamics across the two periods, a linear approximation to it would lead to a choice of smaller coefficients on oil price increases for the later period.

A similar phenomenon is observed when one includes the volatile oil prices of 1947 (see col. 3 in table 5). Estimation of equation (7) for t = 1948:2–1972:4 again yields substantially lower coefficients on the oil price terms than were obtained for t = 1949:2–1972:4,[11] and indeed the relation between oil prices and output is no longer significant at the .05 level (col. 3 in table 5). A Chow test for structural change confirms that the 1948–72 linear relation does not adequately capture the 1947 experience, $F(4,86)$ = 5.37, p = .0007. Nevertheless, when one averages in the 1947 experience by estimating

[11] The original investigation started with t = 1949:2, i.e., was restricted to data beginning in 1948:2, since this is the first date for which some of the detrended series were available.

equation (7) for t = 1948:2–1972:4 as though it were a single stable relation, the estimated coefficients have a much better fit to post-1973 experience than did those estimated for t = 1949:2–1972:4, giving rise to a postsample mean squared forecast error of 1.22×10^{-4} for the period 1973:1–1980:3, as opposed to 1.46×10^{-4} for a purely autoregressive relation on y. Likewise, the data fail to reject the null hypothesis of no structural change between this average relation estimated for t = 1948:2–1972:4 and a second regression estimated for t = 1973:1–1980:3, $F(9,112) = 1.27$, $p = .26$.

There are thus at least some aspects of the relation between oil prices and output which are quite similar across the different periods. One might accordingly try to reconcile the two dynamic multipliers illustrated in figure 2 with a single functional form, interpreting the two paths as derivatives averaged over two parts of a nonlinear relation. However, nonlinearity is clearly not the only explanation for the discrepancy. Even though equation (7) may represent a feedback-free reduced-form relation, any changes in the structural equations of the system would of course also change the coefficients in this relation. One obvious candidate for such change is the secular inflation rate, the periods 1947:2–1948:1 and 1973:1–1980:3 being characterized on average by general price increases some five to six times as great as those during 1948:2–1972:4. The same nominal oil price increase could be expected to lead to a smaller output effect during inflationary times than in noninflationary times, and this is exactly what was found in figure 2 and table 5.

There are a number of other factors which could also give rise to instability in a reduced-form relation such as (7). In late 1947 and since 1972, but at no time in between these dates, Texas oil fields were at 100 percent production. Movements in the price of crude would represent fundamentally different signals of supply and demand during the regulatory regime than they would outside it. Likewise, oil price increases have sometimes been accompanied by contemporary accounts of consumer rationing; if oil prices have historically served as a proxy for such quantity constraints, equation (7) would falsely anticipate a contraction in output for an increase in the price of crude that might not have been associated with any physical shortages. Finally, to the extent that a deliberate monetary contraction is part of the sequence of events subsequent to the oil price increases that led to recession, a change in this regime could also alter the effective impact multipliers associated with (7).

V. Conclusions

Seven of the eight postwar recessions in the United States have been preceded by a dramatic increase in the price of crude. What further can be said about this correlation in the light of the econometric evidence presented above?

1. There are few grounds for claiming that the correlation between oil prices and output represents just a statistical coincidence. The evidence since 1973 in itself is sufficient to motivate a suspicion of a systematic relation between oil prices and output, and searching for a similar pattern in a different data set (1948–72) calls for clear rejection of the null hypothesis of no relation at the .01 significance level and, for some tests, at the .001 level. Accordingly, a systematic account of why oil price increases should have been followed 3–4 quarters later by output declines seems to be called for.

2. I find little support for the proposition that over the period 1948–72 some third set of influences was responsible for both the oil price increases and the subsequent recessions. None of the six variables in Sims's (1980*b*) macroeconomic system, singly or collectively, exhibited any unusual behavior in the year prior to the oil price increases that could have been used statistically to predict the oil price episodes, and only import prices, which one might have expected to be the series *least* indicative of endogenous business conditions, were statistically informative about future oil prices based on 8-quarter lags. I further observe that (*a*) this latter correlation seems to be attributable precisely to that component of import price changes that would not have been predicted on the basis of previous changes in U.S. output, prices, or money growth rates; (*b*) it is in fact those oil price changes that would not have been predicted on the basis of previous import price changes that are statistically informative about future output; and (*c*) import prices could not by themselves have been used to predict the subsequent economic downturns. Moreover, the conclusion that import prices over the period 1948–72 were statistically informative about future oil prices was not found to be robust with respect to an alternative specification that perhaps relies on more realistic distributional assumptions. If some third macroeconomic variable was in fact responsible for both the oil price increases and the subsequent recessions, its effect is not apparent in this small version of the macroeconomy.

In searching a variety of other series for evidence of unusual statistical behavior prior to the oil price shocks, I have found that the series most useful in predicting oil prices are, again, least likely to be regarded as key endogenous indicators of economic activity. Inventories, capacity utilization, the Bureau of Economic Analysis (BEA) leading indicator series, interest rates, and the stock market would all have failed to predict the major oil price changes over the period 1948–72. One likewise cannot mimic the oil price–GNP relation using wholesale prices generally, nor could a variety of aggregate or specific commodity price indexes have been used to predict the oil price increases. The two series which I have found to be statistically informative about future oil price changes over this period are (*a*) the aggregate incidence of strike activity and (*b*) coal prices. As in the analysis of import prices, neither of these series could itself have been used to predict the subsequent output declines, and it is again that component of each series that would not have been predicted on the basis of previous macroeconomic activity that is most useful in predicting future oil prices.

This is not to argue that endogenous price, output, or financial variables had no influence on oil prices over the period 1948–72, even though that literal assertion is consistent with all of the hypothesis tests that I have undertaken. Undoubtedly the oil industry and its regulators were conscious of the erosion of the real price of crude effected through inflation and were anxious to make up for this loss at any opportunity. What does seem to be the case, however, is that historically these opportunities derived from events which truly were exogenous with respect to the American economy, such as the nationalization of Iranian assets, the Suez crisis, the secular decline in energy reserves, strikes by oil and coal workers, and other economic developments specific to the energy sector. Insofar as exogenous events of this sort account for the particular timing of oil price increases, the regularity in the timing between oil price increases and the subsequent recessions in turn becomes difficult to attribute to their common dependence on some third set of influences endogenous to the macroeconomy.

If the correlation between oil price increases and real output cannot be explained as just a coincidence or as just another correlation between endogenous macro variables, the case is strengthened for the third interpretation: the timing, magnitude, and/or duration of at least some of the recessions prior to 1973 would have been different had the oil price increase or attendant energy shortages not occurred. This is not to say that oil price increases are either a necessary or a sufficient condition for postwar recessions. In the light of the recession of 1960 and the oil price increases of 1970–71, they are clearly neither. Nor is it to assert that this correlation should be viewed as an immutable structural relation. Changes in expected inflation, the response of monetary policy to oil shocks, or the regime in which oil prices are determined could be expected to give rise to a different dynamic pattern. But what does seem to be true is that the post-OPEC world has more in common with its predecessor than many might suppose. What is needed is not to abandon the demand-oriented interpretation of the fifties and sixties or the supply-oriented approach to the seventies but rather to resynthesize the histories told for both.

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