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The Effects of Oil Shocks on the Economy: A Review of the Empirical Evidence

Updated January 18, 2006

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The Effects of Oil Shocks on the Economy: A Review of the Empirical Evidence

Summary

Congress is concerned with preventing economic recessions and mitigating the effects of recessions. Eight of the nine post-war recessions were accompanied by sharp increases in the price of oil. The last four recessions followed this pattern: the 1973-1975 recession followed the oil embargo; the double dip recession of 1980-1982 followed the second oil shock, which was caused by the Iranian revolution and Iran-Iraq War; the 1990-1991 recession followed the oil price spike induced by the Gulf War; and the 2001 recession followed a sharp rise in oil prices from 1999 to 2000. Policymakers are concerned that the recent rise in oil prices could again spillover into the wider macroeconomy.

The coincidence of recessions and oil shocks does not prove that oil price changes have any effect on the economy. To make that case, one must use statistical methods to hold other economic factors constant. This report surveys the econometric literature on oil shocks to provide quantitative estimates of how large an effect oil price changes have on economic activity. It also reviews the statistical robustness of these findings and discusses some of the limitations of these types of statistical analyses.

Economic theory suggests that oil shocks lead to higher inflation, a contraction in output, and higher unemployment in the short run. It is the rise in energy prices, rather than "high" energy prices, that causes these macroeconomic problems. Effective policy responses are difficult because expansionary policy would exacerbate the inflationary pressures whereas contractionary policy would exacerbate the contraction in output.

There is a fair degree of consensus surrounding the range of estimates: for comparable studies, the cumulative effect of a 10% increase in oil prices during a one-quarter (3 month) period would be to reduce economic output by 0.2-1.1% over the next year from its baseline level. The magnitude of these estimates suggests that normal fluctuations in the price of oil would cause only minor fluctuations in economic growth. However, the estimates suggest that major oil shocks, in which oil prices rise for several consecutive quarters, often by more than 10% per quarter, could lead to recessions, all else equal. Some of the findings are not statistically robust. A few studies dissent from these findings.

Many studies find that the effects of oil on economic activity are waning. For example, a 2004 study found that a 10% increase in oil prices would only reduce GDP by 0.2% in 1998. Surprisingly, many studies found oil to have had stronger economic effects before the mid-1970s, although the major post-war oil shocks occurred since the mid-1970s. The studies suggest that the relationship between oil prices and economic activity is not a simple linear one (e.g., episodic oil price declines have negligible economic effects), but there is no straightforward way to identify a more accurate relationship.

This report will be updated as new research becomes available.

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Congress is concerned with preventing economic recessions and mitigating the effects of recessions. Eight of the nine post-World War II recessions were preceded by or accompanied with sharp increases in the price of oil. The last four recessions followed this pattern: the 1973-1975 recession followed the oil embargo; the double dip recession of 1980-1982 followed the second oil shock, which was caused by the Iranian revolution and Iran-Iraq War; the 1990-1991 recession followed the oil price spike induced by the Gulf War; and the 2001 recession followed a sharp rise in oil prices from 1999 to 2000. This would seem to be persuasive evidence that oil prices play a strong role in determining the business cycle. But the coincidence of recessions and oil shocks does not, by itself, prove that oil price changes cause economic recessions. To make that case, one must use statistical methods to hold other economic factors constant. This report surveys the econometric literature on oil shocks to provide quantitative estimates of how large an effect oil price changes have on economic activity. It also reviews the statistical robustness of these findings and discusses some of the limitations of these types of statistical analyses. Before examining the empirical record, it is useful to explore why economists believe oil shocks might affect the economy, and explore the channels through which that effect is transmitted.

Theoretical Considerations

Due to the central role energy plays in the functioning of our economy, changes in energy prices are not the same as changes in the price of most other goods. Energy "shocks" can have macroeconomic consequences, in terms of higher inflation, higher unemployment, and lower output.

Economic theory suggests that economies suffer from recessions due to the presence of "sticky prices." If markets adjusted instantly, then recessions could be avoided: whenever economic conditions changed, price and wage changes would automatically bring the economy back to full employment. In actuality, however, there are menu costs,[1] information costs, uncertainty, and contracts in our economy that make prices sticky. As a result, adjustment takes time, and unemployment and economic contraction can result in the interim.

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[1] Products with high "menu costs" are those which are costly to re-price, and therefore have sticky prices. Restaurant menus, periodicals, and catalog items are examples of products with high menu costs.

Historically, energy price shocks have proven particularly troublesome for the U.S. economy. Sharp spikes in the price of oil have preceded nine of the 10 post-war recessions, including the latest one. When oil prices rise suddenly, the overall inflation rate is temporarily pushed up because other prices do not instantly adjust and fall. At the same time, because energy is an important input in the production process, the price shock raises the cost of production. Because other prices do not instantly fall, the overall cost of production rises and producers must cut back production, which causes the contraction in output and employment, all else equal. There may also be adjustment costs to shifting toward less energy intensive methods of production, and these could temporarily have a negative effect on output. Typically, the effect on output occurs over a few quarters. The recent energy price spike followed this pattern, with oil prices rising in the second half of 1999 through the first half of 2000, and output growth slowing in the third quarter of 2000.[2]

The magnitude of an oil shock's effect on the economy should depend on how much oil that economy uses. As the ratio of energy use to GDP in the United States has declined over time, one would expect the economic effects of an oil shock to lessen. This may help explain why the recent oil shock has had a smaller economic effect than in the past.

The effects described thus far can be thought of as occurring on the supply side of the economy. Oil shocks may also affect aggregate demand. When energy prices rise they involve an income transfer from consumers to producers. Since producers are also consumers, aggregate demand is likely to fall only temporarily as producers adjust their consumption to their now higher incomes. This adjustment is likely to be longer when the income recipients are foreigners than when they are Americans. A second effect on demand can be expected to occur because the rise in energy prices will probably push up the overall price level because other prices do not fall immediately in the face of a decline in demand. The increase in the price level will reduce the real value of the available amount of money in the hands of buyers, and this reduction in the real money stock will also reduce spending. A third effect on demand can occur if the rise in energy prices increases uncertainty and causes buyers to defer purchases. This effect is also likely to be of a short run nature. The magnitude of all three effects will depend on how much energy prices rise and how long they remain high.

Rising oil prices also affect the international balance of payments in the short run. If the cost of U.S. oil imports increases following a price rise, this constitutes a transfer in purchasing power from U.S. consumers to foreign oil producers. How this affects the current account deficit (trade deficit) depends, in turn, on how foreign oil producers decide to use this purchasing power. If they use it to purchase U.S. goods, then U.S. exports would increase and there would be little effect on the current account deficit. If they use it to purchase U.S. assets — whether corporate stocks, Treasury bonds, or by simply leaving the revenue in a U.S. bank account —

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[2] If rising energy prices affect the economy through this transmission mechanism, then falling energy prices should have the opposite effect on the economy: they should temporarily lower inflation and raise output, all else equal. Many of the studies to follow find that this is not true, however.

then it would represent an inflow of foreign capital to the United States, which would increase the current account deficit.

For those oil-exporting countries that maintain a floating exchange rate against the dollar, the dollar would be likely to depreciate following an oil shock relative to their currencies. But many of the major oil-exporting countries maintain a fixed exchange rate against the dollar; for this reason, the value of the dollar would be unlikely to be greatly affected by an oil shock in the short run. In the long run, however, the real value of the dollar must fall to pay for the more expensive oil imports; against countries who fix their nominal exchange rate to the dollar, this will occur through relative price adjustment (i.e., higher inflation in oil producing countries than in the United States). Short-run exchange rate adjustment may also occur more slowly because world oil market transactions are made using the U.S. dollar.

Theory suggests that oil shocks reduce economic growth and increase inflation simultaneously. This makes an effective policy response difficult.

Both the inflation and output effects of energy shocks are temporary: that is, once prices adjust, the economy returns to full employment and its sustainable growth path.[3] This observation yields an important insight: it is not the *level* of energy prices that affects economic growth and inflation, but rather the *change* in energy prices. Thus, if policymakers wish to mitigate the effect of energy prices on output and inflation, they should be concerned with rising energy prices and should not be concerned with "high" energy prices, even if the high prices are permanent. The only permanent macroeconomic effect of higher energy prices is their negative effect on the terms of trade. The "terms of trade" is a measure of standard of living that refers to the labor and capital embodied in U.S. exports that can be exchanged for the labor and capital embodied in foreign imports. It means that the United States has to give up more of the goods it produces than previously to obtain a barrel of oil. Permanently higher energy prices lead to a one-time permanent decline in the terms of trade and the standard of living of U.S. consumers, all else equal.

Policy Implications. Historically, formulating an effective policy response to oil shocks has been difficult. Expansionary fiscal or monetary policy increases aggregate demand and inflationary pressures. In typical downturns, monetary and fiscal policy can safely become expansionary without triggering a significant increase in inflation because the fall in demand reduces inflationary pressures. In oil shocks, policymakers must be simultaneously concerned with the fall in economic activity and the rise in prices. By tackling one problem, they risk exacerbating the other. For example, if policymakers use expansionary fiscal or monetary policy to offset the fall in output, prices may rise further and inflationary expectations could become embedded. This was the problem in the 1970s. Inflation, which was already rising

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[3] This point is not always explicitly made in the time series analyses reviewed below, which tend to end their estimates at the last time lag that yields statistically significant data or arbitrarily cut off the estimates after a few lags to meet a statistical criterion concerning the limit on the number of variables allowed.

before the oil shocks, continued to accelerate following the oil shock of 1973 until it reached double digits in 1974. Once the public came to expect higher inflation, the subsequent expansionary policy measures had less and less of a positive effect on aggregate demand, making the purported tradeoff between inflation and unemployment less and less favorable.[4] Following the second oil shock of 1979, a Federal Reserve that was determined to stamp out double-digit inflation chose instead to tackle the inflationary pressures caused by the oil shock by raising interest rates. This decision exacerbated the effect on output, contributing to the most severe economic contraction since the Great Depression.

Another reason why policy responses have been unable to prevent oil shocks from leading to recessions historically is because policy changes are hampered by lags in policy recognition, implementation, and effectiveness. Because oil shocks are typically unpredictable events, policy cannot be modified far enough ahead of time to prevent a downturn.

Examining the Empirical Record

The remainder of this report reviews the econometric literature on oil shocks, which has attempted to quantitatively estimate how much of an effect oil prices have on macroeconomic variables such as GDP growth, inflation, and unemployment. Technical terms are defined in a glossary at the end of the report.[5]

Early Studies

Darby had one of the earliest econometric studies that attempted to estimate the economic effects of oil shocks.[6] His study aimed to determine what had caused the 1973-1975 recession. He hypothesized that it could have been due to four causes: the removal of the Nixon price control regime (because GDP was overstated during the regime), the breakdown in the Bretton Woods exchange rate regime, the slowdown in money growth (contractionary monetary policy), or the oil shock. He estimated that the 1973 oil shock caused a total cumulative decrease in GNP of 2.5%. Although the oil shock's effect on the economy was statistically significant, statistical tests could not rule out the possibility that it was the removal of price controls, rather than the oil shock, that caused the recession.

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[4] Expansionary monetary policy leads to an increase in output only because prices do not adjust instantly to the increase in the money stock. If prices adjusted instantly, there would be no increase in output. Thus, a given change in the money stock would have a smaller effect on output when inflationary expectations are high.

[5] A broader literature review can be found in Donald Jones, Paul Leiby, and Inja Paik, "Oil Price Shocks and the Macroeconomy: What Has Been Learned Since 1996," *Energy Journal*, vol. 25, no. 2, 2004, p. 1.

[6] Michael Darby, "The Price of Oil and World Inflation and Recession," *American Economic Review*, vol. 72, no. 4, Sept. 1982, p. 738. The study covered 1957:Q1-1976:Q4. The regression results had an R-squared of 0.9984 and the oil price variables were jointly significant at the 5% level.

The next year, Hamilton published what many would consider to be the seminal study on oil shocks.[7] He drew attention to the fact that all but one of the post-war recessions had been preceded by a sharp rise in the price of oil, and set out to demonstrate statistically that, contrary to conventional wisdom, it was these oil price rises that caused the recessions. He demonstrated that oil prices, to use a term from economics, *Granger-caused* GNP.[8] To prove that oil prices and GNP were not both being determined by some third variable, he demonstrated that no other macroeconomic variable Granger-caused oil prices. He estimated that a 10% increase in the price of oil in this quarter would increase GNP by 0.04% in the next quarter, then decrease it by 0.07% after two quarters, another 0.5% after three quarters, and 0.6% after a year compared to the level GNP would have reached had the price of oil been constant.[9] Considering that during the major oil shocks prices rose by 20% in some quarters and rose for several quarters in a row, these estimates suggest the effect of oil shocks on the economy are quite large. However, statistical tests suggest that his equation was mis-specified or the relationship changed over time, and should be split in two at 1973. Surprisingly, although oil still Granger-caused GNP after 1973, he estimated that it had a much smaller effect on GNP from 1973 to 1980, when the first two major oil shocks occurred. He was one of the first to note that oil affected GNP with a lag — the effect on GNP was nearly ten times larger after four quarters than it was after two quarters.

The link between oil price increases and lower output growth is established.

Extensions

During the late 1980s and early 1990s, standard regression specifications no longer showed oil shocks to have a substantial effect on economic growth. Several papers were written attempting to explain why, using more sophisticated and complex mathematical relationships and statistical techniques.

Knut Mork was one of the first authors to find that in a standard regression, when extended through 1988 and controlling for other macroeconomic factors, the effect of oil price changes on the growth rate of gross national product (GNP) was now

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[7] James Hamilton, "Oil and the Macroeconomy Since World War II," *Journal of Political Economy*, vol. 91, no. 2, 1983, p. 228. The regression covered the period from 1948:Q2 to 1980:Q3 and the oil variables were jointly significant at the 1% level.

[8] Granger causation is a statistical test of causation based on the predictive power of past information. In this case, oil Granger-causes GNP if past values of oil increase the predictive power of future values of GNP beyond what is predicted by past values of GNP (and past values of any other variables included in the equation.) Oil is said to Granger-cause GNP if the predictive power it adds is statistically significant. Of course, this test is not definitive, and is subject to many of the shortcomings, such as omitted variable bias, described below in the Caveats section.

[9] Quarterly data have not been annualized. Thus, cumulative effects for one year can be roughly calculated by adding up quarterly effects. Technically, the estimates presented in the report are only mathematically accurate over small changes, but this report uses 10% changes for illustrative purposes.

small sand statistically insignificant.[10] In the mid-1980s, there had been a series of oil price declines, and Mork hypothesized that, unlike oil price increases, price declines had little effect on the economy. His regressions confirmed his hypothesis — when the distinction between price increases and decreases was made, the effect of price increases on GNP growth doubled, whereas price declines had a small and statistically insignificant effect. He estimated that a 10% temporary increase in the price of oil in this quarter would lower the GNP growth rate by 0.31 percentage points after one quarter, another 0.15 percentage points after two quarters, 0.49 percentage points after three quarters, and 0.49 percentage points after four quarters.[11]

The link breaks down — more sophisticated statistical methods are incorporated to try to re-establish it. Controlling for the volatility of oil prices is one method.

Lee, Ni, and Ratti re-confirmed that when newer data is added the effect of oil price increases on economic growth using the standard linear relationship between oil price changes and economic growth becomes statistically insignificant.[12] They claimed 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. (p. 42)

When they include an "oil price shock" variable that "can be thought of as being a measure of how different a given oil price movement is from the prior pattern"(p. 42)

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[10] Knut Mork, "Oil and the Macroeconomy When Prices Go Up and Down," *Journal of Political Economy*, vol. 97, no. 3, 1989, p. 740. The main regression covered 1949:Q1-1988:Q2 and had an R squared of 0.518. The oil price increase variables were jointly significant at the 1% level, while the price decrease variables were jointly insignificant. These results are extended through 1992 in Knut Mork, Oystein Olsen, and Hans Mysen, "Macroeconomic Responses to Oil Price Increases and Decreases in Seven OECD Countries," *Energy Journal*, vol. 15, no. 4, 1994, p. 19. The authors find that both price increases and decreases reduce GDP growth, and these results are statistically significant. A 10% increase in oil prices reduces growth by a cumulative 0.5 percentage points, and surprisingly a 10% price decrease reduces growth by a cumulative 0.8 percentage points.

[11] Balke, et al. (2002) used statistical tests to determine what third variable statistically explained why oil price increases had a larger effect on growth than price decreases. They concluded that interest rates could explain the asymmetry. They hypothesized that the role played by interest rates could reflect the "pricing in" of oil shock effects by forward looking financial markets or delays in capital investment and balance sheet effects due to oil price uncertainty. Nathan Balke, Stephen Brown, and Mine Yucel, "Oil Price Shocks and the U.S. Economy: Where Does the Asymmetry Originate?" *The Energy Journal*, vol. 23, no. 3, 2002, p. 27.

[12] Kiseok Lee, Shawn Ni, and Ronald Ratti, "Oil Shocks and the Macroeconomy: The Role of Price Variability," *Energy Journal*, vol. 16, no. 4, 1995, p. 39. Their regressions span 1950:Q3 to 1992:Q3. The variable real oil price change was statistically insignificant but the oil price shock variable was significant at the 1% level.

in the regression along with an oil price change variable, their results become statistically significant.

Similarly, Ferderer believed that oil price volatility was the missing factor that could explain oil's macroeconomic effects and added a variable to capture volatility to his regressions that previous studies lacked.[13] He argued that volatility could be costly in terms of shifting resources across sectors and causing investment uncertainty. He measured volatility as the standard deviation of daily prices. Using industrial production growth as a proxy for economic growth (in order to study the data over monthly intervals), he found that monthly oil price changes could statistically "explain" 5.7-18.5% of the fluctuations in industrial production, and oil price volatility could explain an additional 11.7-16.1% of the fluctuations. By contrast, monetary policy could explain only 11.6-12.0% of the fluctuations in industrial production. He confirmed Mork's findings that oil price increases had a greater effect on the economy than price decreases.

Hooker found that oil prices no longer Granger-cause economic growth or unemployment after 1973, even though all three oil shocks occurred during this period.[14] His results held for a variety of structural specifications. In reply to Hooker's work, Hamilton suggested that the relationship was not statistically significant after 1973 because many of the price increases since 1986 came on the heels of even larger decreases.[15] Hamilton doubted that these types of price increases would affect the economy. He devised a net oil price increase variable to control for this phenomenon, but still found smaller economic effects since 1973 and still did not find that his new variable, "the net oil price increase," Granger-caused economic growth.

Hamilton has posited that the reason standard regressions do not find that oil has a strong effect on economic growth is due to mis-specification. If the effect of oil on the economy is best represented by a non-linear mathematical relationship, then standard linear regressions may pick up very weak and misleading effects. In a later paper, Hamilton demonstrated that non-linear specifications suggest that oil has

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[13] J. Peter Ferderer, "Oil Price Volatility and the Macroeconomy," *Journal of Macroeconomics*, vol. 18, no. 1, winter 1996, p. 1. His regression covered the period January 1970 to December 1990. His oil price volatility measure was statistically significant at the 1% level and his measure for the level of oil prices was statistically insignificant. For more recent work, see Hui Huo and Kevin Kleissen, "Oil Price Volatility and U.S. Macroeconomic Activity," *Federal Reserve Bank of St. Louis Review*, vol. 87, no. 6, Nov./Dec. 2005, p. 669. They find that a 10% increase in oil price volatility would reduce GDP growth by 0.2 percentage points in the next quarter. Their results are statistically significant at the 5% level.

[14] Mark Hooker, "What Happened to the Oil Price-Macroeconomy Relationship?" *Journal of Monetary Economics*, vol. 38, 1996, p. 195. His regressions cover the period 1948:Q1-1994:Q2.

[15] James Hamilton, "This is What Happened to the Oil Price-Macroeconomic Relationship," *Journal of Monetary Economics*, vol. 38, 1996, p. 215. His regressions cover the period 1948:Q1-1994:Q2.

stronger effects than linear specifications.[16] Unfortunately, since there is an infinite number of non-linear specifications to choose from, there is no easy way to identify the correct one. Hamilton also noted that regression results may be hampered because the oil price can no longer be treated as exogenous, that is, it can now be driven by demand or supply. Using the net oil price increase measure proposed in his earlier work (1996), he found that a 10% increase in the price of oil (when it is not following a prior price decrease) in the current quarter will lower GDP in the next quarter by 0.13%, another 0.13% two quarters later, 0.22% three quarters later, and 0.45% four quarters later. The sum of these effects is 0.2 percentage points smaller than in Hamilton (1983).

A recent paper by Jimenez-Rodriguez and Sanchez updates Mork's, Hamilton's, and Lee et al's respective work.[17] Using standard vector autoregression methods, the authors find that a 10% increase in the oil price reduces GDP growth in the U.S. by a cumulative 0.39 percentage points after eight quarters. Using Mork's variation, they find that a 10% oil price increase reduces growth by 0.46 percentage points after eight quarters, but a 10% decrease increases growth by only 0.11 percentage points. Using Hamilton's net oil price measure increases the effect of a 10% price increase to 0.54 percentage points after eight quarters. Using Lee's method, which focuses on price volatility, yields the largest results: the 10% price increase now reduces growth by 0.61 percentage points after eight quarters. These results are somewhat smaller than the earlier studies had yielded.

A problem with many of these time-series studies is that they assume that the relationship between oil prices and GDP is constant over time. But since energy use as a share of GDP has fallen over time, one would expect oil prices to have a smaller effect on GDP as time passes. Huntington takes this into account and, using panel data for 14 countries, estimates that a 10% increase in oil prices in 1998 (latest year) would reduce U.S. GDP by 0.23%.[18]

In a recent paper, Hooker attempted to estimate how oil shocks affect inflation when controlling for other macroeconomic variables such as unemployment and price controls.[19] He found that the effects of oil price increases were much greater before

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[16] James Hamilton, "What is an Oil Shock?" *National Bureau of Economic Research working paper 7755*, June 2000. His regressions cover the period 1949:Q2-1999:Q4. Oil's effects on growth were statistically insignificant after one and two quarters, significant at the 10% level after three quarters, and at the 1% level after four quarters.

[17] Rebeca Jimenez-Rodriguez and Marcelo Sanchez, "Oil Price Shocks and Real GDP Growth: Empirical Evidence for Some OECD Countries," European Central Bank working paper 362, May 2004. Their results cover the period 1972:II-2001:4 and the oil variables are jointly significant, with the exception of price decreases in the Lee model.

[18] Hillard Huntington, "Shares, Gaps, and the Economy's Response to Oil Disruptions," Energy Economics, vol. 26, 2004, p. 415.

[19] Mark Hooker, "Are Oil Shocks Inflationary? Asymmetric and Nonlinear Specifications versus Changes in Regime," *Journal of Money, Credit, and Banking*, vol. 34, no. 2, May 2002, p. 540. His regressions cover the period 1962:Q2-2000:Q1 and had an adjusted R squared of 0.92. The oil variables are independently significant at the 1% level, but jointly

(continued...)

1981 than after that date. After 1981, he found that oil price increases had only a small effect on the core inflation rate (excluding food and energy) as measured by the personal consumption expenditures deflator. He estimated that a 10% increase in the price of oil in the current quarter would lower core inflation by 1 percentage point in the next quarter and raise it by 0.5 percentage points two quarters after the increase. Thus, he finds no positive net effect on inflation.

Oil Shocks or Monetary Policy?

Despite the remarkable historical coincidence between oil shocks and recessions, a strain of research has suggested that there might nonetheless be some third force responsible for the recessions. In particular, the research has tried to separate the effects of the oil shocks on the economy from the effects of simultaneous changes in monetary policy. Some of the research has concluded that had it not been for the changes in monetary policy, the oil shocks would have had little effect on economic growth.

In an early paper, Gisser and Goodwin tried to capture the effects of monetary policy, fiscal policy, and oil price changes on economic growth, inflation, and unemployment.[20] They measure monetary policy by the growth rate of the money supply and fiscal policy by the full employment measure of federal expenditures. They estimated that a 10% increase in the price of oil in the current quarter would reduce GNP growth by 0.2% in this quarter, another 0.01% in the next quarter, 0.02% after two quarters, 0.3% after three quarters, and 0.5% after four quarters. Similarly, a 10% increase in the price of oil is estimated to increase the inflation rate (as measured by the GDP deflator) by 0.1% this quarter, and an additional 0.2% after one, two, three, and four quarters. A 10% increase in the price of oil is estimated to increase the unemployment rate by 1.6% this quarter, decrease unemployment by 0.4% after one quarter, increase unemployment by 0.2% after two quarters, 2.4% after three quarters, and 3.2% after four quarters. (The unemployment estimates seem questionably large, given the much milder estimated effects on growth.) Monetary policy is estimated to have a much larger effect than the oil shocks: the effect of a 10% change in the money supply is estimated to be about twice as large as a 10% change in the oil price for GNP and about six times as large for the price level and unemployment. The effects

Oil shocks coincide with recessions. But are the recessions really caused by the oil shock, or are they caused by monetary policy?

[19] (...continued)
insignificant.

[20] Micha Gisser and Thomas Goodwin, "Crude Oil and the Macroeconomy: Tests of Some Popular Notions," *Journal of Money, Credit, and Banking*, vol. 18, no. 1, Feb. 1986, p. 95. Their regressions results span the period 1961:Q1-1982:Q4 and had an R squared of 0.32 for GNP growth, 0.58 for inflation, and 0.23 for unemployment. The oil variables are jointly significant at the 1% level in all three cases. The oil, monetary, and fiscal variables are jointly significant at the 1% level for GDP growth, but statistically insignificant for inflation and unemployment.

of fiscal policy on GNP and unemployment are smaller than the effects of oil price changes, although larger than the effects on the price level. The authors also demonstrated that oil Granger-caused GNP, the price level, and unemployment. Contrary to other studies, they also found that after controlling for monetary and fiscal policy, there was no structural break in the oil-GNP relationship after 1973. However, they do confirm that there was a break in the oil-price level and oil-unemployment relationship.

Dotsey and Reid attempted to synthesize the work of Romer and Romer, which claimed that contractionary monetary policy was the cause of post-war recessions, with the work of Hamilton, surveyed above, which claimed that the recessions were caused by oil shocks.[21] They estimated that a 10% increase in the price of oil lowered GNP growth by a total of 0.7 percentage points over the next four quarters. (Similar to Mork, they estimated the effects of price increases and decreases separately, and found that price decreases had a smaller and statistically insignificant effect on growth.) By contrast, a 1 percentage point increase in the federal funds rate was estimated to reduce GDP growth by 0.1 percentage points over the next four quarters. They also estimated the effect of oil price increases on unemployment and found that a 10% increase in oil prices would increase the unemployment rate by a total of 0.4 percentage points over the next 24 months.

Bernanke, et al. were interested in finding out what effects monetary policy changes had when they were unanticipated.[22] They chose to study oil shocks because these are one of the only macroeconomic phenomena that most economists would agree are both unanticipated and exogenous. First, they estimated the effect of a 10% increase in the price of oil when monetary policy responds as it has historically. They estimated that over 24 months, GDP would fall by 3.1% and prices would rise by 0.09% relative to a baseline. To separate the effects of the oil shock from the effects of the change in monetary policy, they then estimated a counter-factual example where monetary policy does not respond to the oil price increase, which they represented with a constant federal funds rate. In this case, GDP was estimated to *rise* by 1.3% and prices by 0.13%. They therefore concluded that oil price shocks have very little negative effect on the economy; rather it is the monetary response to

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[21] Michael Dotsey and Max Reid, "Oil Shocks, Monetary Policy, and Economic Activity," *Federal Reserve Bank of Richmond Economic Review*, vol. 78, no. 4, July 1992, p. 14. For GNP, the regression covered the period 1955:3-1991:3 and the R squared was 0.32. The sum of oil price increase variables was statistically significant at the 1% level; however, the sum of oil price decrease variables was statistically insignificant. For unemployment, the regression covered the period 1950:1-1990:12 and had an R squared of 0.977. The sum of the oil variables was significant at the 1% level.

[22] Ben Bernanke, Mark Gertler, and Mark Watson, "Systematic Monetary Policy and the Effects of Oil Price Shocks," *Brookings Papers on Economic Activity 1*, 1997, p. 91. Their regressions cover the period 1965-1995. None of their results are statistically significant.

oil shocks that leads to the historical coincidence between oil shocks and recessions.[23] [24]

The work of Bernanke, et al. raises an interesting conceptual question: while the effects of oil shocks and monetary policy can be statistically separated, can they be separated in reality? Bernanke, et al. attribute the tightening of monetary policy following oil shocks as the Fed's response to the increase in inflationary pressures that oil shocks are commonly believed to cause. Commenting on the Bernanke paper, Sims points out that the assumption that monetary policy could remain unchanged in response to an increase in inflationary pressures is not a sustainable policy, and thus falls prey to the Lucas critique (see below). It is unlikely that private individuals would have no reaction to the implementation of an unsustainable policy, making the statistical separation of oil price effects from monetary effects problematic.[25] This would suggest that one can reasonably question whether there is a practical distinction between attributing a recession to an oil shock or attributing it to the monetary response to an oil shock.

Hamilton and Herrera pursue this line of reasoning in a critique of the Bernanke paper.[26] While Bernanke's regressions can mechanically be interpreted to imply that monetary policy could prevent a recession, Hamilton and Herrera point out that these regressions would imply that the federal funds rate would have to have been an improbable 9 percentage points lower in 1973 to prevent a recession. Using the Lucas critique, it is unlikely that private individuals' expectations would have remained unchanged in light of such a significant policy change. Hamilton and Herrera also argue that Bernanke et al. underestimate the effects of oil shocks because they use too short a lag length. Bernanke et al. assume that changes in oil prices affect the economy for the next seven months, whereas Hamilton and Herrera suggest a lag length of at least 12 months would be more appropriate since many works find the largest economic effects of oil price changes to come after three and four quarters. In particular, by using a longer lag than Bernanke, they find that

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[23] Using similar methods, Ferderer (1996) found the opposite results: the effects of oil shocks were larger than the effects of monetary policy. See the section titled Extensions.

[24] Similarly, Barsky and Kilian construct a theoretical model that attributes falling output and rising inflation to monetary policy rather than oil shocks. In their model, inflation can continue to rise while output falls because inflationary expectations change sluggishly. They also question if oil shocks were caused by consumer demand, in which case they cannot be treated as exogenous (see below). Robert Barsky and Lutz Kilian, *Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative*, National Bureau of Economic Research, Working Paper 8389, July 2001. See also Ben Hunt, *Oil Price Shocks: Can They Account for the Stagflation in the 1970s?*, International Monetary Fund, Working Paper 05/215, Nov. 2005.

[25] Christopher Sims, "Comments," *Brookings Papers on Economic Activity 1*, 1997, p. 146. To address this criticism, Bernanke, et al. also run simulations in which the federal funds rate is held constant but expectations are assumed to adjust more quickly. Under this scenario, output still rises and inflation rises slightly more quickly.

[26] James Hamilton and Ana Maria Herrera, "Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy," *Journal of Money, Credit, and Banking*, forthcoming.

countering oil shocks with expansionary monetary policy has much larger effects on inflation since monetary policy affects inflation with a significant lag.

The Effects of Oil Shocks on Employment

A related strain of research studied the effects of oil shocks on employment. Since economic growth has a strong effect on unemployment in the short run, one would expect oil shocks to affect unemployment if they affect economic growth.[27]

Carruth, Hooker, and Oswald estimated that oil shocks had a larger effect on unemployment than economic growth.[28] They showed that oil shocks Granger-caused unemployment (unlike GDP[29]) up to the present (1995) and estimated that a 10% increase in the price of oil would increase the unemployment rate by 0.2 percentage points. Although this is a relatively small effect, they found that the effect of oil price changes on unemployment before 1978 was more than three times larger. They found that their model, based on oil prices and interest rates, forecasts unemployment more accurately than commercial forecasts.

Oil shocks change both the overall level of employment and the allocation of employment across industries.

Davis and Haltiwanger focused on oil's effect on employment in the manufacturing sector, broken down by industry.[30] They hypothesize that oil price changes have distinct "aggregate" effects and "allocative" effects on manufacturing employment. The aggregate effects on employment are caused by the slowdown in GDP growth that oil price increases cause. The allocative effects on employment come from the fact that some industries are harmed more than others — and some are actually helped — by a price increase. Thus, some jobs are shifted from one industry to another so that the net allocative effect of an oil price change on employment is zero. They found that

[27] Two papers already reviewed in this report investigated the effects of oil shocks on unemployment. See Gisser and Goodwin (1986) and Dotsey and Reid (1992).

[28] Alan Carruth, Mark Hooker, and Andrew Oswald, "Unemployment Equilibria and Input Prices: Theory and Evidence from the United States," *The Review of Economics and Statistics*, vol. 80, no. 4, 1998, p. 621. The regression covered the period from 1955:Q4 to 1995:Q2. The R squared was 0.837 and the oil variable was statistically significant at the 1% level.

[29] These results are curious since short-term fluctuations in unemployment are usually thought to be caused by fluctuations in GDP. Otherwise, the fluctuations would represent changes in the natural rate of unemployment, and there has not been any well-known link established between the price of oil and the natural rate of unemployment.

[30] Steven Davis and John Haltiwanger, "Sectoral Job Creation and Destruction Responses to Oil Price Changes," *National Bureau of Economic Research*, working paper 7095, April 1999. The regression spanned from 1972:2 to 1988:4 and the oil variables were individually insignificant at the 5% level, except for the seven-quarter lag variable.

> a unit standard deviation positive oil shock triggers the destruction of an extra 290,000 production worker jobs and the creation of an extra 30,000 jobs in the first two years after the shock.... After four years, the net employment response to a unit positive oil shock is only 60,000 fewer jobs, but the gross reallocation response amounts to 410,000 jobs or more than 3 percent of employment.

By comparison, they estimated that a unit standard deviation tightening in monetary policy leads to a net loss of 140,000 manufacturing jobs after two years. Looking at the data on an industry level, they estimated that the effects differ greatly by industry depending on the characteristics of that industry. For example, categorized by the energy intensity of production, the decline in employment was almost twice as large for industries in the 90th percentile than industries in the 10th percentile. Because their study excluded the service sector, which accounts for most employment, their results cannot be meaningfully extrapolated to judge the effects of oil price changes on overall unemployment.[31]

Some Caveats

Quantitatively estimating the effect of oil shocks on the economy is more difficult than it sounds. In the sciences, statistical robustness is obtained by running numerous controlled randomized experiments in order to sift out randomness in the data to identify the true relationships between variables. If uncertainty emerges concerning the role one factor plays, one can change the experiment to isolate that factor's effect. In macroeconomics, experiments are not controlled and they cannot be run over and over again. Since World War II, we have had only 10 "experiments" with recession, and it is highly doubtful that the U.S. economy is the same test case today as it was in, say, 1957. Instead, economists must hypothesize the relationships between different economic factors expressed through mathematical relationships and compare the historical correlation of those variables to see if the hypothesis holds. If the mathematical relationship chosen to represent the relationship is incorrect or changes over time, or other variables which have an effect are missing from the regression, then the estimates will be incorrect. Studies that attempt to identify more sophisticated relationships than the simple linear one can be accused of "data mining" to find the biggest (or smallest) effect possible.

> *To accurately estimate the effects of oil shocks on the economy, one must avoid a number of common pitfalls.*

There are some common pitfalls that lead to econometric studies giving "biased" or incorrect estimates for the relationship between variables. Some of these pitfalls are nearly impossible to avoid, particularly in macroeconomics. This report will review four such pitfalls — omitted variable bias, structural misspecification, problems with endogeneity, and the Lucas Critique. These problems suggest that econometric estimates, while useful, should always be

[31] In an earlier paper, Loungani demonstrated that the reallocation of employment across industries led to an increase in unemployment only when the reallocation was caused by oil shocks. Prakash Loungani, "Oil Price Shocks and the Dispersion Hypothesis," *Review of Economics and Statistics*, vol. 68, no. 3, Aug. 1986, p. 536.

considered with caution. In addition, even when measured accurately, there is a question of statistical robustness.

Omitted Variable Bias. A common problem that econometricians try to avoid is omitted variable bias. If a regression does not control for a factor that affects one's dependent variable, then the estimated effects of the explanatory variables that are included will be biased. The importance of explanatory variables positively correlated with the missing variable will be overstated, the importance of negatively correlated variables will be understated. This is a particularly important problem in economics precisely because experiments cannot be re-run or truly randomized. In microeconomics, it may typically be feasible to include all of the relevant factors of non-trivial size, although proxy variables may be needed. But in macroeconomics, this assumption seems more problematic; there are simply too many factors influencing the economy to capture them all. Most of the regressions reviewed in this report used oil and only a few other key economic variables as explanatory variables. Yet a look at the current recession points to many additional factors — many unquantifiable in nature — that have taken a toll on the U.S. economy. These include the effects of September 11, the corporate accounting scandals, the large decline in the stock market, and so on. If these factors were not included in a regression, the regression would attribute their effects instead to the recent run-up in oil prices (and any other correlated explanatory variables), overstating oil's importance.

Structural Misspecification. The fact that a study finds no relationship between two variables does not mean that no relationship exists in reality. Likewise, studies can identify relationships where no relationship in fact exists. Regressions relate data series to one another according to some mathematical function; if that mathematical function does a poor job of describing the relationship in reality, then the results will be artificially weak. The problem is that there is an infinite number of mathematical equations that can be used to express a relationship and often there is not a strong theoretical reason for favoring any one. As a result, econometricians most frequently assume a linear relationship between the variables (often after taking the natural logarithm of the data); this assumption is made more out of convention than due to any strong reason for preferring a linear relationship over any other.[32]

Thus, in most of the studies surveyed above, a 10% change in the oil price is estimated to have an effect that is 10 times greater than a 1% change. This assumption seems unlikely to represent reality accurately. Experience and common sense suggest that while the major oil shocks have had significant effects on the economy, small and fleeting movements in the oil price have virtually no impact. Yet a linear relationship would scale these two events equally. While theory can point to alternatives, unfortunately, representing the statement "oil price changes only matter if they are steep, sudden, long-lasting, and do not reverse previous price movements in the opposite direction" in mathematical form is neither simple nor straightforward.

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[32] There are many other problems of this type that make econometric estimates problematic. For example, the standard regression method is valid only if the error terms are assumed to be normally distributed. Otherwise, different methods must be used.

All of the studies reviewed in this report used time series analysis to estimate the effects of oil prices. Time series analysis is vulnerable to a special type of structural misspecification: it must assume that the relationship between the explanatory variables and the dependent variable is constant over time. For example, a 10% increase in the oil price must have the same economic effects in 1952 as it has in 2002. But if oil affects the economy through the production process, oil shocks would be expected to have a smaller effect on the economy if the economy became more energy efficient in terms of energy use relative to GDP. Historically, energy consumption per dollar of GDP has dropped significantly over the past three decades, with the economy now using less than half as much energy per dollar as it did in the 1970s. In order to correct for such changes, statistical tests are used to look for structural breaks. The time series can then be divided into sub-samples, each estimated separately. But if the series is divided, the study loses a degree of statistical robustness because it is based on fewer observations.

Problems with Endogeneity. Virtually all important macroeconomic phenomena are interrelated, usually in complex ways. This makes econometric estimation difficult. In the simple regression, causation runs from the explanatory variables to the dependent variable. For the simple regression method to be valid, neither the dependent variable, nor another explanatory variable, nor some missing or unobserved variable can influence any explanatory variable. This qualification seldom if ever holds in macroeconomics, which means that more complex, and less straightforward, econometric methods must be used or the estimations will be invalid. Such methods exist, but have shortcomings of their own, and are not always used by the econometrician.

For example, the exchange rate, interest rates, and fiscal policy all influence phenomena such as economic growth, inflation, and unemployment. But, in turn, their values are determined by the very phenomena that they influence; this is how markets reach equilibrium. Thus, to determine the effects of a change in monetary or fiscal policy on economic growth, one cannot simply run a regression in which economic growth is the dependent variable and the budget deficit and interest rates are independent variables. Even oil prices, which might seem to be a good candidate for exogeneity because of the role played by OPEC, are likely to be endogenously determined. Although OPEC has some control over the supply side of the market, price is also determined on the demand side, which is influenced by factors such as growth in income.

One way of avoiding endogeneity problems in time series analysis is by using a statistical method called vector autoregression, which simply assumes that all variables affect each other. Two shortcomings have been raised with this method that are worth mentioning here. First, critics complain that vector autoregression is atheoretical: the method eschews any attempt to identify relationships between variables in theoretical terms. While this makes it a more flexible method, its critics argue that no theory is not the same as the right theory. Econometrics will only lead to accurate results if the underlying theory accurately describes reality. Second, there is a tradeoff between the number of explanatory variables one can have and the number of observations with which one is working. (With time series data, the number of observations is limited to how far back in time one is willing to go, which raises another set of problems discussed in the previous sub-section.) Because all of the variables must be regressed on each other and because the use of time lags creates more variables, in practice vector autoregressions can have only a few explanatory variables, as opposed to traditional macroeconomic models which have had as many as hundreds.

Lucas Critique. Many econometric estimations of macroeconometric phenomena fall prey to the "Lucas Critique" set out by Nobel Laureate Robert Lucas. Econometric estimates derived from historical data, particularly when they include variables that policymakers can influence, implicitly assume that the future will be similar to the past. One of Robert Lucas' main contributions to economics was the development of the theory of "rational expectations," in which he argued that, contrary to much mainstream economic theory of the time, economic theory should always be based on the assumptions that private individuals are fully informed and act rationally to maximize their self-interests. If people adjust their expectations when circumstances change, the future is unlikely to be the same as the past. Thus, many econometric estimates are inconsistent with rational expectations. For example, by looking at historical patterns, one can use econometric analysis to estimate the effects of changes in the federal funds rate on economic growth. For the estimated effect to be valid in forecasting future behavior, one must assume that individuals do not change their behavior or learn from past mistakes. Taken literally, this would lead to perverse predictions. For example, if individuals were fooled by a "monetary surprise" (i.e., an unanticipated and opportunistic change in monetary policy) in the past, this type of econometric modeling would predict that they would continue to be fooled indefinitely in the future.

Furthermore, when making predictions about the effects of policy alternatives, one can assume a policy variable to take any value. Yet if this value had occurred historically, because of the role of expectations, it could have changed all of the other estimated parameters in the regression. If this were true, the model would have little predictive power. For example, if policymakers had always responded to oil shocks by sharply tightening monetary policy, an econometric model might suggest that oil shocks have little effect on inflation. An econometrician could then use his model to demonstrate that an expansionary monetary policy could be employed to cope with oil shocks with little effect on inflation. Yet had this policy been employed historically, expectations might have adjusted (when people saw oil prices rise, they would anticipate all other prices to rise) to make oil shocks far more inflationary.

Robustness of Results. Even if an econometric study avoided all the problems discussed above and perfectly represented reality, simply taking estimates at face value tells only half of the story. As well as worrying about the size of an estimate, statisticians are concerned with its statistical robustness. A study may find that oil shocks have a very large effect on the economy, but if there is significant unexplainable variation in the sample, one should be skeptical about the results. This report has reported two common measures of robustness: the statistical significance of specific explanatory variables and the R-squared of the study as a whole. Statistical significance is determined by how much the sample data varies from the best estimate of the relationship between the dependent and explanatory variables. An estimate is statistically significant at, say, the 1% confidence level if 99 out of

100 samples will be different from zero. The R-squared measures how much of the variation in the dependent variable can be explained by the explanatory variable; if none of the variation can be explained the R-squared would be zero, if all can be explained it would be one.

Conclusion

All of the studies reviewed in this report found oil shocks to have some effect on the economy. There is a fair degree of consensus surrounding the range of estimates: for comparable studies, the cumulative effect of a one-quarter, 10% increase in oil prices was to lower economic growth by 0.2-1.1% over the next four quarters compared to GDP under a baseline in which the oil price does not change (see **Table 1**). The effect takes place over a number of quarters, with research typically finding weaker effects at first. The magnitude of these estimates suggests that normal fluctuations in the price of oil would cause only minor fluctuations in economic growth. However, the estimates suggest that major oil shocks, in which oil prices rise for several consecutive quarters, often by more than 10%, could lead to recessions, all else equal. Only the study by Bernanke et al. dissents from this conclusion by claiming that while oil shocks have historically had a large negative effect on economic growth, the historical experience is attributable to the monetary response to the shock, rather than the shock itself. Hooker (2002) was unable to find oil to have any effect on core inflation.

Although the magnitude of the estimates is large enough to make oil shocks a policy concern, the results are not statistically robust enough to silence all doubts. Oil prices no longer Granger-cause economic growth in straightforward ways. The effect of oil price changes on the economy was statistically insignificant in many studies. Some studies had low R-squared values, which means that many of the determinants of economic activity remain unexplained. Studies which attempted to identify more sophisticated relationships than the simple linear one could be accused of “data mining” to find the biggest (or smallest) effect possible.

Furthermore, every study that explored the issue found that oil’s broad effects on the economy were waning, and more recent studies tended to find oil to have smaller effects. Particularly puzzling was that many studies found oil to have stronger economic effects before the mid-1970s, despite the fact that all of the major oil shocks occurred since the mid-1970s.

This report was limited to surveying studies that specifically focused on oil’s impact on the economy. Many macroeconometric studies not reviewed have focused on other determinants of economic activity, such as monetary policy, and have neglected the role of oil entirely. It is fair to say that some economists remain unconvinced that oil plays a crucial role in the business cycle.

All macroeconometric studies are prone to a number of unavoidable pitfalls. If they were reliable and if our understanding of the economy were better, macroeconomic policy concerns would vanish. It is not merely a question of developing more sophisticated statistical techniques; some pitfalls stem from the unpredictability of human nature that ultimately determines economic outcomes. Nevertheless, these studies contribute valuable insight into important phenomena such as oil shocks.

Table 1. Summary of Findings

Study	Major Findings
Darby (1982)	1973 oil shock reduced cumulative GNP by 2.5%
Hamilton (1983)	GNP responds to oil price change with lag; oil had larger effect on GDP before 1973; 10% oil price increase reduces GNP by 1.1% over the next year
Gisser and Goodwin (1986)	controls for monetary policy and fiscal policy; finds monetary policy to have larger effect than oil price change; 10% oil price increase reduces GNP by 1.0% over the next year
Mork (1989)	only oil price increases have significant effect on output, price decreases have negligible effect; 10% oil price increase reduces GNP growth by 0.36 percentage points over the next year
Dotsey and Reid (1992)	oil price increase had larger effect on GNP than monetary policy; 10% oil price increase reduces GNP growth by 0.7 p.p. over the next year
Lee, Ni, Ratti (1995)	oil price changes only affect GNP if they persist
Ferderer (1996)	controlling for oil price volatility helps explain relationship between oil price increases and GNP
Bernanke et al (1997)	argues that oil shocks do not cause recessions; rather, the response of monetary policy to oil shocks causes recessions
Carruth et al (1998)	oil prices do not have significant effect on GNP, but they have a significant effect on unemployment; 10% oil price increase increases unemployment by 0.2 p.p. over the next year
Davis and Haltiwanger (1999)	oil price increases both destroy manufacturing jobs and shift jobs across industries; one standard deviation oil price increase destroys 290,000 and creates 30,000 manufacturing jobs
Hamilton (2000)	demonstrates that non-linear models do a better job explaining the relationship between oil prices and output than linear models; 10% oil price net increase reduces GNP by 0.9% over the next year
Hooker (2002)	does not find oil price increases to have any significant effect on core inflation; 10% oil price increase reduces core inflation by 0.5% over the next two quarters
Huntington (2004)	effect of oil price on economy is greater if economy uses more energy; 10% oil price increase reduces GDP by 0.2% in 1998
Jimenez-Rodriguez and Sanchez (2004)	updates Hamilton's, Mork's, and Lee et al's findings using recent data; 10% oil price increase reduces GDP growth by 0.4-0.6 p.p. over next two years

Notes: p.p.= percentage points. Unless otherwise noted, all estimates are compared to the economic variable under a baseline scenario in which the oil price does not change.

Glossary[33]

confidence level — the percentage of samples that will contain the true unobservable value. For example, at the 1% confidence level, the sample will contain the true value 99% of the time. (For a discussion, see section titled robustness of results.)

data mining — using the same data set to estimate several different models in a search to find the "best" model, resulting in biased estimates.

dependent variable — the variable whose behavior the regression is attempting to explain in terms of other variables which influence it.

econometrics — using statistical methods to explain economic phenomena by relating a variable to other explanatory variables.

endogenous — an explanatory variable that is determined by another variable in the equation or correlated with the equation's error term. (For a discussion, see section titled Problems with Endogeneity)

exogenous — an explanatory variable that is not determined by any other variable in the equation and is not correlated with the equation's error term. (For a discussion, see section titled Problems with Endogeneity)

GDP (gross domestic product) — a measure of the economic output generated within the United States.

GNP (gross national product) — a measure of the economic output generated by American citizens.

Granger causation — a variable is said to Granger-cause another variable if the first variable has predictive power for future values of the latter variable at statistically significant levels when past values of the latter variable have been taken into account.

joint (statistical) significance — a set of variables are said to be jointly significant if they jointly differ from zero at a given confidence level.

regression — a statistical method to "explain" changes in a variable by comparing changes in that variable to changes in independent variables.

R squared — the percentage of the variation in the dependent variable that can be explained by the explanatory variables. (For a discussion, see section titled robustness of results.)

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[33] This glossary draws heavily on Jeffrey Woolridge, *Introductory Econometrics*, South-Western College Publishing (Australia: 2000)

standard deviation — a common measure of variance in a sample; **"one standard deviation"** is a useful measurement standard when estimating changes in variables because it always represents the same value when a sample has a normal distribution.

statistical significance — a variable is said to be statistically significant if it differs from zero at a given confidence level. (For a discussion, see section titled Robustness of Results.)

structural break — a situation where the relationship between dependent and explanatory variables is not constant over time (For a discussion, see section titled Structural Misspecification.)

structural specification — choosing a mathematical function that is the best representation of the relationship in reality. (For a discussion, see section titled Structural Misspecification.)

time series — data for a set of variables that spans a time period.