
Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market

Author(s): Lutz Kilian

Source: *The American Economic Review*, Jun., 2009, Vol. 99, No. 3 (Jun., 2009), pp. 1053-1069

Published by: American Economic Association

Stable URL: <http://www.jstor.com/stable/25592494>

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at <https://about.jstor.org/terms>



is collaborating with JSTOR to digitize, preserve and extend access to *The American Economic Review*

JSTOR

Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market

By LUTZ KILIAN*

A common approach in both empirical and theoretical work on oil price shocks is to evaluate the response of macroeconomic aggregates to exogenous changes in the price of oil. Implicit in this approach is a thought experiment, in which one varies the price of oil, while holding all other variables constant. This thought experiment is not well defined for two reasons. First, reverse causality from macro aggregates to oil prices means that cause and effect are no longer well defined when relating changes in the real price of oil to macroeconomic outcomes (see Robert B. Barsky and Kilian 2002). Second, the price of oil (like the price of any other commodity) is driven by distinct demand and supply shocks. Not only does each of these shocks have different dynamic effects on the real price of oil and hence on the US economy, but global demand shocks, in particular, may have direct effects on the US economy as well as an indirect effect working through the price of oil (and the prices of other industrial commodities). This fact immediately invalidates the *ceteris paribus* assumption, even controlling for reverse causality.

This paper proposes a structural VAR model of the global crude oil market that jointly addresses these two issues. The first objective is to identify the underlying demand and supply shocks in the global crude oil market. The identification of these shocks is important not just for explaining fluctuations in the real price of oil, but also for understanding the response of the US economy associated with oil price fluctuations. Using a newly developed measure of monthly global real economic activity, a structural decomposition of the real price of crude oil into three components is proposed: crude oil supply shocks; shocks to the global demand for all industrial commodities; and demand shocks that are specific to the global crude oil market. The last shock is designed to capture shifts in the price of oil driven by higher precautionary demand associated with market concerns about the availability of future oil supplies. The paper provides estimates of the dynamic effects of these shocks on the real price of oil and estimates of how much each of these shocks contributed to the evolution of the real price of oil during the 1975–2007 period.

The central message of this paper is that oil price increases may have very different effects on the real price of oil, depending on the underlying cause of the price increase. For example, an increase in precautionary demand for crude oil causes an immediate, persistent, and large increase in the real price of crude oil; an increase in aggregate demand for all industrial commodities causes a somewhat delayed, but sustained, increase in the real price of oil that is also substantial; and crude oil production disruptions cause a small and transitory increase in the real price of oil within the first year.

Decompositions of fluctuations in the real price of oil show that oil price shocks historically have been driven mainly by a combination of global aggregate demand shocks and precautionary demand shocks, rather than oil supply shocks, as is commonly believed. For example, the surge in the price of oil after 2003 was driven primarily by the cumulative effects of positive global

* Department of Economics, University of Michigan, 611 Tappan Street, Ann Arbor, MI 48109-1220, and Centre for Economic Policy Research (e-mail: lkilian@umich.edu). I thank Luca Guerrieri, Ana María Herrera, Eric Sims, and three anonymous referees for helpful comments.

demand shocks. Likewise, the increase in the real price of oil after 1979 was driven by the superimposition of strong global demand driven by a booming world economy and a sharp increase in precautionary demand. Typically, disruptions of crude oil production play a less important role, suggesting that the traditional approach of linking major oil price increases to exogenous shortfalls in crude oil production must be rethought. When exogenous political events do affect oil prices, as happened after the Iranian Revolution and during the Persian Gulf War, my analysis suggests that it is less the physical supply disruptions than the increased precautionary demand for oil triggered by increased uncertainty about future oil supply shortfalls that is driving the price of oil.

These findings also help us assess the macroeconomic implications of oil price shocks for the US economy. An oil price change driven by an unanticipated global aggregate demand shock, for example, will have a very different effect than an oil price change caused by an unanticipated increase in precautionary demand driven by fears about future oil supply shortfalls. Hence, it is important that we understand the extent to which increases in the real price of oil are driven by one shock or another, before formulating policy responses. My analysis helps explain the puzzle that the sharp increase in crude oil prices since 2003 has not been followed by a major US recession, so far. This increase failed to cause a major recession because it was driven primarily by sustained strong demand for crude oil fueled by a booming world economy rather than oil supply disruptions or unanticipated increases in the precautionary demand for oil.

The remainder of the paper is organized as follows. In Section I, I introduce a new measure of monthly global real economic activity based on data for dry cargo bulk freight rates. This measure is used in disentangling demand and supply shocks in the global crude oil market. Section II focuses on the identification of the structural shocks that drive the real price of oil. I quantify these shocks and estimate their dynamic effects on the real price of oil. I also quantify their historical contribution to the real price of oil. Section III investigates the impact of the shocks identified in Section II on US macroeconomic aggregates. The concluding remarks are in Section IV.

I. Modeling the Global Crude Oil Market

The price of crude oil is determined in global markets. A useful approach to classifying the key determinants of the real price of oil, building on the work of Barsky and Kilian (2002, 2004), distinguishes three demand and supply shocks: shocks to the current physical availability of crude oil (*oil supply shocks*), shocks to the current demand for crude oil driven by fluctuations in the global business cycle (*aggregate demand shocks*); and shocks driven by shifts in the precautionary demand for oil (*precautionary demand shocks*). Precautionary demand arises from the uncertainty about shortfalls of expected supply relative to expected demand. It reflects the convenience yield from having access to inventory holdings of oil that can serve as insurance against an interruption of oil supplies (see Ron Alquist and Kilian (forthcoming) for a formal analysis). Such an interruption could arise because of concerns over unexpected growth of demand, over unexpected declines of supply, or over both. One can interpret precautionary demand shocks as arising from a shift in the conditional variance, as opposed to the conditional mean, of oil supply shortfalls. Such shifts in uncertainty may arise, even controlling for the global business cycle and the global supply of crude oil.

Of these three shocks, oil supply shocks have been studied extensively based on data on global crude oil production (see, e.g., James D. Hamilton 2003; Kilian 2008a, b). Recent research has documented that these oil supply shock measures alone do not explain the bulk of oil price fluctuations (Kilian 2008a). While it is evident from informal evidence that demand shocks play an important role in the crude oil market, the problem of quantifying these demand shocks has, thus

far, proven elusive. One difficulty is that there are no readily available indices that capture shifts in the demand for industrial commodities driven by the global business cycle. An additional difficulty is that the expectation shifts underlying precautionary demand shocks are not observable. Even if one could identify the observables that are driving these expectations, the link from observables to shifts in the uncertainty about future oil supply shortfalls is highly nonlinear, and there is little hope of being able to estimate this link from the data.

Rather than modeling expectations directly, this paper pursues an alternative strategy. I devise an explicit measure of the changes in global real activity that affect the demand for all industrial commodities. Having controlled for both oil supply shocks and shocks to the business-cycle driven demand for all industrial commodities, I allow a structural dynamic simultaneous-equations model to pin down the oil market-specific component of demand as the residual.

This oil market-specific demand shock could, in principle, capture any number of omitted factors, but, whatever these factors are, the model ensures that they must be orthogonal to crude oil supply shocks and to world demand for industrial commodities. In Section IIA, I discuss a number of alternative interpretations of the oil market-specific demand shock (including preference shocks abroad and weather shocks) and provide evidence that this residual effectively represents a precautionary demand shock. This interpretation also is consistent with related evidence in Alquist and Kilian (forthcoming) based on data from oil futures markets. While my analysis does not rule out the existence of additional, complementary explanations, any alternative interpretation must satisfy the conditional facts developed in this paper.

A. A Monthly Measure of Global Real Economic Activity

The objective of constructing a monthly index of global real economic activity in this paper is not to obtain a proxy for global real value added, but rather a measure of the component of worldwide real economic activity that drives demand for industrial commodities in global markets. The index developed in this section is based on dry cargo single voyage ocean freight rates and is explicitly designed to capture shifts in the demand for industrial commodities in global business markets.¹

It is widely accepted that world economic activity is by far the most important determinant of the demand for transport services (see, e.g., Klovland 2004). As documented by Stopford (1997), at low levels of freight volumes the supply curve of shipping is relatively flat in the short and intermediate run, as idle ships may be reactivated or active ships may simply cut short layovers and run faster. As the demand schedule for shipping services shifts due to increased economic activity, the slope of the supply curve becomes increasingly steep and freight rates increase. At full capacity the supply curve becomes effectively vertical, as all available ships are operational and running at full speed. Only in the long run will additional shipbuilding lower freight rates, often at a time when the initial high levels of economic activity have already subsided. Following a global business cycle upswing there is likely to be a rather drawn-out trough period in the shipping market, as new ships are still being launched, long after the business cycle peak has passed, and excess capacity of shipping prevails. Only gradually will the scrapping of older ships and rising demand due to the business cycle offset this depression in the shipping market.

¹ This approach to measuring real economic activity is not without precedence. Economists have long observed a positive correlation between ocean freight rates and economic activity (see, e.g., L. Isserlis 1938; Jan Tinbergen 1959; Martin Stopford 1997; Jan T. Klovland 2004). Similar techniques have been used by economic historians to measure business cycles. Shipping rate indices such as the *Baltic Exchange Dry Index* are also being used by market practitioners in assessing global demand pressures.

This line of reasoning suggests that increases in freight rates may be used as indicators of strong cumulative global demand pressures. I will use this insight to identify periods of high and low real economic activity. The proposed index is measured at monthly frequency and can be constructed as far back as January 1968. While an index of real economic activity based on global dry cargo freight rates offers clear advantages compared to, for example, measures of global industrial production, it is not free of drawbacks. In particular, the presence of a ship-building and scrapping cycle may weaken the link between real economic activity and the freight rate index. Given the procyclical-ity of shipbuilding, one would expect the real freight rate index to lag increases in real economic activity (as spare capacity in shipping cushions the impact of higher demand on freight rates) and to lead to decreases in real economic activity (as the arrival of new ships depresses freight rates), thus accentuating upswings in real economic activity. On the other hand, the proposed index is a direct measure of global economic activity which does not require exchange-rate weighting, which automatically aggregates real economic activity in all countries, and which already incorporates shifting country weights, changes in the composition of real output, and changes in the propensity to import industrial commodities for a given unit of real output.

Construction of the Index.—The index of global real economic activity derived below is based on representative single-voyage freight rates available in the monthly report on “Shipping Statistics and Economics” published by Drewry Shipping Consultants Ltd. It is based on various bulk dry cargoes consisting of grain, oilseeds, coal, iron ore, fertilizer, and scrap metal.² The upper panel of Figure 1 shows the raw data. Freight rates are typically quoted in US dollars per metric ton.

There is no continuous series for the entire sample period. Taking simple averages of the freight rates in the upper panel would ignore the existence of fixed effects for different routes, commodities, and ship sizes. In constructing an index of dry bulk cargo freight rates, I eliminate these fixed effects as follows: I first compute the period-to-period growth rates for each series in the first panel of Figure 1, as far as the data are available. I then take the equal-weighted average of these growth rates, and cumulate the average growth rate, having normalized January of 1968 to unity. The resulting index is shown in the second panel of Figure 1.³ The next step is to deflate this series with the US CPI. Finally, the real index must be detrended. As is well known, the cost of shipping dry cargo has fallen in real terms over time. That trend reflects technological advances in shipbuilding. It may also be related to long-run trends in the demand for sea transport. As my interest in this paper centers on cyclical variation in ocean freight rates rather than on long-term trends, I linearly detrend the real freight rate index. The deviations of the real freight rates from their long-run trend are shown in the last panel of Figure 1. The linear regression analysis in Section II is based on the assumption that the level of global real economic activity as it relates to industrial commodity markets is proportionate to this index.

An obvious concern is that dry cargo freight rates may increase during oil price shocks not because both are driven by higher demand for commodities, but because the provision of shipping services uses bunker fuel oil as an input. In the econometric analysis below I therefore allow for feedback from crude oil prices to shipping freight rates. The only restriction I impose is that innovations to the shipping rates (and hence to the real activity index) do not respond to changes in the price of crude oil within the same month. This assumption is fully consistent with the fact

² Quotes are provided for different commodities, routes, and ship sizes. These quotes were entered manually into a spreadsheet, since the data are available in hardcopy only. Grain is included in this index because the earliest data on dry cargo rates are reported only in the form of indices that include grain among other dry cargoes. For later periods, there is no evidence that freight rates for grains behave differently from freight rates for other dry cargoes.

³ Ideally, one would like to apply different weights for different growth rates, but such weights are not provided by Drewry's Shipping Consultants. For the same reason, equal weights are routinely used in the construction of commodity price indices.

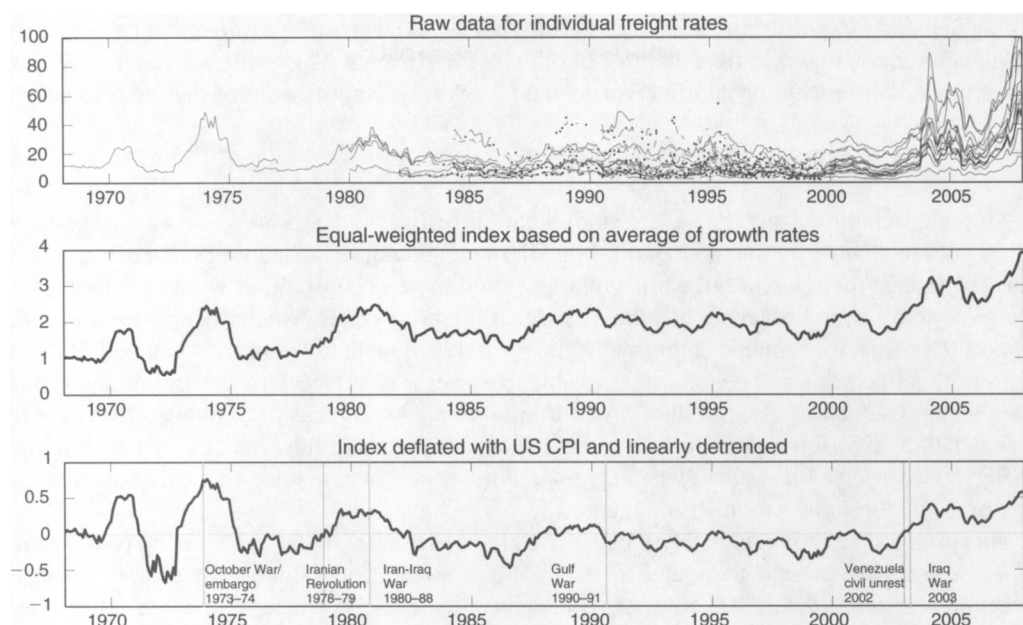


FIGURE 1. MONTHLY INDEX OF GLOBAL REAL ECONOMIC ACTIVITY BASED ON DRY CARGO BULK FREIGHT RATES (1968:1–2007:12)

Notes: The monthly raw data were manually collected from *Drewry's Shipping Monthly*, various issues since 1970. The two oldest series in the first panel are indices of iron ore, coal, and grain shipping rates compiled by Drewry's. The remaining series are differentiated by cargo, route, and ship size and may include, in addition, shipping rates for oil-seeds, fertilizer, and scrap metal. In the 1980s, there are about 15 different rates for each month; by 2000 that number rises to about 25; more recently that number has dropped to about 15.

that the contemporaneous correlation between shipping rates and bunker fuel prices is essentially zero. Moreover, records in the *Oil and Gas Journal* indicate that from 1970 to 1973 the real price of bunker fuel changed very little, yet the index of real economic activity underwent major fluctuations not unlike those in later periods.

The Global Business Cycle in Industrial Commodity Markets.—There is little direct evidence of how the global business cycle affects industrial commodity markets, but there is some anecdotal evidence. Many researchers have noted that the 1972–1974 period was characterized by a global boom, as was to a lesser extent the 1978–1980 period (see, e.g., Joel Darmstadter and Hans H. Landsberg 1976). We also know that the mid-1970s and the early 1980s were characterized by worldwide recessions. Finally, we know that there has been a global boom in commodity markets since the early 2000s driven by strong economic growth worldwide, but particularly in Asia. Figure 1 is fully consistent with the anecdotal evidence on the relative importance and timing of these fluctuations in global real economic activity. The two periods of highest real activity are between late 1970 and early 1971 and between late 1972 and early 1975, with additional periods of sustained high real activity between late 1978 and late 1981 and after late 2002. There also is a much smaller sustained expansion between early 1988 and early 1990. The sustained high levels of real activity since 2002 are very much reminiscent of those observed after 1979, but have been more persistent. The vertical lines in the last panel of Figure 1 correspond to major political events in oil markets. Many of these events coincided with periods of high real economic activity and hence

strong demand for industrial commodities. Thus, one would want to be careful about associating the concurrent increases in the real price of oil with these events. This evidence underscores the importance of disentangling the effects of demand shocks and supply shocks on the real price of oil.

II. Decomposing the Real Price of Oil

Numerous empirical and theoretical studies have investigated the response of macroeconomic aggregates to changes in the price of oil. Implicit in this literature is the thought experiment that one can change the price of oil, while holding everything else constant, as would be the case if the price of oil were exogenous. To the extent that the price of oil is actually endogenous with respect to the macroeconomic aggregates of interest, this thought experiment is violated. If there is no well defined cause, it becomes impossible to estimate its effect. This general principle has been recognized dating back to the Cowles Commission. As Thomas F. Cooley and Stephen F. LeRoy (1985, 295) summarize, it is inadmissible to inquire about the effect of a change in one endogenous variable on another, when the underlying experiment that led to the assumed variation in the endogenous variable is ambiguous.

This problem has not completely escaped attention. Implicitly or explicitly, many researchers have assumed that at least the major increases in the price of oil can be treated as exogenous. Recent research has demonstrated that this interpretation, which seemed reasonable at the time, does not hold up to scrutiny (see, e.g., Kilian 2008a). This means that without knowing what drove up the price of oil in the first place, it will be impossible to predict accurately the implications of higher oil prices. In this section, I present a methodology for decomposing unpredictable changes in the real price of oil into mutually orthogonal components with a structural economic interpretation. This decomposition has immediate implications for how macroeconomists and policymakers should think about oil price fluctuations.

A. The Structural VAR Model

Consider a VAR model based on monthly data for $\mathbf{z}_t = (\Delta prod_t, rea_t, rpo_t)'$, where $\Delta prod_t$ is the percent change in global crude oil production, rea_t denotes the index of real economic activity constructed in Section I, and rpo_t defers to the real price of oil. The rea_t and rpo_t series are expressed in logs. The sample period is 1973:1–2007:12.⁴ The structural VAR representation is

$$(1) \quad \mathbf{A}_0 \mathbf{z}_t = \boldsymbol{\alpha} + \sum_{i=1}^{24} \mathbf{A}_i \mathbf{z}_{t-i} + \boldsymbol{\varepsilon}_t,$$

where $\boldsymbol{\varepsilon}_t$ denotes the vector of serially and mutually uncorrelated structural innovations. I postulate that \mathbf{A}_0^{-1} has a recursive structure such that the reduced-form errors \mathbf{e}_t can be decomposed according to $\mathbf{e}_t = \mathbf{A}_0^{-1} \boldsymbol{\varepsilon}_t$:

$$\mathbf{e}_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil \text{ supply shock}} \\ \varepsilon_t^{aggregate demand shock} \\ \varepsilon_t^{oil specific-demand shock} \end{pmatrix}$$

⁴ The starting date is dictated by the availability of the oil production data from the US Department of Energy. I compute the log differences of world crude oil production in millions of barrels pumped per day (averaged by month). The real oil price series is obtained based on the refiner acquisition cost of imported crude oil, as provided by the US Department of Energy since 1974:1 and extended backward as in Barsky and Kilian (2002). The nominal oil price has been deflated by the US CPI.

This model postulates a vertical short-run supply curve of crude oil. Shifts of the demand curve driven by either of the two oil demand shocks result in an instantaneous change in the real price of oil, as do unanticipated oil supply shocks that shift the vertical supply curve. The restrictions on A_0^{-1} may be motivated as follows. Crude oil supply shocks (referred to as *oil supply shocks* for short) are defined as unpredictable innovations to global oil production.⁵ Crude oil supply is assumed not to respond to innovations to the demand for oil within the same month. That exclusion restriction is plausible because, in practice, oil-producing countries will be slow to respond to demand shocks, given the costs of adjusting oil production and the uncertainty about the state of the crude oil market.⁶

Innovations to global real economic activity that cannot be explained based on crude oil supply shocks will be referred to as shocks to the global demand for industrial commodities (or *aggregate demand shocks* for short).⁷ The model imposes the exclusion restriction that increases in the real price of oil driven by shocks that are specific to the oil market will not lower global real economic activity immediately, but with a delay of at least a month. This restriction is consistent with the sluggish behavior of global real economic activity after each of the major oil price increases in the sample.

Finally, innovations to the real price of oil that cannot be explained based on oil supply shocks or aggregate demand shocks by construction will reflect changes in the demand for oil as opposed to changes in the demand for all industrial commodities (referred to as *oil-specific demand shocks* for short). The latter structural shock will reflect, in particular, fluctuations in precautionary demand for oil driven by uncertainty about future oil supply shortfalls. Whereas this shock potentially could also reflect other oil market-specific demand shocks, there are strong reasons to believe that it effectively represents exogenous shifts in precautionary demand. First, there are no other plausible candidates for exogenous oil market-specific demand shocks. For example, while it may seem plausible that the surge in the real price of oil since 2003 was driven by an increased preference of Asian consumers for energy-using durables such as automobiles, as I will show below, the observed increase in the real price of oil is not associated with an increase in oil-specific demand, allowing us to rule out that interpretation. Likewise, there is no evidence that the observed oil-specific demand shocks are associated with unexpectedly cold winters or other weather shocks. Indeed, one would expect weather-related shocks to average out on a global scale. Second, the large impact effect of oil-market specific shocks documented in Section IIB is difficult to reconcile with shocks not driven by expectation shifts. Third, the timing of these shocks and the direction of their effects is consistent with the timing of exogenous events such as the outbreak of the Persian Gulf War that would be expected to affect uncertainty about future oil supply shortfalls on a priori grounds. Fourth, the overshooting of the price of oil in response to oil market-specific demand shocks coincides with the predictions of theoretical models of precautionary demand shocks driven by increased uncertainty about future oil supply shortfalls

⁵ In an earlier version of this paper, I further decomposed changes in the production of crude oil into crude oil supply shocks driven by exogenous political events in the Middle East, building on recent work in Kilian (2008a, b), and other crude oil supply shocks. This distinction does not change the main results of this paper.

⁶ If changing oil production is costly, oil producers set production based on expected trend growth in demand, and do not revise the production level in response to high-frequency variation in demand. Changes in the trend growth of demand are difficult to detect at high frequency. It takes a long time span of data to detect such a change, which suggests that production plans will be changed only infrequently. This view is consistent with evidence from interviews of Saudi officials in the early 1980s (see Daniel Yergin 1992). It is also consistent with the fact that the state-owned Saudi oil company produces forecasts of oil demand only once a year.

⁷ The term *aggregate demand* in this context does not refer to the demand for all goods and services, as in introductory macroeconomic models, but rather to the demand for all industrial commodities. I abstract from idiosyncratic shocks to the demand or supply of dry cargoes. These shocks are presumed to average out in the construction of the index of real economic activity.

(see Alquist and Kilian, forthcoming). Finally, the movements in the real price of oil induced by this shock are highly correlated with independent measures of the precautionary demand component of the real price of oil based on futures prices. Using oil futures market data since 1989, Alquist and Kilian (forthcoming) show that this correlation may be as high as 80 percent, notwithstanding the use of a completely different dataset and methodology.

Despite its simplicity, the identification scheme used in this paper allows for the possibility that the high real price of oil in recent years, as well as in the 1970s, was driven in part by unusually low US interest rates, reflecting the low opportunity cost of holding oil inventories, as well as the weakening dollar (also see Barsky and Kilian 2002). Since lower interest rates, all else equal, tend to stimulate global demand for all industrial commodities, such demand will be reflected in the measure of aggregate demand for industrial commodities by construction. The identification scheme also allows for the possibility that the Organization of Petroleum Exporting Countries (OPEC) may have acted as a cartel during part of the estimation sample. OPEC has historically tended to restrict supply in order to prop up the price of oil. Such reductions in the supply of oil will be captured by the oil supply shock in the model. In any event, there is little evidence that cartel activities mattered for the sample period in question, making this point largely moot (see, e.g., Ian Skeet 1988; Pedro Almoguera and Ana María Herrera 2007).

B. Empirical Results

The reduced-form VAR model is consistently estimated by the least-squares method. The resulting estimates are used to construct the structural VAR representation of the model. Inference is based on a recursive-design wild bootstrap with 2,000 replications (see Silvia Gonçalves and Kilian 2004).

Quantifying the Evolution of the Oil Demand and Oil Supply Shocks.—Figure 2 plots the time path of the structural shocks implied by the model (expressed as annual averages to improve the readability of the plot). Figure 2 shows that, at any point in time, the real price of oil responds to a multitude of shocks, the composition of which evolves over time. A case in point is the oil price shock of 1979/80. There is no evidence of a global oil supply disruption in 1978 or 1979 (despite the cutbacks associated with the Iranian Revolution, which were more than offset by increased oil production elsewhere), but there was a disruption in 1980 associated with the outbreak of the Iran-Iraq War. The years 1978, 1979, and 1980 were characterized by repeated large positive shocks to global aggregate demand. There also was a large unanticipated increase in oil-specific demand in 1979 (but not in 1978 or 1980), consistent with the fact that the Iranian Revolution, the Iranian hostage crisis, and the Soviet invasion of Afghanistan all raised concerns about the future availability of oil supplies from the Middle East in 1979. This account of what happened in 1979–1980 is fully consistent with the discussion of this episode in Barsky and Kilian (2002, 2004), but, unlike that earlier line of work, we now can assess the quantitative importance of each of these factors.

How Do Global Oil Production, Real Economic Activity, and the Real Price of Oil Respond to Demand and Supply Shocks in the Crude Oil Market?—Figure 3 shows the responses of global oil production, real economic activity, and the real price of oil to one-standard deviation structural innovations.

All shocks have been normalized such that an innovation will tend to raise the price of oil. An unexpected oil supply disruption causes a sharp decline in global oil production upon impact, followed by a partial reversal of that decline within the first year. This pattern is consistent with the view that oil supply contractions in one region tend to trigger production

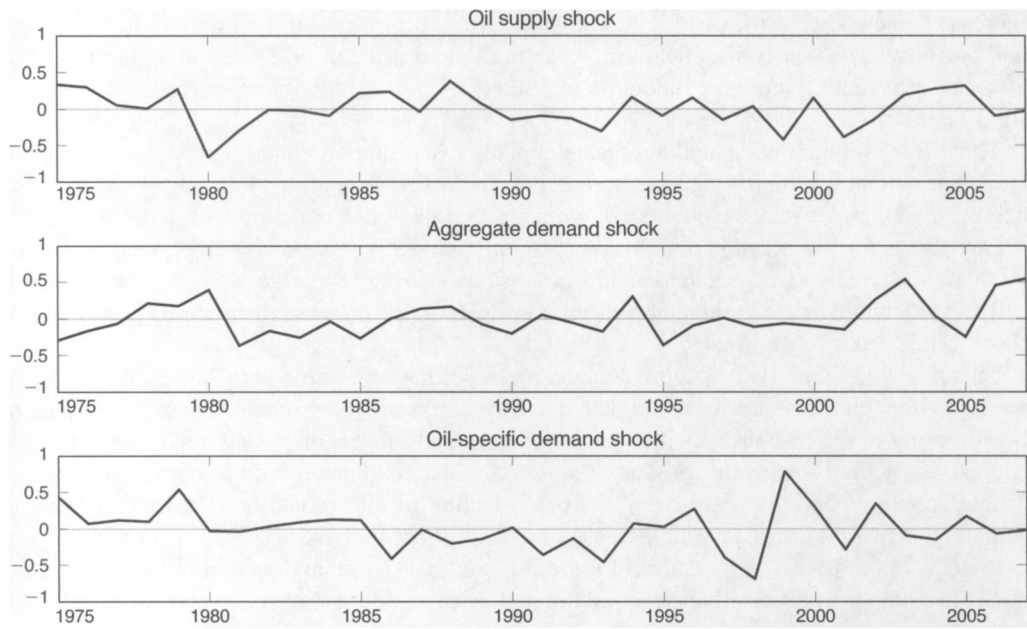


FIGURE 2. HISTORICAL EVOLUTION OF THE STRUCTURAL SHOCKS, 1975–2007

Note: Structural residuals implied by model (1), averaged to annual frequency.

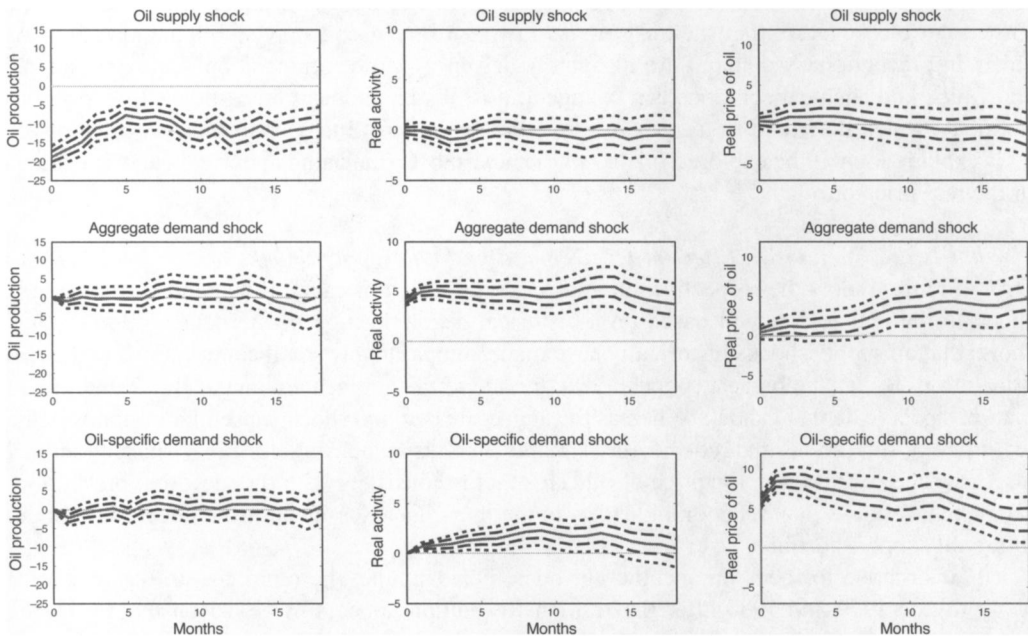


FIGURE 3. RESPONSES TO ONE-STANDARD-DEVIATION STRUCTURAL SHOCKS

(Point estimates with one- and two-standard error bands)

Notes: Estimates based on model (1). The confidence intervals were constructed using a recursive-design wild bootstrap.

increases elsewhere in the world. At the same time, this shock triggers a small, transitory, and partially statistically significant increase in the real price of oil for about eight months. It also causes a small temporary reduction of real economic activity that is partially statistically significant.

The effect of an unanticipated aggregate demand expansion on global real economic activity is very persistent and highly significant. It begins to decline only after 14 months. Unanticipated aggregate demand expansions temporarily increase global oil production with a delay of half a year. There is some indication that this increase in crude oil production is subsequently offset by production decreases. Aggregate demand expansions also cause a large, persistent, and statistically significant increase in the real price of oil. Much of this increase the price triggered by this shock is delayed by half a year.

Unanticipated oil market-specific demand increases have an immediate, large, and persistent positive effect on the real price of oil that is highly statistically significant. There is evidence of overshooting in the response, as predicted by theoretical models of precautionary demand (see Alquist and Kilian forthcoming). These shocks are also associated with a temporary increase in real economic activity and a very short-run decline in oil production. Oil market-specific demand increases do not cause an increase in global oil production.

Perhaps the most striking result in Figure 3 is the fact that unanticipated oil supply disruptions have only a small positive effect on the real price of oil. Part of the explanation is that oil supply disruptions in one region tend to trigger endogenous expansions of crude oil production elsewhere in the world that help offset the initial production shortfall. The small response of the real price of oil is also consistent with related evidence that oil supply shocks have little systematic predictive power for changes in the real price of oil (see Kilian 2008a); yet it raises the question of what—if not crude oil supply disruptions—accounts for the apparent large increases in the real price of oil following major exogenous political events in the Middle East. Figure 3 suggests that the answer lies in sharp increases in precautionary demand. As shifts in precautionary demand are ultimately driven by expectations about future oil supply shortfalls, and such expectations can change almost instantaneously in response to exogenous political events, they tend to trigger an immediate and sharp increase in the real price of oil. This explanation will be explored further in the next subsection using historical decompositions of the real price of oil.

What Is the Cumulative Effect of Oil Demand and Oil Supply Shocks on the Real Price of Oil?—Figure 4 plots the respective cumulative contribution of each oil demand and oil supply shock to the real price of oil based on a historical decomposition of the data. The first panel shows that oil supply shocks historically have made comparatively small contributions to the real price of oil. By far the biggest contributions are due to the aggregate demand shock and the oil market-specific demand shock. Whereas the aggregate demand shock caused long swings in the real price of oil, the oil market-specific demand shock is responsible for fairly sharply defined increases and decreases in the price of oil. This fact is consistent with the view that precautionary demand shocks may reflect rapid shifts in the market's assessment of the uncertainty about future oil supply shortfalls.

It is instructive to focus on specific episodes. For example, the rapid rise in the real price of oil in late 1979 and 1980 after the Iranian Revolution appears to be driven mainly by the superimposition of a sharp increase in precautionary demand in 1979 on a slower-moving strong increase in real economic activity that started two years earlier. While the cumulative effect of oil market-specific demand peaked prior to the outbreak of the Iran-Iraq war and slowly subsided in the early 1980s, real economic activity continued to sustain the real price of oil well into the early 1980s. Throughout this period, oil supply shocks served only to amplify some of

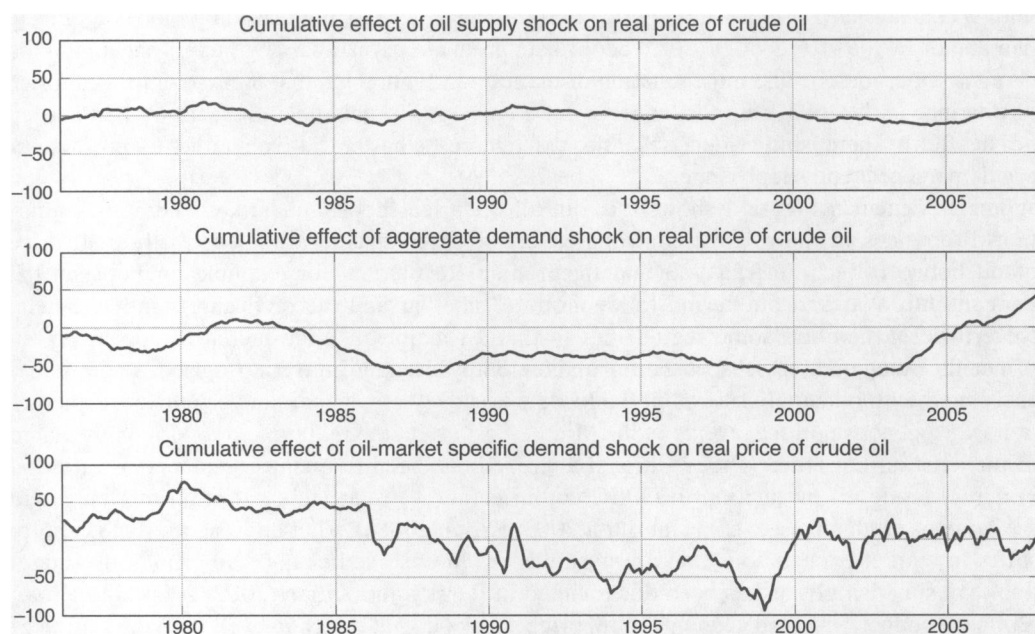


FIGURE 4. HISTORICAL DECOMPOSITION OF REAL PRICE OF OIL
(1976:1–2007:12)

Note: Estimates derived from model (1).

the short-run dynamics of the real price of oil, sometimes raising the price of oil and sometimes lowering it. The increased importance of oil market-specific demand shocks starting in 1979 is consistent with an increase in precautionary demand. That was the year not only of Khomeini's arrival in Iran, but also of the Iranian hostage crisis and the Soviet invasion of Afghanistan, all of which raised persistent fears of a regional war and the destruction of oil fields in Iran and Saudi Arabia.

The sharp fall in the real price of oil following the collapse of the OPEC cartel in late 1985 appears to be due more to a decline in oil market-specific demand than the direct effect of the increase in Saudi oil production (first panel) or the fall in real economic activity (second panel). The initial perception that the breakdown of OPEC was irreversible is likely to have sharply lowered precautionary demand at this point. This sharp drop was partially reversed in 1987, amid attempts by OPEC to reunite. Similarly, the sharp spike in the real price of oil in 1990–1991 after the invasion of Kuwait is almost entirely due to an increase in precautionary demand.⁸ Oil supply disruptions had some effect on the real price of oil in the early 1990s, but that effect was small. The disproportionate reduction in oil market-specific demand following the Asian crisis of 1997–1998, when the real price of oil fell to an all-time low, suggests that at this point precautionary demand all but vanished.⁹ This effect was gradually reversed after oil prices recovered starting in 1999. There also is clear evidence of a fall in precautionary demand associated

⁸ Kilian (2008a) arrives at the same conclusion using a different methodology.

⁹ It can be shown that this drop in oil market-specific demand predates the sharp drop in oil inventories in 1999–2000 and hence is unlikely to be driven by inventory adjustments. Rather, inventory policies seem to have changed in response to falling oil prices.

with 9/11. The sharp rise in the real price of oil in 1999–2000 is not driven by global aggregate demand or by the efforts of OPEC to coordinate production, but again by factors specific to the demand for crude oil. The most striking observation in Figure 4 is that the rise in the real price of oil since early 2002 is almost entirely due to a surge in real economic activity that started around 2001. There is no evidence that this price increase has been driven either by precautionary demand or by oil supply shocks.

The evidence in Figure 4 shows that not all oil price shocks are alike. There are important differences in the relative contribution of the three structural shocks to the real price of oil between the Iran-Iraq War and the Iranian Revolution, for example, or between the Persian Gulf War and the period following the Iraq War and the civil unrest in Venezuela. Nevertheless, there are some regularities in that all major oil price increases appear driven primarily by demand shocks in the oil market. This is true even during episodes commonly associated with oil supply shocks in the Middle East. My results paint a very different picture of how exogenous political events in the Middle East affect the real price of oil than postulated in the existing literature. The traditional approach has been to quantify exogenous variation in actual crude oil production in OPEC countries and to relate this variation to changes in the price of crude oil (see, e.g., Hamilton 2003; Kilian 2008a). That approach fails to capture shifts in market expectations that are not reflected in observed changes to crude oil production. Not surprisingly, as has been documented in Barsky and Kilian (2002, 2004) and Kilian (2008a), production-based accounts of oil price shocks do not match up well with the timing of oil price changes and with historical accounts of the crude oil market during oil crises such as the Iranian Revolution. The results of this section, in contrast, suggest that the most important channel by which exogenous events such as wars or revolutions affect the real price of oil is through their effect on precautionary demand for oil. The latter channel can produce immediate and potentially large effects on the real price of oil through shifts in the uncertainty about future oil supply shortfalls, even when crude oil production has not changed. This point has been recognized for a long time, but it has never been quantified before, the fundamental difficulty being that expectation shifts related to uncertainty about future oil supply shortfalls are not observable and not linearly related to observables.

Sensitivity Analysis.—The approach to identifying structural shocks to the real price of oil adopted in this paper heavily relies on delay restrictions that are economically plausible only at monthly frequency. Measuring shifts in the demand for industrial commodities driven by global real economic activity is a challenge, especially at monthly frequency. An alternative measure of monthly global real economic activity would be world industrial production. Even for indices of industrial production, however, the problems of exchange rate weighting remain, and technological changes over time may affect the link from rising production to the global demand for industrial commodities. Moreover, suitable monthly data on world industrial production do not exist. The closest available proxy is an index of OECD industrial production that excludes emerging economies in Asia such as China and India, whose demand for industrial raw materials is thought to have fueled the surge in industrial commodity and oil prices after 2002. Linearly detrended OECD industrial production exhibits the same patterns during the 1970s and early 1980s as the index based on shipping rates, but fails to capture the boom since 2002. Using this index as a measure of real activity in the VAR model of Section II yields very similar estimates of the responses to oil supply shocks and to oil-specific demand shocks. It also produces a statistically significant and positive response to aggregate demand shocks, but, predictably, that response is smaller than in the baseline model. The model by construction attributes much of the recent build-up in oil prices to the precautionary demand shock rather than the aggregate demand shock, because OECD industrial production data do not reflect the growth of industrial

production in Asia at the end of the sample. This sensitivity analysis highlights the importance of using a truly global measure of real activity.

III. Understanding the Effects of Oil Price Disturbances on the US Economy

A. Regression Model

A question of considerable interest is how the structural innovations in model (1) relate to US macroeconomic aggregates such as CPI inflation (π_t) or real GDP growth (Δy_t). The main problem in answering this question is that the latter aggregate is not available at monthly frequency.¹⁰ While one could construct an analogous structural VAR model on data aggregated to quarterly frequency, at that frequency the identifying assumptions would no longer be credible. Instead I construct measures of the quarterly shocks by averaging the monthly structural innovations for each quarter:

$$\hat{\zeta}_{jt} = \frac{1}{3} \sum_{i=1}^3 \hat{\varepsilon}_{j,t,i}, \quad j = 1, 2, 3,$$

where $\hat{\varepsilon}_{j,t,i}$ refers to the estimated residual for the j th structural shock in the i th month of the t th quarter of the sample.¹¹ Under the identifying assumption that within a given quarter there is no feedback from Δy_t and π_t to $\hat{\zeta}_{jt}$, $j = 1, 2, 3$, these shocks can be treated as predetermined and we can examine their effects on US macroeconomic aggregates based on the regressions:

$$(2) \quad \Delta y_t = \alpha_j + \sum_{i=0}^{12} \phi_{ji} \hat{\zeta}_{jt-i} + u_{jt}, \quad j = 1, 2, 3$$

and

$$(3) \quad \pi_t = \delta_j + \sum_{i=0}^{12} \psi_{ji} \hat{\zeta}_{jt-i} + v_{jt}, \quad j = 1, 2, 3,$$

where u_{jt} and v_{jt} are potentially serially correlated errors. In this regression model the impulse response coefficients at horizon h correspond to ϕ_{jh} and ψ_{jh} , respectively. Thus, the number of lags is determined by the maximum horizon of the impulse response function, which is set to 12 quarters. In conducting inference on the response estimates implied by models (2) and (3), the possible presence of serial correlation in the error term is dealt with by using block bootstrap methods.¹²

The assumption that $\hat{\zeta}_{jt}$, $j = 1, 2, 3$, is predetermined with respect to US real GDP growth is not testable, but may be defended as follows. First, consider $\hat{\zeta}_{1t}$. To the extent that an unanticipated reduction (expansion) in crude oil supply would be associated with a decline (increase) in US real GDP growth within the quarter, the oil supply shock and innovations to US real GDP should be positively correlated. To the extent that an unanticipated increase in US real GDP growth

¹⁰ I do not use interpolated real GDP growth data. One reason is that interpolation is known to cause spurious dynamics in general. In this case, in particular, there also is a second reason not to use interpolation. Standard interpolation methods use monthly data on industrial production to infer movements in real GDP within the quarter. Since industrial production is a measure of gross output that may behave very differently from real GDP (a measure of value added) in response to oil shocks, as discussed in Barsky and Kilian (2002), the concern is that interpolated "monthly" real GDP data will behave like industrial production, thus invalidating the analysis.

¹¹ Although these quarterly averages will not be exactly uncorrelated, their empirical correlation is so low that little is lost by treating them as uncorrelated.

¹² All results shown below are for block size 4 and 20,000 bootstrap replications. Results based on block size 8 are very similar. It is important to note that these confidence intervals do not account for the fact that the residuals used in the regressor matrix are generated regressors. Controlling for this problem is complicated by the fact that the regression procedure involves data at both monthly and quarterly frequency.

would tend to call forth within the quarter an increase in global crude oil production, the correlation of real GDP innovations with the global oil supply shock should also be positive. Since the empirical correlation is very low, as can be verified by computing the autoregressive residuals of US real GDP growth and correlating them with $\hat{\zeta}_{1t}$, we know that neither direction of causality matters much at quarterly frequency, and that the global oil supply shock can be treated as predetermined with respect to US real GDP growth.

Next consider $\hat{\zeta}_{2t}$. If the intuition were right that positive innovations to US real GDP growth stimulate global demand for industrial commodities, we would expect the correlation between innovations to US real GDP growth and global aggregate demand shocks to be positive. To the extent that causation runs the other way from global demand shocks for industrial commodities to innovations to US real GDP growth, that correlation should also be positive. The fact that the contemporaneous correlation of these innovations, computed as discussed before, is essentially zero in the data implies that neither causal link is quantitatively important at the quarterly frequency. Hence, we may treat global aggregate demand shocks as predetermined with respect to US real GDP growth.

Finally, consider $\hat{\zeta}_{3t}$. Positive innovations to US real GDP growth may raise precautionary demand; yet unanticipated increases in precautionary demand will increase the price of oil and hence may lower US real GDP growth on impact. Since it is conceivable that these two effects may offset one another at least in part, we cannot use the low empirical correlation of these innovations to argue that there is no feedback from US real GDP innovations to the precautionary demand shock. Nevertheless, a plausibility check helps defend the assumption that $\hat{\zeta}_{3t}$ is predetermined. Precautionary demand reflects uncertainty about the shortfall of future oil supply relative to expected demand for oil at *medium-term* or *long-term* horizons. An innovation to quarterly US real GDP growth will have negligible effects on the estimate of that trend component under any conceivable model of trend growth in demand, and hence negligible effects on precautionary demand.

B. Does It Matter for US Macroeconomic Performance Why the Price of Oil Increased?

Figure 5 summarizes the responses of the level of US real GDP and the level of the CPI to each of the three shocks defined earlier. The results in Figure 5 illustrate important differences in how the oil demand and oil supply shocks underlying the real price of oil affect US macroeconomic aggregates. Unanticipated oil supply disruptions significantly lower real GDP on impact. The response of real GDP is negative at all horizons, but the one-standard-error bands imply statistical significance for the first two years only. The corresponding response of the consumer price level is largely flat and mostly statistically insignificant. If anything, there is evidence of a slight decline in the price level after three years. An unanticipated aggregate demand expansion causes a statistically insignificant increase in real GDP in the first year, followed by a decline below the initial level in the second year. In the third year, the response remains negative and becomes statistically significant. The corresponding effect on the price level shows a sustained increase that reaches its maximum in the third year and is statistically significant starting in the third quarter. Unanticipated oil market-specific demand increases result in a gradual reduction in real GDP that reaches its maximum after three years. The decline is statistically significant in year 3. At the same time, this shock causes a sustained and highly statistically significant increase in the price level.

The chief results can be summarized as follows. First, oil supply disruptions cause a temporary decline in real GDP and have little effect on the price level. Second, positive aggregate demand shocks initially have (if anything) a positive net effect on the economy, consistent with the interpretation that in the short run the direct stimulating effect of higher global demand on the US

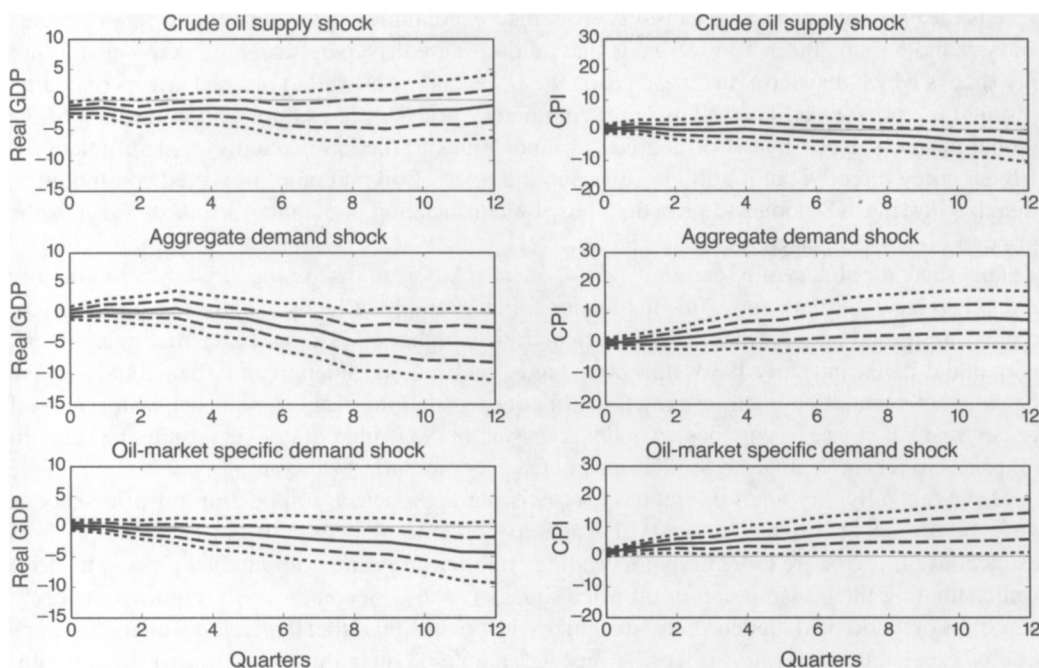


FIGURE 5. RESPONSES OF US REAL GDP AND CPI LEVEL TO EACH STRUCTURAL SHOCK
(Point estimates with one- and two-standard error bands)

Note: The plots show the cumulated responses estimated from models (2) and (3).

economy will dominate the indirect growth-retarding effect of higher oil (and other commodity) prices. Over time, that stimulus wears out and the adverse effect of the higher commodity prices triggered by this shock dominates, making the effects of the positive aggregate demand shock recessionary with a delay. Whereas the direct and the indirect effect on real GDP are of opposite sign, both tend to raise the price level. Third, positive precautionary demand shocks lower real GDP and raise consumer prices.

Given the earlier evidence that much of the recent increase in oil prices has been driven by global aggregate demand shocks, the fact that the US economy has proved surprisingly resilient to this increase so far makes sense in light of these results. This delay is what we would expect in response to a series of positive aggregate demand shocks. More generally, the evidence in Figure 5 helps us understand the fact that regressions of macroeconomic aggregates on oil prices have proven unstable. To the extent that the composition of the demand and supply shocks underlying increases in the price of oil has evolved over time, and each of these shocks is associated with a distinct response pattern, this outcome is exactly what we would expect.

IV. Conclusion

A recurring question in theoretical, empirical, and policy work is what the effects of higher oil prices are on US macroeconomic aggregates. The main point of the paper has been that the traditional thought experiment that this literature appeals to in answering this question is not well defined because it implicitly presumes that one can hold everything else fixed, while varying the price of oil. There are two reasons why this *ceteris paribus* assumption is inappropriate.

One is the existence of reverse causality from macroeconomic aggregates to oil prices (see, e.g., Barsky and Kilian 2002). The second is that oil prices are driven by structural demand and supply shocks which may have direct effects on the US economy as well as indirect effects operating through the price of oil (as well as other commodity prices). For example, an innovation to the global business cycle (that is orthogonal to innovations to the US economy) will stimulate the US economy directly, but it will also drive up the price of oil and other imported commodities, thereby slowing US domestic growth. Thus, by construction, we cannot think of varying the price of oil without varying other variables.

This second point, while seemingly self-evident if we were discussing any other commodity market, is new and has powerful implications. For example, it helps explain the instability of regressions based on oil prices and, in particular, why higher oil prices seem to matter less today than in the 1970s and early 1980s (this point has been discussed at length in Kilian 2008c). It also helps us understand how strong growth and booming stock markets can coexist with rising oil prices, and why there has not been a major recession in the United States yet despite the surge in oil prices in recent years (also see Kilian and Cheolbeom Park, forthcoming).

More generally, my analysis implies that existing approaches to modeling oil price shocks must be rethought. First, it suggests that macroeconomic models built on the assumption of exogenous oil prices are potentially misleading and their usefulness for applied work is unclear. Understanding the transmission of oil price shocks to the US economy will require an entirely new class of theoretical models that endogenizes the price of oil rather than relying on the assumption of exogenously given oil prices. A recent example of such a model is Martin Bodenstein, Christopher J. Erceg, and Luca Guerrieri (2007).

Second, models of endogenous oil prices should focus on the demand side of the oil market. My analysis showed that the traditional emphasis on physical oil supply shocks in explaining oil price shocks is misplaced. Instead, expectation shifts deserve a much greater role in models of the oil price. A recent example of such a model is Alquist and Kilian (forthcoming). Likewise, the impact of the global business cycle on the demand for oil (including structural shifts in the demand for oil related to the emergence of new economies) requires explicit modeling. The work by Bodenstein et al. (2007) is a first step in this direction.

Third, my analysis sheds light on the interpretation of macroeconomic VAR models that include the price of oil. To the extent that each of the demand and supply shocks in the crude oil market is predetermined, the innovation to the real price of oil will also be predetermined, because it can be written as a weighted average of these structural shocks. This fact allows one to estimate the effect of an average oil price innovation on macroeconomic aggregates from recursively identified vector autoregressions in which the percent change in the real price of oil is ordered first. Under standard assumptions, the resulting response estimates will be asymptotically valid as a measure of the expected response to this shock (see Kilian 2008c). Nevertheless, since this expectation by construction reflects the average composition of oil demand and oil supply shocks in the sample period, these estimates may be misleading when it comes to judging the macroeconomic effects of a specific oil price shock.

Fourth, empirical models of the monetary policy response to oil prices in the tradition of Ben S. Bernanke, Mark Gertler, and Mark W. Watson (1997) may provide an approximation to the actual policy behavior of the Federal Reserve during certain historical episodes, but they are fundamentally misspecified in that they postulate the same response to oil price innovations regardless of the composition of that shock. There is no compelling economic reason for the Federal Reserve to respond to oil price innovations in general, once the price of oil is treated as endogenous. Rather, the Fed must focus on the underlying determinants of the price of oil. This point has recently been illustrated in the context of a specific example by Anton Nakov and Andrea Pescatori (2007).

REFERENCES

- Almoguera, Pedro, and Ana María Herrera. 2007. "Testing for the Cartel in OPEC: Noncooperative Collusion or just Noncooperative?" <http://www.msu.edu/~herrer20/documents/OPEC.pdf>.
- Alquist, Ron, and Lutz Kilian. Forthcoming. "What Do We Learn from the Price of Crude Oil Futures?" *Journal of Applied Econometrics*.
- Barsky, Robert B., and Lutz Kilian. 2002. "Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative." In *NBER Macroeconomics Annual 2001*. Volume 16, ed. Ben S. Bernanke and Kenneth Rogoff, 137–83. Cambridge, MA: MIT Press.
- Barsky, Robert B., and Lutz Kilian. 2004. "Oil and the Macroeconomy since the 1970s." *Journal of Economic Perspectives*, 18(4): 115–34.
- Bernanke, Ben S., Mark Gertler, and Mark W. Watson. 1997. "Systematic Monetary Policy and the Effects of Oil Price Shocks." *Brookings Papers on Economic Activity*, 1: 91–142.
- Bodenstein, Martin, Christopher J. Erceg, and Luca Guerrieri. 2007. "Oil Shocks and External Adjustment." International Finance Discussion Paper 897.
- Cooley, Thomas F., and Stephen F. LeRoy. 1985. "Atheoretical Macroeconometrics: A Critique." *Journal of Monetary Economics*, 16(3): 283–308.
- Darmstadter, Joel, and Hans H. Landsberg. 1976. "The Economic Background." In *The Oil Crisis*, ed. Raymond Vernon, 15–38. New York: Norton.
- Gonçalves, Silvia, and Lutz Kilian. 2004. "Bootstrapping Autoregressions with Conditional Heteroskedasticity of Unknown Form." *Journal of Econometrics*, 123(1): 89–120.
- Hamilton, James D. 2003. "What Is an Oil Shock?" *Journal of Econometrics*, 113(2): 363–98.
- Isserlis, L. 1938. "Tramp Shipping Cargoes and Freights." *Journal of the Royal Statistical Society*, 101(1): 53–136.
- Kilian, Lutz. 2008a. "A Comparison of the Effects of Exogenous Oil Supply Shocks on Output and Inflation in the G7 Countries." *Journal of the European Economic Association*, 6(1): 78–121.
- Kilian, Lutz. 2008b. "The Economic Effects of Energy Price Shocks." *Journal of Economic Literature*, 46(4): 871–909.
- Kilian, Lutz. 2008c. "Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?" *Review of Economics and Statistics*, 90(2): 216–40.
- Kilian, Lutz, and Cheolbeom Park. Forthcoming. "The Impact of Oil Price Shocks on the U.S. Stock Market." *International Economic Review*.
- Klovland, Jan T. 2004. "Business Cycles, Commodity Prices and Shipping Freight Rates: Some Evidence from the pre-WWI Period." Paper presented at Workshop on Market Performance and the Welfare Gains of Market Integration in History, Florence, Italy.
- Nakov, Anton, and Andrea Pescatori. 2007. "Inflation-Output Gap Trade-off with a Dominant Oil Supplier." <http://www.clevelandfed.org/research/workpaper/2007/wp0710.pdf>.
- Skeet, Ian. 1988. *OPEC: Twenty-Five Years of Prices and Politics*. Cambridge Energy Studies Series. Cambridge: Cambridge University Press.
- Stopford, Martin. 1997. *Maritime Economics*. 2nd ed. London: Routledge.
- Tinbergen, Jan. 1959. "Tonnage and Freight." In *Jan Tinbergen Selected Papers*, ed. L. H. Klaassen, L. M. Koyck, and H. J. Witteveen, 93–111. Amsterdam: North Holland.
- Yergin, Daniel. 1992. *The Prize: The Epic Quest for Oil, Money, and Power*. New York: Free Press.