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Abstract: There is an important distinction between the price of gasoline in the U.S. and the price of crude oil in global markets that is often ignored in discussions of the impact of higher energy prices. This paper makes explicit the relationship between demand and supply shocks in these two markets. Building on a recently proposed structural VAR model of the global crude oil market, it explores the implications of a joint VAR model of the global market for crude oil and the U.S. market for motor gasoline. It is shown that it is essential to understand the origins of a given gasoline price shock, before predicting the likely path of the price of gasoline or of gasoline consumption, since each demand and supply shock is associated with responses of different magnitude, pattern and persistence. The paper assesses the overall importance of these shocks in explaining the variation in U.S. gasoline prices and consumption growth, as well as their relative contribution to the surge in U.S. gasoline prices since 2002. The findings have important implications for the future evolution of the real price of gasoline. Although there is considerable uncertainty about the determinants of the price of gasoline, this paper makes the case that the real price of gasoline is likely to remain high for several years.

Key words: Gasoline price; price of crude oil; demand shocks; supply shocks; dynamic effects.

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1. Introduction

There is an important distinction between the price of gasoline and other motor fuels in the U.S. and the price of crude oil in global markets that is often ignored in discussions of the impact of higher energy prices. This paper makes explicit the relationship between demand and supply shocks in these two markets. Building on a structural vector autoregressive (VAR) model of the global crude oil market proposed in Kilian (2008a), the paper explores the implications of a joint VAR model of the global market for crude oil and of the U.S. retail market for motor gasoline.[1]

A considerable body of work has focused on the effects of crude oil price shocks on the U.S. economy. The reader is referred to two recent reviews of the literature by Hamilton (2008) and Kilian (2008b). A much smaller literature has focused on the effect of retail energy price shocks on the economy (see, e.g., Edelstein and Kilian 2008). There also has been some work attempting to link movements in crude oil and gasoline prices (see, e.g., Borenstein, Cameron and Gilbert 1997). One limitation of this literature, addressed in Kilian (2008a), is that it treats unpredictable changes in crude oil prices and gasoline prices as exogenous and fails to distinguish between the underlying oil demand and oil supply shocks. That distinction is crucial in understanding the apparent instability of the statistical relationship between crude oil prices and the economy. It also is essential in predicting accurately the evolution of the economy following crude oil price shocks. A given unanticipated increase in the price of imported crude oil may be associated with very different effects on the U.S. economy, depending on which combination of oil demand and oil supply shocks triggered this increase.

The same distinction between demand and supply shocks obviously applies to the retail gasoline market. While crude oil is the main input in the production of motor gasoline, the retail price of gasoline will in addition be affected by shocks to the U.S. demand for gasoline as well as by shocks to the ability of U.S. refiners to refine crude oil. Refinery fires, changes in the regulatory environment or refinery outages caused by hurricanes, for example, may cause increases in the retail price of gasoline that are not driven by events in the global crude oil market. Thus, we can only hope to understand the evolution of gasoline prices in the context of a model that includes both the crude oil demand and supply shocks that drive the global price of crude oil and the additional gasoline demand and supply shocks that affect the domestic retail

[1] Related work based on the VAR methodology of Kilian (2008a) includes Alquist and Kilian (2008), Kilian, Rebucci and Spatafora (2008), and Kilian and Park (2008).

gasoline market, allowing for feedback between these markets. The joint VAR model proposed in this paper is a first attempt at modeling these relationships.

Estimates of this joint model suggest that each demand and supply shock has distinct dynamic effects on the real price of imported crude oil and on the real retail price of gasoline in the U.S. The response estimates illustrate that some shocks cause the real prices of crude oil and of retail gasoline to move in the same direction, whereas other shocks cause them to move in opposite directions. The differential response of these prices to an unanticipated refining outage in particular sheds light on the behavior of oil and gasoline prices following Hurricanes Rita and Katrina. We also study the effect of these shocks on U.S. gasoline consumption. Again there are striking differences in the dynamic effects of each shock on the use of gasoline. The central message of this paper is that it is essential to understand the origins of a given gasoline price shock, before predicting the likely path of the price of gasoline or of gasoline consumption, since each shock is associated with movements in gasoline prices and consumption of different magnitude, pattern and persistence.

This raises the question of the overall importance of each shock for the determination of gasoline prices and consumption. It is shown that, in the long run, close to 80% of the variation in the growth rate of U.S. gasoline consumption is driven by domestic gasoline demand shocks, 10% by refining shocks, 6% by demand shocks specific to the crude oil market, and 5% by global aggregate demand shocks. In contrast, in the long run, 59% of the variation in the real price of gasoline in the U.S. is driven by oil-market specific demand shocks, 33% by shocks to global demand, and 8% by refining shocks with essentially no role for domestic gasoline demand shocks or global oil supply shocks.

While these estimates provide a useful estimate of the average contribution of each shock since the 1970s, they may be misleading when assessing a specific historical episode such as the rapid surge in the U.S. retail price of real gasoline since 2002. The econometric model shows that this build-up in gasoline prices consisted of three main components whose relative contribution to the real price of gas has varied over time: The primary explanation has been strong and persistent demand in global commodity markets (consistent with a strong economic growth in many advanced economies and with the integration of emerging economies in the global economy). In addition, especially starting in late 2005, the upward pressure on gasoline prices was temporarily aided by precautionary demand shocks specific to the oil market and by adverse supply shocks in the U.S. refining industry. In contrast, there is no evidence that the recent build-up of gasoline prices has been associated with production decisions by OPEC or other crude oil supply shocks. Nor is there evidence that speculation in oil markets is behind the recent increase in gasoline prices. Likewise shocks to U.S. domestic demand for gasoline played no role. This result has important implications for the future evolution of real price of gasoline. Although there is considerable uncertainty about the determinants of the price of gasoline, this paper makes the case that the real price of gasoline is likely to remain high for several years.

The remainder of the paper is organized as follows. Section 2 reviews some of the salient features of U.S. gasoline prices and the price of imported crude oil. It also highlights the key determinants of these prices. In section 3, I describe the joint model of the global crude oil market and the U.S. retail gasoline market with special emphasis on the identifying assumptions. The model highlights the distinction between demand and supply shocks in both markets. Section discusses the effects of these shocks. In section 4.1, I evaluate the dynamic effects of each demand and supply shock on the price of imported crude oil as well as the U.S. retail price of gasoline. In section 4.2, I evaluate the corresponding responses of U.S. gasoline consumption. Section 5 studies the extent to which these shocks account for the variation in gasoline prices and gasoline consumption growth since 1973. In section 6, I focus on the question of what is behind the surge in gasoline prices since 2002. Section 7 discusses the likely future evolution of the path of U.S. gasoline prices. The concluding remarks are in section 8.

2. The Key Determinants of the Price of Gasoline

Figure 1 illustrates the relationship between the inflation-adjusted U.S. retail price of gasoline and the corresponding price of imported crude oil since 1973. Both series have been expressed in percent deviations from their respective means.[2] Figure 1 illustrates that there is no apparent trend in the inflation-adjusted oil price series, but considerable volatility. Historically, the movements in the real price of gasoline have been qualitatively similar, but less pronounced than in the real price of imported crude oil. Notwithstanding a considerable degree of co-movement, the co-movement is far from perfect. For example, since January 2005 the real price of crude oil has risen much faster than the real price of gasoline.

Of particular interest is the surge in real gasoline prices after 2002. At the end of 2007 both prices adjusted for inflation had reached levels last seen in 1981. One of the central

[2] The data are obtained from the Department of Energy and the Bureau of Economic Analysis (BEA).

questions of this paper is why this surge occurred. Given the importance of crude oil imports in producing refined products such as motor gasoline, it is natural to focus on developments in global crude oil markets as the likely cause of that increase. Figure 2 shows some of the key determinants of the price of imported crude oil. The upper panel demonstrates that the trend growth in global crude oil production since 1984 has leveled out since 2005. This pattern is consistent with capacity constraints in crude oil production being binding, following a long period of underinvestment in exploration and drilling.

In contrast, measures of global real activity such as the freight rate index of Kilian (2008a) shown in the second panel suggest strong growth in global demand for all industrial commodities (including crude oil) since 2002.[3] Since the increase in the index of real activity in Figure 1 is not mirrored by similar increases in OECD industrial production data, it is apparent that it must reflect increased demand from non-OECD countries, notably countries in emerging Asia. This impression is also supported by the BEA data on U.S. retail consumption of gasoline in the third panel. Following a period of steady growth since 1981, real gasoline consumption in the United States leveled off in 2002, so the source of increased demand for crude oil must lie elsewhere.

In short, this casual analysis of the data suggests that global demand for crude oil has outstripped the world's ability to supply crude oil, resulting in higher crude oil and gasoline prices. This excess demand does not reflect increased use of oil and its by-products in the United States, but rather additional demand for oil (and other industrial commodities) arising from emerging economies that traditionally did not use much oil. An alternative view has been that the surge in oil and gasoline prices since 2002 has reflected speculation in crude oil markets. In this view, investors buy crude oil now and store it in anticipation of higher future oil prices with the intention of selling it at a profit. If this explanation were true, one would expect a noticeable

[3] One advantage of using this type of index is that it automatically accounts for any additional demand for industrial commodities generated by the depreciation of the U.S. dollar in recent years. The idea of using fluctuations in dry cargo freight rates as indicators of shifts in the global real activity dates back to Isserlis (1938) and Tinbergen (1959), Also see Stopford (1997) and Klovland (2004). The panel of monthly freight-rate data underlying the global real activity index was collected manually from Drewry's Shipping Monthly using 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 oilseeds, 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. The index is constructed by extracting the common component in the freight rate data. The raw index is expressed in dollars per metric ton and must be deflated using the U.S. CPI and detrended. For details on the construction and interpretation of this index see Kilian (2008a).

increase in crude oil inventories in recent years. The inventory data, however, suggest that OECD petroleum inventories if anything have fallen slightly since mid-2006, while the price of oil has risen sharply. Moreover, as Figure 3 shows, there is no evidence of a substantial increase in global oil inventories since 2002, casting doubt on the hypothesis that speculation has been fuelling high oil and gasoline prices. Finally, the data show broad-based increases in all industrial commodity prices rather than merely in the price of crude oil, which is inconsistent with any explanation of this surge that is specific to the crude oil market.

The next section introduces a formal model of these relationships based on the data in Figures 1 and 2. The sample period is 1973.2-2007.12. The data frequency is monthly, which allows the use of identification restrictions that would be economically implausible for data measured at quarterly or annual frequency.

3. A Joint Model of the Global Crude Oil Market and the U.S. Retail Market for Gasoline

In this section, I propose a VAR model that jointly explains the five variables shown in Figures 1 and 2. The set of variables includes (in the order listed) the percent change of world production of crude oil, the measure of global real economic activity proposed in Kilian (2008a), the real price of imported crude oil, the real price of gasoline and other motor fuels in the U.S., and the percent growth rate of the quantity of gasoline and motor fuels consumed in the U.S. I postulate that these five variables are driven by five structural shocks: (1) crude oil supply shocks (*oil supply shocks*); (2) shocks to the demand for all industrial commodities in global markets (*aggregate demand shocks*); (3) demand shocks that are specific to the global crude oil market (*oil-market specific demand shocks*); (4) shocks to the supply of gasoline in the U.S. (exemplified by *refinery shocks*); (5) shocks to the U.S. demand for gasoline (*gas demand shocks*).

Crude oil supply shocks in the model are defined as linearly unpredictable changes in the growth of global crude oil production.[4] The aggregate demand shock is designed to capture shifts in the demand for all industrial commodities (including crude oil) driven by the global business cycle as well as structural shifts in the demand for industrial commodities such as the emergence of industrialized economies in Asia. The oil-market specific demand shock is designed to capture

[4] An alternative approach would be to forecast global oil supply based on projections of oil companies. In practice, such information is inherently judgmental, prone to error, and often incomplete or not available at all to the public. Thus, time series methods seem better suited for projecting likely global production levels in the near term and for identifying oil supply shocks.

shifts in the real price of oil driven by higher precautionary demand associated with fears about future oil supply shortfalls. While there are possible alternative sources of oil-market specific demand shocks, Alquist and Kilian (2008) and Kilian (2008a) shows that these other explanations do not appear empirically plausible. Examples of gasoline supply shocks are refinery fires that shut down the operation of U.S. refiners and reduce the domestic supply of gasoline or changes in regulation that restrict gasoline output. In contrast, gasoline demand shocks reflect shifts in consumer preferences, changes in demographic structure and the degree of urbanization, and other shifts in gasoline demand not immediately related to the real price of gasoline.

The identifying assumptions are (1) that world crude oil production does not respond within the month to demand shocks in the crude oil market, nor does world crude oil production respond to shocks to demand or supply in the U.S. gasoline market within the same month; (2) oil-market specific demand shocks do not affect, within the month, real economic activity as it relates to global industrial commodity markets; (3) while shocks to the supply of or demand for crude oil may have an immediate effect on gasoline prices, the demand for crude oil remains unaffected within the same month by demand and supply shocks specific to the U.S. gasoline market; (4) shocks to the demand for gasoline that are orthogonal to shocks to the demand for crude oil do not affect the price of gasoline within the same month; (5) shocks to the supply of gasoline such as refineries shutting down due to accidents or changes in the regulatory environment (as discussed in Muehlegger 2006), however, may affect the price of gasoline within the same month. Implicitly, the model imposes the restriction that domestic gasoline supply and gasoline demand shocks do not affect the real price of crude oil imports within the same month. These identifying assumptions imply a recursive structure for the innovations in the structural VAR model. The structural VAR representation is

(1) $$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t ,$$

where *p* is the lag order, ε_t denotes the vector of serially and mutually uncorrelated structural innovations. Given the identifying assumptions above, A_0^{-1} has a recursive structure such that the reduced-form errors e_t can be decomposed according to $e_t = A_0^{-1}\varepsilon_t$.

$$e_t \equiv \begin{pmatrix} e_t^{\Delta \text{ global oil production}} \\ e_t^{\text{global real economic activity}} \\ e_t^{\text{real price of crude oil}} \\ e_t^{\text{real U.S. price of gasoline}} \\ e_t^{\text{U.S. gasoline consumption}} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{45} & a_{55} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{oil supply shock}} \\ \varepsilon_t^{\text{aggregate demand shock}} \\ \varepsilon_t^{\text{oil-market specific demand shock}} \\ \varepsilon_t^{\text{refinery shock}} \\ \varepsilon_t^{\text{gasoline demand shock}} \end{pmatrix}$$

The model includes 14 lags and is estimated by the method of least-squares.[5] The restrictions on A_0^{-1} embody the following economic structure:

3.1. The Global Crude Oil Market

The first block of the model relates to the global crude oil market. It consists of the first three variables. The model postulates a vertical short-run supply curve of crude oil (conditional on all lagged variables). The rationale for this assumption is that changing oil production is costly. Hence, oil producers set production based on expected trend growth in demand. They do not revise the production level in response to unpredictable high-frequency variation in the demand for oil, since changes in the trend growth of demand are difficult to detect at high frequency.

Given the vertical short-run supply curve, shifts of the oil 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 (such as a cutback of oil supplies for exogenous political reasons). This block of the model is identical to the model used in Kilian (2008a).

3.2. The U.S. Retail Gas Market

The remaining two variables constitute the second block that represents the U.S. retail gasoline market. In the model, the U.S. retail price of gasoline is effectively set by U.S. refiners. Domestic refiners set retail prices by adding a markup to the price of imported crude oil.[6] U.S. refiners are price takers in the global crude oil market. Increases in the price of imported crude

[5] The lag order choice is necessarily a compromise. It was chosen to ensure that the responses to oil demand and supply shocks are similar to those reported in Kilian (2008a) based on a three-variable model with 24 lags, while retaining tractability in the larger five-variable system of interest here, which does not allow the inclusion of 24 lags.

[6] I abstract from the additional markup charged at the gas pump, since the markup charged by wholesale merchants and retailers is likely to be small (see, e.g., Davis (2007) for the retail market and Davis and Hamilton (2004) and Douglas and Herrera (2007) for the wholesale market). For our purposes that markup can be absorbed into the refinery shock..

oil are being passed on by U.S. refiners to the retail price of gasoline within the same month, as are exogenous shocks to the cost of refining.

The retail supply curve for gasoline is treated as perfectly elastic in the short run. The presumption is that gas station owners have enough gasoline stored in underground tanks to supply the required quantities of gasoline at the current retail price. Given that the consumption of gasoline typically evolves very smoothly and predictably, we abstract from the possibility that gas station owners may run out of gas. While unanticipated shifts in gasoline demand in the model do not move the price of gasoline instantaneously, they are allowed to affect the price of gasoline with a delay of one month. In other words, in the model, refiners respond to shifts in the domestic demand for gasoline only with a delay of at least one month. The rationale is that refiners rely on reports about retail gas consumption from gas stations, as gas station owners refill their tanks. Given the difficulty of distinguishing a temporary blip in demand from a change in trend, refiners will not respond to reports of increased retail consumption unless the increase in demand is widespread and sustained. Thus, innovations to the real retail price of gasoline are attributable to either gasoline supply shocks arising at the refining stage or cost shocks from the U.S. refiners' point of view reflecting changes in the price of imported crude oil.

Beyond these restrictions on the contemporaneous feedback at monthly frequency, the model allows for unrestricted feedback among all variables within and across blocks, consistent with the well-established notion that energy prices must be treated as fully endogenous (see, e.g., Barsky and Kilian 2002, 2004).

4. Impulse Response Analysis

4.1. How Gasoline and Crude Oil Prices Respond to Demand and Supply Shocks

Figure 4 shows the responses of the real price of imported rude oil and the real price of gasoline in the U.S. to the three shocks that drive the global crude oil market. Impulse response estimates are shown for a horizon of up to 24 months. All supply shocks have been normalized to represent a supply disruption. The demand shocks have been normalized to represent a demand expansion. The impulse response confidence intervals in this and subsequent figures have been constructed using a recursive-design wild bootstrap (see Gonçalves and Kilian 2004). The qualitative pattern of the response estimates conforms to basic economic theory.

The first row of Figure 4 shows that an unanticipated permanent reduction in world crude oil supplies causes the real price of crude oil to rise temporarily. The response is statistically significant at some horizons based on one standard error bands. The response peaks after half a year. The real price of gasoline exhibits a similar pattern, but the response is much weaker and statistically insignificant.[7]

An unanticipated increase in global demand for industrial commodities, as shown in the second row, causes a persistent increase in the real price of crude oil. Only after one year, the response has reached its maximum and it takes more than two years for the response to decline. The response of the real price of gasoline exhibits the same pattern, but on a smaller scale. Both responses are highly statistically significant.

The third row focuses on the responses to oil-market specific demand shocks. Such shocks typically arise from an increase in the precautionary demand for crude oil driven by increased uncertainty about future crude oil supply shortfalls (see Kilian 2008a). Large shifts in oil-market specific demand occurred, for example, in 1979, when the Iranian Revolution, the Iranian hostage crisis and the Soviet invasion of Afghanistan coincided with strong global demand for oil. Large shifts also occurred following the collapse of OPEC in late 1985 and after the invasion of Kuwait in 1990. Figure 4 shows that an unanticipated increase in the precautionary demand for crude oil would be associated with an immediate and sharp increase in both crude oil and gasoline prices. Again the response of the real price of gasoline is smaller. Both responses are highly statistically significant.

Figure 5 shows the corresponding responses to demand and supply shocks that are specific to the U.S. gasoline market. An unanticipated disruption of U.S. refinery output (such as a refinery fire) causes an immediate, persistent and highly statistically significant increase in the real price of gasoline, as shown in the first row. The same shock, however, causes a temporary drop in the real price of imported crude oil. This result is intuitive because refineries reduce their *supply* of gasoline following an unexpected outage, causing the price of gasoline to increase. At the same time, refineries that are shut down can no longer process crude oil, causing the *demand* for crude oil to fall and the real price of crude oil to decline.

This point is of immediate practical relevance. Following Hurricanes Rita and Katrina in 2005, many pundits predicted a rise in the price of crude oil. That increase never materialized. In

[7] The model does not distinguish between crude oil supply shocks driven by exogenous political events in the Middle East, as discussed in Kilian (2008c,d) and other exogenous shocks to crude oil production. This distinction could be incorporated into the VAR framework above, but is largely immaterial in the present context, as discussed in Kilian (2008a).

fact, the real price of crude oil fell slightly, while the real price of gasoline in the U.S. skyrocketed. Since the reduction in global crude oil production associated with these natural events paled in comparison with the reduction in refining capacity in the Gulf of Mexico (and since other U.S. refineries were already working at full capacity), this episode is best interpreted as an unanticipated U.S. refining disruption rather than an unanticipated global oil supply disruption. The results in Figure 5 help us understand the price responses.

The second row illustrates the consequences of an unanticipated increase in the U.S. demand for gasoline. The real price of gasoline peaks with a delay of two months. The response is statistically significant based on one standard error bands. In contrast, the real price of crude oil shows no statistically significant response. In fact, the error bands are so wide that only the one-standard error bands fit inside the plot. This result is consistent with the view that U.S. gasoline demand shocks are too small to affect the global demand for crude oil.

4.2. How U.S. Gasoline Consumption Responds to Demand and Supply Shocks

Figure 6 focuses on the corresponding response of the quantity of gasoline consumed in the United States. Since all shocks that shift the real price of imported crude oil on impact in the model are considered adverse supply shocks for the U.S. retail gasoline market, we would expect that all shocks but positive U.S. gasoline demand shocks should lower real consumption of gasoline in the U.S. This interpretation is borne out by Figure 6. Figure 6 highlights that nevertheless there are important difference across shocks. For example, an oil supply disruption causes the consumption of gasoline to drop temporarily only. The trough occurs after about half a year. In contrast, the aggregate demand shock causes the consumption of gasoline to fall gradually. The initial response is fairly small, but the response builds over time. Only after one year, the full impact becomes apparent. Oil-market specific demand shocks and refining shocks have a much larger effect on oil consumption on impact. Whereas refining shocks cause gasoline consumption to "overshoot" on impact, oil-market specific demand shocks only reach their full impact with a delay. Finally, positive gasoline demand shocks cause a persistent increase in gasoline consumption, but much of the impact response is undone in the following month.

In summary, Figures 4-6 demonstrate that demand and supply shocks in the global crude oil market and in the U.S. gasoline market have distinctly different effects on U.S. gasoline consumption and on the real prices of crude oil and gasoline, making it important to differentiate between price shocks driven by one or another of these demand and supply shocks.

5. What Fraction of the Variation in U.S. Gasoline Prices and Growth in U.S. Gasoline Consumption Can Be Attributed to Each Shock?

A natural concern is how much of the variation of U.S. retail gasoline prices can be attributed to each demand and supply shock. This question may be answered by computing variance decompositions based on the estimated VAR model of section 3. Table 1 reports the average contribution of each shock to the total variation in the real price of gasoline in percentage terms. On impact, 82% of the variation in gasoline prices is accounted for by refining shocks, followed by oil-market specific demand shocks that account for an additional 18% in impact. The remaining shocks play no role. In contrast, in the long run, the importance of refining shocks declines to 8%, whereas that of oil-market specific shocks increases to 59%. Aggregate demand shocks play an increasingly important role with a delay of half a year, reaching 33% in the long run. The explanatory power of oil supply shocks and gasoline demand shocks remains below 1% at all horizons. The very limited role of gasoline demand shocks at all horizons supports the view that fluctuations in the real gasoline price are determined almost exclusively on the supply side of the U.S. gasoline market.

Table 2 shows the corresponding decomposition of the variation in the growth rate of U.S. gasoline consumption. That variation is dominated by gasoline demand shocks which account for 89% on impact and 78% in the long run. Refining shocks explain 9% of the variation on impact and 10% in the long run. Shocks in the crude oil market are less important, but gain in importance over time. In the long run, oil supply shocks account for 2% of the variation, aggregate demand shocks for 5% and oil-market specific demand shocks for 6%. The data are consistent with the view that U.S. gasoline consumption is only moderately sensitive to gasoline supply shocks.

These estimates are based on historical averages for the period since 1973. In practice, the relative importance of each shock may be quite different from one historical episode to the next. In fact, it has been observed that historically no two oil price shocks have been alike (see Kilian 2008a). It therefore is instructive to decompose the historical movements in the real price of gasoline and to trace out the cumulative effect of each shock on the real price of gasoline through time. Of particular interest is the most recent surge in gasoline prices.

6. What Has Been Behind the Surge in U.S. Gasoline Prices since 2002?

Figure 7 identifies the cumulative effect of each of the structural demand and supply shocks identified in the previous subsection on the real price of gasoline since 2002. The first row of Figure 7 shows that overall crude oil supply shocks have had a negligible effect on gasoline prices. The bulk of the increase in U.S. gasoline prices since 2002 has been associated with steady pressure from increasing global demand for crude oil, along with other industrial commodities, as shown in the second row.

In addition, at various points in time, there has been upward pressure on real gasoline prices from shifts in precautionary demand, as shown in the third row of Figure 7. One example is early 2002. More importantly, there was a temporary rise in the real price of oil in 2005 and 2006. The initial rise largely occurred following Hurricanes Rita and Katrina (possibly reflecting a misinterpretation of the effects of these events on the crude oil market). The subsequent even larger buildup in 2006 is more likely linked to concerns about Iran and Iraq and the continued strength of the world economy. In contrast, the effect of the Iraq War in early 2003 on U.S. gasoline prices was fairly small and short-lived.

An important test of the plausibility of the identifying assumptions is the behavior of gasoline and crude oil prices following Hurricanes Rita and Katrina in 2005. As discussed earlier, the primary effect of this exogenous event was not the reduction in U.S. crude oil production (which was negligible on a world scale), but the reduction of crude oil refining capacity in the Gulf of Mexico. Given that other U.S. refineries were already operating close to capacity at the time, this event constituted a major unanticipated reduction of the supply of gasoline in the U.S., which would be expected to raise the price of gasoline sharply. The fourth row of Figure 7 indeed shows a sharp increase of U.S. gasoline prices driven by adverse refinery shocks in late 2005. Only half a year later, the price seems to have stabilized again, although there is evidence of intermittent unanticipated refining shortages in 2006 and 2007 as well.

In contrast, the effect of exogenous shocks to gasoline demand, as shown in the last row, has been negligible throughout this period. We conclude that the recent build-up in gasoline prices consists of three main components whose relative contribution to the real price of gas has varied over time: (1) The bulk of the increase can be explained by strong and persistent demand in global commodity markets (consistent with a strong economic growth in many advanced economies and with the integration of emerging economies in the global economy); especially starting in late 2005, the upward pressure on gasoline prices was temporarily aided by (2) precautionary demand shocks specific to the oil market and (3) adverse supply shocks in the U.S. refining industry. There is no evidence that the recent build-up of gasoline prices has been associated with production decisions by OPEC or other crude oil supply shocks. Nor is there evidence that speculation in oil markets is behind the recent increase in gasoline prices, as such speculation ought to be reflected in a sharp increase in oil-market specific demand.

This analysis is broadly consistent with related evidence in Kilian (2008a) on the relative contribution of demand and supply shocks to the price of crude oil since 1978. That evidence suggests that efforts to link U.S. gasoline price increases to crude oil production shortfalls alone are doomed to failure, given the overriding importance of shocks to the demand for crude oil not just in the most recent period, but also during earlier oil price shock episodes. This, of course, does not preclude that crude oil production shortfalls may assume a more important role in the future. If there is a shortfall of crude oil production in some country, much depends on the duration of this shortfall and on the ability of other oil-producing countries to offset the shortfall. The fact that, in the past, global oil production has tended to recover or even to increase following oil supply shocks is no guarantee that additional supplies will be forthcoming when needed in the future.

7. The Future Evolution of U.S. Gasoline Prices

Predicting crude oil prices (and by extension the price of gasoline) is an all but impossible task even at horizons as short as one year. Recent work by Alquist and Kilian (2007) has shown that simple no-change forecasts of the price of crude oil remain the most accurate forecasts in practice. In other words, the change in the price is unpredictable. Given the close relationship between global crude oil prices and domestic retail gasoline prices, the same result is likely to apply to U.S. gasoline prices. The problem with forecasting the change in gasoline prices is not so much that we do not understand its determinants, but that it is difficult to predict the future evolution of these determinants.

Abstracting from unpredictable refinery outages, the future evolution of U.S. gasoline prices depends primarily on developments in the global crude oil market. Although past oil price increases have been followed by substantial increases in crude oil production with a delay of a few years, there is reason to be skeptical that substantial increases in oil production will be forthcoming in the foreseeable future. Part of the problem is that oil exploration had been neglected, as the price of oil fell in the late 1990s. A more important problem is that the political environment in many oil-producing countries discourages oil companies from making the much needed large-scale investments. In particular the threat of expropriation of successful investments in many countries prevents investments from taking place at the needed pace. A third problem is that much of the additional crude oil likely to be available in the short run is heavy crude oil that U.S. refineries are ill-equipped to process. Building new refineries in the United States takes many years. Thus, a fair presumption is that the crude oil market will remain supply-constrained for the next few years.

With crude oil production remaining flat or increasing only slightly, the price of crude oil and hence the price of gasoline will depend first and foremost on the extent to which countries in emerging Asia will continue to grow. Clearly, the current expansion in Asia will not continue unabated, all the more so as rising energy prices will leave their mark abroad and the U.S. economy is already slowing. While a decline in demand seems inevitable, what is not clear is how soon that decline will occur and by how much global demand for industrial commodities will slow down. If past global expansions are a guide (which cannot be taken for granted since the current expansion is driven by very different factors than the expansions of the 1970s), global demand will recede only gradually. This is a direct implication of the model proposed in this paper. In that case, U.S. gasoline prices will remain high for the time being. Barring a major economic collapse in emerging Asia, prices will stabilize only as the world economy learns to economize on the use of oil and gasoline and as the supply of crude oil expands. Both corrective forces will take time to take effect.

In addition, there is reason to be concerned that oil-market specific developments, which for the most part have played no role since 2002, could become more important in the future. Sharp shifts in the precautionary demand for oil reflecting uncertainty about political developments in the Middle East tend to occur only when demand for crude oil exceeds supply. When they do occur, they tend to cause sharp increases in the price of crude oil, as the model developed in this paper has demonstrated. Under the current conditions, the world economy is particularly vulnerable to threats of military conflict in the Middle East. A good example is Iran’s threat to close the Straits of Hormuz if Iran were to be attacked by Israel. Such developments could potentially cause U.S. gasoline price movements that dwarf the effect of sustained strong global demand for industrial commodities.

8. Concluding Remarks

The VAR model proposed in this paper produces empirically plausible results, but is not without limitations. For example, the model abstracts from wholesale trade in gasoline as well as the distinction between domestically produced and imported crude oil. It also ignores composition effects arising from different grades of crude oil and their yield in terms of different refined products. These omissions are not necessarily a problem. As with any empirical model there is a trade-off between realism and tractability. Moreover, it is not clear whether time series of suitable data would be available to incorporate these additional features.

The model also abstracts from possible time-variation in the reduced form parameters. To the extent that this time variation is caused by shifts in the composition of demand and supply shocks, this is not a concern. To the extent that it reflects changes in the energy efficiency of the U.S. economy, the results in this paper are best viewed as an approximation. The analysis in Edelstein and Kilian (2008, Figure 2), however, suggests that the average gasoline share in consumer expenditures between 1970 and 1986 was not much higher than since 1987, suggesting that this effect is of second-order importance.

Finally, the VAR model also ignores the possibility of asymmetries in the transmission of oil price increases to retail gasoline prices. It is not clear how restrictive that simplification is. A number of studies have documented evidence of asymmetries in the response of the price of gasoline to crude oil price increases and crude oil price decreases using daily, weekly or bi-weekly data (see, e.g., Borenstein, Cameron and Gilbert 1997). It is not clear, however, how important these high-frequency asymmetries are at monthly frequency nor does the violation of symmetry appear to have been tested formally.[8] Further investigation of the evidence of asymmetries at monthly frequency is an important area of research.

[8] There is more compelling statistical evidence in favor of asymmetries in the relationship between daily gasoline prices as quoted on NYMEX and wholesale gasoline price (see Davis and Hamilton 2004; Douglas and Herrera 2007). Again it remains to be seen how important that evidence is at monthly frequency.

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Table 1: Percent Contribution of Each Demand and Supply Shock to the Overall Variability of the Real U.S. Price of Gasoline

Horizon	Oil Supply Shock	Aggregate Demand Shock	Oil-Specific Demand Shock	Refining Shock	Gasoline Demand Shock
1	0.02	0.00	17.61	82.37	0
2	0.51	0.17	45.95	53.35	0.02
3	0.59	0.82	61.73	36.51	0.35
6	0.59	4.70	74.58	19.90	0.23
12	0.37	16.76	70.35	12.36	0.15
∞	0.07	32.93	58.94	7.98	0.08

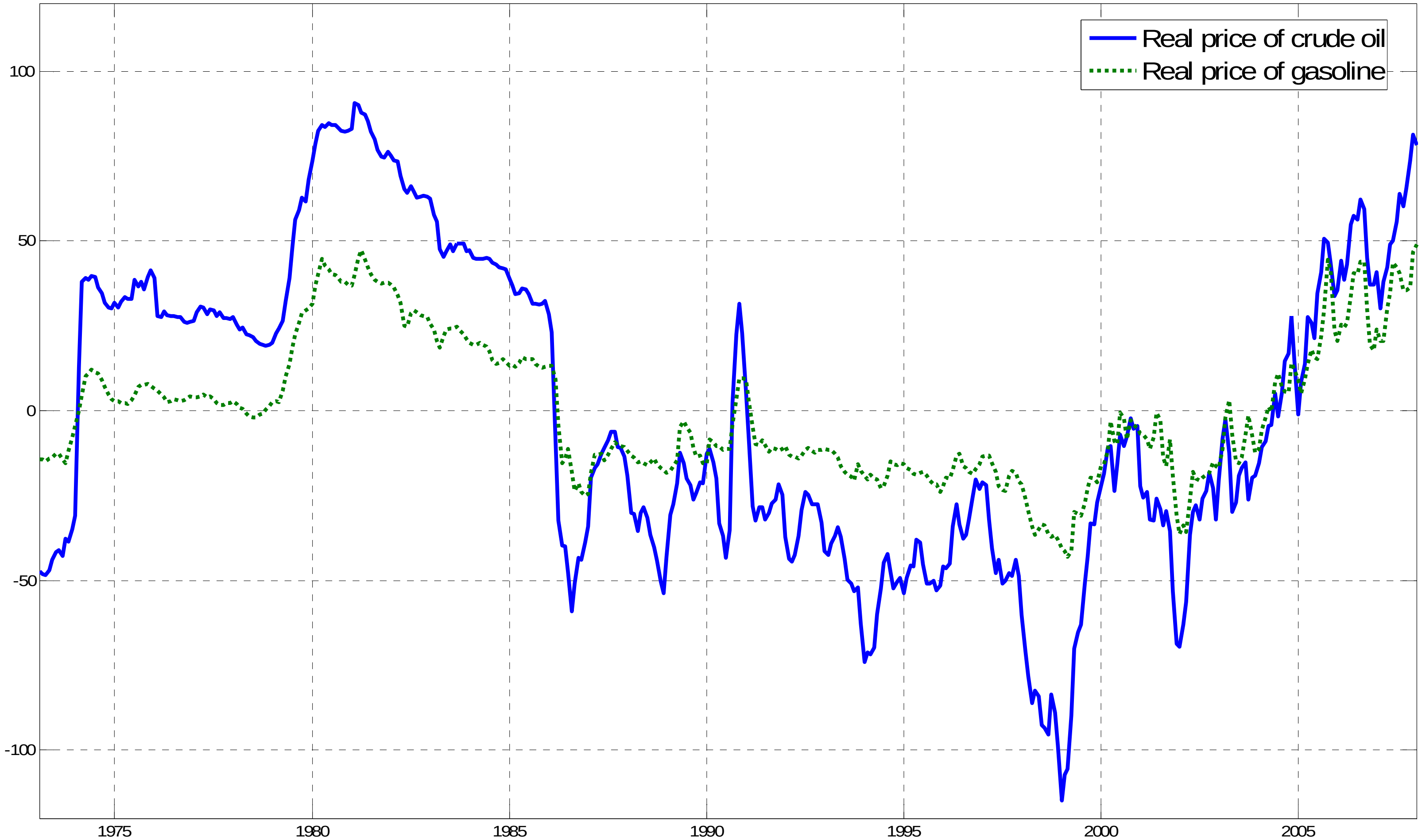
NOTES: Based on a variance decomposition of the structural VAR model (1).

Table 2: Percent Contribution of Each Demand and Supply Shock to the Overall Variability of the Growth of Real U.S. Consumption of Gasoline

Horizon	Oil Supply Shock	Aggregate Demand Shock	Oil-Specific Demand Shock	Refining Shock	Gasoline Demand Shock
1	0.03	0.31	2.08	8.67	88.92
2	0.02	0.83	2.24	6.36	90.55
3	0.02	1.74	2.36	6.86	89.02
6	0.75	2.63	3.85	6.92	85.85
12	1.61	4.25	4.51	8.52	81.10
∞	2.02	4.55	5.56	9.68	78.19

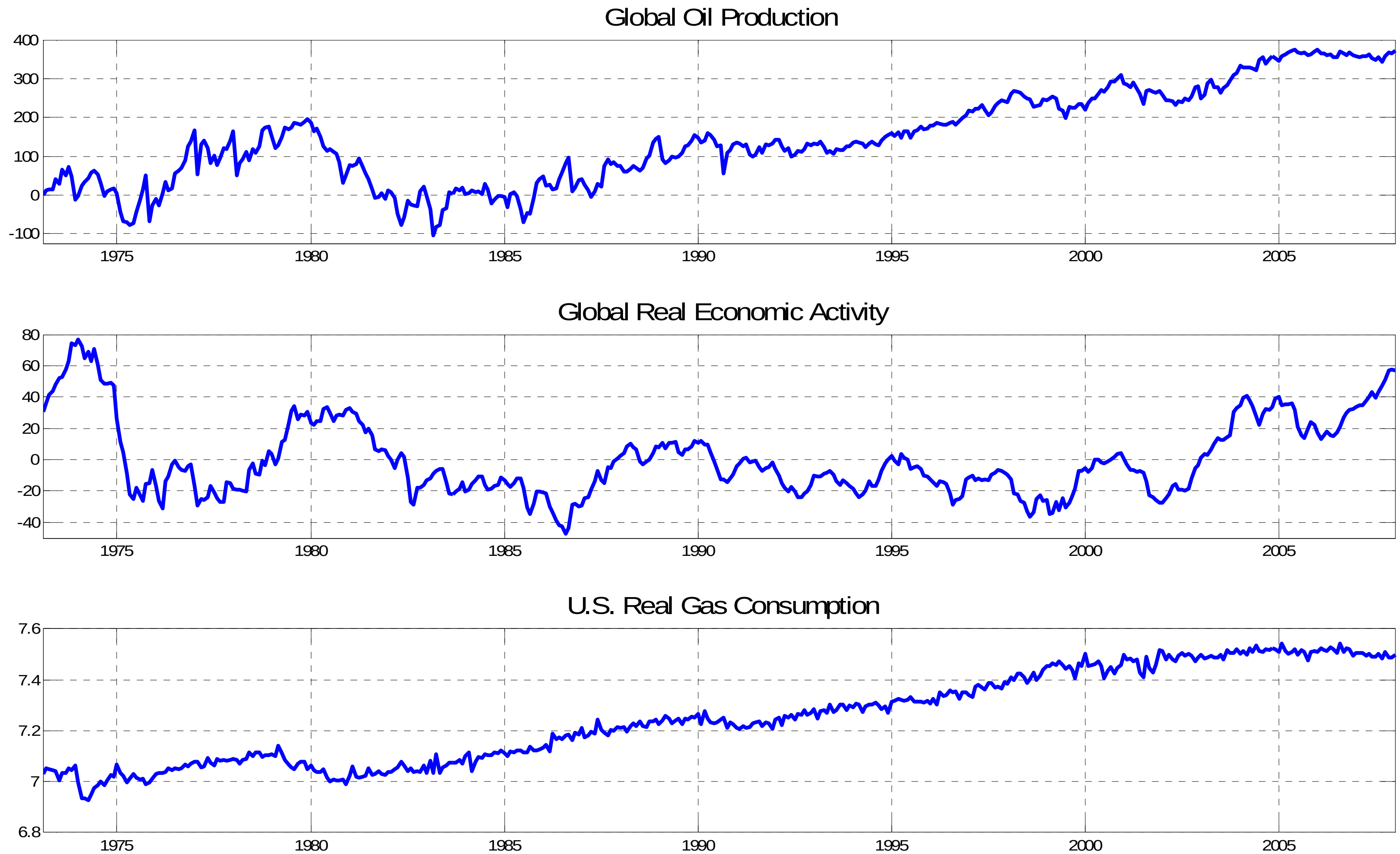
NOTES: See Table 1.

Figure 1: Real Price of Imported Crude Oil and Real U.S. Retail Price of Gasoline 1973.1-2007.12



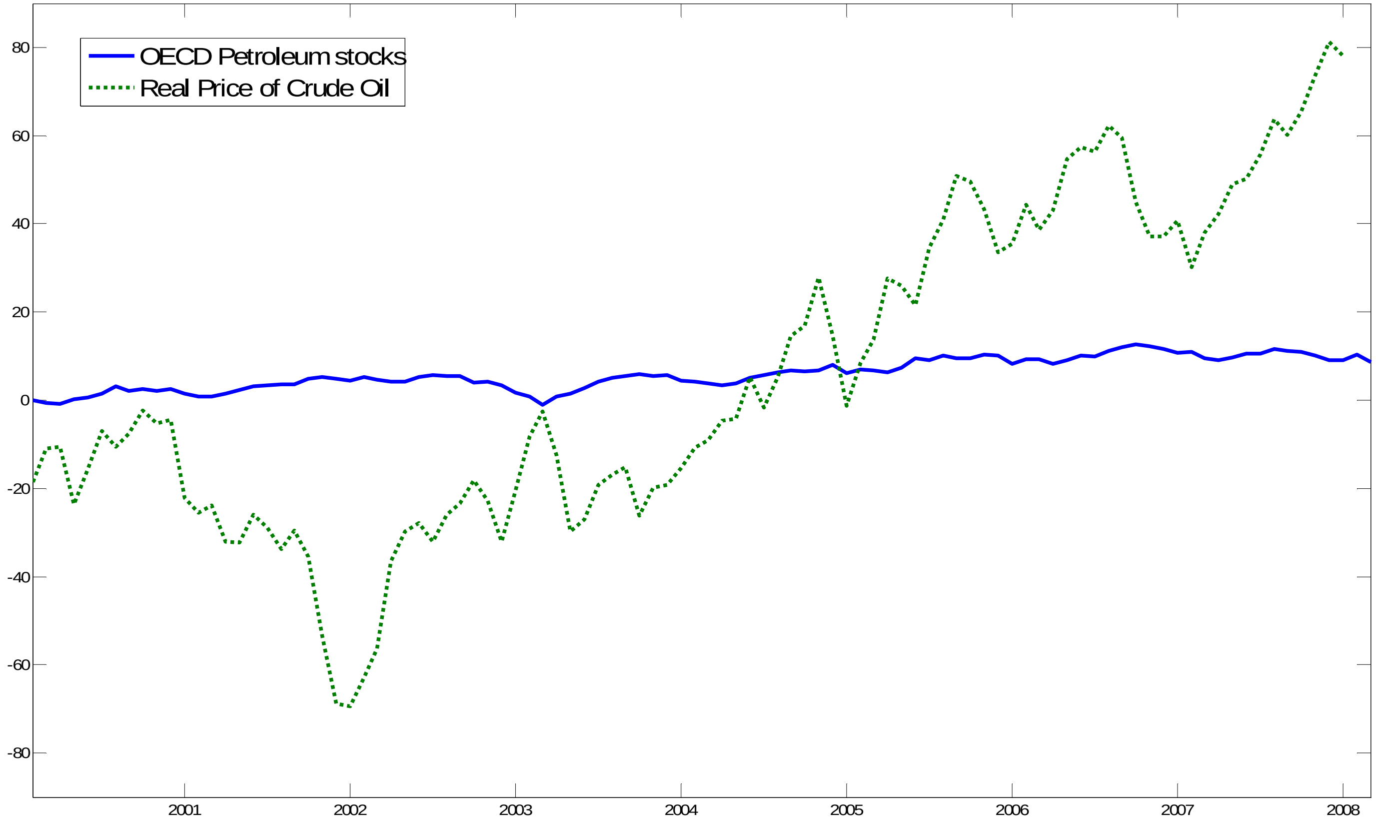
NOTES: The oil price series is based on an index of the U.S. refiners' acquisition cost of imported crude oil. The price of motor gasoline is an index computed by the Bureau of Economic Analysis. Both series have been adjusted for U.S. CPI inflation and demeaned.

Figure 2: Key Determinants of the Real U.S. Price of Gasoline
1973.1-2007.12



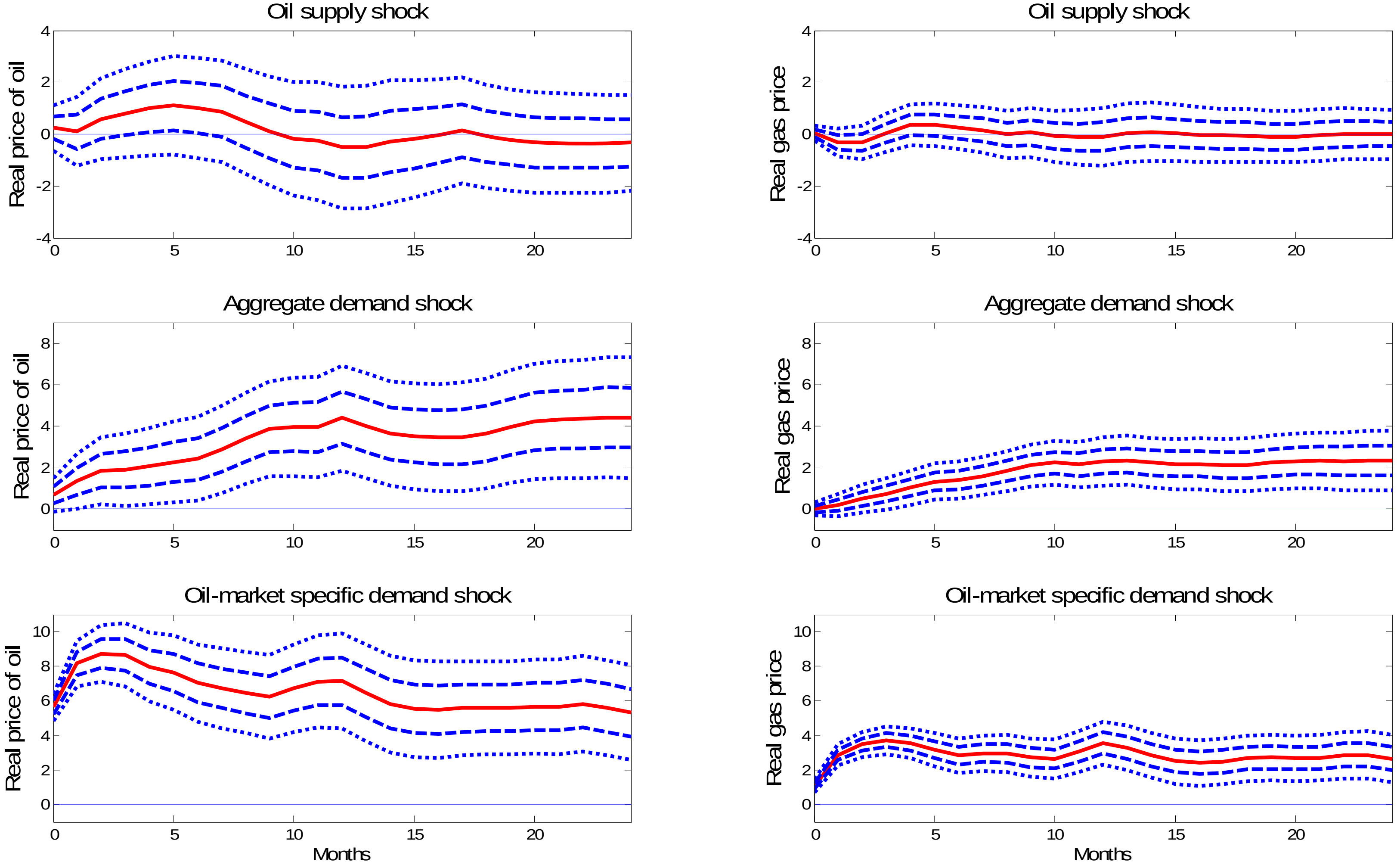
NOTES: For a description of these variables see section 2.

Figure 3: OECD Petroleum Inventories and the Real Price of Oil since 2000



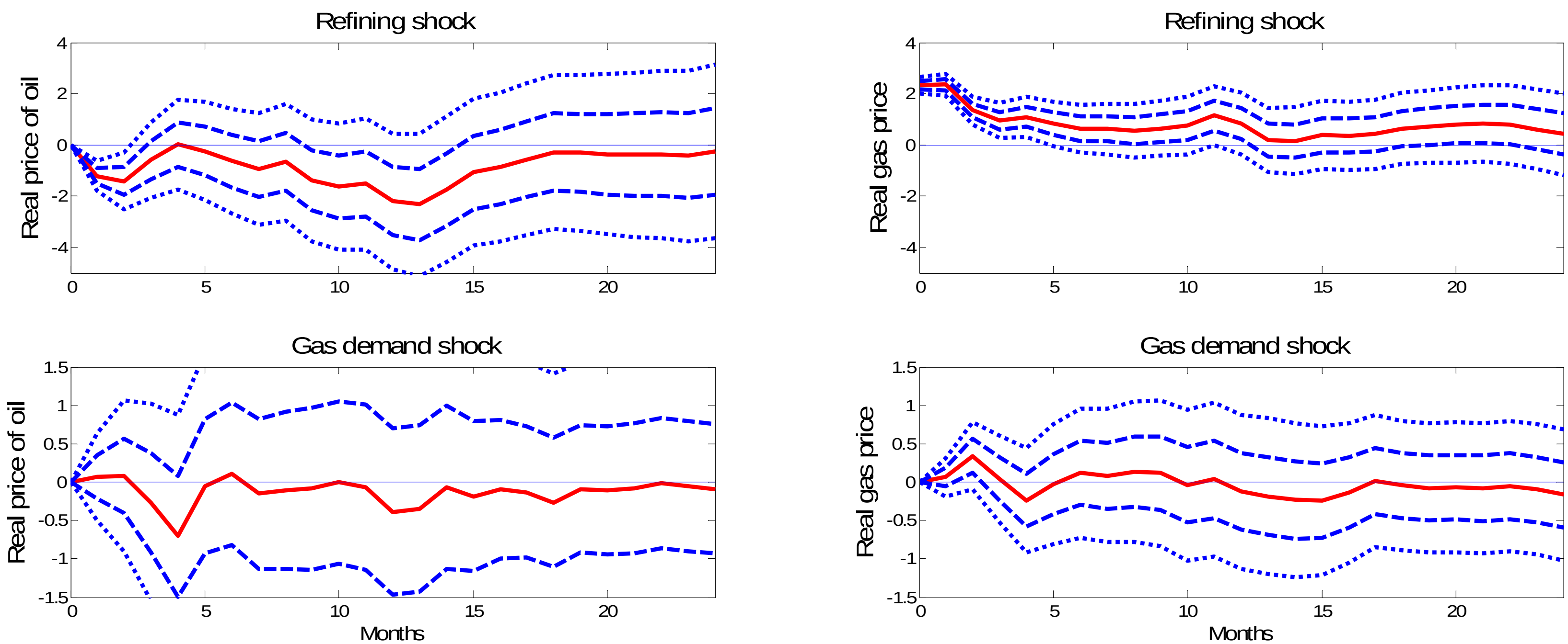
NOTES: Log-scale. The OECD inventory data have been normalized such that 2000.1is zero.

Figure 4: Price Responses to One-Standard Deviation Structural Shocks in Crude Oil Market Estimates with One and Two-Standard Error Bands



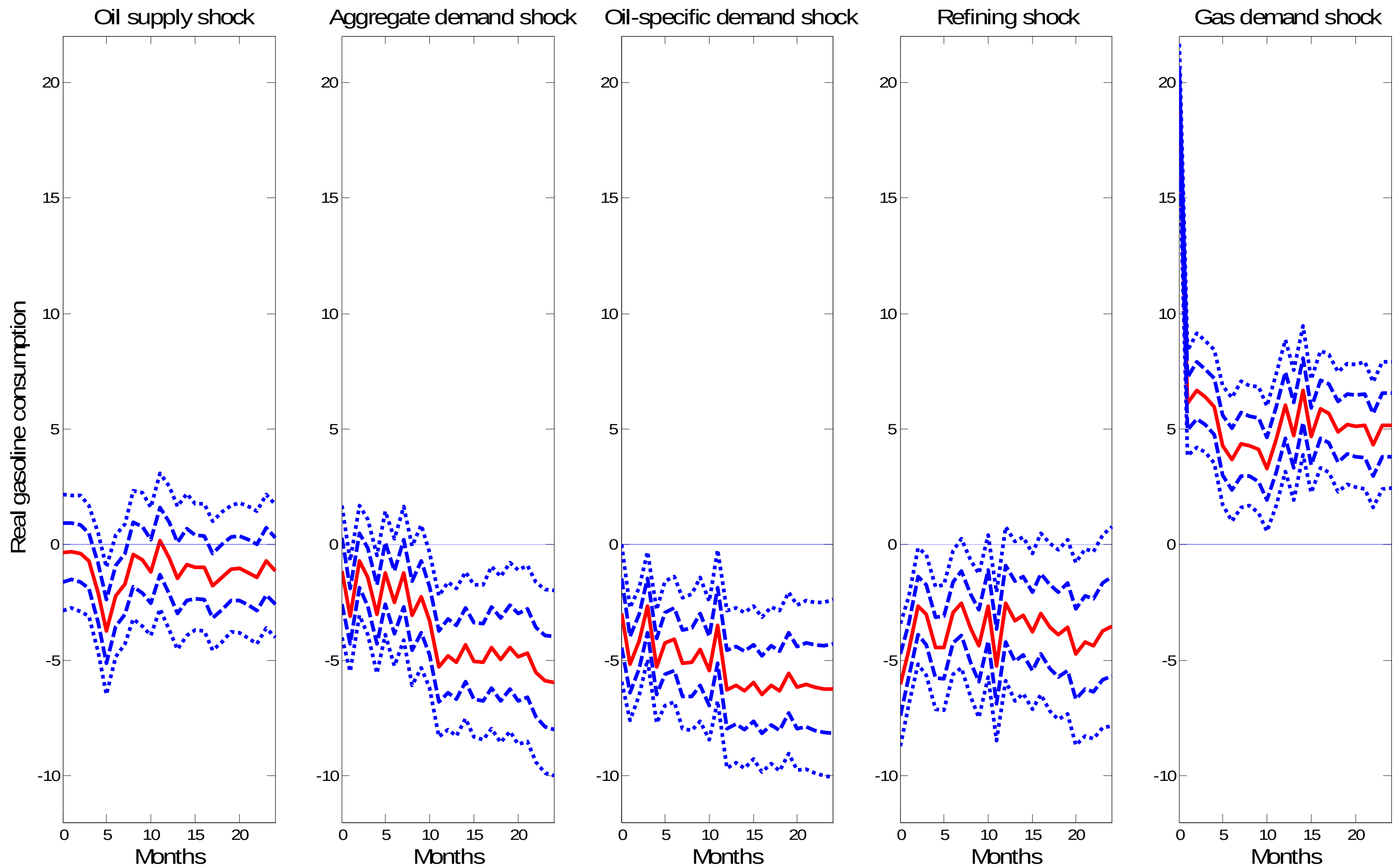
NOTES: Estimates based on model (1). The confidence intervals were constructed using a recursive-design wild bootstrap.

Figure 5: Price Responses to One-Standard Deviation Structural Shocks in Gasoline Market Estimates with One and Two-Standard Error Bands



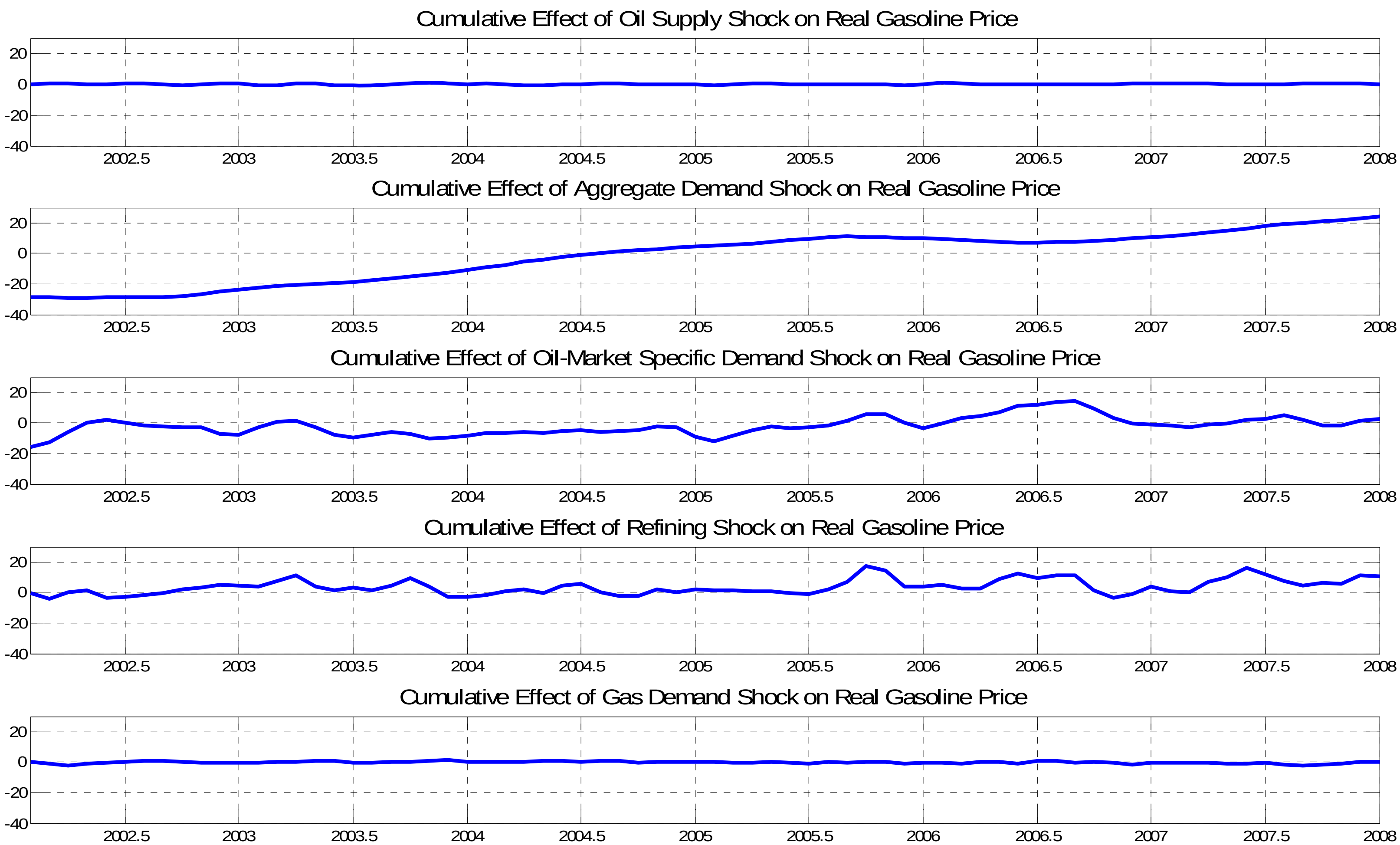
NOTES: Estimates based on model (1). The confidence intervals were constructed using a recursive-design wild bootstrap.

Figure 6: Responses of U.S. Gasoline Consumption to Demand and Supply Shocks
Estimates with One and Two-Standard Error Bands



NOTES: Estimates based on model (1). All shocks are one-standard deviation shocks. The confidence intervals were constructed using a recursive-design wild bootstrap.

Figure 7: Historical Decomposition of the Real Price of Gasoline 2002.1-2007.12



NOTES: Fitted values derived from model (1).