

Explaining Fluctuations in Gasoline Prices: A Joint Model of the Global Crude Oil Market and the U.S. Retail Gasoline Market

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January 25, 2009

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 evolution of U.S. gasoline prices since 2002.

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

JEL: Q43

Acknowledgements: I thank Lucas Davis, Ana-María Herrera, the editor and three anonymous referees for helpful comments on an earlier draft of this paper.

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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 gasoline and other motor fuels.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 fails to distinguish between the underlying oil demand and oil supply 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. 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.

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 process 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

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). These papers focus on the effect of demand and supply shocks in the global crude oil market on the U.S. stock market, on inflation and real GDP growth, the balance of payments, and the oil futures markets. In contrast, this paper for the first time provides an integrated model of the global crude oil market and the U.S. retail gasoline market with the objective of understanding the evolution of U.S. retail gasoline prices.

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 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 consumption 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 growth. It is shown that, in the short run, 80% of the fluctuations in the real price of gasoline are determined by refining shocks and 19% by oil-market specific demand shocks. In the long run, 50% of the variation in the real price of gasoline in the U.S. is driven by oil-market specific demand shocks, 45% by shocks to the global business cycle, and 3% by refining shocks with essentially no role for domestic gasoline demand shocks or global oil supply shocks. For gasoline consumption a somewhat different picture emerges. In the short run 91% of the variation in the growth rate of U.S. gasoline consumption is driven by gasoline demand shocks and 7% by shocks at the refining stage. In the long run, 80% of the variation in the growth rate of U.S. gasoline consumption is driven by domestic gasoline demand shocks, 10% by refining shocks, 5% by demand shocks specific to the crude oil market, and 4% by shocks to the global business cycle.

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 between 2002 and mid-2008. The econometric

model shows that this surge in gasoline prices consisted of three main components whose relative contribution to the real price of gas has varied over time: The by far most important explanation was repeated positive demand shocks in global commodity markets (consistent with unexpectedly strong economic growth in many advanced economies and with the integration of emerging economies in the global economy). In addition, the upward pressure on gasoline prices was temporarily aided by positive demand shocks specific to the oil market and by adverse supply shocks in the U.S. refining industry, but none of these pressures persisted. The model also sheds light on the sharp decline in gasoline prices since mid-2008. While this decline reflects in part a dramatic unexpected decline in global real economic activity starting in May of 2008, even more importantly it has been associated with negative oil-market specific demand shocks. Thus, there are important differences in the causes of the upswing of this gasoline price cycle and its downswing.

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 4.1 reviews the history of these shocks. In section 4.2, 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 4.3, 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 between 2002 and mid-2008 and the drop in gasoline prices since then. Section 7 discusses the difficulty of generating reliable forecasts of 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

² The gasoline price is the chain-weighted consumer price deflator for gasoline and other motor fuel provided by the BEA. The data source is line 119 in Tables 2.4.4U of the *Underlying Detail Tables* of the *Supplemental Estimates* in

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. Although the contemporaneous correlation of the two series is 0.95, 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 and other motor fuels.

Of particular interest is the surge in the real price of gasoline after 2002. By the end of 2007, both prices adjusted for inflation had reached levels last seen in 1981. One of the central questions of this paper is why this surge occurred and what explains the subsequent fall in gasoline prices since mid-2008. 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 gasoline and other motor fuel. The upper panel demonstrates that the trend growth in global crude oil production since 1984 leveled out after 2005.³ This pattern is consistent with capacity constraints in crude oil production being binding between 2005 and mid-2008, 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) between 2002 and mid-2008.⁴ Since the increase in the index

the *National Income and Product Accounts* provided by the Bureau of Economic Analysis at <http://bea.gov/national/index.htm>. The gasoline price has been deflated by the consumer price index for all urban consumers, available from FRED at <http://research.stlouisfed.org/fred2>. This price will be referred to as the real price of gasoline throughout this paper. The price of crude oil is based on refiners' acquisition cost for imported crude oil, as reported in the *Monthly Energy Review* of the Energy Information Administration. The series has been extrapolated backwards as in Barsky and Kilian (2002) and deflated by the same consumer price index as the price of gasoline and other motor fuel, resulting in the real price of crude oil.

³ The global oil production data are measured in millions of barrels of oil and have been expressed as cumulative percent changes. The data source is the *Monthly Energy Review* of the Energy Information Administration.

⁴ 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 data set is restricted to dry cargo rates. 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 nominal spot rates. The raw index is expressed in dollars per metric ton and must be deflated using the U.S. CPI and detrended to account for the secular decline in shipping rates. For details on the construction and interpretation of this index see Kilian (2008a). For this paper, this

of real activity in Figure 1 is not mirrored by similar increases in OECD industrial production data, as discussed in Kilian (2008a), 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 Bureau of Economic Analysis (BEA) data on U.S. retail consumption of gasoline in the third panel.⁵ 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.

Moreover, the sharp drop in gasoline prices after mid-2008 coincided with a dramatic slowdown in global real economic activity as well as gradual decline in U.S. gasoline consumption. Since global crude oil production during this period fell slightly, it is evident that the collapse of gasoline prices must have been associated with a reduction in the global demand for crude oil. In short, this casual analysis of the data suggests that until mid-2008 global demand for crude oil outstripped the world's ability to supply crude oil, resulting in higher crude oil and gasoline prices. This excess demand reflected not so much 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. As global demand both in emerging Asia and in the OECD fell in late 2008, so did the price of crude oil (and hence the price of gasoline).

An alternative view has been that the surge in oil and gasoline prices between 2002 and mid-2008 reflected speculation in crude oil markets. In this view, investors in search of high returns bought crude oil and stored it in anticipation of higher future oil prices with the intention of selling it at a profit. If this explanation were correct, one would have expected a noticeable increase in above-ground crude oil inventories, when an increasing number of speculators entered the oil futures markets after 2003 (see Alquist and Kilian 2008). The inventory data, however, suggest that OECD petroleum inventories have been remarkably stable before and after 2003, while the real price of oil has risen sharply. As Figure 3 shows, there is no evidence of a substantial increase in OECD oil inventories since 2002, casting doubt on the hypothesis that speculation has been fueling high oil and gasoline prices. In addition, the data show broad-based

series has been extended using the Baltic Exchange Dry Index, which is available from Bloomberg. The latter index is essentially identical to the nominal index compiled by Kilian, but only available since 1985.

⁵ Real gasoline consumption is defined as nominal personal consumption expenditures on gasoline and other motor fuel, divided by the chain-weighted consumer price deflator for gasoline and other motor fuel. In other words, this is an index of the quantity of gasoline and other motor fuel consumed. The data source is line 119 in Tables 2.4.4U and 2.4.5U of the *Underlying Detail Tables of the Supplemental Estimates in the National Income and Product Accounts* provided by the Bureau of Economic Analysis at <http://bea.gov/national/index.htm>.

increases in all industrial commodity prices rather than merely in the price of crude oil, which is inconsistent with any explanation of the surge in oil prices that is specific to the crude oil market. While it is conceivable that speculation extended to all industrial commodity markets that permitted futures trading, prices of industrial commodities that were not traded in public exchanges rose just as fast as those that were (see Bini-Smaghi 2008), casting doubt on that hypothesis. Moreover, broad-based speculation in industrial commodity markets would still fail to explain the stability of oil inventory holdings after 2003. Although one could make the case that above-ground oil storage facilities were perhaps in fixed supply, preventing inventories from increasing, under that alternative scenario one would have expected inventory holdings by speculators to crowd out inventory holdings by refineries, resulting in a decline in the production of refined products after 2003. Again there is no evidence of such a decline.

The next section introduces a formal model of these relationships based on the data in Figures 1 and 2. The sample period is 1973.2-2008.10. 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

The proposed VAR model jointly explains the evolution of the five monthly 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 other motor fuels consumed in the U.S. The price series are expressed in percent deviations from their long-run average. The real activity index is expressed in percent deviations from trend. 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.⁶ 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 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 for a given 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:

⁶ 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.

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

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.⁷ 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.⁸

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

⁷ 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.

⁸ This assumption is consistent with the fact that the Saudi oil company AARAMCO uses models to predict expected demand growth, but does not update that model more than once a year. It is also consistent with anecdotal evidence based on interviews with Saudi officials in the early 1980s, when demand fell faster than the demand growth expected by the Saudis. Moreover, in related work, Kilian and Vega (2008) have shown that there is no evidence of feedback from U.S. macroeconomic news to oil prices at the monthly horizon.

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.⁹ U.S. refiners are price takers in the global crude oil market. Increases in the price of imported crude 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 gasoline distributors 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 distributors 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 distributors, as gas distributors 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.¹⁰

Beyond these restrictions on the contemporaneous feedback at monthly frequency, the model allows for unrestricted feedback among all variables within and across blocks, consistent

⁹ 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.

¹⁰ In section 4.3 I will relax this assumption and show that the empirical results are robust to reasonable departures from this baseline.

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. Demand and Supply Shocks since March of 1974

Figure 4 plots the estimated monthly structural residuals of model (1). The observations start in 1973.4, reflecting the lags used up in estimating the VAR model and in constructing monthly growth rates. By construction all structural shocks in the model have the same variance. Several events clearly stand out. For example, the largest single aggregate demand shock occurred in late 2008, as the credit crisis unfolded. The largest positive oil-market specific demand shock occurred in 1990 after Iraq's invasion of Kuwait. The largest negative oil-market specific shock occurred in early 1986 with the collapse of OPEC. By far the largest refining shock is associated with Hurricanes Rita and Katrina in late 2005. In contrast, the negative gasoline demand shocks in late 2008 are not unusual by historical standards.

While large shocks naturally attract attention, it is important to keep in mind that typical episodes of sharp movements in gasoline prices involve not a one-time demand or supply shock in a given month, but rather a sequence of shocks occurring over several months, if not years. In fact, a sequence of several small shocks of the same sign and type may have more dramatic effects on the real price of gasoline than any single large shock of that type. This is particularly true of the sequence of positive aggregate demand shocks after 2002. Moreover, a typical surge in gasoline prices will reflect a combination of different demand and supply shocks. Finally, since each latent demand and supply shock in the model causes movements in all five variables of the model, these shocks should not be mistaken for exogenous movements in any one observable variable.

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

Figure 5 shows the responses of the real price of imported crude oil and the real price of gasoline in the U.S. to the three types of shocks that drive the global crude oil market. Impulse response estimates are shown for a horizon of up to 24 months. The supply shock has been normalized to represent an oil supply disruption. The demand shocks have been normalized to represent a demand expansion. We focus on responses to one-standard deviation demand and supply shocks. This ensures that the shock underlying the impulse response function is of a typical magnitude

by historical standards. By construction, approximately one third of the historically observed shocks have exceeded a shock of this magnitude.

The qualitative pattern of the response estimates conforms to basic economic theory. The first row of Figure 5 shows that an unanticipated reduction in world crude oil supplies causes the real price of crude oil to rise. The response peaks after half a year, but is statistically insignificant at all horizons.¹¹ The real price of gasoline also increases, albeit with a delay. The initial response is negative, but not distinguishable from zero, after accounting for estimation uncertainty. The subsequent positive response is equally statistically insignificant and much weaker than for the real price of crude oil.¹² The weak response of the real price of oil to oil supply disruptions is consistent with recent work that has cast doubt on the quantitative importance of such shocks (see, e.g., Kilian 2008b).

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. The response reaches its maximum after one year. The response of the real price of gasoline exhibits the same qualitative 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 5 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. The responses overshoot before declining. Again the response of the real price of gasoline is smaller. Both responses are highly statistically significant.

To summarize, in most cases, the point estimates of the responses have the expected sign. Oil supply shocks have no precisely estimated effects, whereas the responses to demand shocks

¹¹ The 80% impulse response confidence intervals in this and subsequent figures have been constructed using a recursive-design wild bootstrap (see Gonçalves and Kilian 2004).

¹² 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).

are fairly tightly estimated. Oil-market specific demand shocks cause a price jump on impact and overshooting, whereas the aggregate demand shock does not. The responses to aggregate demand shocks reach their maximum effect after a year and die out slowly, whereas the responses to oil-market specific demand shocks peak after about a quarter year and decline more rapidly.

Figure 6 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 and highly statistically significant increase in the real price of gasoline that remains statistically significant for four months, as shown in the first row. The same shock, however, causes a temporary drop in the real price of imported crude oil that remains statistically significant for three months. 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 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 6 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 six months. The response is statistically significant at horizons 2 and 6. In contrast, the real price of crude oil shows no statistically significant response, although the estimated response function peaks after 6 months. This result is consistent with the view that U.S. gasoline demand shocks are too small in general to have precisely estimated effects on the global demand for crude oil.

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

Figure 7 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 7. Figure 7 highlights that nevertheless there are important differences 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 and is statistically significant. 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 and is highly statistically significant. 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. Both responses are highly statistically significant. Finally, positive gasoline demand shocks cause a persistent and statistically significant increase in gasoline consumption, but much of the impact response is undone in the following months.

In summary, Figures 5-7 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.

An important question is to what extent these estimates would change if the assumption of a flat short-run gasoline supply curve were not literally correct. To address this issue, I experimented with VAR models that impose a weak degree of feedback from demand shifts to the price of gasoline. The degree of feedback can be parameterized as follows. Let θ denote the element in the 4th row and 5th column of A_0 in model (1). θ measures the elasticity of the price of gasoline with respect to contemporaneous shifts in demand. In estimating model (1), we can impose a value for θ that is greater than zero and solve numerically for the remaining unrestricted parameter of A_0 conditional on that identifying assumption (for a similar approach see Abraham and Haltiwanger 1995). The choice of θ has implications for the supply curve. If θ is equal to zero, as assumed in the baseline model, the supply curve is flat. For $\theta > 0$ the supply curve is upward sloping. Consider $\theta \in \{0, 0.1, 0.2, 0.3, 0.4\}$. Table 1 shows that, relative to the benchmark of no feedback, the responses to shocks in the gasoline market shown in Figure 6 are remarkably robust to reasonable departures from the baseline model. Increases in θ

amplify the effect of gasoline demand shocks on the real price of gasoline and lower their effects on the real price of oil. They also amplify the effect of refinery shocks on the real price of oil and lower their effect on the real price of gasoline. In all cases the shape of the response function and the timing of the peak of the response function are unaffected. This robustness check suggests that the assumption of a flat short-run gasoline supply curve (conditional on past information) need not be literally true for the baseline VAR analysis to be informative.

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 forecast error variance decompositions based on the estimated VAR model of section 3. Table 2 reports the average contribution of each shock to the total variation in the real price of gasoline in percentage terms. On impact, 80% of the variation in gasoline prices is accounted for by refining shocks, followed by oil-market specific demand shocks that account for an additional 19% on impact. The remaining shocks play no role. In contrast, in the long run, the importance of refining shocks declines to 3%, whereas that of oil-market specific shocks increases to 50%. Aggregate demand shocks play an increasingly important role with a delay of half a year, reaching 45% in the long run. The explanatory power of oil supply shocks and gasoline demand shocks remains below 2% 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 3 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 91% on impact and 80% in the long run. Refining shocks explain 7% 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 4% and oil-market specific demand shocks for 5%. 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 episodes of 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 evolution of gasoline prices since 2002.

6. What Explains the Fluctuations in U.S. Gasoline Prices since 2002?

Figure 8 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 8 shows that overall crude oil supply shocks have had a negligible effect on gasoline prices. This finding 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 suggested 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.¹³

The bulk of the increase in U.S. gasoline prices between 2002 and mid-2008 was associated with steady pressure from unexpectedly increasing global demand for crude oil, along with other industrial commodities, as shown in the second row. This factor alone accounts for much of the evolution of the real price of gasoline until mid-2008. 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 8. One example is early 2002. There also was a temporary rise in the real price of gasoline 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 gradual 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. Finally, there was a slight increase in early 2008, as oil supply shortfalls seemed increasingly likely. These demand pressures, however, were not as persistent as those from

¹³ 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.

positive aggregate demand shocks, and had little effect on the overall direction of the real price of gasoline over extended periods.

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 8 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.

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 surge in gasoline prices between 2002 and mid-2008 consisted of three main components whose relative contribution to the real price of gas has varied over time: (1) Most of the increase can be explained by strong and persistent demand in global commodity markets (consistent with a strong unexpected economic growth in many advanced economies and with the integration of emerging economies in the global economy); especially in late 2005, when global real activity temporarily slowed, the upward pressure on gasoline prices was aided by (2) precautionary demand shocks specific to the oil market and (3) adverse supply shocks in the U.S. refining industry. Based on Figure 8, there is no evidence that the surge in gasoline prices between 2002 and mid-2008 was 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 discussed earlier.

What then drove gasoline prices down after mid-2008? There is no evidence that oil supply shocks, gasoline demand shocks or refinery shocks contributed to this decline. Instead, the model suggests a combination of reduced global demand and reduced oil-market specific demand. There is an interesting contrast between the increase in the price of gasoline until mid-2008 and its decline since then. Whereas the upswing of this cycle is well explained by global aggregate demand shocks, the downswing is not. Although the daily Baltic Exchange Dry Index peaked in May of 2008 and there has been a dramatic unexpected drop in global real activity in late 2008, as shown in Figures 2 and 4, negative aggregate demand shocks have rather delayed

effects on the real price of gasoline, as illustrated in Figure 5. By construction, therefore, the unexpected global economic slowdown alone cannot explain the rapid drop in gasoline prices in recent months (see Figure 8). One would, however, expect this dramatic slowdown, if it is not reversed, to exert downward pressure on oil and gasoline prices for years to come.

In contrast, negative oil-market specific shocks (such as negative precautionary demand shocks) are capable of inducing quite dramatic and instantaneous drops in gasoline prices, as shown in Figure 5. A similarly sharp, albeit smaller, drop in the real prices of oil and gasoline occurred in 1986 after OPEC's collapse. As expected, the VAR model assigns an important contribution to reduced oil-market specific demand after mid-2008 (see Figures 4 and 8). The currently available data required for the estimation of model (1) end in October of 2008. If the sample period could be extended to December of 2008, one would expect the role of negative oil-market specific demand shock to increase further.

This result makes sense. It seems impossible to rationalize the rapid drop in oil and gasoline prices in recent months if not as a result of expectations shifts. As expected demand for crude oil drops, precautionary motives vanish and the price of oil (and hence of gasoline) enters a free-fall. This pattern is qualitatively similar to earlier episodes, but much more pronounced, since traders price in the risks of financial panic and another Great Depression.

7. Implications for Forecasts 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 are 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. This point is best illustrated by outlining the view an informed forecaster might have taken as of late 2007 on the basis of real-time estimates of the structural VAR model proposed in this paper.

At that point in time, one would have made the case that, abstracting from unpredictable refinery outages, the future evolution of U.S. gasoline prices was likely to depend primarily on developments in the global crude oil market. Although past oil price increases had been followed

by substantial increases in crude oil production with a delay of a few years, there was reason to doubt that substantial increases in oil production would be forthcoming in the foreseeable future. Part of the problem was that oil exploration had been neglected for many years, as the price of oil fell to an all-time low in recent history in the late 1990s. As the price of oil recovered, a more important problem became that the political environment in many oil-producing countries discouraged oil companies from making the much needed large-scale investments. In particular the threat of expropriation of successful investments in many countries prevented investments from taking place at the needed pace. A third problem was that much of the additional crude oil likely to be available in the short run was heavy crude oil that U.S. refineries were ill-equipped to process. Building new refineries in the United States takes many years. Thus, a fair presumption as of late 2007 would have been that the crude oil market would 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 would have been expected to depend first and foremost on the extent to which countries in emerging Asia would continue to grow. Since the economic expansion in Asia was not expected to continue unabated, all the more so as there were signs that the U.S. economy was already slowing and that rising energy prices were about to leave their mark abroad as well, a forecaster would have expected the price of oil to fall more likely than not. Although a decline in demand seemed inevitable as of late 2007, what was not clear ex ante was how soon that decline would occur and by how much global demand for industrial commodities would slow down. Taking past global expansions as a guide and extrapolating from the VAR model estimates in this paper, a reasonable forecast would have been that global demand was expected to recede only gradually. Hence, a forecaster would have expected U.S. gasoline prices to remain high for the foreseeable future. Barring a major economic collapse in emerging Asia, in the short run, gasoline prices would have been expected to 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 would have taken time to take effect.¹⁴

¹⁴ In addition, there was reason to be concerned that oil-market specific developments, which for the most part had played no role since 2002, could become more important in 2008. 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 conditions of late 2007, the world economy was particularly vulnerable to threats of military conflict in the Middle East. A good example was Iran's threat to close the Straits of

Nothing in that forecast would have prepared us for the collapse of gasoline prices in late 2008, so where did the forecast go wrong? It turns out that global aggregate activity indeed slowed down in mid-2008, as expected, but that retreat was quickly turned into a rout by the global financial crisis in late 2008, which most market participants did not anticipate. Global real activity dropped faster than at any time in recorded history. The financial crisis in turn triggered expectations shifts that further reduced demand for oil, as market participants pondered the end of the world as we know it. Within weeks, the market turned from a situation in which everyone wanted to hold oil to one in which no one wanted to be caught holding oil. As the price of crude oil inputs dropped, so did the price of gasoline. This outcome illustrates that even a forecast taking careful account of the factors known at the time, would have turned out to be very wrong. As of today, the oil market is demand constrained rather than supply constrained.

Our inability to predict the determinants of the price of gasoline does not detract from the usefulness of the analytical framework proposed in this paper. In fact, this framework helps in understanding the evolution of gasoline prices in recent months. It illustrates, however, that understanding past price movements need not translate into the ability to forecast gasoline prices with any reasonable degree of accuracy. Clearly, the future evolution of gasoline prices will depend on how quickly the world economy will recover from the financial crisis. Barring a recovery in the United States, it will depend in particular on how self-sustained economic growth in emerging Asia has become. These determinants of the real price of gasoline are as uncertain as ever.

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.

Hormuz if Iran were to be attacked by Israel. Such developments had the potential to cause U.S. gasoline price movements that would have dwarfed the effect of sustained strong global demand for industrial commodities, but were essentially unpredictable and hence would have been ignored by most forecasters.

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, and there is reason to be skeptical of the validity of the estimates of asymmetric response functions in the literature (see Kilian and Vigfusson 2009).¹⁵ Further investigation of the evidence of asymmetries at monthly frequency is an important area of research.

¹⁵ In related work based on monthly data and improved tests of asymmetries, Kilian and Vigfusson (2009) find no evidence of asymmetries in the transmission of gasoline price shocks to the consumption of gasoline. Davis and Kilian (2009), using monthly data, find no evidence of asymmetric responses to changes in gasoline taxes. There is some 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: Peak Responses under Alternative Assumptions about the Slope of the Short-Run Gasoline Supply Curve

θ	Refining Shock		Gas Demand Shock	
	Real Oil Price	Real Gas Price	Real Oil Price	Real Gas Price
0	-3.16	2.31	0.95	0.69
0.1	-3.17	2.30	0.90	0.73
0.2	-3.16	2.29	0.84	0.76
0.3	-3.15	2.26	0.79	0.79
0.4	-3.12	2.23	0.74	0.81

NOTES: θ denote the element in the 4th row and 5th column of A_0 in model (1). In estimating model (1), we impose a value for θ and solve numerically for the remaining unrestricted parameter of A_0 conditional on that identifying assumption. If θ is equal to zero, as assumed in the baseline model, the short-run supply curve of gasoline is flat. For $\theta > 0$ the supply curve is upward sloping. The location of the peaks is unchanged across all specifications, as is the shape of the response functions.

Table 2: 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	0.00	0.80	18.82	80.38	0
2	0.65	2.15	45.60	51.54	0.06
3	0.71	4.84	60.22	33.63	0.60
6	0.76	13.56	69.67	15.46	0.54
12	0.55	28.48	61.05	8.58	1.34
∞	1.22	45.23	50.14	2.90	0.50

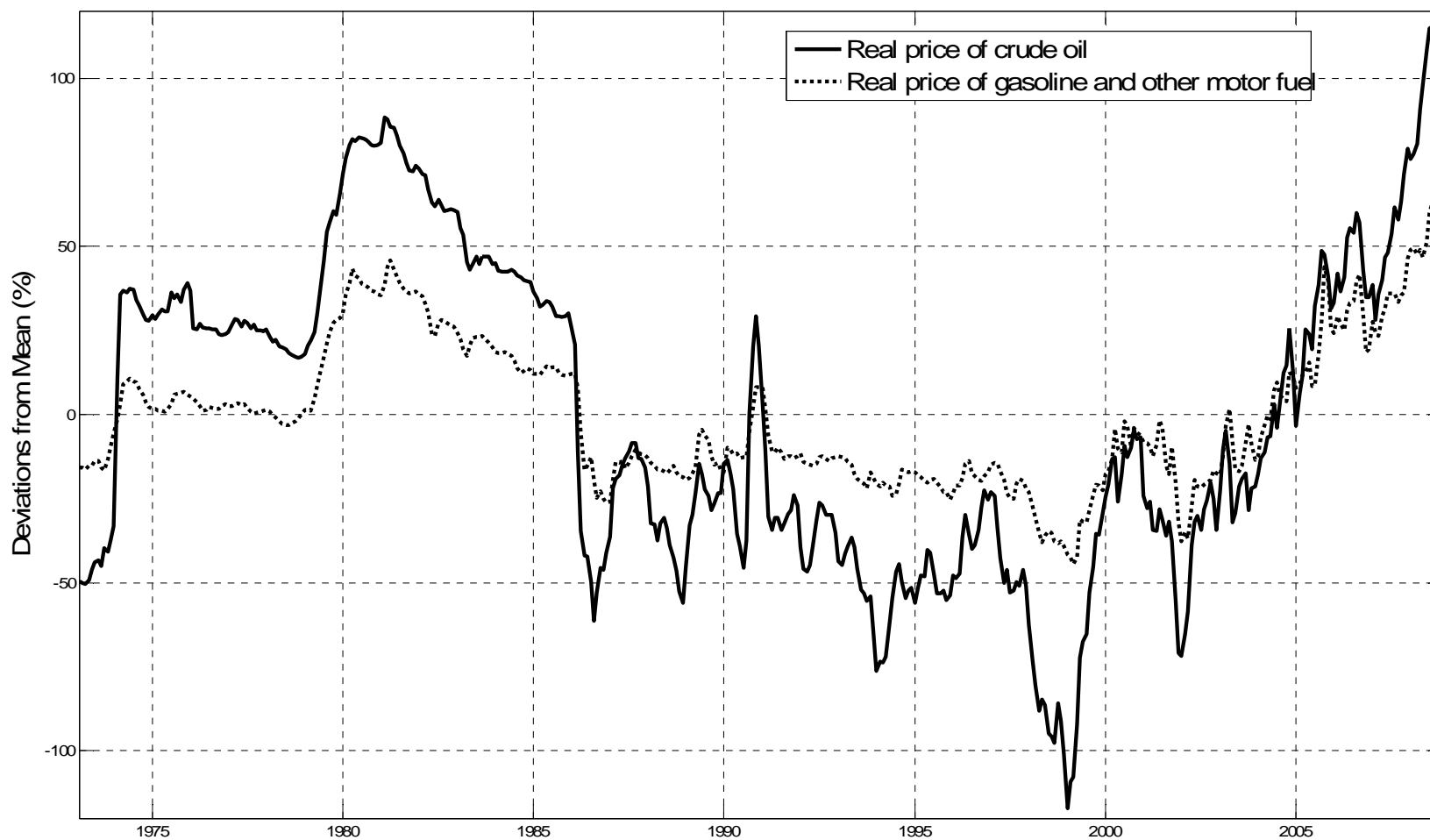
NOTES: Based on a forecast error variance decomposition of the structural VAR model (1).

Table 3: 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	0.00	0.00	2.03	7.03	90.94
2	0.01	0.77	1.88	4.95	92.39
3	0.01	0.89	1.94	5.80	91.36
6	0.79	1.89	3.15	5.91	88.26
12	1.56	3.35	4.16	7.84	83.09
∞	2.03	3.55	5.27	9.52	79.62

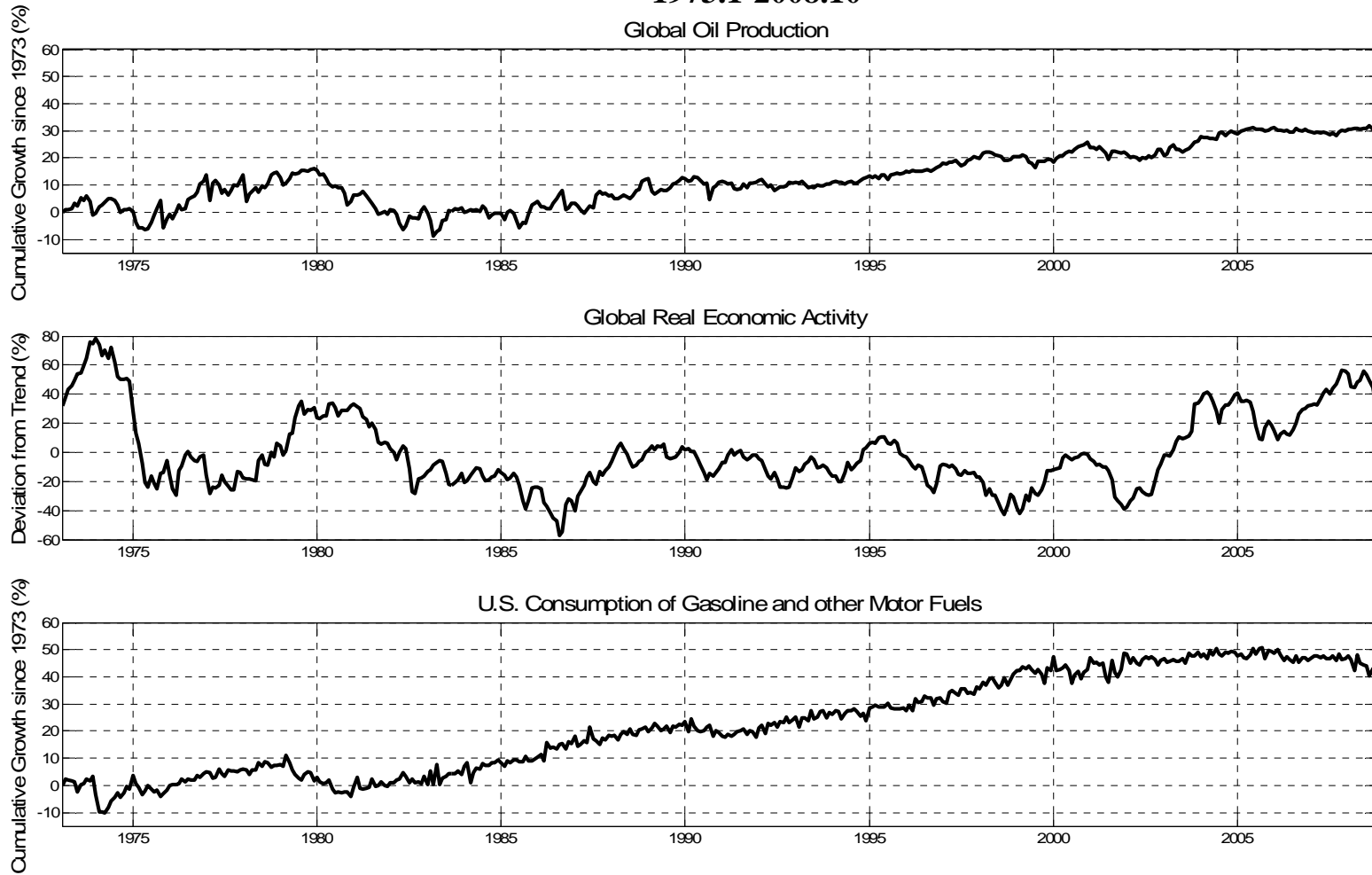
NOTES: See Table 2.

**Figure 1: Real Price of Imported Crude Oil and Real U.S. Retail Price of Gasoline
1973.1-2008.10**



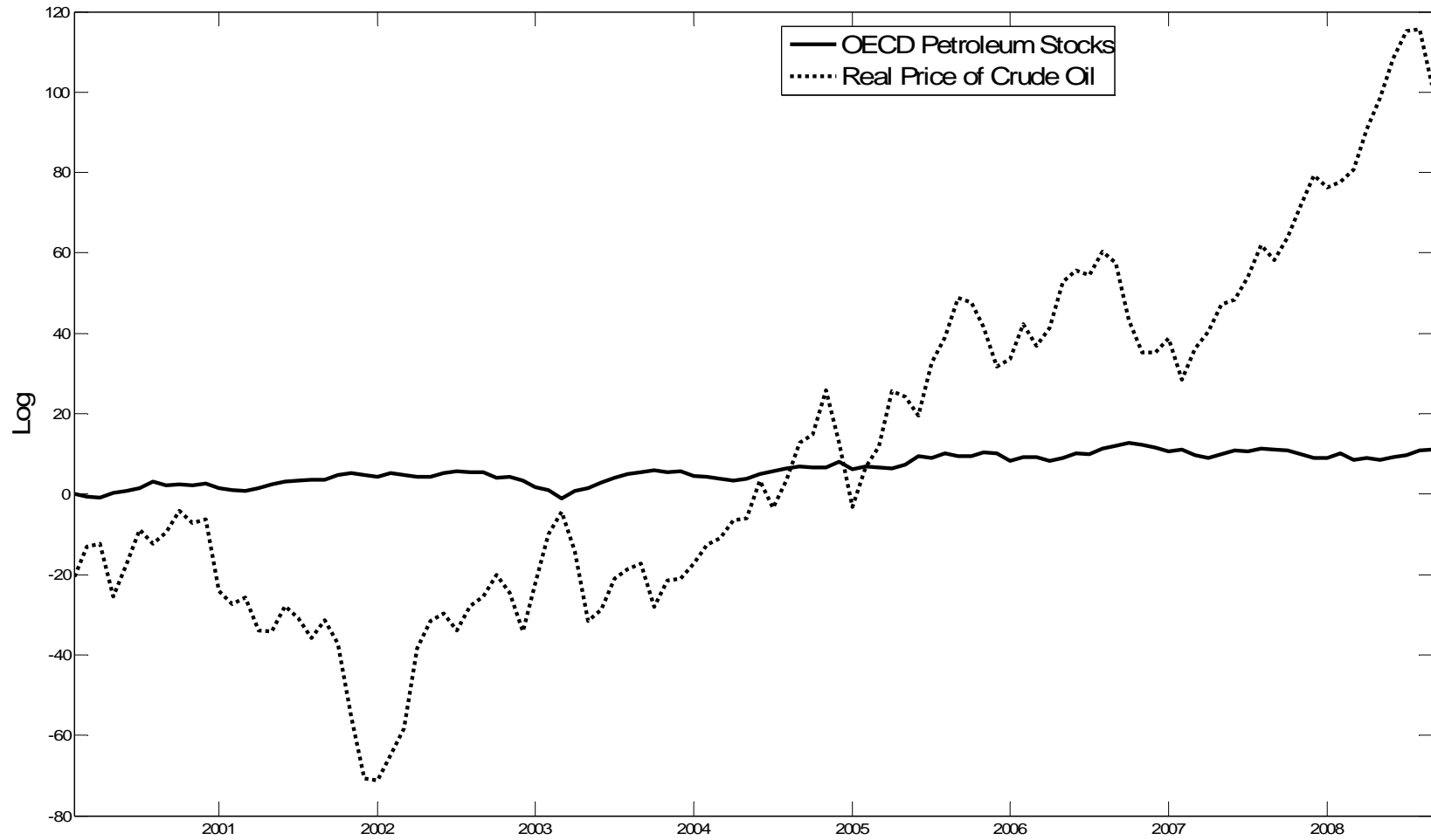
NOTES: The oil price series is based on an index of the U.S. refiners' acquisition cost of imported crude oil. The price of gasoline and other motor fuel is an index computed by the Bureau of Economic Analysis. Both series have been adjusted for U.S. CPI inflation and demeaned. The correlation of the two series is 0.95.

**Figure 2: Key Determinants of the Real U.S. Price of Gasoline
1973.1-2008.10**



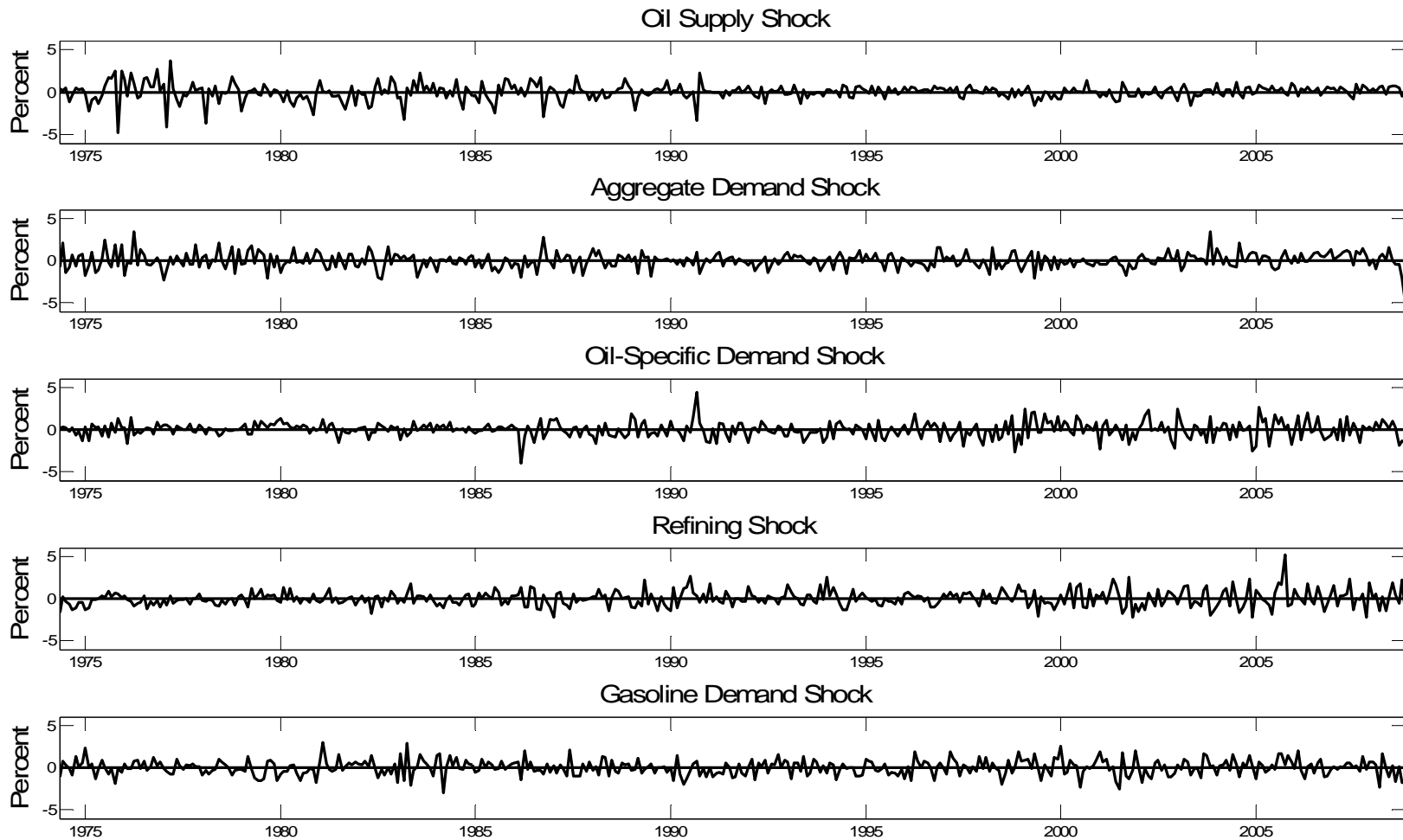
NOTES: For a description of these variables see section 2.

**Figure 3: OECD Petroleum Inventories and the Real Price of Oil
2000.1-2008.8**



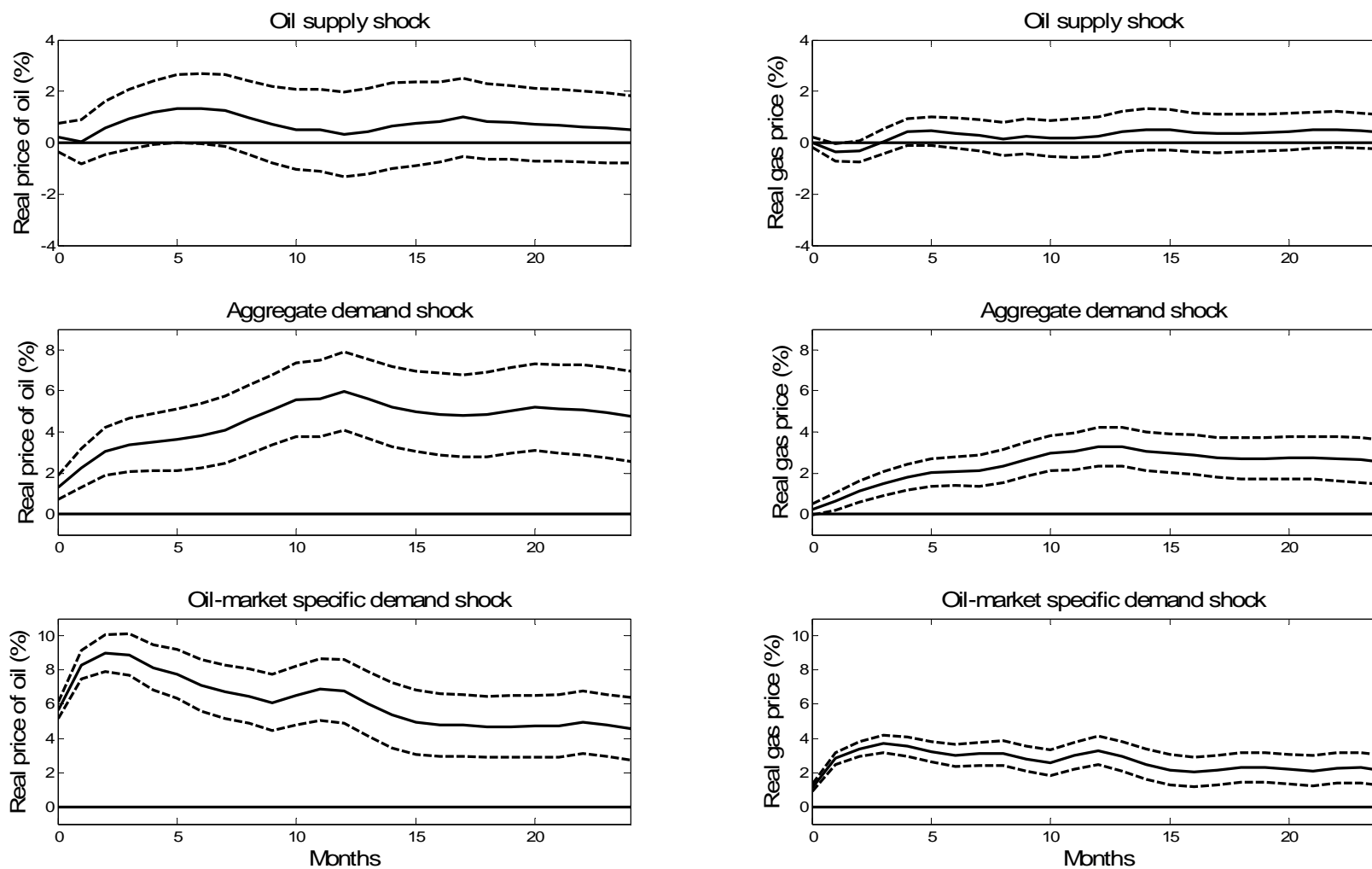
NOTES: The OECD inventory data have been normalized such that the inventory value in logs is zero in 2000.1.

**Figure 4: History of Demand and Supply Shocks in Structural VAR Model
1974.4-2008.10**



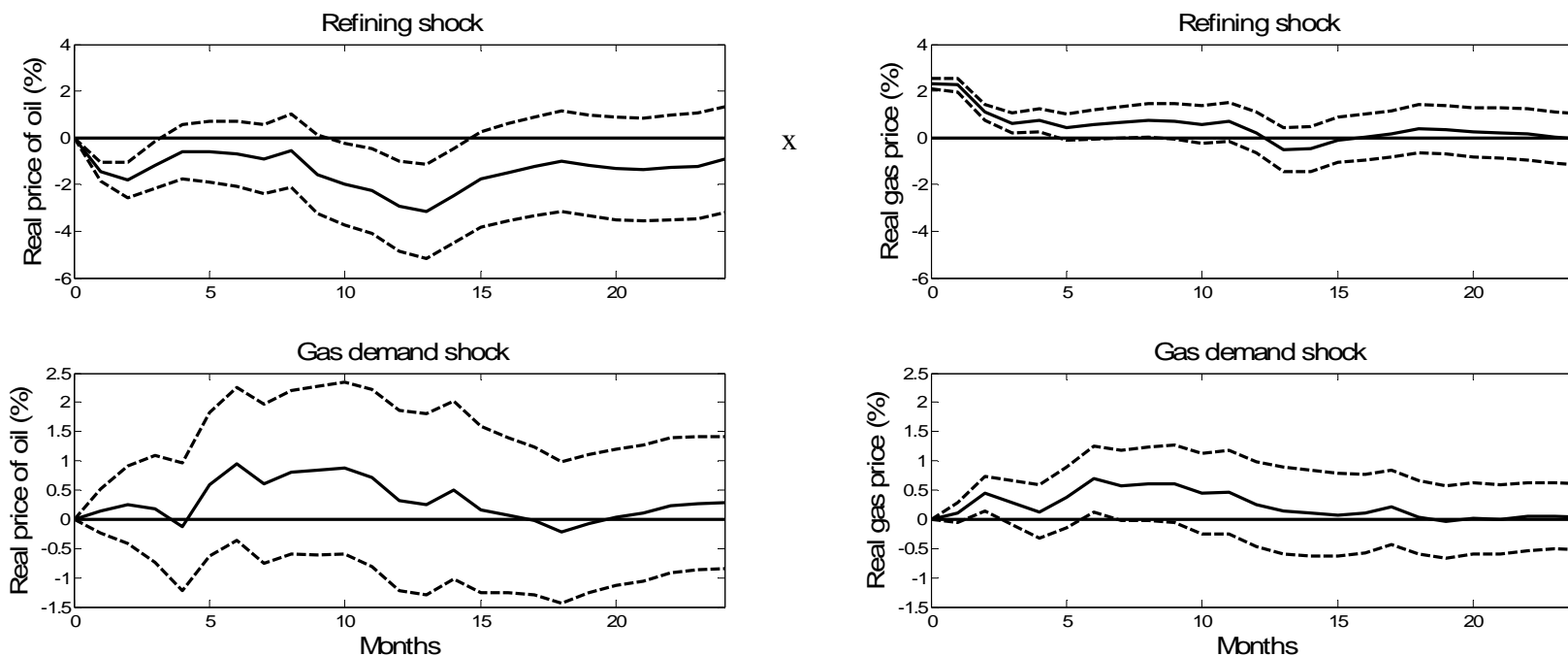
NOTES: Estimates based on model (1). All structural shocks are constructed to have the same variance.

Figure 5: Price Responses to One-Standard Deviation Structural Shocks in Crude Oil Market with 80% Confidence Bands



NOTES: Estimates based on model (1). The confidence intervals were constructed using a recursive-design wild bootstrap. All shocks have been normalized such that they imply an increase in the real price of crude oil.

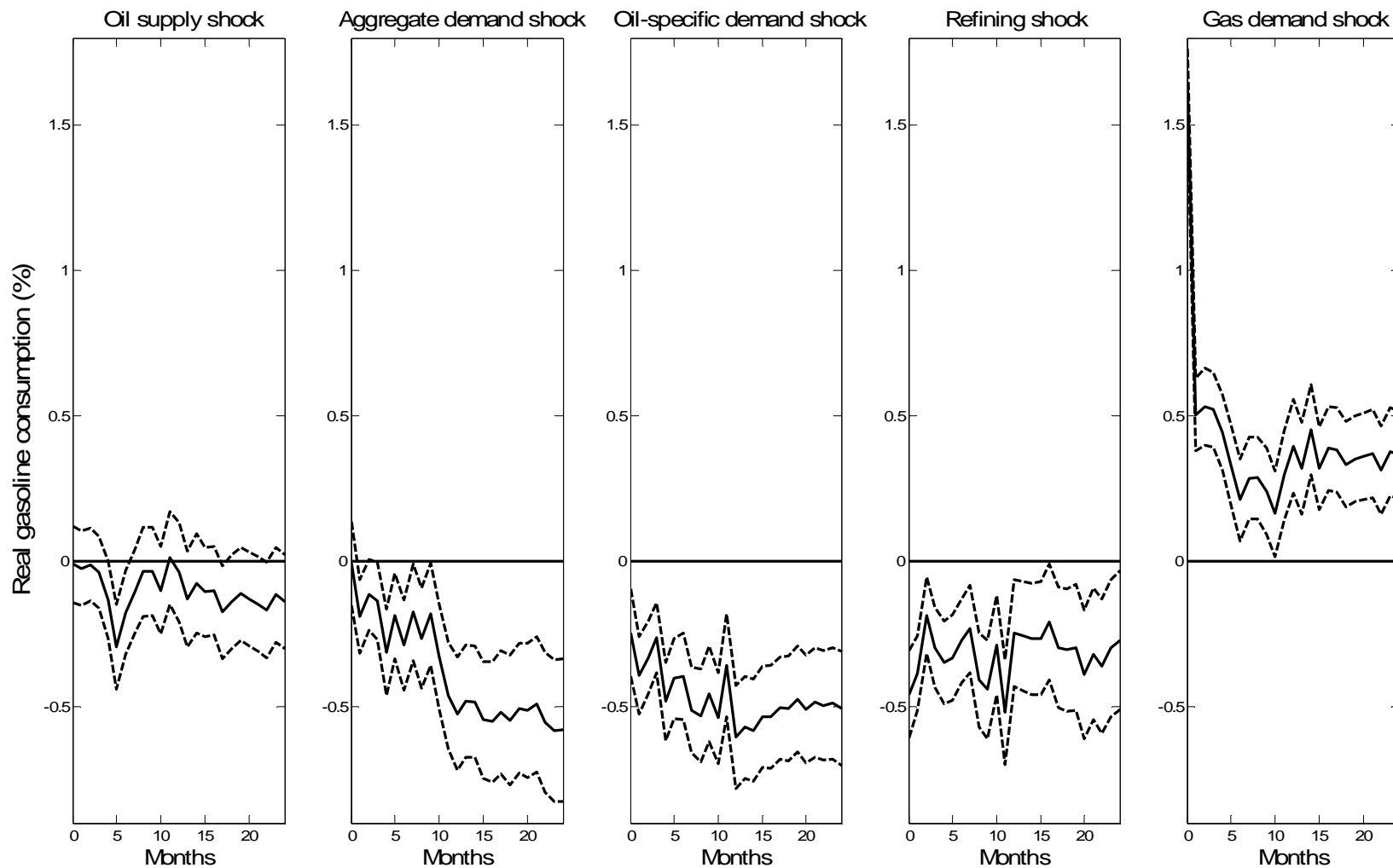
Figure 6: Price Responses to One-Standard Deviation Structural Shocks in Gasoline Market with 80% Confidence Bands



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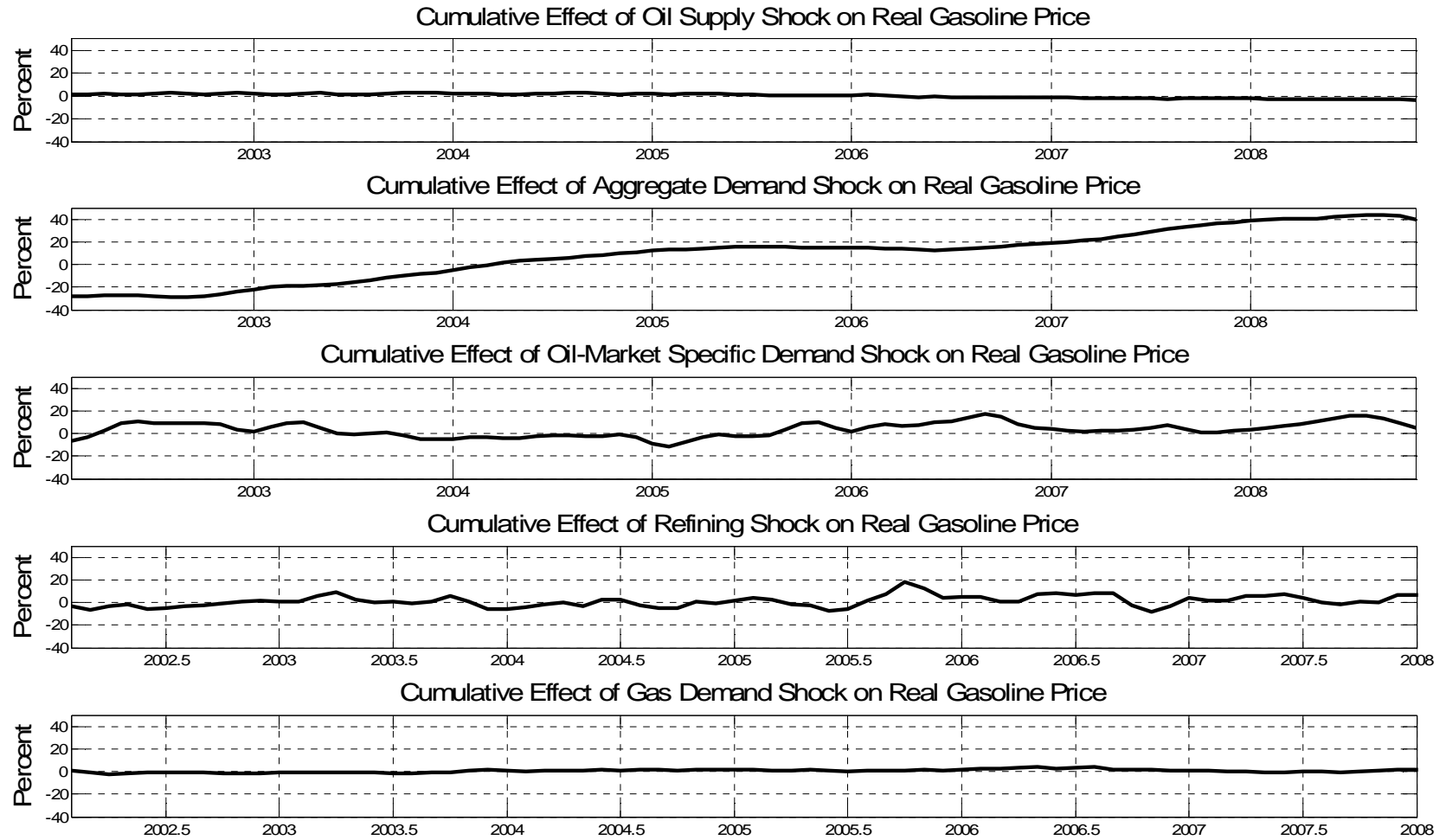
NOTES: Estimates based on model (1). The confidence intervals were constructed using a recursive-design wild bootstrap. All shocks have been normalized such that they imply an increase in the real price of gasoline.

Figure 7: Responses of U.S. Gasoline Consumption to Demand and Supply Shocks with 80% Confidence 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 8: Historical Decomposition of the Real Price of Gasoline
2002.1-2008.10**



NOTES: Fitted values derived from model (1).