MACRO-LINKAGES, OIL PRICES AND DEFLATION WORKSHOP
JANUARY 6–9, 2009

The Economic Effects of Energy Price Shocks

Lutz Kilian
University of Michigan and CEPR

The Economic Effects of Energy Price Shocks*

Lutz Kilian†

University of Michigan and CEPR

July 12, 2008

Abstract

Large fluctuations in energy prices have been a distinguishing characteristic of the U.S. economy since the 1970s. Turmoil in the Middle East, rising energy prices in the U.S. and evidence of global warming recently have reignited interest in the link between energy prices and economic performance. This paper addresses a number of the key issues in this debate: What are energy price shocks and where do they come from? How responsive is energy demand to changes in energy prices? How do consumers' expenditure patterns evolve in response to energy price shocks? How do energy price shocks affect U.S. real output, inflation and stock prices? Why do energy price increases seem to cause recessions, but energy price decreases do not seem to cause expansions? Why has there been a surge in the price of oil in recent years? Why has this new energy price shock not caused a recession so far? Have the effects of energy price shocks waned since the 1980s and, if so, why? As the paper demonstrates, it is critical to account for the endogeneity of energy prices and to differentiate between the effects of demand and supply shocks in energy markets, when answering these questions.

KEYWORDS: Crude Oil; Gasoline; Price Shocks; Propagation; Channels of Transmission; Asymmetry; Elasticity.

JEL: E21, Q43.

---

*I thank Paul Edelstein for excellent research assistance. Lucas Davis and Ana-María Herrera provided helpful comments on an earlier draft of the paper, as did three anonymous referees and the editor.

†Department of Economics, University of Michigan, 611 Tappan Street, Ann Arbor, MI 48109-1220. E-mail: lkilian@umich.edu.

1 Introduction

The price of energy is only one of many prices faced by households and firms, yet it attracts a disproportionate amount of attention in the media and from policymakers and economists. A common perception is that energy price increases are fundamentally different from increases in the prices of other goods. One reason is that energy prices at times experience sharp and sustained increases not typical of other goods and services. A second reason is that these price increases matter more than in the case of other goods because the demand for energy is comparatively inelastic. For example, most workers have to drive to work every day and thus have little choice but to acquiesce to higher gasoline prices. Similarly, households have little choice but to endure higher natural gas prices, as they cannot afford to leave their homes unheated. A third reason that energy prices are perceived to be different is that energy price fluctuations seem to be determined by forces that are exogenous to the U.S. economy such as political strife in the Middle East. A fourth reason is that major energy price increases in the past have often been followed by severe economic dislocations, suggesting a causal link from higher energy prices to recessions, higher unemployment and possibly inflation.

In this paper, I selectively review the recent literature on the effect of energy price shocks on the U.S. economy. For a complementary survey of the relationship between oil prices and the macroeconomy the reader is referred to Hamilton (2008). My objective is not to provide a comprehensive survey of the literature. Rather I wish to highlight some recent methodological developments and to outline how these developments have altered our perceptions of where energy price shocks originate, how they are transmitted, and how much they affect the economy. The paper addresses a number of the key questions in the ongoing debate about the economic effects of energy price shocks: Where do energy price shocks originate? How responsive is energy demand to changes in energy prices? How do consumers' expenditure patterns evolve in response to energy price shocks? How do energy price shocks affect U.S. real output and inflation and the U.S. stock market? Why do energy price increases seem to cause recessions, but energy price decreases do not seem to cause economic expansions? Why has there been a surge in the price of crude oil in recent years? Why has this new energy price shock not caused a recession so far? Have the effects of energy price shocks waned since the 1980s and, if so, why?

The remainder of the paper is organized as follows. In section 2, I discuss the identification of exogenous shifts in energy prices with special emphasis on alternative specifications of energy price shocks and alternative frameworks for estimating the effects of energy price shocks. Section 3 provides an overview of the effects of unanticipated changes in energy prices on U.S. consumer expenditures and firms' investment expenditures. I discuss the most prominent channels of transmission and the empirical evidence in their support. I also address the question of whether there is an asymmetry in the responses to energy price increases and energy price decreases. Section 3 also contains detailed estimates of the responsiveness of energy consumption to higher energy prices and, more generally, assesses how consumers' expenditure patterns evolve in response to energy price shocks. The section concludes with a discussion of the link between crude oil prices and monetary policy. In section 4, I address the question of why the effects of energy price shocks have weakened since the second half of the 1980s. Section 5 illustrates how disentangling demand and supply shocks in oil markets can help us understand the evolution of energy prices. This section also demonstrates the differential impact of demand and supply shocks in the global oil market on U.S. real GDP, consumer prices, and stock prices. The concluding remarks are in section 6.

2 Methodological Issues Raised by the Endogeneity of Energy Prices

It is widely accepted that energy prices in general and crude oil prices in particular have been endogenous with respect to U.S. macroeconomic conditions dating back to the early 1970s. Endogeneity here refers to the fact that not only do energy prices affect the U.S. economy, but that there is reverse causality from U.S. and more generally global macroeconomic aggregates to the price of energy. Clearly, both the supply of energy and the demand for energy depend on global macroeconomic aggregates such as global real economic activity and interest rates (see Barsky and Kilian 2002, 2004). Thus, a correlation between energy prices and macroeconomic outcomes does not necessarily imply causation. One response to this problem has been to apply statistical transformations to the price of energy to extract the exogenous component of oil prices. The leading example of this approach is the net oil price increase measure proposed by Hamilton (1996, 2003).[1]

2.1 Measures of Net Oil Price Increases

Building on work by Mork (1989), Lee, Ni and Ratti (1995) and Hamilton (1996), Hamilton (2003) suggested that, although the price of crude oil itself is not exogenous with respect to U.S. macroeconomic aggregates, a suitable nonlinear transformation of the price of oil (based on the amount by which nominal oil prices exceed their maximum value over the previous three years) is. Such

[1] The net oil price increase is defined as the difference between the current price of oil and the maximum price over the previous year (or alternatively the previous three years) if the current price exceeds the previous maximum, and zero otherwise. A number of alternative oil price transformations have been suggested by, among others, Lee, Ni and Ratti (1995). Hamilton (2003) shows that these alternative measures tend to produce results similar to the net increase measure.

transformed regressors have been used widely in studying the impulse responses of U.S. sectoral and macroeconomic aggregates to oil price shocks. The purpose of the statistical transformation of oil prices is to isolate the component of the price of crude oil that can be attributed to political events in the Middle East, which in turn are exogenous to global macroeconomic conditions. In support of exogeneity of the net oil price measure, Hamilton showed that using the oil price changes predicted by exogenous oil supply variations as instruments in a regression of real GDP growth on lagged percentage changes in nominal oil prices results in estimates of the structural regression coefficients that look remarkably similar to the reduced-form estimates obtained from regressing GDP growth on net oil price increases instead. Hamilton concluded that the latter reduced-form relationship effectively represents a causal relationship, lending credence to the practice of treating net oil price increases as exogenous.[2]

Although Hamilton's analysis represents an important step forward in this literature, there is reason to be skeptical of the exogeneity of the net oil price increase measure because of the nature of the instruments used by Hamilton. As is well known, weak instruments produce biased instrumental variable (IV) regression estimators and hypothesis tests with large size distortions (see Stock, Wright and Yogo (2002) for a review). In the presence of many variables to be instrumented, as in the IV regressions presented in Hamilton (2003), weak instrument problems may be detected based on the $g_{\min}$ statistic of Cragg and Donald (1993). Critical values for a formal test of the null hypothesis of weak instruments have been compiled by Stock and Yogo (2005). Table 1 presents IV regression estimates of the type presented in Hamilton (2003) in support of the exogeneity of the net increase measure of the price of crude oil. In addition to the specification favored by Hamilton (2003), which is shown in column (1), I include a number of alternative specifications involving different measures of exogenous crude oil supply shocks developed in Kilian (2008a,b), different sample periods, and different measures of nominal and real oil prices. Table 1 shows that in *all* cases the estimated $g_{\min}$-statistics are far below the least conservative critical value of about 4, suggesting that a weak-instrument problem cannot be ruled out. The presence of weak instruments would render the IV estimates inconsistent and standard inference on the dynamic effects of exogenous variations in the price of oil invalid, invalidating any comparison with the reduced-form evidence. Consequently, we have no credible evidence that the responses to net oil price increases correspond to those of truly causal models.

This evidence of weak instruments is not surprising, as it has been shown that measures of exogenous oil supply shocks driven by political events in the Middle East fail to explain much of

[2] For example, Hamilton (2003, p. 395) writes that nonlinear transformations "... filter out many of the endogenous factors that have historically contributed to changes in oil prices" and "seem in practice to be doing something rather similar to isolating the exogenous component of oil price changes" (p. 391).

the observed fluctuations in crude oil prices. This result is robust across alternative specifications of exogenous political oil supply shocks. For example, at most one fourth of the observed increase in the price of oil in 1973/74 can be explained based on such shocks (see Kilian 2008a). In fact, recent evidence in Kilian (2008c) suggests that crude oil supply shocks, narrowly defined as unanticipated changes in world crude oil production, are far less important for understanding crude oil prices than are shocks to the demand for crude oil. This point will be discussed in more detail in section 5.

The fact that net oil price increases are not measures of exogenous oil price shocks can also be seen more directly. For example, Kilian (2008a) shows that oil price shocks detected by the nonlinear transformation proposed by Hamilton (2003) occur at times when exogenous oil supply shocks in the Middle East were conspicuously absent, and that there are major exogenous events that are not followed by oil price shocks. Kilian also shows that the same procedure applied to other industrial commodity prices generates spurious evidence of exogenous price shocks. Hence, oil price series must be treated as endogenous whether they have been transformed to net oil price increases or not.

The lack of exogeneity of the price of oil is not as much of a problem as it may seem, because exogeneity is not required for estimating the economic effects of changes in oil prices. A much weaker and more defensible assumption than strict exogeneity of the price of oil is that innovations to the oil price series (whether transformed or not) are predetermined with respect to U.S. macroeconomic aggregates. In other words, the price of oil responds to changes in macroeconomic conditions only with a delay. Under this assumption, recursively identified vector autoregressions with energy prices ordered first may be used to estimate the dynamic effect of a change in energy prices. Indeed, this assumption forms the basis of a number of influential papers in the literature including Davis and Haltiwanger (2001) and Lee and Ni (2002) that focus on the linearly unpredictable component of the net increase in oil prices. The assumption of predeterminedness typically is inappropriate when working with annual data, but may provide a good approximation when working with quarterly and in particular with monthly data. Thus, there are clear advantages to studying the effects of energy price shocks in a high-frequency time series context compared to panel studies using data at lower frequencies.[3] The implementation of this VAR approach is discussed in more detail in section 2.5. Although the exactly identifying assumption that energy prices are predetermined with respect to domestic macroeconomic aggregates is not testable within the VAR framework, the working hypothesis that the feedback from shocks to domestic macroeconomic aggregates to the global price of oil is negligible within the same month has been regarded as plausible by many researchers. Ongoing work by Kilian and Vega (2008) tests this hypothesis formally using regressions of daily

[3] In the latter case, it becomes necessary to find suitable instruments for energy price changes. For example, Cullen, Friedberg and Wolfram (2004) use weather data as exogenous instruments for home energy costs.

changes in oil prices on U.S. macroeconomic news.

2.2 The Effect of Changes in the Energy Share

It is sometimes argued that regressions of macroeconomic aggregates on unanticipated energy price changes are potentially misleading in that they fail to account for the declining share of energy in value added since the 1970s. Indeed this share has been falling from a maximum of 5% in 1981 to a low of 1% in 1998, but by 2005 the share had recovered to its original level of 3.3% in 1977.[4] Interestingly, the pattern of these fluctuations seems to reflect primarily changes in the price of crude oil rather than shifts in energy use. While not trivial, the observed fluctuations in the energy share in value added are largely immaterial for estimates of energy price shocks because the share does not fluctuate enough on a quarter-to-quarter basis. Weighted and unweighted quarterly energy price changes have a correlation of 99%. Thus, little is lost by studying the effect of unweighted energy price shocks, as has been demonstrated in Edelstein and Kilian (2008b). Weighting can be important, however, in constructing measures of the retail energy price shocks faced by households and firms, as the next subsection illustrates.

2.3 On the Choice of the Energy Price Series

Much of the work on energy price shocks has focused on the price of crude oil. This approach reflects the perception that the bulk of the fluctuations in energy prices since the 1970s has been driven by disturbances in global crude oil markets that are reflected in the price of imported crude oil and are transmitted from the crude oil market to retail energy prices. While it is true that disturbances in global crude oil markets are typically reflected in gasoline prices, this is not the only major source of shocks to gasoline prices. A good example is provided by the effects of Hurricanes Rita and Katrina in late 2005. Whereas the reduction of U.S. crude oil supply associated with these exogenous events was negligible on a global scale, the reduction in refining capacity was not. It constituted both a decline in the demand for crude oil (associated with a fall of crude oil prices) and a decline in the supply of gasoline and other refined products, reflected in a sharp increase in gasoline prices. This example illustrates that from a consumer's point of view a direct measure of retail gasoline prices may be more relevant than a measure of crude oil prices.

As of 2002, according to the BEA, gasoline accounts for 48.7% of all energy used by consumers, compared with 12.3% for natural gas and 33.8% for electricity. Since gasoline is by far the most im-

[4] See Edelstein and Kilian (2007b). Following Rotemberg and Woodford (1996), the energy share in value added is approximated by the sum of nominal value added in oil and gas extraction and imports of petroleum and petroleum products, divided by nominal GDP. No disaggregate value added data are available prior to 1977.

portant form of energy consumed in the United States and the one with the most volatile price, little would be lost by focusing on gasoline prices alone in studying the response of consumer expenditures. In contrast, in studying firm behavior neither gasoline nor crude oil prices will be representative of energy prices. For producers, based on 2002 BLS data, electricity makes up 40.3% of energy use, natural gas 14.5%, and unleaded gasoline only 14%, followed by diesel fuel (11.4%) and jet fuel (9.7%). The difference in weights has important implications for the magnitude of energy price shocks. For example, during the Persian Gulf War in 1990, crude oil prices rose by 83%, whereas the intermediate energy prices faced by firms only rose by 12%. This example illustrates that the choice of energy price series may matter a great deal. Different questions may require a different measure of energy price shocks.

2.4 Alternative Specifications of Energy Price Shocks

In studying the effects of energy price shocks, a natural baseline is the hypothesis that firms and consumers respond proportionately to a percent change in energy prices, regardless of the magnitude of the change. We will refer to this model as the percent change or C specification. There are other behavioral models, however, that involve nonlinear transformations of the price of energy. One alternative is the possibility that consumers and firms only respond to large shocks. For example, the presence of costs to monitoring energy expenditures and of costs of adjusting consumption patterns might make households reluctant to respond to small energy price changes (see Goldberg 1998). One may allow for that possibility by defining energy price shocks as increases or decreases that exceed, say, one standard deviation of the percent change in energy prices. We will refer to this model as the large percent change or LC specification. A third possibility is that consumers and firms respond only to changes in energy prices that are unprecedented in recent history. This view calls for a measure of the net energy price increase of the type proposed by Hamilton (1996, 2003). While Hamilton focuses on net energy price increases, Edelstein and Kilian (2007a,b) extend this measure to include net energy price declines that are constructed in a similar fashion. They document statistically significant responses of U.S. macroeconomic aggregates to both net increases and net decreases. The resulting model will be referred to as the net percent change or NC specification. Figure 1 illustrates the differences between these three specifications for U.S. retail energy prices. The example in Figure 1 (as well as all subsequent empirical analysis in this paper) is based on the real price of energy, which is the price relevant for resource allocation.[5]

An important question is how to choose between these alternative behavioral models. Edelstein

[5] For further discussion of the distinction between nominal and real energy prices see, e.g., Hamilton (2005) and Kilian (2008a).

and Kilian (2007a,b) show that the C specification cannot be rejected in favor of the LC specification in general. Whether the C or NC specification is more appropriate remains an active area of research. Since the NC specification is not nested in the C specification, it is not straightforward to test these specifications, or even to compare the magnitudes of the responses implied by the two specifications. In this paper, I will focus on the C specification, but note that the qualitative results would be similar under the NC specification, and indeed in most cases for all three specifications.

2.5 Alternative VAR Frameworks for Modeling Energy Price Shocks

Models that treat innovations to energy prices as predetermined with respect to macroeconomic aggregates at high frequency have been used in the literature for many years (see, e.g., Rotemberg and Woodford 1996; Davis and Haltiwanger 2001; Lee and Ni 2002; Leduc and Sill 2004; Blanchard and Galí 2007). The assumption of predetermined energy prices rules out instantaneous feedback from U.S. macroeconomic aggregates to energy prices, but allows energy prices to respond to all past information. This assumption permits the consistent estimation of the expected response of real U.S. macroeconomic aggregates to an innovation in energy prices. In conjunction with the assumption that there are no other exogenous events that are correlated with the exogenous energy price innovation, these impulse responses can be interpreted as the causal effect of the energy price innovation (see Cooley and LeRoy 1985).

VAR models based on the assumption of predetermined energy prices are not without limitations, however, even if the feedback from domestic macroeconomic shocks to energy prices is negligible in the short run. Notably, these models do not distinguish between energy price innovations driven by supply shocks and demand shocks in energy markets. The latter distinction can be crucial because different demand or supply shocks in energy markets tend to elicit different responses of macroeconomic aggregates. In section 5, I will discuss an alternative VAR approach that makes this distinction apparent. Impulse response estimates derived under the assumption of predetermined energy prices can still be interpreted as an estimate of the economic effects of an average energy price shock during the sample period in question. While these response estimates are asymptotically valid, in small samples they may be sensitive to changes in the composition of the underlying demand and supply shocks. Moreover, they are potentially misleading when it comes to the interpretation of specific energy price shock episodes. Finally, such responses also obscure the fact that energy price shocks driven by demand shocks may proxy for a number of other changes in the economy associated with the underlying demand shocks. This point will be discussed in more detail in section 5. Nevertheless, estimates of average responses to energy price shocks provide a useful benchmark and allow us to test the implications of various economic models of the transmission of energy price shocks.

A convenient vehicle for assessing the average economic effects of energy price shocks on a given macroeconomic aggregate is a recursively identified bivariate vector autoregression (VAR), in which the percent change in real energy prices is ordered first and the macroeconomic aggregate of interest is ordered second. For example, we may assess the response of real consumption to a real energy price innovation by specifying a model in the percent change of the real price of energy and the percent growth in real consumption. Generalizations to other specifications of energy price shocks are straightforward. In section 3.1 and 3.2, I use this bivariate workhorse model to quantify in detail the responses of consumption and investment expenditures to real energy price shocks. These results will be used in assessing the empirical support for the main channels of transmission discussed in the literature.

There is no loss of generality from restricting ourselves to a bivariate model under the maintained assumption of predetermined energy price innovations, if we are only interested in consistently estimating the effects of energy price innovations on macroeconomic aggregates. If, in addition, we want to assess the precise nature of the transmission, a bivariate model will not suffice. For example, it is common in the literature to estimate larger-dimensional VAR models of the effects of unanticipated oil price shocks that include a monetary policy-reaction function (see, e.g., Bernanke, Gertler and Watson 1997, 2004; Balke, Brown and Yücel 2002; Lee and Ni 2002; Hamilton and Herrera 2004; Herrera and Pesavento 2007). Such VAR models can be useful in assessing the extent to which the overall response of macroeconomic aggregates to unanticipated energy price changes is driven by the response of the central bank to the change in energy prices. Since these larger-dimensional structural VAR models require additional identifying assumptions and since they are typically less precisely estimated, there is no reason to depart from the baseline bivariate VAR model for the purpose of the analysis in sections 3.1 and 3.2. Models of the reaction of monetary policy to oil price shocks will be discussed in section 3.4.

3 The Effect of Energy Price Shocks on the Economy

The standard approach to modeling energy price shocks has been to focus on the effects of an exogenous increase in the price of imported crude oil. Such terms-of-trade shocks traditionally have been thought to matter for the domestic economy through their effects on production decisions (see, e.g., Kim and Loungani 1992; Backus and Crucini 2000). In this view, oil is treated as an intermediate input in domestic production. How imported oil enters the production function for domestic value added is one of the most studied and least resolved issues in empirical macroeconomics (Backus and Crucini 2000).

There are well-known problems in explaining a decline in real GDP based on this intermediate input cost or supply channel. The first problem is that the interpretation of crude oil as an intermediate input in the value added production function is questionable if we think of oil as an imported commodity. Under standard assumptions, imported oil enters the production function of domestic gross output, but it does not enter the production function of domestic value added (see, e.g., Rotemberg and Woodford 1996). Since gross output is separable in value added and imported energy, holding capital and labor fixed, oil price shocks do not move value added. Hence, oil price shocks by definition cannot be interpreted as productivity shocks for real GDP (see Barsky and Kilian 2004). The second problem is that, to the extent that oil prices affect domestic output, under standard assumptions their impact should be bounded by the cost share of oil in gross domestic production, which is known to be very small. Indeed standard production-based models of the transmission of energy price shocks are not capable of explaining large fluctuations in real output.

There are three proposals in the literature for dealing with this problem. All three involve modifications of the baseline supply-shock model to generate quantitatively important effects of oil price shocks on real GDP. The first proposal is Rotemberg and Woodford's (1996) model which relies on large and time-varying markups to generate large effects of oil price shocks on real GDP. The second proposal is Atkeson and Kehoe's (1999) putty-clay model which appeals to capital-energy complementarities in production. The third proposal is due to Finn (2000). Finn establishes that in a perfectly competitive model, in which energy is essential to obtaining a service flow from capital, there may be a large effect of oil price shocks on real GDP. In all three models, the supply channel of the transmission of energy price shocks may be quantitatively important, yet there is no consensus which, if any, of these models has empirical support. For example, it remains to be shown that mark-ups in the U.S. economy are as large and as time-varying as required for the Rotemberg and Woodford model to generate large effects on value added. Likewise, it remains to be shown that changes in capacity utilization in response to oil price shocks are indeed as important and pervasive in the real world as they are in Finn's model. Similarly, the microeconomic evidence on the existence and quantitative importance of capital-energy complementarities is mixed at best. A second unresolved issue is whether these models can account for a large share of business cycle fluctuations in real GDP. A third issue is that all three models postulate that oil prices follow an exogenous stochastic process, an assumption that is at odds with both the data and standard economic models of the oil market, as discussed in section 2.

These caveats are important because in the absence of an empirically supported model of the supply channel, there is no reason to expect global oil price shocks to exert major effects on the domestic economy. In part in response to these challenges, another branch of the literature has developed that focuses on the reduction in the demand for goods and services triggered by energy price shocks rather than treating energy price shocks as aggregate supply shocks for the U.S. economy (or as productivity shocks for U.S. domestic production). In this alternative view, the primary channel of transmission is on the demand side of the economy. For example, in a recent survey on the effects of energy price shocks, Hamilton (2008) stresses that a key mechanism whereby energy price shocks affect the economy is through a disruption in consumers' and firms' spending on goods and services other than energy. This view is consistent with anecdotal evidence of how oil price shocks affect U.S. industries. Most U.S. firms perceive energy price shocks as shocks to the demand for their products rather than shocks to the cost of producing these products (see Lee and Ni 2002). This view is also shared by many policymakers. There is a widespread perception that an increase in energy prices slows economic growth primarily through its effects on consumer spending (see, e.g., Bernanke 2006a). In the remainder of section 3, I outline the economic rationale for the demand channel of transmission and assess its empirical support. I focus on the response of real consumption first, before considering real investment expenditures in section 3.2.

3.1 How Do Consumer Expenditures Respond to Higher Energy Prices?

3.1.1 The Channels of Transmission

The literature has focused on four complementary mechanisms by which consumption expenditures may be directly affected by energy price changes. First, higher energy prices are expected to reduce discretionary income, as consumers have less money to spend after paying their energy bills.[6] All else equal, this *discretionary income effect* will be the larger, the less elastic the demand for energy, but even with perfectly inelastic energy demand the magnitude of the effect of a unit change in energy prices is bounded by the energy share in consumption. Second, changing energy prices may create uncertainty about the future path of the price of energy, causing consumers to postpone irreversible purchases of consumer durables (see Bernanke 1983, Pindyck 1991). Unlike the first effect, this *uncertainty effect* is limited to consumer durables.[7] Third, even when purchase decisions

[6] Implicit in this view is the assertion that higher energy prices are primarily driven by higher prices for imported energy goods, and that at least some of the discretionary income lost from higher prices of imported energy goods is transfered abroad and is not recycled in the form of higher U.S. exports. In the case of a purely domestic energy price shocks (such as a shock to U.S. refining capacity), it is less obvious that there is an effect on aggregate discretionary income. First, the transfer of income to the refiner may be partially returned to the same consumers in the form of higher wages or higher stock returns on domestic energy companies. Second, even if the transfer is not returned, higher energy prices simply constitute an income transfer from one consumer to another that cancels in the aggregate.

[7] Alternatively, one might expect durables consumption to fall in response to a positive energy price shock, as consumers wait for more energy-efficient technologies to become available. As shown in section 3.1.4 that explanation

are reversible, consumption may fall in response to energy price shocks, as consumers increase their *precautionary savings*. This response may arise if consumers smooth their consumption because they perceive a greater likelihood of future unemployment and hence future income losses. By construction, this effect will embody general equilibrium effects on emplyment and real income otherwise ignored by the demand channel of transmission. In addition, the precautionary savings effect may also reflect greater uncertainty about the prospects of remaining gainfully employed, in which case any unexpected change in energy prices would lower consumption. Finally, consumption of durables that are complementary in use with energy (in that their operation requires energy) will tend to decline even more, as households delay or forego purchases of energy-using durables. This *operating cost effect* is more limited in scope than the uncertainty effect in that it only affects specific consumer durables. It should be most pronounced for motor vehicles (see Hamilton 1988).[8]

These four direct effects have in common that they imply a reduction in aggregate demand in response to unanticipated energy price increases. In addition, there may be *indirect* effects related to the changing patterns of consumption expenditures. A large literature has stressed that shifts in expenditure patterns driven by the uncertainty effect and operating cost effect amount to allocative disturbances that are likely to cause sectoral shifts throughout the economy (see, e.g., Davis (1987) and Hamilton (2008) for a review). For example, it has been argued that reduced expenditures on energy-intensive durables such as automobiles may cause the reallocation of capital and labor away from the automobile sector. As the dollar value of such purchases may be large relative to the value of the energy they use, even relatively small changes in energy prices (and hence in the purchasing power of consumers) can have large effects on output and employment (see Hamilton 1988). A similar reallocation may occur within the same sector, as consumers switch toward more energy-efficient durables (see Hamilton 1988; Bresnahan and Ramey 1993). In the presence of frictions in capital and labor markets, these intersectoral and intrasectoral reallocations will cause resources to be unemployed, thus causing further cutbacks in consumption and amplifying the effect of higher energy prices on the real economy. This indirect effect could be much larger than the direct effects listed earlier, and is considered by many economists to be the primary channel through which energy price shocks affect the economy (see, e.g., Davis and Haltiwanger (2001) and Lee and Ni (2002) and the references therein). Concerns over reallocation effects also help explain the preoccupation of policy makers with the effects of energy price shocks on the automobile sector (see, e.g., Bernanke 2006b).

is unlikely to be empirically relevant.

[8] This last effect need not involve a reduction in the number of automobiles sold. It can also take the form of consumers substituting small energy-inefficient automobiles for large energy-inefficient automobiles. If the latter automobiles tend to be lower priced, aggregate real consumption of automobiles may fall, even when the number of automobiles sold does not (see Bresnahan and Ramey 1993).

Unlike the discretionary income effect, the uncertainty effect and the reallocation effect necessarily generate asymmetric responses of macroeconomic aggregates to unanticipated energy price increases and decreases. The asymmetry arises because these effects amplify the response of macroeconomic aggregates to energy price increases, but reduce the corresponding response to falling energy prices. In sections 3.1 and 3.2, I will deliberately abstract from the possible presence of such asymmetric effects. As will be discussed in section 3.3, there is no compelling statistical evidence against the symmetry hypothesis, and the symmetric model appears to fit the real consumption data rather well. The historical reasons for the prominence of asymmetric models in empirical and in theoretical work on oil price shocks, and the reasons why the apparent evidence of asymmetries is likely to be spurious, are discussed in section 3.3.

3.1.2 Estimating the Energy-Price Elasticities of Energy Demand

A central question in the literature is how price-elastic the demand for energy is. Such estimates play an important role in assessing the potential impact of a carbon tax, for example, in assessing alternative regulatory policies, and in understanding the transmission of energy price shocks. The response of real consumption may be estimated by applying the bivariate regression model described in section 2 to various forms of energy consumption. All energy prices have been weighted by the nominal expenditure share on energy to obtain a measure of the gains and losses of households' purchasing power associated with energy price fluctuations (see Edelstein and Kilian 2007a). The sample period is 1970.2-2006.7. The results are expressed as elasticities with respect to the price of energy, evaluated at the average energy share. The upper panel of Table 2 shows that consumption of all forms of energy declines in response to energy price increases. The elasticity estimate for total energy consumption is -0.45 with error bounds of -0.27 and -0.66, but there are important differences across different forms of energy.

The strongest responses are observed for gasoline and for heating oil and coal. Contrary to the conventional wisdom, *gasoline* consumption responds immediately to unanticipated energy price increases reaching an elasticity of -0.48 after one year. The strikingly large response of -1.47 for heating oil and coal is likely due to households' ability to store heating oil in tanks. This storage feature allows households to delay purchases of new heating oil when the price of heating oil is high and to fill the tank completely when prices are low.[9] In contrast, electricity and natural gas are inherently unstorable, and gasoline may not be stored for safety reasons beyond the tank capacity of a car. Indeed, the declines in electricity consumption and in natural gas use are smaller and not statistically significant.

[9] For a discussion of this storable goods feature see Dudine, Hendel, and Lizzeri (2006).

It is useful to put these estimates into perspective by comparing them with estimates based on other methodologies. Using a structural model, Reiss and White (2005) arrive at an estimate of the short-run electricity price elasticity of electricity demand of -0.39. The point estimate in Table 2 is only -0.15 after twelve months, but the 95% confidence interval for the elasticity estimate includes -0.39. Dahl and Sterner (1991), in a comprehensive survey, report estimates of the short-run gasoline price elasticity of gasoline demand between -0.08 and -0.41. It is not clear, however, how well identified their estimates are. Our point estimate of -0.48 is larger with 95% error bands of -0.32 and -0.69, respectively.[10] These estimates suggest that the demand for energy is not as unresponsive to energy prices as is sometimes believed. Further work at a more disaggregate level is likely to prove useful in refining these estimates.

3.1.3 Estimating the Energy-Price Elasticities of Non-Energy Consumption

The lower panel of Table 2 summarizes the corresponding elasticities of major non-energy real consumption aggregates. All estimates have the expected negative sign and most are statistically significant. Table 2 demonstrates that the overall elasticity of -0.15 is driven mainly by a reduction in vehicles purchases. The elasticity of demand for vehicles is -0.84. It can be shown that this estimate in turn primarily reflects reduced consumer demand for cars. There is much weaker evidence of reduced demand for other durables.

It is useful to put these results in perspective. The sharp rise in gasoline prices in recent years has renewed interest in the question of how much higher energy prices affect consumer expenditures. Our analysis allows us to assess the overall effect of such a price increase on household consumption. Suppose, for example, that gasoline prices unexpectedly increase by 25 cents per gallon (which translates into a 6.85% increase in the overall price of energy, assuming all other energy prices remain unchanged). Then, one year later, a typical household with $4000 to spend per month will cut back its expenditures by $41 based on the full-sample estimates (or by $20 based on the post-1987 estimates). This example illustrates that it takes repeated surprise increases in gasoline prices to generate large effects on household consumption.

It is instructive to disaggregate further the responses of consumption aggregates to higher energy prices. First, consider the likely consequences of an energy price increase based on the discretionary income effect alone. Given that households may choose to borrow or to dissave as a short-run

[10] Recently, Hughes, Knittel, and Sperling (2007) have reported a sharp decline in the elasticity of gasoline demand when comparing estimates for 1975-1980 and for 2001-2006. If we split our sample in half, we observe a similar decline in the price elasticity of overall energy demand, but there are important differences across different forms of energy. Whereas the elasticity of gasoline demand and the elasticity of demand for heating oil and coal have declined consistent with the finding in Hughes et al., that of electricity demand has actually increased, and the elasticity of natural gas consumption has remained unchanged.

response to higher energy prices, it is quite possible for the impact effect of such a shock on consumption to be smaller than consumers' loss in purchasing power, even when energy demand is inelastic. Such consumption smoothing is likely to be short-lived, however, and in the long run the response should be bounded by the magnitude of the purchasing power loss. Hence, a reasonable upper bound on the discretionary income effect is the initial reduction in purchasing power.

In practice, the long-run response could be much smaller than this bound to the extent that demand for energy declines over time, as households increasingly utilize extensive and intensive margins of adjustment in response to purchasing power losses driven by higher energy prices. It stands to reason that such efforts at energy conservation will increase over time. Beyond simple remedies such as driving less or changing the thermostat, households will gradually upgrade their home heating and insulation systems or trade in their gas-guzzling car for a more energy-efficient vehicle. Thus, a tighter bound may be obtained by taking account of the elasticity of energy demand obtained in the upper panel of table 2. Taking account of the price elasticity of energy demand in Table 2, the reduction in discretionary income associated with a 1% increase in energy prices is bounded by -0.04%. It can be shown that the response of total consumption is avout four times as large and hence too large to be accounted for by a discretionary income effect alone.

Where does the excess decline come from? A decline in nondurables and services consumption by more than this bound can be interpreted as an indication that consumers reduce expenditures because they increase their precautionary savings. The data imply a marginally statistically insignificant precautionary savings effect of -0.08 percentage points for nondurables and a statistically significant effect of -0.07 percentage points for services. The corresponding precautionary savings effect of -0.16 percentage points implied for durables other than vehicles is not statistically significant. The excessively high response of vehicles compared to other durables, in contrast, is an indication of the presence of an operating cost effect. The operating cost effect on vehicles consumption lies between -0.60 and -0.65 percentage points and is statistically significant. Taken together, these three effects imply a much larger reduction of real consumer expenditures in response to an unanticipated energy price increase than would be expected based on the small share of energy in consumption, but the overall effect on aggregate consumption is nevertheless small.

3.1.4 How Do Expenditure Patterns Change in Response to Energy Price Shocks?

Section 3.1.3 investigated the response of major real consumption aggregates to the gains and losses in purchasing power associated with energy price shocks. It is equally important to understand how individual expenditure items respond to such shocks. Shifts in expenditure patterns play an important role in theories of the demand channel of the transmission of energy price shocks. They are central to the existence of a reallocation effect, for example. Despite the preponderance of anecdotal evidence on how energy price shocks affect specific types of expenditures (such as gasoline consumption, purchases of SUVs, or dining out), to date there exists virtually no quantitative evidence of these effects.[11] Given the central importance of the automobile industry in many accounts of the transmission of energy price shocks, this subsection focuses on the responses of the components of motor vehicle consumption. The extent to which consumers buy smaller and more energy-efficient cars in response to purchasing power losses, in particular, plays a central role in policy discussions of the effect of higher oil prices (see Bresnahan and Ramey 1993). Figure 2 presents selected impulse response functions that shed light on this margin of adjustment. The impulse response functions are based on results in Edelstein and Kilian (2007a) and were estimated in the same manner as in previous subsections with the results normalized to represent a 1% increase in energy prices.

Motor Vehicle Consumption An unanticipated 1% increase in energy prices causes a highly significant drop of -0.76% in the overall consumption of *motor vehicles and parts*. Figure 2 allows us to examine more closely different types of vehicles. Consumption of *pleasure boats* declines by -1.25% after 18 months. The response is persistent and highly statistically significant at most horizons. Consumption of *pleasure aircraft* declines by -1.05%. The response is persistent, and statistically significant based on one standard error bands at virtually all horizons. Consumption of *recreational vehicles* drops sharply and highly significantly in the short run, reaching a low of -1.58%, and remains statistically significant based on one standard error bands at long horizons. In contrast, consumption of *motorcycles* does not change nor does consumption of *motor vehicle rentals* (not shown). While these results are generally consistent with the overall response of vehicles consumption, the combined consumption share of all these vehicles of 0.47% is small. Clearly, the bulk of the vehicles response is driven by automobile consumption.

If we are interested in whether there is an effect from reduced demand for automobiles on the automobile industry, the relevant metric is the effect of unanticipated increases in energy prices on the demand for new automobiles. Figure 2 shows that elasticity of demand for *new automobiles* is about -0.71, but the estimate is only statistically significant based on one standard error bands. This elasticity estimate is close to the fuel cost elasticity of -0.5 reported in Goldberg (1998) based

[11] A detailed investigation of the responses of a large number of expenditure items (not reported to conserve space) confirms that there is evidence of shifts in expenditure patterns, although the responses may differ greatly by expenditure item. For example, the data show that restaurant and lodging expenditures are adversely affected by energy price shocks, as are sales of airline tickets. Automobile purchases are by far the most responsive expenditure item. Purchases of other durables such as furniture or appliances, by comparison, are far less sensitive to energy price fluctuations. The most surprising result is the low degree of responsiveness of nonessential expenditures on entertainment, sports and other leisure activities. Expenditures on public transportation and on food at home are among the few expenditures that increase in response to unanticipatedly higher energy prices.

on a structural model and micro data.

The level of statistical significance of the response of new car purchases is surprisingly low considering the importance attached to reduced demand for new cars in the literature. A possible explanation is that the effects of energy price shocks are not so much driven by an overall reduction in the demand for cars, but by an increase in the demand for energy-efficient small cars at the expense of energy-inefficient large cars. This view seems to fit not just the 1970s, but also the 2000s, as SUVs and pick-up trucks became increasingly unattractive to consumers. While we do not have data on the consumption of automobiles broken down by energy efficiency, we can contrast the real consumption of *new domestic automobiles* with that of *new foreign automobiles*.[12] To the extent that U.S. automobile manufacturers tend to produce less energy-efficient cars, a disproportionate decline in the consumption of domestically produced new cars would be evidence in favor of a shift in demand. Figure 2 shows a strong decline in new domestic automobile consumption that is statistically significant based on one standard error bands at most horizons and based on two standard error bands at some horizons. In contrast, consumption of new foreign automobiles initially increases, consistent with the perception that there is increased demand for foreign, more energy efficient cars. The increase is statistically significant based on the one standard error bands. After four months, consumption of new foreign cars slumps as well, although the effect is not as persistent, statistically significant only based on the one standard error bands, and smaller than for domestic autos. It can be shown that the excess response of the consumption of domestically produced automobiles over its foreign-produced counterpart is statistically significant for months 2, 3 and 4. The excess decline reaches its maximum of -0.88% after two months. The long run response is -0.63% and not statistically significant. An important question is how economically significant the decline in automobile consumption is. What the data tell us is that a permanent shock of the magnitude associated with Hurricane Katrina could wipe out 10.3% of the domestic demand for U.S. automobiles.

The consumption data on new automobiles do not include light trucks or trucks. A different approach to determining the importance of shifts among different types of automobiles is to focus on unit sales reported by the BEA. While these data ignore the price of a given car (and hence differences in quality), they do allow us to assess whether purchases of light trucks (including minivans, SUVs, and pickup trucks) respond differently to unanticipated losses in purchasing power than purchases of regular automobiles. There has been much discussion of the softening market for SUVs in recent years. Figure 2 shows a mostly significant decline in *unit auto sales* based on one standard error bands (consistent with the evidence on new auto consumption). The decline in *unit light truck sales*

[12] Domestic cars are defined by the BEA to include cars assembled in the United States, Canada, or Mexico.

is much larger and significant even based on two standard error bands at most horizons, whereas the smaller decline in *unit heavy truck sales* is significant only based on one standard error bands. The latter two responses approach -1.05% and -0.86%, respectively. This evidence strengthens the case for the operating-cost channel. Assuming that all producers of light trucks are equally affected by such a shock, a permanent shock associated with an event such as Hurricane Katrina would reduce the number of light trucks sold by about 11.2%, making this channel economically significant for U.S. companies such as Ford, GM and Chrysler, which devote between 35% and 80% of their production to trucks.[13]

These results also shed light on the notion that consumption of durables (and vehicles in particular) falls, because households postpone purchases until more energy efficient durables become available. This explanation would lead us to expect (all else equal) a recovery of durables consumption with some delay. Clearly, that recovery will be captured by the VAR model only to the extent that it occurs within the first six months. Standard lag order selection criteria do not favor longer lags, however, suggesting that this recovery, if it exists, must be small or must occur with a delay of several years. Moreover, the disaggregate data on motor vehicles consumption in Figure 2 suggest that energy-efficient substitutes are readily available in practice. There is clear evidence of consumers substituting toward energy-efficient vehicles.

3.2 How Do Investment Expenditures Respond to Higher Energy Prices?

As noted in Hamilton (2008), energy price shocks may be transmitted not only through cutbacks or shifts in consumer expenditures, but through similar adjustments in firms' investment expenditures. There are two main channels by which energy price shocks may affect nonresidential investment. One channel is that an increase in the price of energy raises the marginal cost of production. This cost channel depends on the cost share of energy. A second channel is through reduced demand for the firm's output, as consumer expenditures fall in response to rising energy prices. For example, Herrera (2007) studies a linear-quadratic inventory model that links shifts in consumer demand in response to energy price shocks to real economic activity. There is also a direct link from reduced demand to cutbacks in nonresidential investment in equipment and structures (see Edelstein and Kilian 2007b).

The response of nonresidential fixed investment need not be symmetric in energy price changes. For example, changes in energy prices are thought to create uncertainty about future energy prices, causing firms to postpone irreversible investment decisions (see Bernanke 1983 and Pindyck 1991).

[13] This information was obtained from unit sales and production data on the company websites.

This uncertainty affect has implications for both supply-side and demand-side accounts of the transmission of energy-price shocks. Specifically, firms may respond to uncertainty about future production costs or to uncertainty about future sales and revenue. In either case, when energy prices rise, the uncertainty effect will reinforce the decline in firms' investment expenditures due to reduced consumer demand and higher energy costs. When energy prices fall, in contrast, the uncertainty effect counteracts the increase in investment expenditures driven by lower costs and increased consumer demand, dampening the increase in investment spending. Notwithstanding these theoretical arguments in support of asymmetries, there is no compelling empirical evidence of asymmetries in the responses of investment expenditures to energy price shocks, with the exception of some subcomponents of equipment investment. We hence will defer the discussion of asymmetries until section 3.3, and focus on empirical estimates from linear symmetric models below.

Table 3 summarizes estimates of the energy price elasticity of investment expenditures after one year. All estimates are based on quarterly investment aggregates reported by the BEA for 1970.II-2006.IV. The analysis again is based on bivariate VAR models as discussed in section 2. The estimated VAR models include quarterly dummies for 1986 for reasons discussed in section 3.3. In reporting the results it is useful to distinguish investment related to mining activities (which in the U.S. are largely accounted for by mining for crude oil, coal and natural gas) from other investment. Whereas mining-related investment will tend to be stimulated by higher energy prices, other investment expenditures will tend to decline, if they respond at all. The net effect is indeterminate and depends on the weight of each component.

Table 3 shows that the energy price elasticity of total nonresidential investment expenditures is only -0.16 and statistically insignificant. Among the subcomponents, only the response of *mining structures* and *mining and oil field machinery* is large and statistically significant. The positive elasticity of 0.09 for *structures* is driven largely by the aggregation of *mining structures* with other structures. Excluding mining, the response is virtually zero. The response of *equipment* has the expected negative sign and is somewhat larger with an elasticity of -0.30, but is statistically insignificant. It can be shown that this estimate is mainly driven by transportation equipment, consistent with the results for durables consumption. Overall, there is no evidence that energy prices exert a large effect on total nonresidential investment expenditures. For comparison, the last row of Table 3 includes the elasticity of residential investment expenditures on structures. The estimate of -1.02 is considerably larger than for comparable nonresidential structures and statistically significant. We conclude that energy price shocks make themselves felt primarily through reduced demand for cars and new houses.

3.3 Are the Responses Asymmetric in Energy Price Increases and Decreases?

A large literature has stressed the potential importance of asymmetric responses of U.S. macroeconomic aggregates to energy price shocks (see, e.g., Balke, Brown and Yücel 2002; Davis and Haltiwanger 2001; Ferderer 1996; Hooker 1996a,b, 2002; Hamilton 1996, 2003; Lee and Ni 2002; Lee, Ni and Ratti 1995; Mork 1989). It is important to distinguish the idea of using a nonlinear transformation of the energy price (such as the LC or NC specification), which by itself does not preclude symmetry in the responses to energy price increases and decreases, from the question of whether the responses to a change in energy prices are asymmetric in the sign of the energy price change. It has been common in empirical work to impose the restriction that the economy does not respond at all to energy price decreases. This view is implicit in the use of the net oil price increase measure, for example, which assigns zero weight to net declines in the price of energy. This specification involves an extreme form of asymmetry. More generally, asymmetries could involve a weaker response to energy price decreases than to energy price increases.

Interest in asymmetries dates back to the late 1980s, when it became apparent that the sharp decline in crude oil prices in 1986 was not followed by a major economic expansion. Given the presumption that the equally sharp increase in crude oil prices in 1979 caused a major economic decline, the absence of a major economic expansion in 1986 seemed to provide iron-clad evidence of the need to allow for asymmetries in the response to crude oil price increases and decreases. This observation has led a number of researchers to incorporate asymmetries into models of the transmission of energy price shocks to the economy such as the uncertainty effect on irreversible investment decisions described in Bernanke (1983) and Pindyck (1991) or the reallocation effect of Hamilton (1988).

Until recently, however, the hypothesis of symmetric responses has not been formally tested.[14] Edelstein and Kilian (2007a,b) perform formal statistical tests for the presence of asymmetries in the response of nonresidential fixed investment to energy price shocks of different sign, but the same magnitude. They allow for a variety of different measures of energy price shocks including percent changes in energy prices, large percent changes and net percent changes. Symmetry in this context

[14] One common approach has been to include oil price increases and decreases as separate variables in a single-equation model for output growth, and to perform a Wald test for the equality of the coefficients on the lags of these variables (see, e.g., Mork 1989, Dotsey and Reid 1992, Hooker 1996, and Hooker 2002). A drawback of this approach is that this test only alerts us to differences in the slope coefficients, whereas we are really interested in whether the impulse responses to positive and negative energy price shocks are different. Another common approach has been simply to inspect the point estimates of the impulse response functions without formal testing (see, e.g., Davis and Haltiwanger 2001). That comparison, however, tells us nothing about the statistical significance of the difference. Nor do tests for pointwise statistical significance of the differences in the impulse response function constitute a formal test of the symmetry assumption.

means that the sum of the impulse response function to energy price increases and of the impulse response function to energy price decreases is jointly equal to zero at all horizons. Based on a comprehensive set of monthly real consumption aggregates and disaggregates, they are unable to reject the null hypothesis of symmetry for any of the major expenditure aggregates. For example, Edelstein and Kilian (2007a) report that all but one p-value in their study is above 0.85 and in the one case where the p-value is only 0.61, the responses are asymmetric in the opposite direction from that implied by economic theory. The average p-value is 0.94.

While the evidence against asymmetries in real consumption responses is subject to considerable sampling uncertainty in some cases, the tests are not without statistical power, as indicated by the rejections of symmetry reported in Edelstein and Kilian (2007b). Moreover, the estimated responses of expectations data from the Michigan Survey of Consumers to the same purchasing power shocks tend to be very symmetric. Together, this evidence suggests that the reallocation effect, the uncertainty effect, and any asymmetry associated with the precautionary saving effect discussed in section 3.1.1 are not a dominant feature of the real consumption data. It is of particular interest that there is no evidence of a reallocation effect, despite the evidence of shifts in expenditure patterns documented in section 3.1.4. A possible explanation is the relatively small share of the U.S. automobile industry in employment. This interpretation is also consistent with the lack of statistical evidence against the symmetry hypothesis in the responses of the U.S. unemployment rate. Notwithstanding some important methodological differences, these results are qualitatively consistent with the plant-level net employment change responses estimated in Davis and Haltiwanger (2001). Both studies show asymmetric point estimates. The chief difference is that Davis and Haltiwanger did not investigate whether these asymmetries are statistically significant, whereas Edelstein and Kilian (2007a) show that they are not.

An immediate implication of this result is there should have been a boom in consumption in 1986. This implication is largely consistent with the data, further supporting the symmetry hypothesis. In 1979, purchasing power declined by 1.69% due to energy price increases, whereas in 1986 purchasing power increased by 1.43% due to energy price decreases. Thus one would expect the effect on real consumption to be roughly symmetric. The symmetric VAR model implies that rising energy prices (all else equal) lowered real consumption by -1.92% in 1979, and raised it by +2.02% in 1986, making these effects nearly symmetric. By comparison, actual real consumption growth in 1979 was -2.20% relative to its mean, whereas in 1986 it was +1.44%. Thus, the linear symmetric model is capable of explaining a substantial part of observed real consumption growth in 1979 and 1986.

Nevertheless, the perception of an asymmetry in economic performance between 1979 and 1986 is correct. The observed behavior of real consumption growth in 1979 and 1986 contrasts sharply with that of real GDP growth. Real GDP growth was -1.81% relative to its mean in 1979 *and* -0.31% relative to its mean in 1986. Thus, the asymmetry alluded to earlier does exist in real GDP growth, but is not reflected in real consumption growth. A comparison of the 1979 and 1986 growth rates of real GDP and its components reveals that the asymmetry originates in nonresidential investment in equipment and structures. In 1979, these investment expenditures grew by -2.80% and +7.54% relative to the mean, respectively, whereas in 1986 they grew by -4.65% and -16.35%. The behavior of firms' investment expenditures in 1986 contrasts sharply with that of private residential fixed investment and of durables consumption.

Edelstein and Kilian (2007a) suggest that an exogenous drop in nonresidential fixed investment expenditures in 1986 was mainly responsible for the low rate of real GDP growth in 1986. A natural candidate for such an exogenous shift in investment expenditures is the 1986 Tax Reform Act, which sharply raised the effective tax rate for many corporations by severely curtailing deductions for capital expenditures and by eliminating the investment tax credit. For most types of equipment, the repeal of the investment tax credit amounted to the elimination of a 10% subsidy on investment. This fact helps explain the sharp drop in nonresidential fixed investment expenditures on equipment in 1986.[15] The even larger drop in nonresidential fixed investment in structures is unlikely to be explained by the repeal of the investment tax credit because it was offset by other changes in the tax code and because business investment dropped even in sectors that were not subject to the investment tax credit prior to 1986 (see, e.g., Auerbach 1987).

Further disaggregation of the BEA data reveals that the decline in nonresidential investment in structures is concentrated in two components. The first component is *commercial structures (including office space)* and *manufacturing structures*, which account for 21% and 6% of total real nonresidential investment in structures, respectively. A likely explanation is that the elimination of real estate tax shelters as part of the 1986 Tax Reform Act contributed to the observed 17% drop (relative to the average growth rate) in these two components in 1986 (see *Survey of Current Business* 1987, p. 4). The second component is nonresidential investment in *mining exploration, shafts and wells*. That component accounts for about 11% of all nonresidential investment in structures and mainly comprises investments in the petroleum, natural gas and coal mining industry. In fact, one third of the total decline in real business investment in structures can be accounted for by the dramatic 65% drop in this component in 1986 below the average growth rate. While one would expect some decline in investment in these industries in response to falling energy prices, this particular drop

[15] For details of the timing of the 1986 Tax Reform Act see Wakefield (1987). Large parts of the Act were effective retroactively in the first quarter of 1986. Regardless of the exact timing of individual provisions, a good case can be made that firms anticipated that many provisions would be enacted retroactively and adjusted their investment decisions accordingly.

was swifter and larger than the corresponding increase in investment in the domestic petroleum and natural gas industry observed after 1979. This asymmetric reaction is consistent with the view that the market treated the breakdown of OPEC in late 1985 as an exogenous shock and responded more strongly than it would have based on the fall of energy prices alone. The evidence is also consistent with the view that there were limited investment opportunities in the domestic petroleum, natural gas and coal mining industry after 1979, making the response of this component of real GDP growth inherently asymmetric (but in the opposite direction of the asymmetries previously discussed in the literature on oil and the macroeconomy).

Hence, there are good reasons for the existence of an asymmetry between 1979 and 1986 in the real GDP growth data. The Tax Reform Act of 1986 and the unprecedented fall in investment in the oil and gas industry also help explain why real consumption did not grow quite as much in 1986 as predicted by a linear econometric model on the basis of falling energy prices alone and why unemployment remained higher than it would have been otherwise. Ignoring this exogenous shift in nonresidential fixed investment, given the short sample, may bias VAR estimates of the responses of nonresidential investment and cause them to look asymmetric in small samples, even when the true responses are not. Indeed, the responses of nonresidential investment in equipment and structures to energy price shocks estimated on the 1970-2006 period appear asymmetric, and the symmetry null can be rejected in several cases. The nature of the asymmetries, however, in many cases departs sharply from the predictions of commonly used economic models of the transmission of energy price shocks.

As Edelstein and Kilian (2007b) show, excluding investment in mining-related activities and including regression dummies to control for the 1986 tax reform and other exogenous shifts in 1986 removes all of the statistical evidence of asymmetries in the response of nonresidential structures. Similarly, there is no compelling evidence of asymmetries in the responses of aggregate nonresidential investment in equipment. There is a marginal rejection of symmetry at the 10% level for only one of the components of equipment investment. In short, there is no compelling evidence of asymmetries for either consumer expenditures or investment expenditures, lending credence to the symmetric response estimates presented in sections 3.1 and 3.2.

3.4 Oil Price Shocks and Monetary Policy

Starting with Bernanke, Gertler and Watson (1997), there has been interest in the extent to which the response of the U.S. economy to crude oil price shocks is driven by the endogenous response of monetary policy, as opposed to the direct effect of oil price shocks on the economy. Motivating this line of work was the perception that the magnitude of the recessions following major oil price increases is too large to be caused by rising oil prices alone. The alternative explanation was proposed that the Federal Reserve chooses to raise interest rates in anticipation of the higher inflation expected as a result of oil price increases, thereby aggravating the relatively benign economic downturn normally expected in response to higher oil prices. This perception has spurred interest in VAR models of the effects of oil price shocks that incorporate monetary policy reaction functions. The inclusion of a monetary policy reaction function results in much larger VAR systems than the models discussed so far, exemplified by the 7-variable system specified in Bernanke et al. (1997).

Based on their VAR model estimates, Bernanke et al. document the cumulative effect of oil price increases on real output relative to trend, including both the direct effect of higher oil prices and the effect associated with the monetary policy response to higher oil prices. The historical decompositions in Bernanke et al. suggest that the oil price shock of 1973/74 overall did not contribute much to the sharp decline in real output relative to trend in 1974/75, consistent with evidence that the Fed was tightening monetary policy well before the oil price shock and did so in response to rising industrial commodity prices which were viewed as an indication of rising future inflation (also see Barsky and Kilian 2002). During the 1979-1983 episode, the model predicts more of a decline in real output below trend than actually occurred from mid-1980 through late 1981, but it does not explain well the sharp decline in real output relative to trend starting in mid-1981, which seems due to an autonomous tightening of monetary policy under Paul Volcker. Similarly, oil prices are only a contributing factor for the decline in real output relative to trend in 1991/92.[16]

Having documented the effects of these three oil price shocks, Bernanke et al. propose a thought experiment in which the Fed instead pursues a policy of holding the Fed Funds rate constant in response to oil price shocks. They show that the resulting path of real output would have been considerably less recessionary and attribute the difference in outcomes to the endogenous policy response to higher oil prices. A direct implication of the Bernanke et al. analysis is that the recessionary consequences of an oil price shock in principle could have been avoided at the cost of higher inflation by simply holding constant the Fed Funds rate. This implication has been challenged by Hamilton and Herrera (2004) who suggest that the monetary expansion required to stabilize the Fed Funds rate and to prevent a decline in real output below trend would be implausibly large. Such an expansion certainly would involve a change in interest rates outside of historical experience and hence would make the analysis subject to the Lucas critique, casting doubt on the validity of the

[16] Subsequently, Hamilton and Herrera (2004) have observed that the magnitude of the effect of oil price shocks on real output is sensitive to the lag order. Allowing for additional lags in the model of Bernanke et al. (1997) results in somewhat larger declines in real output after the two oil price shocks of the 1970s, but only after the 1990/91 shock does the price of oil explain the bulk of the decline in real output below trend.

analysis (see Bernanke, Gertler and Watson 2004). There also are concerns about other aspects of the VAR model used in Bernanke, Gertler and Watson (2004) such as the use of interpolated real output data.

With the exception of Herrera and Pesavento (2007), more recent studies have focused on the importance of endogenous policy responses to oil price shocks in the context of theoretical macroeconomic models (see, e.g., Leduc and Sill 2004, Carlstrom and Fuerst 2006, Dhawan and Jeske 2007a).[17] The importance of this channel depends to a large extent on the definition of the counterfactual and on the modeling assumptions, making further empirical work on endogenous monetary policy responses all the more important.

4 Has the U.S. Economy Become Less Responsive to Energy Price Shocks?

It has been widely observed that energy price shocks do not appear to affect the U.S. economy as much as they used to (see, e.g., Herrera and Pesavento 2007).[18] This observation can be substantiated by comparing responses of consumption aggregates estimated on the first half (1970.2-1987.12) and the second half (1988.1-2006.7) of the sample used in sections 3.1.3 and 3.1.4. As shown in Edelstein and Kilian (2007a), after normalizing the scale of the impulses to be the same across the two subsamples to make the magnitudes of the impulse responses comparable, striking differences emerge. Evaluated at the average energy share for the full sample, the response of total real consumption to an unanticipated 1% energy price increase drops from -0.30% after 18 months in the first half of the sample to -0.08% in the second half. The corresponding decline for durables is from -0.84% to -0.24%. Vehicles consumption declines from -1.31% in the first half to -0.49% in the second half of the sample. The decline in durables consumption excluding vehicles shrinks from -0.44% in the first half of the sample to -0.01% in the second half. The response of nondurables shrinks from -0.29% to -0.02% and that of services from -0.18% to -0.07%. A similar reduction occurs in the response of real residential fixed investment (not shown). The response drops from -4.7% to -1.3%. Finally, the rise in unemployment associated with an unanticipated purchasing power loss drops from 1.53% to 0.36%.

[17] Bodenstein, Erceg and Guerrieri (2008) study the optimal policy response using a utility-based welfare metric. Closely related work by Nakov and Pescatori (2007) has challenged the notion that the Federal Reserve should respond to oil price shocks from a welfare point of view.

[18] A weakening of the statistical relationship between oil prices and the U.S. economy in the mid-1980s has been noted as early as Hooker (1996b, p. 222) and Davis and Haltiwanger (2001, p. 482). There also is a widely held view among policymakers that the surges in oil prices in the 1970s and 1980s had much more prononced economic effects than the more recent increases (see, e.g., Bernanke 2004).

There are several possible explanations for the declining importance of energy price shocks. One conjecture is that this result is related to the declining share of energy in consumption in the late 1980s and 1990s. Since our results are based on purchasing power changes rather than unweighted energy price changes, they already control for changes in the expenditure share of energy, eliminating this explanation. A second conjecture is that the variability of purchasing power shocks may have declined in the second half of the sample. Further analysis shows that in fact the variability of both total changes and linearly unpredictable changes in purchasing power has *increased* in the second half of the sample. The innovation standard deviation increased from 0.08 to 0.11. The average magnitude of positive innovations increased from 0.056 to 0.076, and the average magnitude of negative innovations increased from -0.049 to -0.073. Moreover, both the maximum and the minimum of the innovations increased.

A third and more plausible explanation is that the structure of the U.S. automobile industry has changed. In the 1970s, U.S. auto manufacturers were simply not producing any small, energy-efficient cars, leaving consumers no choice but to buy small cars from abroad. Thus, the U.S. auto industry was hit particularly hard by rising energy prices and falling demand for large cars (see, e.g., Bresnahan and Ramey 1993, Davis and Haltiwanger 2001). In contrast, by the late 1980s and 1990s the differences between domestic and foreign auto producers had been greatly reduced, as domestic auto manufacturers offered small and energy efficient cars of their own, while foreign manufacturers were beginning to branch out into the market for jeeps, SUVs, vans and pickup trucks. Thus, the U.S. auto industry became relatively less vulnerable to energy price increases than in the 1970s.

This point is illustrated by comparing the responses of new domestic and foreign automobiles in the two subsamples. Whereas in the first subsample expenditures on new domestic automobiles in response to a 1% increase in energy prices drop by -2.8% after two months and by -1.7% after 18 months, in the second half the short-run response drops to -0.7% and the long-run response to -0.3%. The strongly significant short-run decline in the first sample is only marginally significant in the second sample. In contrast, in the first half of the sample, after one month expenditures on new foreign automobiles rise significantly by 1.3%, followed by an insignificant decline of -0.99% after five months and a long-run response of -0.3%. In the second half of the sample, the initial increase in the response has become small and insignificant, the decline after 5 months has shrunk to -0.4% and the long-run response to -0.1%. While it is still true that the consumption of new domestic autos is more responsive to energy price shocks than the consumption of new foreign autos, the differences are much smaller than they used to be.

There is also a fourth and complementary explanation. As the U.S. automobile industry restructured itself after the energy price increases of the 1970s, the share of domestically produced automobiles in total U.S. real expenditures on new cars declined (from 88% in 1970 to 60% in 1988 and 57% in 2006), as did the employment share of the industry (from a peak of 1.3% in 1973 to 0.9% in 1988 and 2005).[19] Thus, the relative importance of the auto industry for the U.S. economy and the potential for spillovers from the automobile industry to other sectors has declined relative to the 1970s, further reducing the precautionary savings effect.

Yet another possibility taken up in the next section is that the nature of the energy price shocks has evolved and that recent energy price shocks have been qualitatively different from earlier shocks. It will be shown that an energy price increase driven by strong global demand for industrial commodities (including crude oil), for example, may have far less adverse consequences for U.S. real output than the same energy price increase driven by adverse global oil supply shocks or by expectations-driven shocks to the precautionary demand for oil. Thus, the origin of energy price increases matters.

5 Disentangling Demand and Supply Shocks in Energy Markets

5.1 A VAR Model of the Global Crude Oil Market

In much of the literature on oil price shocks, oil price innovations have implicitly been equated with oil supply shocks. This view was questioned in Barsky and Kilian (2002, 2004), but only recently the relative role of oil demand and oil supply shocks in determining the real price of oil has been quantified. Kilian (2008c) uses a structural VAR model to explore the implications of demand and supply shocks in the global crude oil market for the real price of oil. The objective is to demonstrate that each of these shocks has distinct effects on the real price of crude oil and on U.S. macroeconomic aggregates. The VAR model includes the percent change in the world production of crude oil, a suitably detrended index of global real economic activity as it relates to industrial commodity markets (which may be thought of as a measure of the business cycle in global industrial commodity markets), and the real price of imported crude oil. The data frequency is monthly and the model includes 24 lags. The sample period is 1973.2-2007.12.[20] It is postulated that these variables are driven by three structural shocks: (1) crude oil supply shocks (*oil supply shocks*);[21] (2) shocks to the demand for *all* industrial commodities in global markets (*aggregate demand shocks*); (3)

[19] See http://bea.gov/bea. There are no data on the share of the automobile industry in real value added prior to 1987. The current share of 1.1% is only slightly lower than in 1987.

[20] For further discussion of the data the reader is referred to Kilian (2008c).

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

demand shocks that are specific to the global crude oil market (*oil-market specific demand shocks*). Whereas 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 price of oil driven by higher precautionary demand associated with concerns about future oil supply shortfalls.[22]

The identifying assumptions used in the VAR model are that (1) world crude oil production does not respond within the month to demand shocks in the crude oil market; and that (2) oil-market specific demand shocks do not affect, within the month, the business cycle in global industrial commodity markets. Assumptions (1) and (2) embody a partial equilibrium model of the global crude oil market. The model postulates that the stochastic supply curve for crude oil is vertical in the short run (conditional on past information) and does not respond to demand shifts within the month. This assumption is reasonable because supply decisions are made based on expectations of medium-term demand. Since changing supply is costly, and innovations to demand will have a negligible effect on expected trend growth in demand, supply will only respond to demand shocks with a delay. The supply curve may be shifted by production disruptions in the Middle East and other exogenous events. The short-run demand curve is downward sloping. It is being shifted by innovations to global aggregate demand and by innovations to oil-specific demand. Thus, all three shocks are allowed to affect the real price of oil within the month. The real oil price innovation is a weighted average of the crude oil demand and crude oil supply innovations.

Figure 3 shows the VAR impulse response estimates for a horizon of up to 15 months. All shocks have been normalized to represent shocks that tend to raise the price of oil. The impulse response confidence intervals have been constructed using a recursive-design wild bootstrap (see Gonçalves and Kilian 2004). The qualitative pattern of the response estimates conforms with basic economic theory. The left panel of Figure 3 shows that an unanticipated reduction in world crude oil supplies increases the global real price of crude oil temporarily. Based on the one-standard error bands, the response is partially statistically significant during the first half year, but small, consistent with related evidence on the quantitative importance of oil supply shocks (see Kilian 2008a). An unanticipated increase in global demand for industrial commodities, as shown in the second panel, causes a persistent increase in the real price of crude oil that is statistically significant at all horizons based on the one-standard error bands. Much of that increase is delayed and the response peaks only

[22] In the context of a theoretical model of the spot and futures market for crude oil, Alquist and Kilian (2008) show that suitable transformations of the percent spread of the oil futures price over the current spot price of oil may also be used to measure the precautionary demand component of the real spot price. Such measures are highly correlated with the fluctuations in the spot price of oil driven by the precautionary demand shocks as identified by VAR models of the type discussed here.

after one year. The third panel focuses on the response to oil-market specific demand shocks. Such shocks typically arise from an increase in the precautionary demand for crude oil (see Kilian 2008c; Alquist and Kilian 2008). Shifts in precautionary demand tend to occur in response to exogenous political events that create uncertainty or reduce the existing uncertainty about possible shortfalls of the global supply of crude oil relative to demand. Figure 3 shows that an unanticipated increase in the precautionary demand for crude oil would be associated with an immediate and sharp increase in the price of crude oil. The response overshoots and declines very slowly. In summary, Figure 3 suggests that the timing, persistence and magnitude of the response of the real price of oil to oil demand and oil supply shocks may differ greatly, making it important to understand the origin of a given oil price shock.

5.2 What Has Been Behind the Recent Surge in Oil Prices?

Historical decompositions based on the VAR model of section 5.1 may be used to shed light on the determinants of rising and falling oil prices since the mid-1970s. Figure 4 plots the cumulative effect on the real price of oil of each of the oil demand and oil supply shocks identified in the preceding subsection. Each panel shows the cumulative impact at each point in time of one of the three shocks. The first row of Figure 4 shows that overall crude oil supply shocks have had a negligible effect on the price of oil compared with oil demand shocks. Much of the volatility of the real price of oil is driven by the two demand shocks. Global aggregate demand shocks have been associated with long swings in the real price of oil. For example, there is clear evidence of persistent aggregate demand pressures on the price of oil in the late 1970s and early 1980s and again after 2002. In contrast, oil-specific demand shock have been associated with much more rapid fluctuations. Notable upswings occurred in 1979, following the Iranian Revolution, the Iranian hostage crisis and the Soviet invasion of Afghanistan, which all raised concerns about the security of oil supplies, and in 1990, following the invasion of Kuwait. The breakdown of OPEC in late 1985 was associated with a sharp drop in precautionary demand for crude oil, as was the Asian crisis of 1997, even after controlling for changes in global demand.[23]

Of particular interest is the question of what has been behind the most recent surge in oil prices. There is no evidence that this build-up has been driven by production decisions by OPEC

[23] Figure 4 suggests that efforts to link crude oil 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 play 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.

or other crude oil supply shocks. Nor is there evidence that oil-specific demand shocks have played an important role after 2002. Figure 4 shows that the bulk of the increase in oil prices since 2002 has been associated with increasing global demand for crude oil, along with other industrial commodities. As discussed in Kilian (2008c), much of that increased demand has been associated with rising demand for industrial commodities (including crude oil) from emerging economies in Asia. It is important to keep this result in mind, when considering the macroeconomic performance of oil-importing economies such as the United States after 2002. As the next subsection demonstrates, changes in the composition of oil price shocks may account for seemingly different impacts of oil price shocks of similar magnitude on the U.S. economy.

5.3 The Differential Impact of Demand and Supply Shocks in Global Oil Markets

There are two reasons why each oil demand and oil supply shock is expected to have distinct effects on the U.S. economy. First, as demonstrated in Figure 3, each of these shocks has different implications for the timing, magnitude and persistence of the path of oil prices. To the extent that the time path of changes in the real price of oil triggered by a (negative) oil supply shock looks different from the time path induced by a (positive) oil demand shock, for example, the magnitude and timing of the resulting responses of the U.S. economy also will be different, even abstracting from other changes triggered by these shocks. Second, oil demand shocks may have additional effects on oil-importing economies that do not operate through the real price of oil. In particular, an unanticipated expansion of global demand for industrial commodities will tend to stimulate the U.S. economy. For example, higher demand for industrial commodities goes hand in hand with higher demand for U.S. exports, even controlling for oil prices. Thus fluctuations in the global business cycle will have a direct stimulating effect on U.S. economic growth in addition to the indirect growth-retarding effect working through higher oil prices (and higher prices of other imported industrial commodities). The relative importance of these effects varies over time. It is not clear a priori which effect will dominate. As will be shown below, the net effect of such a shock on U.S. real GDP and stock returns actually is positive in the short run (although not significantly so), but negative in the long run.

These two points also have important implications for applied work. To the extent that a given oil price change is a composite of several underlying oil demand and oil supply shocks, each of which induces different dynamics for the reasons discussed above, it can be misleading to focus on the response of the U.S. economy to an average oil price shock. A case in point is the increase in the real price of oil since 2002. The fact that this increase was driven mainly by repeated positive aggregate demand shocks (reflecting primarily strong growth in countries such as India, China and other emerging economies), as shown in Figure 4, helps explains why this particular oil price shock did not induce a sharp recession or stock market correction, as traditional models of oil price shocks would have suggested (see Kilian 2008c; Kilian and Park 2008). Thus, changes in the composition of oil price shocks (reflecting the time variation in oil demand and oil supply shocks) go a long way toward explaining the apparent instability of the statistical relationship between oil prices and macroeconomic aggregates. The apparent decline in the responsiveness of the U.S. economy to energy price shocks, documented in section 4, indeed can be attributed in part to the changing composition of demand and supply shocks.

5.3.1 Real GDP and CPI Inflation

Figure 5 illustrates the responses of U.S. real GDP and U.S. consumer prices to the oil demand and oil supply shocks identified based on the VAR model of section 5.1. Under the assumption that these shocks are predetermined with respect to U.S. macroeconomic aggregates, response estimates may be obtained from regressions of real GDP growth and inflation, respectively, on a constant and a distributed lag of the shock in question (see Kilian 2008c). Figure 5 confirms that each demand and supply shock in the global crude oil market generates a unique pattern of responses.

The first column of Figure 5 shows that an unexpected global crude oil supply disruption leads to a temporary statistically significant decline in the level of real GDP. Based on the one-standard error bands, the response is statistically significant for the first seven quarters. In contrast, the response to an unanticipated increase in global aggregate demand for industrial commodities is an initial (statistically insignificant) increase in U.S. real GDP, followed by a decline below the original level of real GDP that becomes statistically significant after about two years. This pattern is consistent with the view that such a shock has both direct and indirect effects on the U.S. economy that work in opposite directions. In the short run, an unanticipated expansion of the business cycle in global commodity markets directly stimulates the U.S. growth. It also raises the real price of oil, thereby indirectly slowing U.S. growth. Initially, the direct positive effect is large enough to offset the negative effect working through higher oil prices (and higher industrial commodity prices more generally). Over time, the stimulus from the global economy weakens and the growth-retarding effect working through higher oil and other commodity prices begins to dominate. Finally, Figure 5 shows that oil-market specific shocks (such as an increase in precautionary demand for crude oil) cause a persistent decline in real GDP. Unlike the decline triggered by an oil supply disruption, the decline triggered by oil-market specific increases in demand reaches its maximum only after about three years. After five quarters, the decline is statistically significant. The second column of Figure

5 shows the corresponding responses of consumer prices measured by the CPI. Adverse crude oil supply shocks cause a statistically insignificant increase in CPI inflation on impact, but almost no increase in the price level. Aggregate demand shocks cause a delayed increase in the price level. The response is significant after three quarters. An oil-market specific demand shock causes a large and even more statistically significant increase in the price level at all horizons.

This evidence helps us understand why the consequences of the increase in crude oil prices since 2002 have been relatively benign so far. Much of this increase in the price of oil was fueled by a booming world economy, and, especially in the short run, the expansionary effects of an aggregate demand shock for industrial commodities help to offset the adverse consequences of higher oil prices. U.S. real GDP declines only with some delay, as the price of energy and other commodities continues to rise, while the economic stimulus from higher global demand weakens. Hence, following several such shocks, the economy tends to remain quite resilient, and seemingly unaffected by higher oil prices.

5.3.2 Stock Markets

The same distinction between oil demand and oil supply shocks also matters for understanding the response of the U.S. stock market to oil price shocks. Using a similar VAR methodology, Kilian and Park (2008) show that the responses of real U.S. stock returns to oil price shocks differ substantially, depending on the underlying causes of the oil price increase. On average, 22 percent of the variation in aggregate stock returns can be attributed to the shocks that drive the crude oil market (most of which is driven by demand shocks), but the contribution of each shock varies over time, making it necessary to understand the origins of a given oil price increase before its consequences for aggregate U.S. stock returns can be assessed.

This point is illustrated in Figure 6 which shows the responses of U.S. stock prices to each of the three oil demand and oil supply shocks already discussed in the preceding subsections. The conventional wisdom that higher oil prices necessarily cause lower returns is seen to apply only to oil-market specific demand shocks such as increases in the precautionary demand for crude oil that reflect concerns about future oil supply shortfalls. In contrast, positive shocks to the global aggregate demand for industrial commodities cause both higher real oil prices and higher stock prices within the first year after the shock. Hence, higher oil prices need not be bad news for the stock market. Finally, shocks to the global production of crude oil, while not trivial, are far less important for understanding changes in stock prices than shocks to global demand for industrial commodities and shocks to the precautionary demand for crude oil. Given the evidence that recent increases in the price of crude oil have been driven primarily by strong global demand for all industrial commodities, this evidence helps explain the apparent resilience of the U.S. stock market to higher oil prices so far. Kilian and Park also show that shocks to the precautionary demand for crude oil provide an explanation for the negative association between stock returns and inflation found in previous studies of the postwar period (see, e.g., Kaul and Seyhun 1990, Hess and Lee 1999), whereas other shocks in the crude oil market do not.

Finally, this type of analysis also reveals interesting differences across industries. For example, shares in the petroleum and natural gas industry as well as the gold and silver mining will appreciate in response to a positive oil-market specific demand shock, while the automobile industry and the retail sector will experience a persistent and significantly negative response to the same shock. In contrast, if the same increase in the price of crude oil is driven by innovations to global real economic activity, the cumulative returns of all four industries will increase during the first year after the shock, but especially that of petroleum and natural gas stocks. A systematic analysis of industry returns suggests considerably stronger and often more significant responses to oil demand shocks than to oil supply shocks, although the degree of sensitivity varies across industries. Outside of the energy sector, the strongest responses to demand shocks are found in industries such as the automobile industry, the retail industry, and tourism-related industries such as restaurants and lodging, consistent with the view that oil price shocks are primarily shocks to the demand for goods and services rather than their supply. The energy intensity of industries is not an important factor in explaining differences in the responses of real stock returns across manufacturing industries.

6 Concluding Remarks

In recent years, our understanding of the nature of energy price shocks and their effects on the economy has evolved dramatically. Only a few years ago, the prevailing view in the literature was that at least the major crude oil prices increases were exogenous with respect to the U.S. economy and that these increases were associated with political disturbances in the Middle East. This view has not held up to scrutiny. Today, we know that simple statistical transformations of the price of oil are not sufficient to identify oil price increases driven by exogenous crude oil supply shocks.

Moreover, it has been shown that direct measures of exogenous shocks to the production of crude oil have low explanatory power for crude oil prices. This evidence suggests that attempts to link major oil price increases to disruptions of crude oil production alone will not be successful. At the same time, the surge in crude oil prices since 2002 has demonstrated that large and sustained increases in oil prices may be driven primarily by demand for crude oil, especially when the ability to increase crude oil production in the near future is limited. This observation is important because it suggests that oil demand shocks may have played a central role in explaining earlier episodes of oil price shocks as well. Indeed, all major oil price shocks have coincided with capacity constraints in crude oil production and strong demand for crude oil.

Recent advances in the literature allow us to quantify the relative importance of demand and supply shocks in the global crude oil market. The analysis reviewed in this paper suggests that, while no two oil price shocks are alike, most oil price shocks since the 1970s have been driven by a combination of strong global demand for industrial commodities (including crude oil) and expectations shifts that increase precautionary demand for crude oil specifically. These expectations shifts reflect the market's uncertainty about future oil supply shortfalls, which in turn reflects expectations about both future demand for crude oil as well as future supplies of crude oil. The nature of the concerns of the market may evolve over time. For example, the threat of an oil embargo or of a Soviet invasion of Iran no longer preoccupies the market today, but the possibility of political upheaval in Saudi Arabia seems more real now than in 1974 or 1979. Likewise, concerns about military action against Iran which were nil in 1974, rose sharply in 1979, then all but vanished, but recently have made a comeback. It is important to keep in mind that these expectations need not be realized in the observed sample period, similar to the phenomenon of a peso problem in foreign exchange markets. It is also important to stress that expected supply disruptions alone are not enough to cause precautionary demand to increase. It is tight supply in conjunction with strong demand for crude oil that causes expectations shifts. For example, at times in the 1980s about 30 oil tankers were attacked in the Persian Gulf in given month, yet the price of oil continued to fall, reflecting the abundant supply of crude oil elsewhere in the world and the low state of global demand for crude oil.

One of the striking findings of the recent literature is that precautionary demand shocks driven by expectations shifts, unlike other oil demand and oil supply shocks, may have immediate and large effects on the U.S. economy. In many ways, they resemble the types of shocks that the earlier literature associated with exogenous political events in the Middle East. These political events indeed matter, but not so much through their effect on crude oil production, but through their effect on expectations of future crude oil production disruptions. A case in point is the invasion of Kuwait in 1990. The reason the price of crude oil skyrocketed in mid-1990 was not so much the cessation of crude oil production in Iraq and Kuwait, but rather the concern that Iraq may invade Saudi Arabia and occupy the Saudi oil fields, causing a much larger oil supply disruption. As we know, this never happened, but it explains the sharp increase in oil prices in mid-1990 (over and above what would have been expected based on the physical reduction of crude oil supply at that point), and it explains the subsequent sharp fall in crude oil prices after the U.S. had moved enough troops to Saudi Arabia in late 1990 to forestall the occupation or destruction of the Saudi oil fields.

In short, we have a much better understanding today of how oil price shocks may arise. There also has been tremendous progress in understanding how energy price shocks affect the U.S. economy. Much of the earlier literature was preoccupied with the effect of changes in the price of crude oil. One recent insight is that there is an important distinction between retail energy prices such as motor gasoline and the price of primary energy goods such as crude oil. As the events of Hurricanes Rita and Katrina demonstrated, shocks to U.S. refining capacity may explain a substantial component of the price of gasoline not captured by crude oil prices. In fact, gasoline and crude oil prices may move in opposite directions. Thus, it is essential to focus on retail (or intermediate) energy prices in studying the response of consumers (or firms) to higher energy prices. It is also important to focus on a broad enough measure of retail or intermediate energy prices. For example, the magnitude of real energy price shocks faced by firms is much smaller in general than the corresponding shocks to crude oil prices, owing to the large share of electric power available at stable prices. In fact, in 1974, crude oil prices rose twice as much as intermediate energy prices. Even more strikingly, in 1990, crude oil prices rose by 83%, whereas intermediate energy prices only rose by 12%.

The traditional view of oil price shocks has been that they act as *aggregate supply* shocks in a traditional textbook model or as *technology* shocks in a modern dynamic stochastic general equilibrium model. Despite some important advances, the nature of this supply channel of transmission and its quantitative importance remains an open issue. An increasingly popular alternative view in the literature, discussed in section 3, is that oil price shocks affect the economy primarily through their effect on consumer expenditures and firm expenditures instead. In this view, higher energy prices cause both a reduction in *aggregate demand* in traditional parlance and a shift in expenditures which in turn causes a ripple effect throughout the economy, as firms adjust their production plans. Models of the demand channel of transmission have the merit of being consistent with anecdotal evidence that oil price shocks are typically perceived as adverse demand shocks at the industry level. Some of these models also hold the promise of generating potentially much larger effects than would be expected based on the small share of energy in consumption. Finally, some models of the demand channel (such as the sectoral shifts model) seem capable of rationalizing apparent asymmetries in the response of the economy to oil price increases and oil price decreases.

The evidence that emerges from the recent literature is that some of the channels of transmission that collectively are referred to as the demand channel in section 3 indeed matter in practice, whereas others do not appear to be quantitatively important. In particular models that imply asymmetric responses to energy price increases and decreases were shown to lack empirical support. A large literature has been devoted to studying apparent asymmetries in the response of the economy to energy price increases and energy price decreases. This literature was motivated by the fact that sharply higher energy prices in 1979 appeared to be followed by a recession, whereas sharply lower energy prices in 1986 were not followed by a major economic expansion. This evidence seemed to call for theoretical models capable of explaining asymmetric responses to energy price increases and energy price decreases. As discussed in this paper, there is reason to believe that the profession may have misinterpreted this evidence. In fact, there is no evidence of asymmetries in real consumption growth and the absence of an increase in investment expenditures in 1986 appears to be driven by an exogenous decline in business investment in 1986, related not to the fall in energy prices but arguably to the 1986 Tax Reform Act. This effect was exacerbated by the response of investment in the petroleum and natural gas industry to the collapse of OPEC in late 1985, which far exceeded the response one would have expected to a decline in energy prices alone. Moreover, composition effects from aggregating investment expenditures related to petroleum, coal and natural gas mining and all other investment expenditures helped generate an apparent asymmetry in the growth of aggregate investment. Hence, the apparent asymmetry in the real GDP growth data seems to be largely a statistical artifact. As the evidence reviewed in this paper suggests, despite asymmetric point estimates in some cases, there is no formal statistical evidence against the symmetry hypothesis.

This result has important implications for demand-driven models of the transmission of energy price shocks. Models of asymmetric transmission mechanisms such as the uncertainty effect of Bernanke (1983) or the reallocation effect of Hamilton (1988) have been widely used in the empirical literature on oil prices to explain the apparent breakdown of the linear relationship between real GDP growth and oil prices in the mid-1980s. The lack of evidence against the symmetry hypothesis suggests that neither the uncertainty effect nor the reallocation effect are quantitatively important in the data. We concluded that there is no compelling reason to abandon linear models that impose symmetry on the response to energy price increases and energy price decreases. Using such models allowed us to quantify the effect of retail energy price shocks on consumer and business investment expenditures. We documented that the demand channel of the transmission of oil prices is indeed more important than the small share of energy in expenditures would suggest. The estimated elasticities for total consumption and total nonresidential investment are -0.15 and -0.16, respectively, or about four times as high as the share argument would suggest. Nevertheless, the overall responses of total consumption and of total nonresidential investment as measured by the energy price elasticities are still fairly small, and of limited importance in explaining business cycle fluctuations. Evidence of larger elasticities was found only for specific expenditure items. It was shown that the bulk of the economy's response is associated with reduced demand for vehicles and reduced residential demand for houses.

An interesting observation in the recent literature is that the effects of energy price shocks have weakened since the second half of the 1980s. For example, the one-year energy price elasticity of total real consumption drops from -0.30% prior to 1987 to only -0.08% after 1987. It can be shown that this phenomenon is not primarily associated with the evolution of the share of energy in consumer expenditures or in value added nor is it caused by a decline in the volatility or magnitude of energy price shocks. Rather it can be explained in part by changes in the composition of U.S. automobile production and by the declining overall importance of the U.S. automobile sector. The declining importance of energy price shocks is also related to the nature of recent energy price shocks. There has been much speculation as to why the recent surge in the price of crude oil in particular has not so far caused a major recession. Part of the answer is that much of that increase was driven by strong global demand for industrial commodities. Such demand shocks have both a stimulating effect on the U.S. economy and adverse effects on economic growth working through higher oil prices in particular and higher industrial commodity prices more generally. Empirical estimates suggest that, in the short run, the positive effects on the U.S. economy dominate, as global commodity prices are slow to respond and the world economy is booming. Only subsequently U.S. real GDP gradually declines, as energy price increases gain momentum and the economic stimulus from higher global demand weakens. This response pattern differs sharply from the effect of higher energy prices driven primarily by shocks to the precautionary demand for crude oil, for example.

The distinction between higher energy prices driven by one shock or another has far-reaching implications, as each shock has different effects on the U.S. economy and on the real price of energy. We illustrated this point for several U.S. macroeconomic aggregates including real GDP, consumer prices and real stock returns. One implication of this analysis is that conventional estimates of the response to unanticipated energy price changes are best thought of as the response to an average energy price shock and in small samples may be sensitive to the choice of sample period, as the composition of the underlying demand and supply shocks evolves over time.

Notwithstanding the many insights the recent literature has yielded, there is still more to be learned about how energy price shocks are transmitted throughout the economy. Future empirical work with disaggregate industry or plant level data augmented by structural models is likely to be promising. A recent example of such work is Herrera (2007). The challenge will be to combine a deeper understanding of the nature of energy price shocks with an explicit model of firm decisions and interactions. One difficulty with such extensions is the absence of disaggregate real GDP data. Many empirical studies have therefore relied on disaggregate gross output data such as measures of industrial production (see, e.g., Lee and Ni 2002, Herrera 2007). This distinction matters because gross output may respond quite differently to energy price shocks than measures of value added such as real GDP (see, e.g., Barsky and Kilian 2002). This fact makes it difficult to relate conclusions of studies based on gross output to standard macroeconomic models based on value added production functions.

There is also considerable scope for developing full-fledged dynamic stochastic general equilibrium (DSGE) models that incorporate global and domestic energy markets. Building on the early contributions of Hamilton (1988), Kim and Loungani (1992), Rotemberg and Woodford (1996), Atkeson and Kehoe (1999), Backus and Crucini (2000), and Finn (2000), among others, there has been renewed interest in DSGE models of the effects of energy price shocks recently. In addition to the extensive work on the relationship between oil prices and monetary policy discussed earlier, a number of additional channels of transmission have been explored. For example, Polgreen and Silos (2006) model the effects of oil price shocks on the skill premium in labor markets. Wei (2003) studies the relationship between oil prices and stock markets. Dhawan and Jeske (2007b) model the energy consumption of households and firms within the context of a DSGE model. Bodenstein, Erceg and Guerrieri (2007) investigate the role of financial risk sharing in a two-country DSGE model of the external adjustments caused by oil price shocks. Wen and Aguiar-Conraria (2006) stress the role of externalities in the propagation of oil price shocks. Notwithstanding this flurry of activity, existing DSGE models with few exceptions have remained extremely simplistic in treating crude oil prices as exogenous driving processes and in avoiding aggregation issues. Clearly, the development of these models is still at an early stage. More refined models that distinguish between demand and supply shocks in the crude oil market, in particular, are likely to yield important additional insights and to put earlier results in perspective. A prominent recent example of such work is Bodenstein, Erceg and Guerrieri (2007). Other examples include Nakov and Pescatori (2007) and Balke, Brown and Yücel (2008).

References

[1] Alquist, R., and L. Kilian (2008), "What Do We Learn from the Price of Crude Oil Futures," mimeo, Department of Economics, University of Michigan.

[2] Atkeson, A., and P.J. Kehoe (1999), "Models of Energy Use: Putty-Putty versus Putty-Clay," *American Economic Review*, 89, 1028-1043.

[3] Auerbach, A.J. (1987), "The Tax Reform Act of 1986 and the Cost of Capital," *Journal of Economic Perspectives*, 1, Summer, 73-86.

[4] Backus, D.K., and M.J. Crucini (2000), "Oil Prices and the Terms of Trade," *Journal of International Economics*, 50, 185-213.

[5] Balke, N.S., Brown, S.P.A., and M.K. Yücel (2002), "Oil Price Shocks and the U.S. Economy: Where Does the Asymmetry Originate?" *Energy Journal*, 23, 27-52.

[6] Balke, N.S., Brown, S.P.A., and M.K. Yücel (2008), "Globalization, Oil Price Shocks and U.S. Economic Activity" mimeo, Federal Reserve Bank of Dallas.

[7] Barsky, R.B., and L. Kilian (2002), "Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative," in B. Bernanke and K. Rogoff (eds.), *NBER Macroeconomics Annual 2001*, 137-183.

[8] Barsky, R.B., and L. Kilian (2004), "Oil and the Macroeconomy Since the 1970s," *Journal of Economic Perspectives*, 18, Fall, 115-134.

[9] Bernanke, B.S. (1983), "Irreversibility, Uncertainty, and Cyclical Investment," *Quarterly Journal of Economics*, 98, 85-106.

[10] Bernanke, B.S. (2004), "Oil and the Economy," remarks at the Distinguished Lecture Series, Darton College, Albany, Georgia, October 21.

[11] Bernanke, B.S. (2006a), "Energy and the Economy," speech to the Economic Club of Chicago, June 15.

[12] Bernanke, B.S. (2006b), "The Economic Outlook," remarks before the National Italian American Foundation, New York, November 28.

[13] Bernanke, B.S., M. Gertler, and M. Watson (1997), "Systematic Monetary Policy and the Effects of Oil Price Shocks," *Brookings Papers on Economic Activity*, 1, 91-142.

[14] Bernanke, B.S., M. Gertler, and M. Watson (2004), "Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy: A Reply," *Journal of Money, Credit, and Banking*, 36, 286-291.

[15] Blanchard, O.J., and J. Galí (2007), "The Macroeconomic Effects of Oil Shocks: Why are the 2000s so Different from the 1970s?" NBER Working Paper No. 13368.

[16] Bodenstein, M., C.J. Erceg, and L. Guerrieri (2007), "Oil Shocks and External Adjustment," mimeo, Federal Reserve Board.

[17] Bodenstein, M., C.J. Erceg, and L. Guerrieri (2008), "Optimal Monetary Policy with Distinct Core and Headline Inflation Rates," forthcoming: *Journal of Monetary Economics*.

[18] Bresnahan, T., and V. Ramey (1993), "Segment Shifts and Capacity Utilization in the U.S. Automobile Industry," *American Economic Review Papers and Proceedings*, 83, 213-218.

[19] Bureau of Economic Analysis (1987), "The Business Situation," *Survey of Current Business*, January.

[20] Carlstrom, C.T., and T.S. Fuerst (2006), "Oil Prices, Monetary Policy, and Counterfactual Experiments," *Journal of Money, Credit, and Banking*, 38, 1945-1958.

[21] Cooley, T.F., and S. LeRoy (1985), "Atheoretical Macroeconometrics: A Critique," *Journal of Monetary Economics*, 16, 283-308.

[22] Cragg, J.G., and S.G. Donald (1993), "Testing Identifiability and Specification in Instrumental Variable Models," *Econometric Theory*, 9, 222-240.

[23] Cullen, J.B., L. Friedberg and C. Wolfram (2004), "Consumption and Changes in Home Energy Costs: How Prevalent is the 'Heat or Eat' Decision?", mimeo, Department of Economics, University of California at San Diego.

[24] Dahl, C., and T. Sterner (1991), "Analyzing Gasoline Demand Elasticities: A Survey," *Energy Economics*, 13, 203-210.

[25] Davis, S.J. (1987), "Allocative Disturbances and Specific Capital in Real Business Cycle Theories," *American Economic Review Papers and Proceedings*, 77, 326-332.

[26] Davis, S.J., and J. Haltiwanger (2001), "Sectoral Job Creation and Destruction Responses to Oil Price Changes," *Journal of Monetary Economics*, 48, 465-512.

[27] Dhawan, R., and K. Jeske (2007a), "Taylor Rules with Headline InflationL A Bad Idea!" mimeo, Federal Reserve Bank of Atlanta.

[28] Dhawan, R., and K. Jeske (2007b), "Energy Price Shocks and the Macroeconomy: The Role of Consumer Durables," mimeo, Federal Reserve Bank of Atlanta.

[29] Dotsey, M., and M. Reid (1992), "Oil Shocks, Monetary Policy, and Economic Activity," *Economic Review of the Federal Reserve Bank of Richmond*, 78, 14-27.

[30] Dudine, P., Hendel, I., and A. Lizzeri (2006), "Storable Good Monopoly: The Role of Commitment," *American Economic Review*, 96, 1706-1719.

[31] Edelstein, P., and L. Kilian (2007a), "Retail Energy Prices and Consumer Expenditures," mimeo, Department of Economics, University of Michigan.

[32] Edelstein, P., and L. Kilian (2007b), "The Response of Business Fixed Investment to Energy Price Changes: A Test of Some Hypotheses about the Transmission of Energy Price Shocks," *B.E. Journal of Macroeconomics*, 7 (Contributions).

[33] Ferderer, J.P. (1996), "Oil Price Volatility and the Macroeconomy: A Solution to the Asymmetry Puzzle," *Journal of Macroeconomics*, 18, 1-16.

[34] Finn, M.G. (2000), "Perfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, 32, 400-416.

[35] Goldberg, P.K. (1998), "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," *Journal of Industrial Economics*, 46, 1-33.

[36] Gonçalves, S., and L. Kilian (2004), "Bootstrapping Autoregressions in the Presence of Conditional Heteroskedasticity of Unknown Form," *Journal of Econometrics*, 123, 89-120.

[37] Hamilton, J.D. (1983), "Oil and the Macroeconomy Since World War II," *Journal of Political Economy*, 91, 228-248.

[38] Hamilton, J.D. (1988) "A Neoclassical Model of Unemployment and the Business Cycle," *Journal of Political Economy*, 96, 593-617.

[39] Hamilton, J.D. (1996), "This is What Happened to the Oil Price-Macroeconomy Relationship," *Journal of Monetary Economics*, 38, 215-220.

[40] Hamilton, J.D. (2003), "What is an Oil Shock?," *Journal of Econometrics*, 113, 363-398.

[41] Hamilton, J.D. (2008), "Oil and the Macroeconomy," forthcoming in S. Durlauf and L. Blume (eds), *The New Palgrave Dictionary of Economics*, 2nd ed., Palgrave MacMillan Ltd.

[42] Hamilton, J.D., and A.M. Herrera (2004), "Oil Shocks and Aggregate Economic Behavior: The Role of Monetary Policy: Comment," *Journal of Money, Credit, and Banking*, 36, 265-286.

[43] Herrera, A-M. (2007), "Inventories, Oil Shocks and Macroeconomic Behavior," mimeo, Department of Economics, Michigan State University.

[44] Herrera, A.-M., and E. Pesavento (2007), "Oil Price Shocks, Systematic Monetary Policy and the 'Great Moderation'," forthcoming: *Macroeconomic Dynamics.*

[45] Hess, P. J. and B. S. Lee (1999), "Stock Returns and Inflation with Supply and Demand Disturbances," *Review of Financial Studies*, 12, 1203-1218.

[46] Hooker, M.A. (1996a), "What Happened to the Oil Price-Macroeconomy Relationship?" *Journal of Monetary Economics*, 38, 195-213.

[47] Hooker, M.A. (1996b), "This Is What Happened to the Oil Price-Macroeconomy Relationship: Reply," *Journal of Monetary Economics*, 38, 221–222.

[48] Hooker, M.A. (2002), "Are Oil Shocks Inflationary? Asymmetric and Nonlinear Specifications Versus Changes in Regime," *Journal of Money, Credit, and Banking*, 34, 540-561.

[49] Hughes, J.E., C.R. Knittel, and D. Sperling (2007), "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand," forthcoming: *Energy Journal*.

[50] Kaul, G., and H.N. Seyhun (1990), "Relative Price Variability, Real Shocks and the Stock Market," *Journal of Finance*, 45, 479-496.

[51] Kilian, L. (2008a), "Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?" *Review of Economics and Statistics*, 90, 216-240.

[52] Kilian, L. (2008b), "A Comparison of the Effects of Exogenous Oil Supply Shocks on Output and Inflation in the G7 Countries," *Journal of the European Economic Association*, 6, 78-121.

[53] Kilian, L. (2008c), "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market," forthcoming: *American Economic Review.*

[54] Kilian, L., and C. Park (2008), "The Impact of Oil Price Shocks on the U.S. Stock Market," mimeo, Department of Economics, University of Michigan.

[55] Kilian, L., and C. Vega (2008), "Do Energy Prices Respond to U.S. Macroeconomic News? A Test of the Hypothesis of Predetermined Energy Prices," mimeo, Department of Economics, University of Michigan.

[56] Kim, I.-M. and P. Loungani (1992), "The Role of Energy in Real Business Cycle Models," *Journal of Monetary Economics*, 29, 173-189.

[57] Leduc, S., and K. Sill (2004), "A Quantitative Analysis of Oil-Price Shocks, Systematic Monetary Policy, and Economic Downturns," *Journal of Monetary Economics*, 51, 781-808.

[58] Lee, K., and S. Ni (2002), "On the Dynamic Effects of Oil Price Shocks: A Study Using Industry Level Data," *Journal of Monetary Economics*, 49, 823-852.

[59] Lee, K., S. Ni, and R.A. Ratti (1995), "Oil Shocks and the Macroeconomy: The Role of Price Variability," *Energy Journal*, 16, 39-56.

[60] Mork, K.A. (1989), "Oil and the Macroeconomy. When Prices Go Up and Down: An Extension of Hamilton's Results," *Journal of Political Economy*, 97, 740-744.

[61] Nakov,A., and A. Pescatori (2007), "Inflation-Output Gap Trade-off with a Dominant Oil Supplier," mimeo, Federal Reserve Bank of Cleveland.

[62] Pindyck, R.S. (1991), "Irreversibility, Uncertainty and Investment," *Journal of Economic Literature*, 29, 1110-1148.

[63] Polgreen, L. and P. Silos (2006), "Crude Substitutions: The Cyclical Dynamics of Oil Prices and the College Premium," *Federal Reserve Bank of Atlanta Working Paper 2006-14*.

[64] Reiss, P.C., and M.W. White (2005), "Household Electricity Demand Revisited," *Review of Economic Studies*, 72, 853-883.

[65] Rotemberg, J., and M. Woodford (1996), "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit, and Banking*, 28, Part 1, 550-77.

[66] Stock, J.H., J.H. Wright, and M. Yogo (2002), "A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments," *Journal of Business and Economic Statistics*, 20, 518-529.

[67] Stock, J.H., and M. Yogo (2005), "Testing for Weak Instruments in Linear IV Regression," in D.W.K. Andrews and J.H. Stock (eds.), *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*, Cambridge: Cambridge University Press, 80–108.

[68] Wakefield, J.C. (1987), "The Tax Reform Act of 1986," *Survey of Current Business*, Bureau of Economic Analysis.

[69] Wei, C. (2003), "Energy, the Stock Market, and the Putty-Clay Investment Models," *American Economic Review*, 93, 311-323.

Table 1: Instrumental Variable Regressions for U.S. Real GDP Growth

Regressand: Δgdp_t	Exogenous oil supply shocks measured as quantitative dummies as in Hamilton (2003)								Exogenous oil supply shocks as defined in Kilian (2007a)				
	1947.II-2001.III		1947.II-2004.III		1973.I-2004.III		1973.I-2004.III		1973.I-2004.III				
Regressors:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
c	×	×	×	×	×	×	×	×	×	×	×	×	×
Δgdp_{t-1}	×	×	×	×	×	×	×	×	×	×	×	×	×
Δgdp_{t-2}	×	×	×	×	×	×	×	×	×	×	×	×	×
Δgdp_{t-3}	×	×	×	×	×	×	×	×	×	×	×	×	×
Δgdp_{t-4}	×	×	×	×	×	×	×	×	×	×	×	×	×
Δnp_{t-1}^{oil}	×	-	×	-	×	-	×	-	×	-	-	-	-
Δnp_{t-2}^{oil}	×	-	×	-	×	-	×	-	×	-	-	-	-
Δnp_{t-3}^{oil}	×	-	×	-	×	-	×	-	×	-	-	-	-
Δnp_{t-4}^{oil}	×	-	×	-	×	-	×	-	×	-	-	-	-
Δrp_{t-1}^{oil}	-	×	-	×	-	×	-	×	-	×	×	×	×
Δrp_{t-2}^{oil}	-	×	-	×	-	×	-	×	-	×	×	×	×
Δrp_{t-3}^{oil}	-	×	-	×	-	×	-	×	-	×	×	×	×
Δrp_{t-4}^{oil}	-	×	-	×	-	×	-	×	-	×	×	×	×
$g_{\min}$	1.568	1.524	1.172	1.121	0.660	0.559	0.563	0.423	0.063	0.055	0.104	0.055	0.137

Notes: The instruments include a constant, four lags of real GDP growth and eight lags of the oil supply shock series. np_t^{oil} and rp_t^{oil} stand for the nominal and real price of crude oil, respectively. × marks regressors included in the final-stage regression. Columns (1)-(6) are based on the PPI for domestic crude oil as reported by the BLS and used in Hamilton (2003); columns (7)-(13) are based on the price of imported crude oil as used in Barsky and Kilian (2004). Columns (1) through (8) are based on the quantitative dummy measure of exogenous oil supply shocks of Hamilton (2003), as extended by Kilian (2008a). Columns (9) and (10) are based on the alternative measure of exogenous oil supply shocks introduced in Kilian (2008a,b). The last three columns are based on variations of this measure. Column (11) excludes the Saudi production response; column (12) drops the 1973 Arab oil embargo; column (13) includes Saudi Arabia in the benchmark starting in 1974. The last line shows the $g_{\min}$ -statistic of Stock and Yogo (2005). The least conservative critical value for the null of weak instruments is about 4.

Table 2: One-Year Energy Price Elasticities
U.S. Consumer Expenditures
1970.2-2006.7

Total Energy Consumption	**-0.45**
Electricity	-0.15
Gasoline	**-0.48**
Heating Oil and Coal	**-1.47**
Natural Gas	-0.33
Total Consumption	**-0.15**
Nondurables	**-0.11**
Services	**-0.10**
Durables	**-0.47**
Vehicles	**-0.84**
Other Durables	-0.19

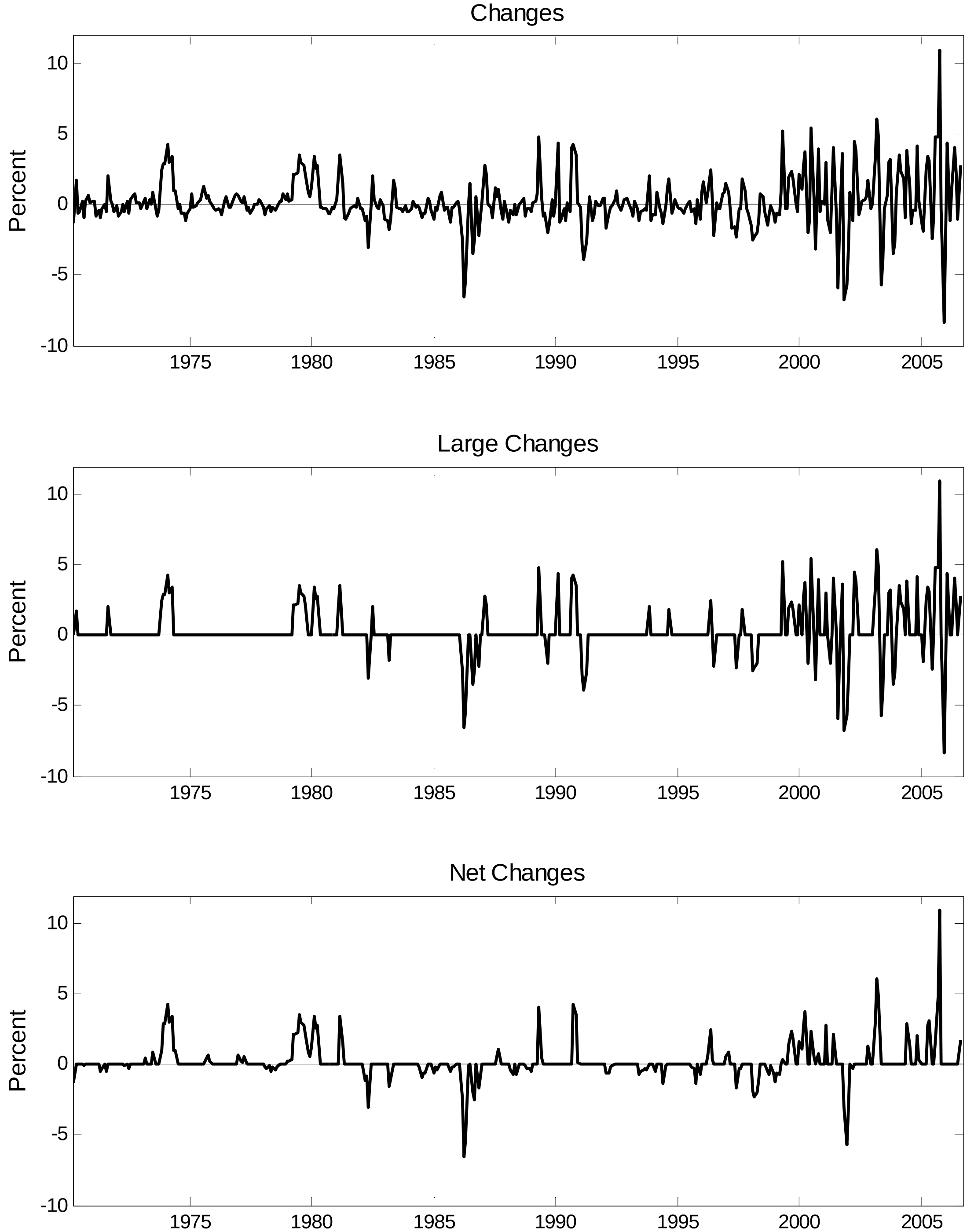
NOTES: Full-sample estimates based on the purchasing power loss associated with a change in weighted retail energy prices. The elasticities have been computed based on the average share of energy in the sample period. All results are based on estimates in Edelstein and Kilian (2007a). Boldface indicates statistical significance at the 5% level.

Table 3: One-Year Energy Price Elasticities
U.S. Investment Expenditures
1970.II-2006.IV

Total Nonresidential Investment	-0.16
Structures	0.09
Structures Excluding Mining	0.03
Mining	**1.39**
Equipment	-0.30
Equipment Excluding Mining and Oil Field Machinery	-0.30
Mining and Oil Field Machinery	**2.13**
Residential Investment in Structures	**-1.02**

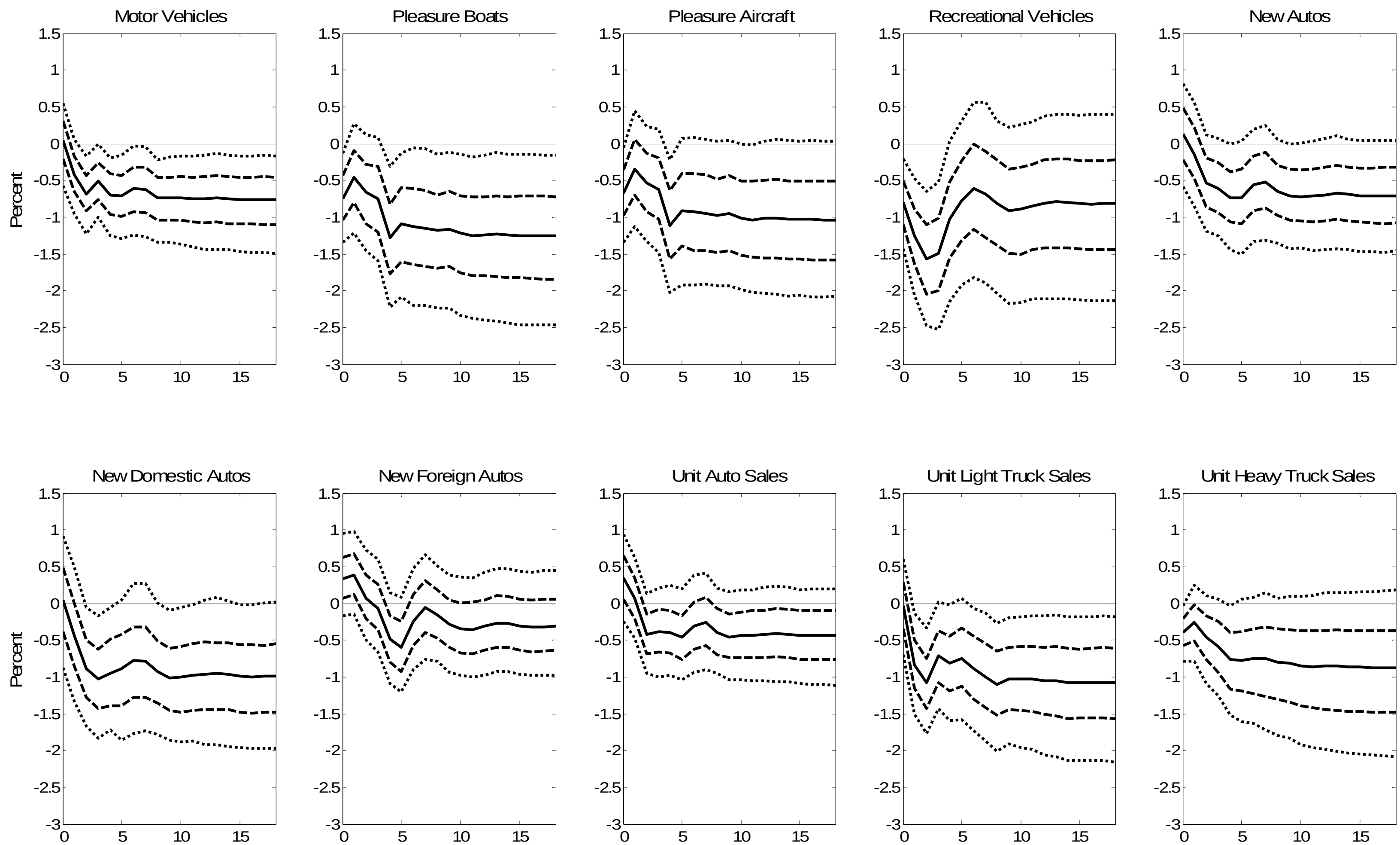
NOTES: Full-sample results with quarterly dummies for 1986. Estimates based on percent change in intermediate producer energy prices. All results are based on estimates in Edelstein and Kilian (2007b). Boldface indicates statistical significance at the 5% level. Expenditures on mining are mainly related to the exploration for and extraction of crude oil, natural gas and coal.

Figure 1: Alternative Specifications of Energy Price Shocks
U.S. Retail Energy Prices
1970.2-2006.7



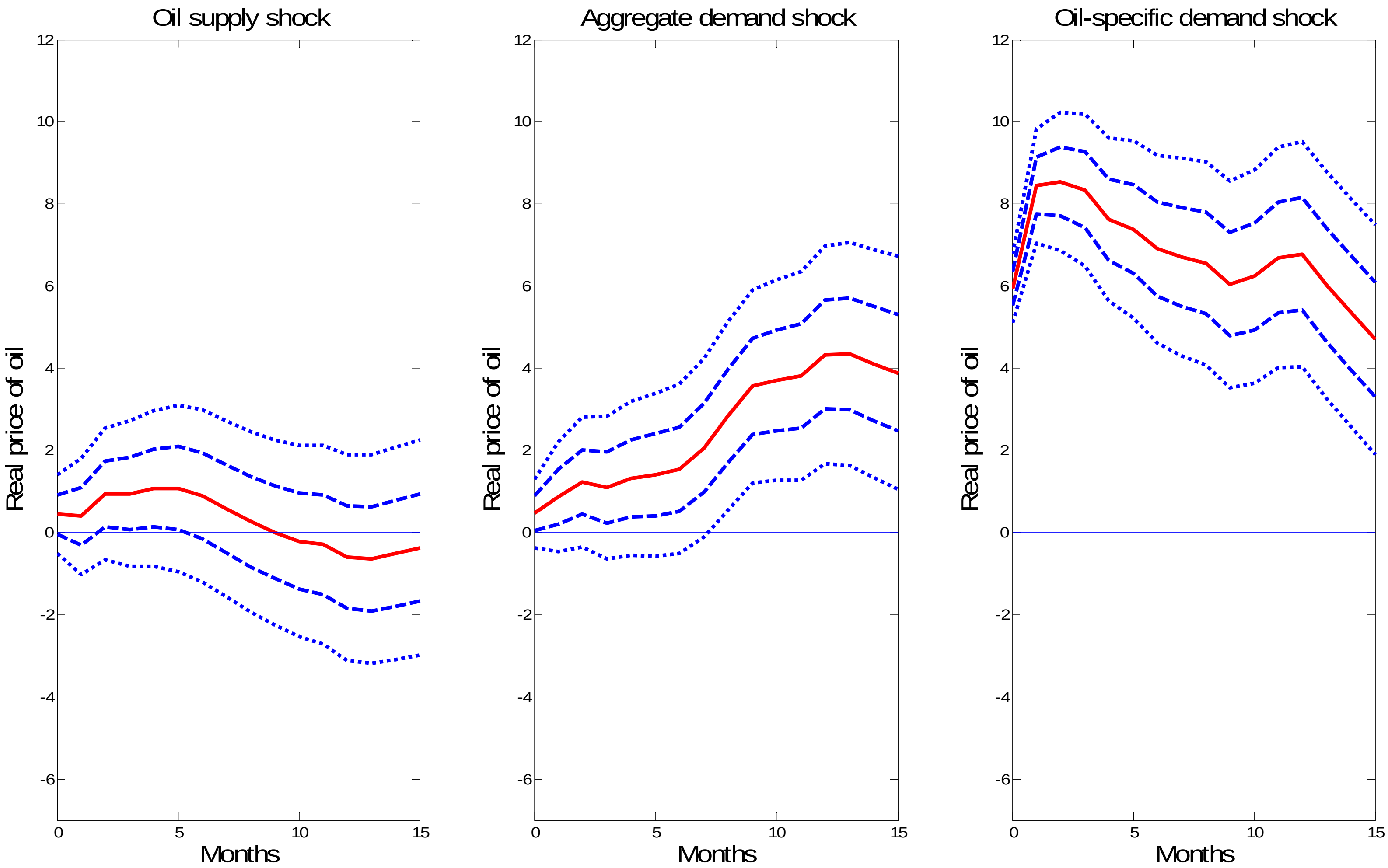
NOTES: Based on PCE price index for consumer energy prices as reported by the BEA. Source: Edelstein and Kilian (2007a).

Figure 2: Response of Real Consumption by Expenditure Item with One- and Two-Standard Error Bands 1970.2-2006.7



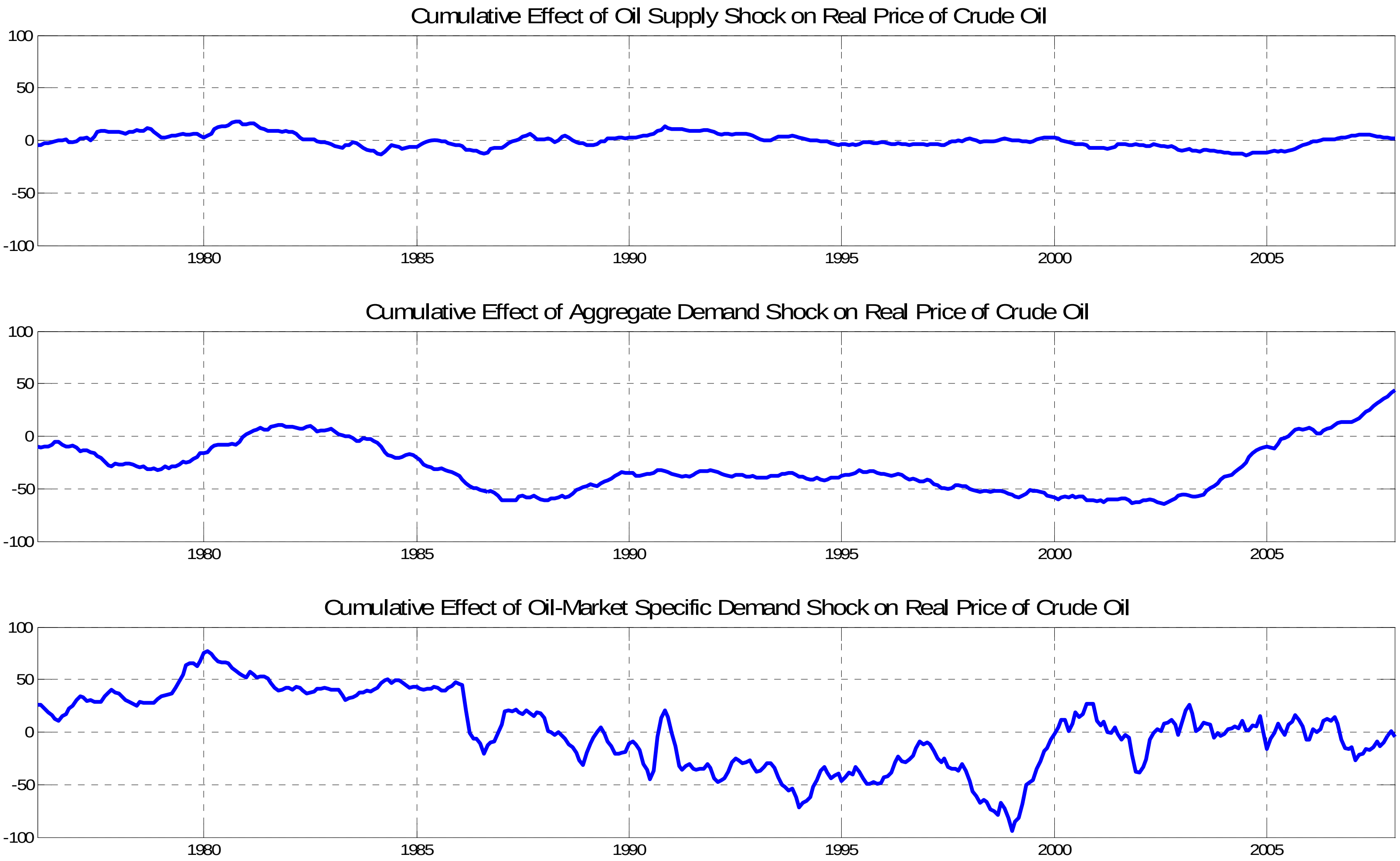
NOTES: Based on PCE price index for consumer energy prices as reported by the BEA. Source: Edelstein and Kilian (2007a).

Figure 3: Responses of the Real Price of Crude Oil to Oil Demand and Oil Supply Shocks
Estimates with One- and Two-Standard Error Bands



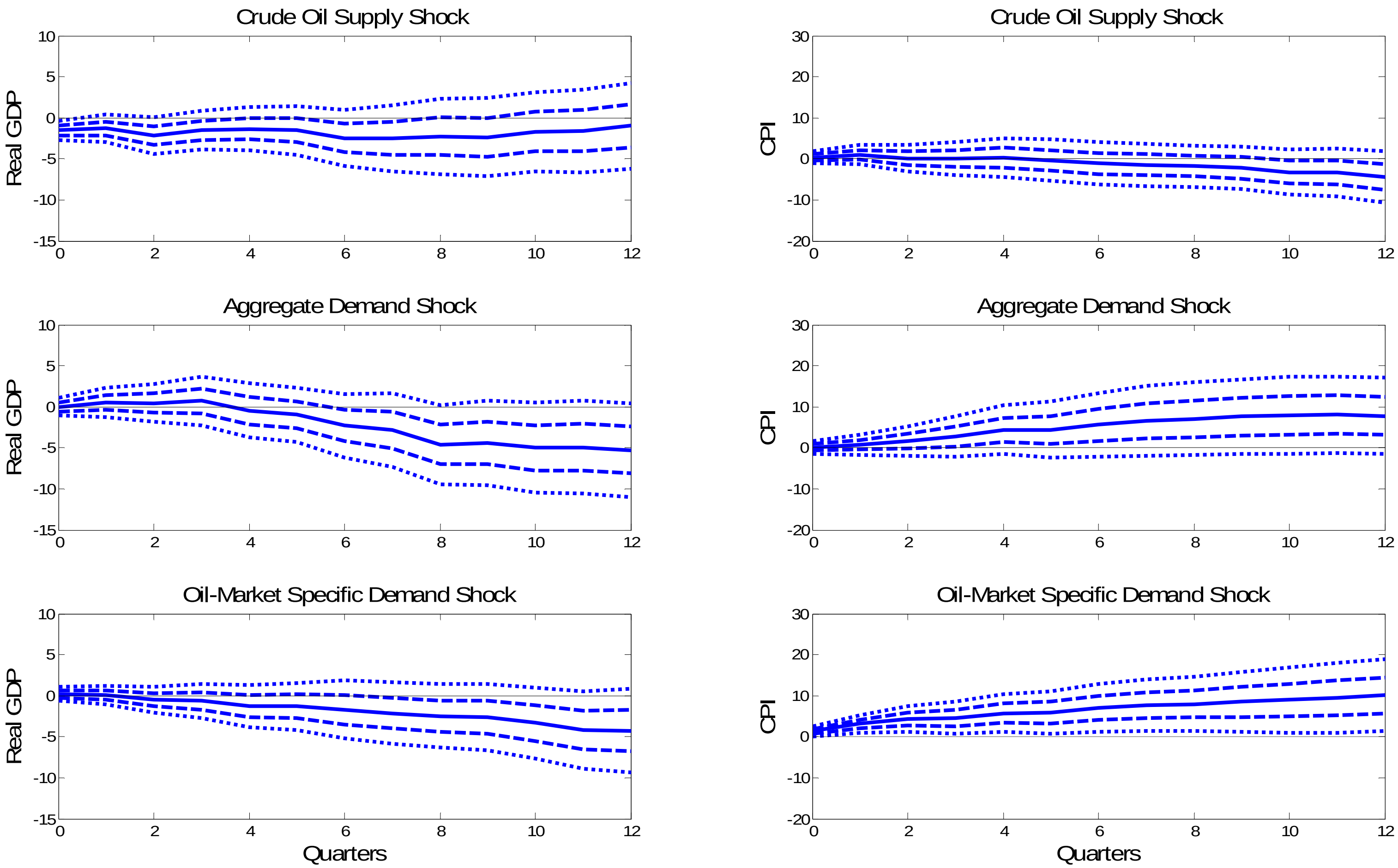
NOTES: Based on Kilian (2008c).

Figure 4: Historical Decomposition of Fluctuations in the Real Price of Crude Oil: 1975.2-2007.12



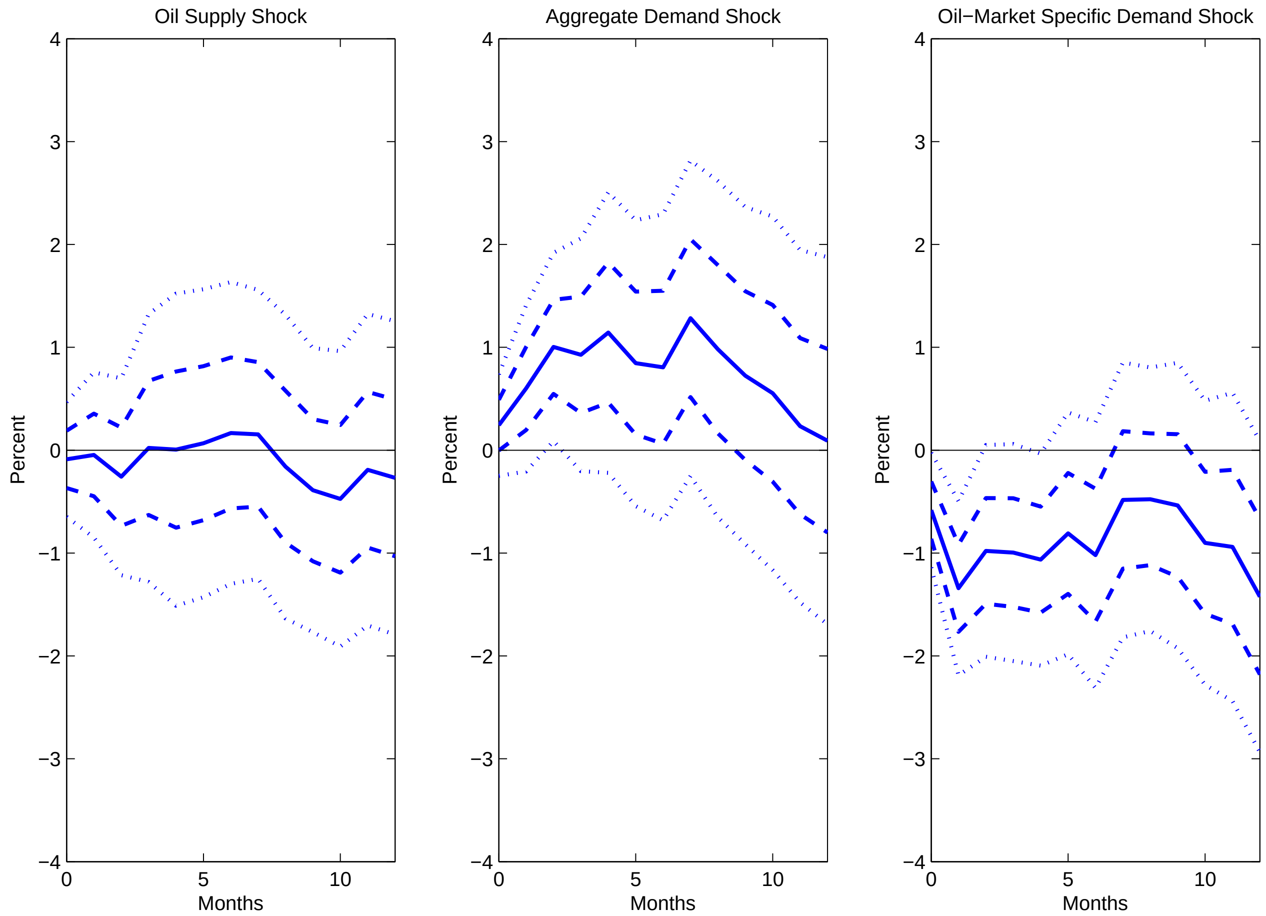
NOTES: Source: Kilian (2008c).

Figure 5: Responses of U.S. Real GDP and Consumer Prices to Oil Demand and Oil Supply Shocks
Estimates with One- and Two-Standard Error Bands



NOTES: Estimates based on the distributed lag model as described in Kilian (2008c). Confidence intervals based on block bootstrap methods. Source: Kilian (2008c).

Figure 6: Cumulative Reponses of Real U.S. Stock Returns to Oil Demand and Oil Supply Shocks Estimates with One- and Two-Standard Error Bands



NOTES: Source: Kilian and Park (2008).