

A Work Project, presented as part of the requirements for the Award of a Masters Degree in Economics
from the Faculdade de Economia da Universidade Nova de Lisboa.

THE MACROECONOMIC EFFECTS OF (DIFFERENT) OIL SHOCKS: A VAR APPROACH

ANDRÉ ROCHA GRAÇA FERNANDES MOREIRA

NR. 167

A Project carried out on the Macroeconomics area, with the supervision of:

Professor Joaquim Pina

2009, June

Final Report

Abstract

This paper investigates the contribution of oil supply, global activity and precautionary oil-demand innovations for the major episodes of increasing oil prices and US macroeconomic fluctuations. The empirical approach employed is based on the recursively identified VAR model of the crude oil market proposed in Kilian (2008). The estimated results attribute the 2002-2008 oil price increase to global activity *and* to precautionary demand shocks (during the 2004-2006 period). Furthermore, based on the responses of US industrial production and producer prices, the distinct innovations are shown to produce different macroeconomic effects. Industrial production, in particular, is shown to respond positively and significantly to global activity shocks in the short-run, complementing and reinforcing Kilian's explanation for the thriving behavior of the US economy between 2002 and 2008. Finally, evidence supporting the relevance of Blanchard and Galí's structural change hypothesis is provided.

1. Introduction

Since the 1970s, oil price shocks have been frequently associated with recessions in industrialized countries. Yet, the most recent oil price increase – from about 30 dollars a barrel in 2002 to approximately 140 dollars in 2008 – failed to produce a significant negative impact on the world economy for several years. This fact has reignited the debate on the economic effects of oil price shocks in the literature.

Although similar in magnitude, the 2002-2008 episode appeared quite different from previous oil price shocks. While earlier spikes in the price of oil had been sharp and immediate, the most recent price increase proved to be much more prolonged and sustained. Several factors have been proposed in trying to explain oil price fluctuations prior to 2002, *e.g.* the low price-elasticity of short-run demand and supply, the vulnerability of supplies to disruptions, the peak in US oil production (Hamilton 2009), and swings in the precautionary demand for oil (Kilian 2008). Concerning the 2002-2008 episode, however, the prevailing view has regarded increases in global economic activity instead – fueled by the rapid growth of China and India – as having played a major role in driving the price of oil up. Realizing that price increases originating from distinct sources could be producing different economic effects, a strand of empirical literature trying to disentangle structural shocks in the crude oil market – in which the current paper fits in – started to evolve.

In an important contribution, Kilian (2008) modeled the crude oil market in a recursively identified VAR framework in order to decompose the real price of oil into three components: crude oil supply shocks, shocks to the global demand for industrial commodities and demand shocks specific to the oil market (regarded as precautionary demand shocks). Kilian's results showed that, while the previous oil shocks had been induced by other factors, the most recent increase in the price of oil was largely driven

by the cumulative effects of positive global demand shocks. The role of the other two shocks was found to be negligible during that period. The impact of the distinct crude oil market innovations both on the macroeconomy (Kilian 2008) and on the stock market (Kilian and Park 2008) was also explored. Providing an important insight, the short-run impact of global demand shocks on both GDP and stock returns was found to be positive for the US, showing that, depending on the underlying structural shock, increasing oil prices need not necessarily produce recessionary effects. The explanation for the resilience of the U.S. economy during the 2003-2008 demand driven oil price increase could thus lie on this type of behavior.

The previous discussion provides the motivation for the current paper. The empirical approach employed is based on a recursively identified VAR model of the crude oil market along the lines of Kilian (2008). Kilian's VAR is modified taking into account Apergis and Miller's (2009) critique so as to include only variables of the same order of integration, *i.e.* $I(1)$. A different measure of global economic activity is also included in place of Kilian's ocean freight rate index. This framework is used in this paper to investigate several issues. First, analysis of the crude oil market is carried out, searching for additional insights into the main sources of oil price fluctuations since the 1970s. Particular interest lies in the most recent oil price surge. The obtained evidence supports the view that the 2002-2008 oil price increase was importantly driven by positive global economic activity shocks. This is in line with Kilian's results. However, an important contribution of positive precautionary demand shocks between 2004 and 2006 is additionally found in this paper, consistent *e.g.* with the Iraq war, changes in Asian consumer preferences or scarcity effects. Second, the macroeconomic effects of different crude oil market innovations are explored, focusing on industrial production and producer prices in the US. The chief advantage of this choice of variables over GDP

and consumer prices – as in Kilian – is that it allows for an integrated VAR approach that – unlike his – does not rule out possible important feedbacks from the US economy to the crude oil market. The results obtained indicate that distinct crude oil market innovations produce different macroeconomic effects. Most importantly, industrial production is shown to respond positively and significantly to increases in the price of oil caused by global activity shocks. This both complements and reinforces previous findings in Kilian regarding GDP, showing that increases in the price of oil may be associated with thriving economic activity in the US. Such a result is acceptable because oil demand shocks of this type, induced by booms in global economic activity, are expected to feed to the economy through two opposite-signed effects. On the one hand, a direct stimulating effect will arise naturally from increases in global demand – *e.g.* through increased exports and investment flows – while, on the other hand, increases in global activity will tend to raise the price of oil at the same time, thus indirectly producing a negative effect on US activity. Finally, the relevance of the structural change hypothesis proposed in the Great Moderation-related literature is assessed in light of this paper’s model. Evidence of a structural break in 1984 is found, consistent with a more muted response of US macroeconomic variables to crude oil market innovations in the post-1984 period. Therefore, simply allowing for differences in effects of the distinct crude oil market innovations does not seem to fully account for the observed change in the oil price-macro-economy relationship, contrary to the view expressed in Lippi and Nobili (2009). Further research on the structural change hypothesis should thus be pursued.

The remainder of the paper is organized as follows: section 2 presents an overview of the relevant literature; section 3 briefly describes the VAR methodology; section 4 discusses the specification of the crude oil market model and the set of

identifying assumptions; section 5 presents an empirical analysis of the crude oil market; section 6 presents empirical results concerning the macroeconomic effects of oil market innovations and assesses the importance of the structural change hypothesis in light of this paper's model; section 7 concludes.

2. Related Literature: A brief overview

Research interest on the economics of oil arose in the 1970s, motivated by the scenario of stagflation in industrialized countries that followed the first and second oil price shocks. The association of stagflation episodes – characterized by low growth, rising unemployment and high inflation – to oil price peaks in the '70s suggested the existence of a causal link between the two. Rasche and Tatom (1977, 1981), Hamilton (1983) and Gisser and Goodwin (1986) were among the first to report a negative relationship between oil prices and economic activity for the US in empirical studies, giving birth to a body of literature that has been growing ever since. Its relevance to the present day is apparent in the words of Hamilton (2005) who stated that “*nine out of ten of the US recessions since World War II were preceded by a spike up in oil prices*”. Still, despite the depth of the existing oil-related literature, the question of whether or not a stable long-term oil price-macroeconomy relationship exists still remains open, as Jones Leiby and Paik (2004) noted.

Hamilton (1983) identified early signs of instability in the empirical link between oil prices and output. This instability started becoming more apparent as large price decreases (*e.g.* in 1986, following the OPEC collapse) failed to produce significant positive economic responses. Early approaches addressing this issue by Loungani (1986) and Davis (1987a,b) provided evidence of a nonlinear relationship that Hamilton (1988) attributed to the existence of oil-induced resource reallocation costs, expected to

aggravate the negative impact of price increases and to offset the positive effect of equivalent price decreases. A related strand of literature, including contributions by Bohi (1989, 1991), Bernanke, Gertler and Watson (1997) and Barsky and Kilian (2002), has placed emphasis on the endogenous response of monetary policy – instead of the oil price changes themselves – in explaining the bulk of the contractionary effects of oil price increases. This view offered an alternative explanation for the asymmetric response of the economy, based on monetary policy reacting to oil price increases but not decreases, a possibility suggested by Balke, Brown and Yücel (2002). Other mechanisms were proposed *e.g.* by Ferderer (1996), who investigated the role of oil price volatility, Huntington (1998), who attributed the asymmetry to the relationship between crude oil and petroleum product prices, and Atkeson and Kehoe (1999), who assumed putty-clay investment technology.

While the discussion on which transmission mechanisms originate the asymmetry has not yet been settled, several alternative nonlinear specifications trying to capture the asymmetric effects of oil price shocks have been proposed. This has allowed for better statistical fit and improved forecasting. Relevant contributions in this area were put forward by Mork (1989) Lee, Ni and Ratti (1995) and Hamilton (1996,2003). Hamilton's net oil price increase, in particular, has been widely used in empirical work. Nonetheless, regardless of their merits, asymmetric measures of oil price shocks would not be the final answer to the oil price-macroeconomy instability issue. Indeed, other important spikes in the price of oil took place after the 1970s, namely in 1990-1991, 2000 and 2003-2008. Still, since the mid-1980s, the industrialized world has witnessed a time of remarkable economic stability¹ – the Great Moderation documented by Blanchard and Simon (2001) and Stock and Watson (2005) – despite large oil price

¹ This paper excludes analysis of the recent financial crisis period since its causes and consequences have not been fully understood.

fluctuations. Consistent with the reduced economic volatility, Hooker (1996) concluded that the oil-macroeconomy relationship had changed in the 1980s, leaving the US economy less vulnerable to oil price shocks. In trying to explain this, two main routes have been pursued. On the one hand, a strand of literature related to the Great Moderation has tried to explain the milder effects of oil price shocks in recent years through structural change. Structural factors such as decreased energy intensity, improved monetary policy and increased flexibility of labor markets have been consistently pointed out in the literature. “Good luck”, a non-structural factor defined as the absence of concurrent adverse shocks, has also been considered. For further discussion see *e.g.* Hooker (2002), Blanchard and Galí (2008) and Herrera and Pesavento (2009). On the other hand, as pointed out in the previous section, a new strand of empirical literature has started to evolve, focusing on disentangling the fundamental demand and supply shocks affecting the price of oil. Recent work on this topic has shown that, depending on the source, shocks yielding equivalent oil price changes may produce quite different economic effects, both in qualitative and quantitative terms. Accordingly, the time-varying effects of oil prices on the macroeconomy can be explained, at least partially, by the dynamics of the relative importance of the different types of shock. Evidence for the US economy regarding GDP, CPI inflation and stock market returns has been put forward by Kilian (2008) and Kilian and Park (2008). Similar implications for the US industrial production have been found in Lippi and Nobili (2008), although using a different approach. The current paper reinforces and complements the conclusions from both these contributions by investigating the impact of crude oil market innovations on US industrial production and producer prices – a set of variables similar to Lippi – using Kilian’s recursively identified VAR approach.

3. The VAR Methodology

The empirical approach in this paper is based on the standard Vector Autoregressive methodology. A Vector Autoregression (VAR) is able to describe the dynamic evolution of a set of variables, based on their common history (Verbeek 2008), while allowing all variables to be treated as endogenous. An important feature of the VAR is that it does not require imposing a priori *incredible identification restrictions*, as Sims (1980) called them. In general, a reduced-form VAR can be written as:

$$y_t = B(L)y_{t-1} + e_t \quad e_t \sim N(0, \Sigma) \quad (1)$$

where $B(L)$ is a lag polynomial of order p and y_t is a vector containing the set of variables of interest. The error terms e_t are assumed to be serially uncorrelated and to have constant variance. Since the right-hand side of (1) contains only predetermined variables, each equation in the VAR system can be consistently estimated by OLS (Enders 2004).

Structural VAR analysis, using impulse response functions, forecast error variance decompositions and historical decompositions, relies on the structural form of the VAR:

$$A_0^{-1}y_t = A(L)y_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N(0, I) \quad (2)$$

where $A(L)$ is a lag polynomial of order p and ε_t is a vector containing the structural innovations. These are related to the reduced form disturbances, e_t , through $e_t = A_0\varepsilon_t$. Since innovation independence is crucial, orthogonality of the structural shocks is assumed to hold throughout. In order to achieve structural shock identification, a matrix A_0 satisfying the following decomposition of the estimated covariance matrix, Σ , is required:

$$\Sigma = E[\varepsilon_t \varepsilon_t'] = A_0 E[e_t e_t'] A_0' = A_0 A_0' \quad (3)$$

Exact identification of an n -variable VAR system may be achieved by imposing $(n^2 - n)/2$ restrictions on the A_0 matrix. For all models in this paper the necessary restrictions are imposed recursively, by means of Choleski decompositions. Impulse response analysis is carried out using two standard error confidence bands, computed from 2000 Monte Carlo replications².

4. Identifying Crude Oil Market Innovations

The point of departure for the subsequent analysis is a model of the crude oil market based on Kilian (2008). Kilian used a recursively identified 3-variable VAR to retrieve three types of crude oil market innovations: oil supply shocks, global activity shocks and oil-specific demand shocks. These are the same I intend to identify. However, some slight modifications to his original framework are to be introduced.

Kilian focused on a set of variables comprising the percentage change in world crude oil production, an index of global real economic activity and the real price of oil. Firstly, Apergis and Miller (2009) noted that Kilian's original model incorporated variables with inconsistent time-series properties. Augmented Dickey-Fuller (ADF) unit root tests confirm that the percentage change in world crude oil production is a stationary series, *i.e.* $I(0)$, while the remaining two series are non-stationary, *i.e.* $I(1)$. Hence, in order to circumvent this problem I propose a model including global crude oil production in levels instead of percentage changes. Secondly, I use a measure of global real economic activity that is different from Kilian's freight rate-based index: a non-energy commodity price index, *i.e.*, an index of commodity prices excluding oil and

² 10.000 replications would increase accuracy but proved to be too computationally intensive. Inference of the main results, however, has been verified not to depend on this choice.

gasoline. While acknowledging that this measure may not be flawless³ – it could certainly be affected by a set of other factors – fluctuations in non-energy commodity prices are still expected to roughly capture changes in global aggregate demand for commodities, reflecting shocks to global economic activity.

Hence, I set up a VAR model of the crude oil market including the following three variables: global crude oil production⁴, *oilprod*, the non-energy commodity price index⁵, *comp*, and the real price of oil⁶, *rpoil*. All variables are expressed in logs. Data frequency is monthly and the sample ranges from 1973:2 to 2007:12, thus covering all the major episodes of spiking oil prices. Consistent with the previous discussion, ADF tests show that all series are I(1). Hence, I follow Sims (1980) and Sims, Stock and Watson (1990) – who clearly recommend against differencing – and estimate the VAR in levels in order to avoid loss of information concerning the joint dynamics of the variables. Possible cointegrating relationships are not included since evidence from the Johansen trace and maximum eigenvalue cointegration tests is largely negative. This choice is in line with most of the relevant oil-related literature. To conclude the specification of the model, the lag length, p , must be chosen. The usual lag selection criteria provide ambiguous results. The Akaike Information Criterion, in particular – the best for monthly data, according to Ivanov and Kilian (2005) – suggests a number of lags ranging from 3 to 16, depending on the model considered. Throughout the remainder of the paper, in order to allow for better comparability, all results refer to models estimated including 12 lags. The choice of 12 lags is supported by the discussion in Hamilton and Herrera (2004), who argued that at least one year worth of

³ Kilian's (2008) dry cargo single voyage ocean freight rate index also has shortcomings. It has been shown to lag increases and lead decreases in economic activity.

⁴ Source: Energy Information Administration (EIA) of the U.S. Department of Energy.

⁵ Source: Commodity Research Bureau.

⁶ Source: EIA, extended backwards to 1973:2 as in Barsky and Kilian (2002). I thank Professor Lutz Kilian for gracefully providing this data.

lags should be included in order to capture all the relevant effects of oil price changes and to control for seasonal factors. It is also consistent with Kilian (2001) who pointed out that, for impulse response analysis, the dangers of underfitting a VAR exceed those of overfitting it. All important conclusions have been verified to be robust to the lag length choice and to hold *e.g.* for $p = 6$ (as in Lippi and Nobili 2009) and $p = 24$ (as in Kilian 2008).

In order to perform structural analysis from such a 3-variable VAR, exact identification requires imposing three restrictions. The Choleski ordering of the variables matters and must be chosen carefully since at least one of the residual correlations, $\rho_{i,j}$, is statistically significant⁷. (See Figure 1)

Figure 1: Residual correlation matrix

	<i>oilprod</i>	<i>comp</i>	<i>rpoil</i>
<i>oilprod</i>	1	-0.027	-0.078
<i>comp</i>	-0.027	1	0.115
<i>rpoil</i>	-0.078	0.115	1

Economic reasoning should therefore be used to the largest possible extent in order to adequately impose the required structure upon the model. In the spirit of Kilian, I intend to identify three types of structural shocks: oil supply shocks, global activity shocks and demand shocks specific to the oil market. All innovations are defined so as to raise the price of oil. An oil supply shock is defined as an innovation that lowers global crude oil production. A global activity shock is defined as a shock that increases the demand for all commodities, thus causing an increase in the non-energy commodity price index. Finally, an oil-specific demand shock is defined as an innovation to the real price of oil

⁷ The correlations are statistically significant if $|\rho_{i,j}| > 2 * \frac{1}{\sqrt{407}}$, i.e. if $|\rho_{i,j}| > 0,09914$.

that is independent from supply shocks and global activity shocks, thus capturing idiosyncratic changes in demand. The necessary restrictions on A_0 are motivated by the identifying assumptions explained below and summarized in (4).

$$\begin{bmatrix} e_t^{oilprod} \\ e_t^{comp} \\ e_t^{rpoil} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{global\ activity\ shock} \\ \varepsilon_t^{oil-specific\ demand\ shock} \end{bmatrix} \quad (4)$$

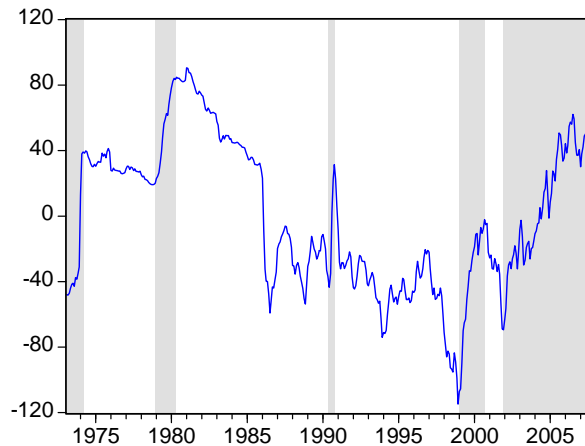
This identification strategy assumes, first, that oil production does not respond to global activity shocks and oil-specific demand shocks within the month. This is consistent with a vertical short-run supply curve, which seems reasonable if one considers both the large costs from changing production decisions and the high volatility of the crude oil market. Second, it assumes that the price of non-energy commodities does not respond contemporaneously to oil market-specific shocks. This is in conformity with the delayed response of global economic activity empirically observed after the main episodes of spiking oil prices. Third and finally, the real price of oil is expected to reflect changes in all the factors affecting the crude oil market. Therefore, it is allowed to respond immediately to all three types of innovations.

Before proceeding, consider the oil-specific demand shock for a moment. Being orthogonal to oil supply and global activity shocks by construction, it is designed so as to capture idiosyncratic changes in the demand for oil alone, as opposed to changes in the demand for all commodities. I follow Kilian's argument in regarding this type of shock as mainly reflecting swings in the precautionary demand for oil, triggered by fears about future supply shortfalls. Therefore, I will from now on refer to such shocks as precautionary demand shocks instead of oil-specific demand shocks.

5. The Crude Oil Market

The history of oil has been characterized by a great deal of price volatility. The major episodes of increasing oil prices are shown in Figure 2. Two occurred during the '70s, in 1974 and 1979, and three more later on, in 1991, 1999 and 2002-2008. It is worth noting that the most recent episode, in particular, appears to have been somewhat different from all of the previous ones in the sense that the price increase was not as immediate, rather being more prolonged and sustained.

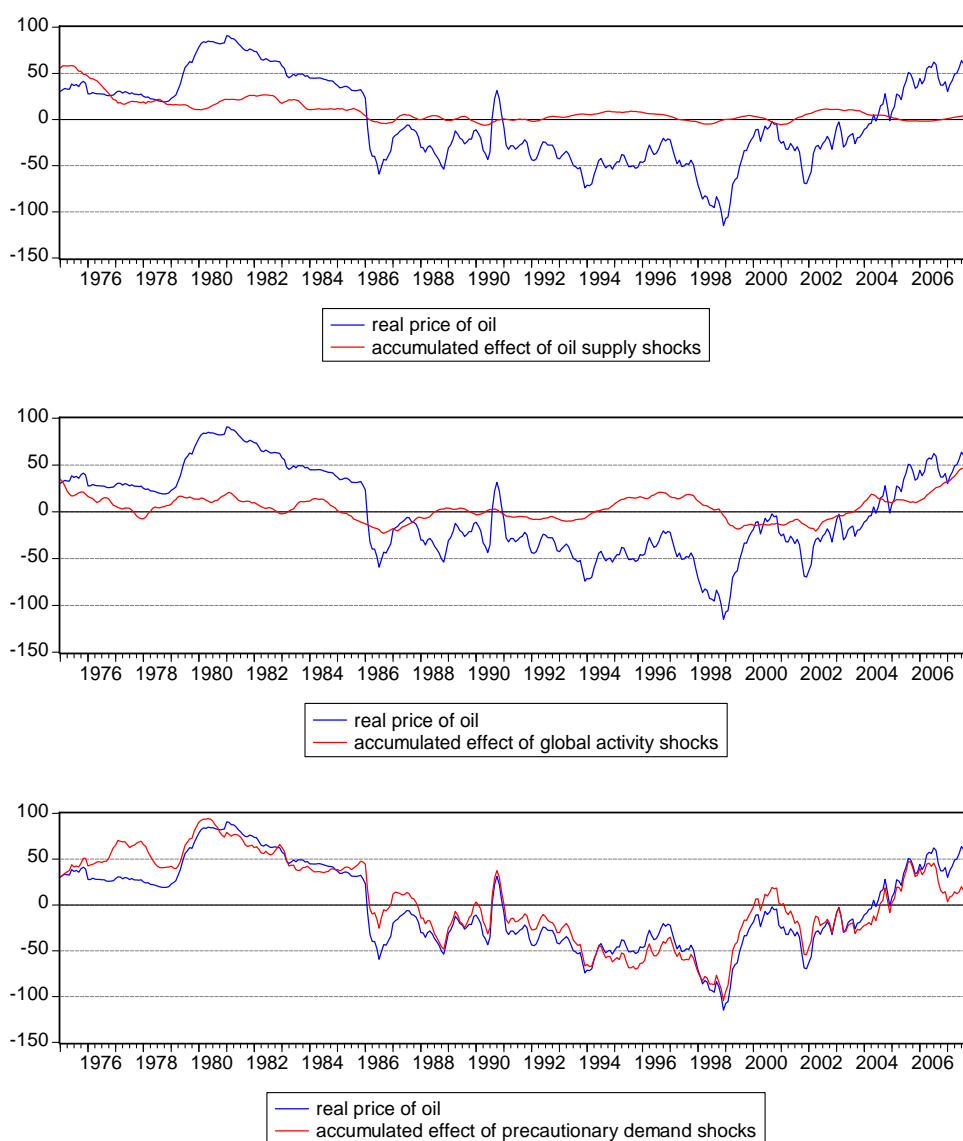
Figure 2: Real price of oil (1973:2-2007:12)



The differences in behavior of the price of oil across oil shocks suggest that different forces may have been driving it in different periods. The structural model of the crude oil market presented in the previous section can be used to shed some light upon this possibility. The historical decomposition of the real price of oil is computed based on the set of identifying restrictions discussed before. Figure 2 shows the accumulated effect of each structural shock on the real price of oil between 1975:1 and 2007:12. Analysis of the post-1975 period indicates that – contrary to the conventional view – oil supply shocks played no important role in the major episodes of increasing oil prices. Rather, evidence suggests that every oil price shock prior to the 2002-2008 episode was induced mainly by large swings in the precautionary demand for oil. A

detailed discussion of the events triggering such swings is outside the scope of this paper and has already been provided in Kilian (2008). Regarding the accumulated effect of global activity shocks on the real price of oil prior to 2003, it appears that innovations to the aggregate world demand have only contributed more or less significantly for the 1979-1980 oil price increase. The role of such shocks during the remaining episodes was negligible.

Figure 3: Historical decomposition of the Real Price of Oil (1975:1-2007:12)

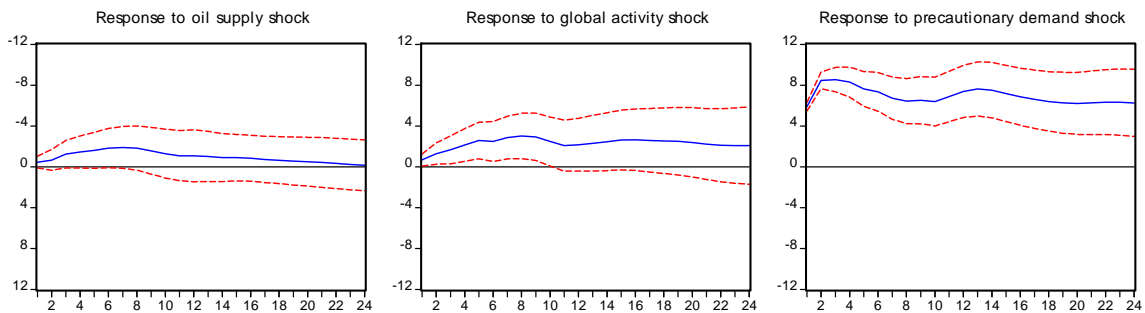


Focusing on the 2002-2008 period, however, the difference relative to previous episodes clearly emerges. Unlike earlier shocks, the prolonged and sustained increase in the price of oil in recent years was largely driven by a series of positive global economic activity shocks. This is in line with Kilian's (2008) results and is further supported by evidence in Lippi and Nobili (2009) and Hamilton (2008). Such a series of shocks may be largely attributed to the rapid growth of newly industrialized Asian countries. The large booms in China and India are commonly regarded as having fueled the world economy until recently. Thus, they are likely to have boosted global demand for oil during the period in question. My results, however, differ from those in Kilian in one important issue. I find a significant role for precautionary demand shocks in raising the price of oil in the 2004-2006 period while his results showed no important contributions from such innovations. The divergence may arise either from the usage of different measures of global economic activity or from the differences in model specification (see section 4). The contribution of precautionary demand shocks for the recent oil price surge may be explained in light of several distinct factors deserving future investigation. The Iraq war, launched in March 2003, is an obvious candidate, although the historical decomposition shows that the largest effect took place only in 2004 and 2005. It would be natural for a war involving such a relevant oil-exporting country to raise fears about supply disruptions, thus boosting precautionary demand and the price of oil. The delayed response of precautionary demand relative to the outbreak of the war could be justified by the fact that the increasing post-war instability only started becoming more apparent outside Iraq – consistent with the sense of failure regarding the war that started to arise in some circles – after some time. An alternative explanation for this finding could lie on significant changes in the preferences of Asian consumers, towards energy-consuming durable goods, induced by the recent wealth increases in China and India.

Another possibility is that the effects of an increased scarcity rent are being captured instead. Such a scarcity rent, regarded by Hamilton (2008) as an important feature of the most recent data, would arise from increasing concerns about future resource depletion.

Given the evidence gathered from the historical decomposition – supporting the idea that distinct factors have been driving prices in different periods – it is important to assess in greater detail how the price of oil responds to each type of structural shock, before extending the analysis to US macroeconomic variables. Figure 4 shows the response of the real price of oil to oil supply shocks, global activity shocks and precautionary demand shocks, up to a 2 year horizon.

Figure 4: Responses of Real Price of Oil



The response to an oil supply shock is shown to be positive during the first two years but is only close to being statistically significant for the first 7 months. The response to a global activity shock, on the other hand, is positive and statistically significant during the first 10 months, corresponding to a gradual but steady increase in the real price of oil. It still remains positive afterwards although slightly decreasing and not statistically significant. Finally, a precautionary demand shock clearly induces a positive response that remains statistically significant for 4 years, clearly causing a larger and more immediate increase in the price of oil than the other two shocks. The impulse response functions obtained are quite similar to those in Kilian, despite the differences in

approach. Moreover, these results prove perfectly consistent with the previous discussion on the characteristics and sources of oil shocks through time.

Since both the magnitude and the shape of the oil price response clearly depend on the underlying structural shock, it seems natural to expect different crude oil market innovations to produce distinct macroeconomic effects. The effects of the different structural shocks on a measure of real economic activity – industrial production – and a measure of the price level – producer price index – for the US are explored in the next section.

6. The Crude Oil Market and the Macroeconomy

The VAR model from section 4 is extended so as to allow for an analysis of the macroeconomic effects of crude oil market innovations. Two additional variables for the US economy are included⁸: the (log of) US industrial production index, *ipi*, and the (log of) US producer price index, *ppi*. ADF unit root tests show that both additional variables are I(1). Again, the extended model is estimated in levels, including 12 lags. This choice of macroeconomic variables is similar to Lippi and Nobili (2009), allowing for an interesting comparability between their results and mine. Lippi and Nobili achieve identification by imposing sign restrictions and identify only two oil market innovations: oil supply shocks and oil-demand shocks. My analysis fundamentally differs from theirs as I use a recursive identification strategy and further disentangle oil demand shocks into global activity shocks and precautionary demand shocks, thus identifying three distinct crude oil market innovations. Although industrial production and producer prices are certainly not perfect proxies for US output and consumer prices – the share of manufactured goods in spending has declined considerably – this analysis

⁸ Source: Organisation for Economic Co-operation and Development.

proves complementary of Kilian's results regarding those variables. The chief advantage of this set of variables over Kilian's is that it allows for an integrated VAR analysis. Kilian, instead, separately regressed GDP growth and CPI inflation on the innovations obtained from his structural crude oil market model. Such an approach rules out possibly important feedbacks from the US economy to the crude oil market. The reason he did so is that GDP data is only available at quarterly frequency while the identifying assumptions discussed in section 4 cease being credible at a quarterly time horizon. Industrial production data, on the other hand, is available at monthly frequency.

In order to exactly identify the resulting 5-variable VAR, 10 restrictions are imposed as shown in (5):

$$\begin{bmatrix} e_t^{oilprod} \\ e_t^{comp} \\ e_t^{rpoil} \\ e_t^{ipi} \\ e_t^{ppi} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{global\ activity\ shock} \\ \varepsilon_t^{oil-specific\ demand\ shock} \\ \varepsilon_t^{ipi\ shock} \\ \varepsilon_t^{ppi\ shock} \end{bmatrix} \quad (5)$$

This identification strategy assumes that all variables in the crude oil market block are predetermined with respect to the US economy – following the standard approach in the literature – and are thus contemporaneously unaffected by US-specific innovations. Conversely, both US industrial production and US producer prices are allowed to respond immediately to all crude oil market innovations. I do not attempt to identify truly structural shocks in the US economy. All subsequent analysis is performed based on the model including industrial production before producer prices. The results, however, have been verified to be insensitive to the ordering of macroeconomic variables.

6.1. Estimation Results

The interest in oil price shocks arises mainly from the perception that they are a relevant source of real economic fluctuations. In order to quantify this claim, the variance decomposition of US industrial production is computed from the model described above. Table 1 shows the percentage of the forecast error variance accounted for by each shock, individually, and by all crude oil market innovations as a group.

Table 1: Variance decomposition of Industrial Production

period	Structural shocks			oil shocks total
	oil supply	global activity	precautionary demand	
1	2.802	3.092	0.181	6.075
6	3.688	13.414	0.059	17.160
12	5.394	10.069	0.810	16.273
24	9.045	4.933	6.521	20.499
48	10.688	4.138	11.473	26.300

Analysis of the variance decomposition confirms that crude oil market innovations account for a significant share of US industrial production fluctuations, amounting to over 16% at a 1 year horizon and approaching 30% as the time horizon expands. Among the three innovations considered, global activity shocks explain most of the forecast error variance during the first year. For larger horizons oil supply shocks and precautionary demand shocks become more important, accounting for over 10% of the long-run variance each.

In order to analyze the macroeconomic impact of crude oil market innovations in greater detail, a set of impulse response functions is computed. Figures 5 and 6 show the responses of US industrial production and US producer prices, respectively, to oil supply, global activity and precautionary demand shocks. It is clear from the impulse

response functions that both the nature and the magnitude of the effects of oil price fluctuations on the US economy depend on the underlying structural shocks.

Figure 5: Responses of Industrial Production

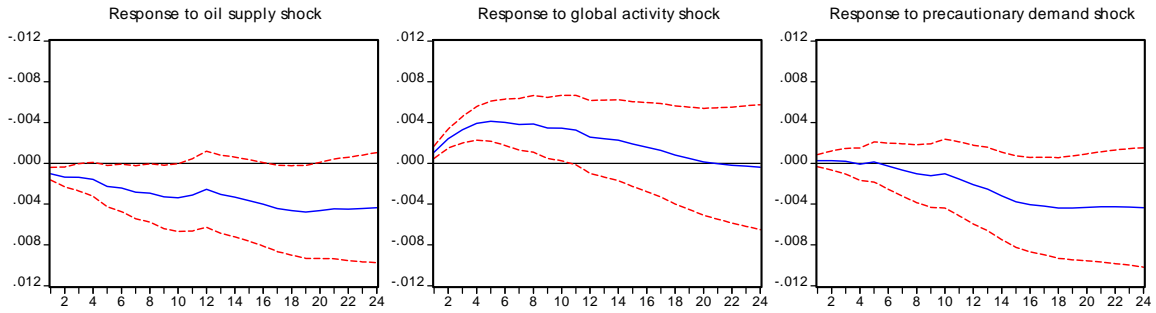
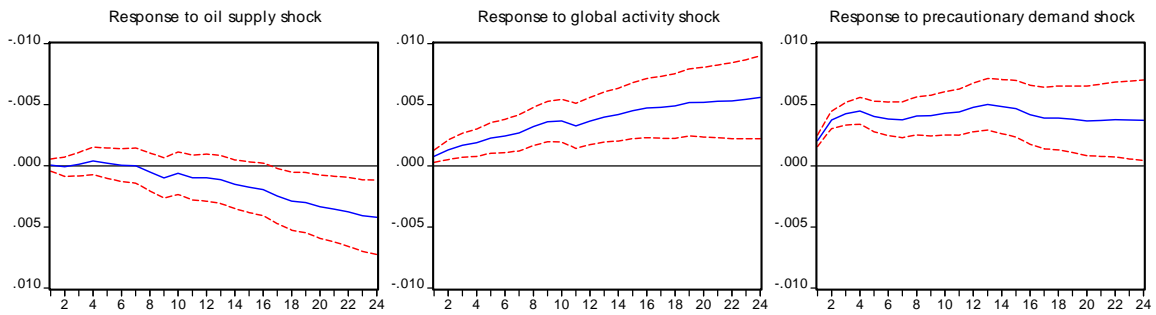


Figure 6: Responses of Producer Prices



An oil supply shock is shown to significantly depress industrial production during most of the first 20 months after the shock. Afterwards, the impact remains negative but becomes non-significant. The impact on producer prices, on the other hand, is non-significant at first and actually becomes significantly negative after the first 15 months. This particular result may look surprising at first. Nonetheless, it can be understood if the positive direct effect of the higher price of oil on producer prices proves to be weaker than the negative indirect effect, induced by the resulting decrease in real economic activity. A global activity shock, on the other hand, is shown to have a significant positive effect on industrial production during the first 10 months after the shock. The impact remains positive although insignificant until the end of the second

year. It thus appears as if the positive direct effect of a global activity shock on the US industrial production dominates the negative indirect effect that works through the increased price of oil, at least in the short-run. Producer prices, in turn, rise in a gradual and sustained manner in response to such a shock. The impact remains statistically significant for 4 years. Such a response arises naturally since, in this particular case, the direct and indirect effects work in the same direction, as both real economic activity and the price of oil tend to increase. Finally, a precautionary demand shock is shown to cause a negative impact on industrial production that, however, is never statistically significant. Its impact on producer prices, on the other hand, is immediate and significantly positive for the first 25 months. It thus appears as if the direct positive effect of the oil price increase on producer prices dominates the negative indirect effect, induced through the decline in real economic activity.

The clear difference in effects of precautionary demand and oil supply shocks on producer prices can be better understood in light of the impulse responses of US industrial production and the real price of oil. Recall from the last section (see Figure 4) that the positive effect of a precautionary demand shock on the price of oil is much stronger and more significant than that of an oil supply shock. Additionally, the negative effect of a precautionary demand shock on industrial production appears to be weaker and less significant than that of an oil supply shock. Since the precautionary demand shock both raises the price of oil more and seems to decrease real economic activity less, its impact on prices will naturally be more inflationary.

The results concerning the impact of global activity shocks on industrial production, on the other hand, appear particularly interesting in explaining the thriving behavior of the US economy during the 2002-2008 period. As discussed in the previous section (see Figure 3) evidence suggests that the most recent surge in the price of oil

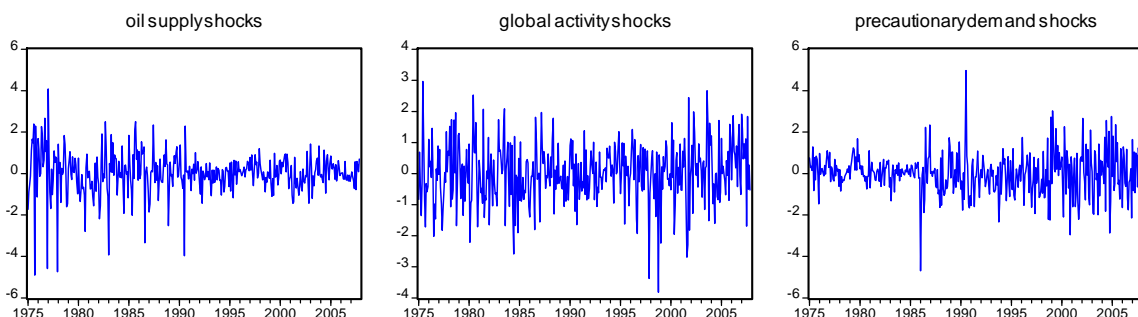
was importantly driven by a sequence of positive global activity shocks. Impulse response analysis of such shocks – showing that increases in the price of oil may be associated to expanding real economic activity – provides an explanation for the apparently puzzling fact that the US did not experience a recession for several years, despite sharp increases in the price of oil.

These results both complement and reinforce Kilian's conclusions concerning US GDP and consumer prices. All impulse response functions obtained in this paper are qualitatively consistent with his, although some slight differences exist. This is to be expected since distinct measures of economic activity and the price level are being used. Specifically, the positive short-run response of industrial production to global activity shocks seems to be more prolonged and more significant than that of GDP. This is not surprising since the production of manufactured goods is likely to be more stimulated by booms in global economic activity – relative to GDP as a whole – through rises in the demand for exports. Furthermore, producer prices – compared to consumer prices – are shown to respond in a more immediate and significant manner to precautionary demand shocks. This can be understood in light of the greater energy intensity of the industrial sector relative to the economy as a whole. This feature of the industrial sector is likely to cause increases in the price of oil to feed more into producer prices than into consumer prices. The main results obtained in this paper are also consistent with Lippi and Nobili (2009) who found similar implications for the US industrial production and producer prices, while only identifying two oil market innovations. Result comparison shows a very similar pattern of macroeconomic responses to oil supply shocks. It suggests also that the oil demand shock identified in their paper captures some mix of the global activity and precautionary demand from this paper.

6.2. Structural Change?

In a recent contribution, Blanchard and Galí (2008) pointed out four relevant factors in explaining the milder effects of oil price shocks on the US economy after the mid 1980s: “good luck”, smaller share of oil in production, more flexible labor markets and improvements in monetary policy. This view integrates in a strand of literature that has focused on the hypothesis of structural change in trying to explain the breakdown in the oil price-macroeconomy relationship, apparent after the beginning of the Great Moderation, in 1984. This strand of Great Moderation-related literature, however, has generally neglected the difference in effects of distinct crude oil market innovations such as the ones identified in the current paper. Instead of trying to disentangle such innovations, conventional approaches have identified a single oil price shock. As a result, the estimated effects of such an oil price shock could actually be capturing some mix of effects of the different crude oil market shocks. This is likely to have contributed for the finding of coefficient instability in models where only the single shock was considered. Figure 7 plots the evolution of the structural innovations since 1975, providing visual evidence supporting the possibility that the relative importance of the distinct structural shocks has been significantly varying over time.

Figure 7: Structural shocks (1975:1-2007:12)



Graphical analysis of the structural shock series indicates that the variance of oil supply innovations decreased after 1991 while that of precautionary demand shocks, on the other hand, became larger after the 1986 period. Since basic evidence suggests that conventional single-shock approaches may have been flawed, up to some extent, it is worth reassessing the structural change hypothesis in light of this paper's model.

I test for a structural break in 1984:1 – the standard date suggested by the Great Moderation literature (*e.g.* McConnell and Perez-Quiros 2000) – using the Chow break point and sample split tests for vector models (see Candelon and Lütkepohl 2001). Inference based on bootstrapped p-values clearly points to the rejection of the null hypothesis of parameter constancy even at the 1% level. Accordingly, I split the full sample into two subsamples – 1973:2-1984:1 and 1984:2-2007:12 – in order to further investigate the differences between both periods.

Table 2 presents the variance decomposition – regarding oil supply and precautionary demand shocks only – of the US industrial production for the first and second subsamples, respectively.

Table 2: Variance decomposition of Industrial Production

period	1 st Subsample		2 nd Subsample	
	oil supply	precautionary demand	oil supply	precautionary demand
1	3.260	15.324	1.448	2.036
6	3.314	12.789	1.210	0.821
12	19.305	12.448	1.103	1.196
24	31.783	11.549	1.604	6.044
48	27.441	10.084	2.727	14.714

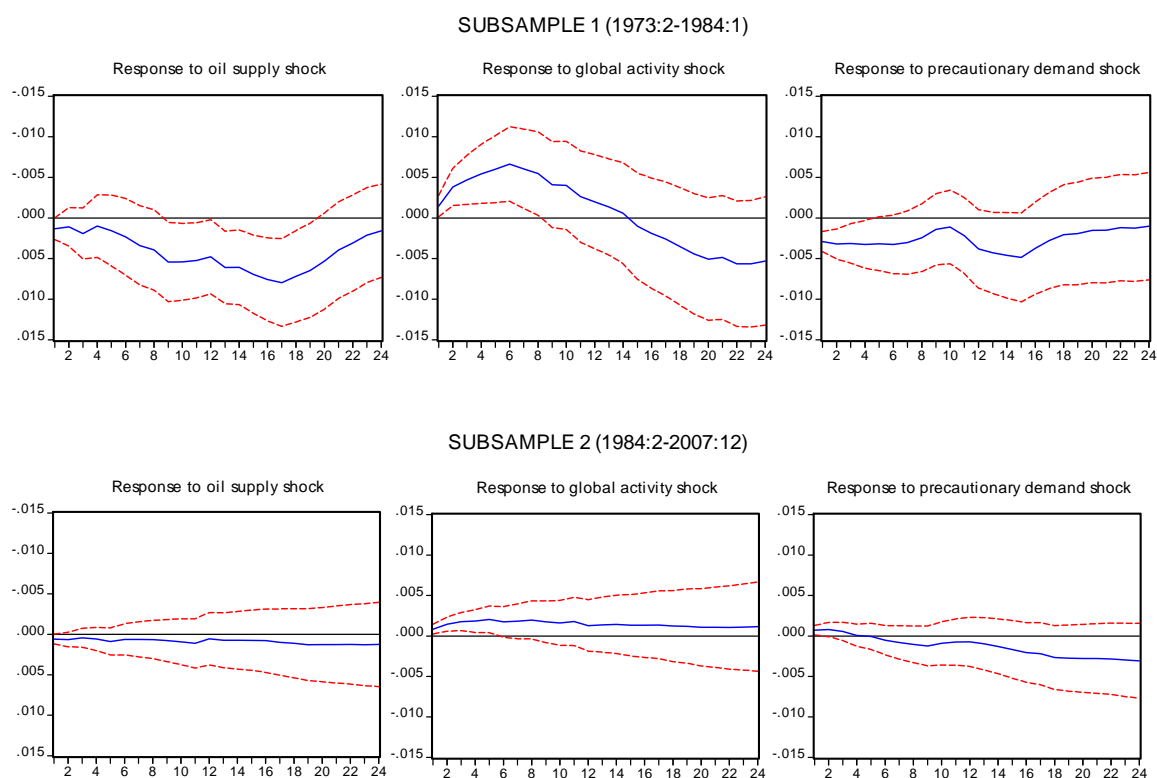
The variance decomposition results appear consistent with the previous discussion on the variance of the structural shocks. In the first subsample, the percentage of the forecast error variance of industrial production explained by oil supply shocks is larger than the share explained by precautionary demand shocks for time horizons over one

year. It is also larger in the first subsample than in the second, for all periods considered. In the second subsample, conversely, a larger share of fluctuations in industrial production is attributed to precautionary demand shocks than to oil supply shocks.

Impulse response analysis may provide further insights into the nature of the changing effects of crude oil market innovations on the real side of the US economy.

Figure 7 plots the responses of US industrial production for both subsamples.

Figure 7: Responses of Industrial Production



The overall picture shows that the impact of one standard deviation innovations on US industrial production has become much more muted after 1984. More specifically, the impact of oil supply shocks has been found to be negative and statistically significant for several periods in the first subsample while in the second subsample, although slightly negative, it is never significant. The effect of global activity shocks, on the other hand, has been found to be significantly positive for 8 months in the first

subsample and for 5 months in the second, although smaller in magnitude. Since these responses are based on one standard deviation innovations, however, it is possible that the milder effects found in the second sample are partly a product of declines in the standard deviations of oil supply and global activity shocks, relative to the pre-1984 period. Among all three innovations, only precautionary demand shocks have a larger standard deviation in the second subsample. Impulse response analysis of the impact of such a shock on industrial production shows that, despite the larger standard deviation, the magnitude of its effect is smaller and generally less significant in the period after 1984. More surprisingly, the impact of a precautionary demand shock on industrial production in the second sample is actually found to be significantly positive for the first 2 months. This finding may be hard to reconcile with standard economic theory unless some other offsetting effect has been at work. This could be evidence supporting *e.g.* changes in the response of monetary policy to such shocks or “good luck” *i.e.* the existence of simultaneous shocks – unaccounted for by the model – with opposite-signed effects. I leave further analysis of this issue for future research. The overall message that seems to stand out from this basic approach is – at odds with Lippi and Nobili (2009) – that the different effects of the distinct crude oil market shocks, on their own, cannot account for all of the change in the oil price-macroeconomy relationship. Hence, this paper finds that the structural change hypothesis remains valid and should be further pursued.

7. Concluding Remarks

This paper offers three main contributions. First, besides reinforcing the prevailing view that the 2002-2008 episode of increasing oil prices was largely induced by positive global economic activity shocks, it provides new evidence supporting a relevant role for

positive swings in precautionary demand, mainly during the 2004-2006 period. The Iraq War, changes in Asian consumer preferences towards more energy intensive durable goods and scarcity rents are put forward as potential explanations for such swings although no evidence favoring any of them in particular is provided. Deeper research concerning this issue would be required. Second, it provides further evidence implying that oil price increases may walk hand in hand with thriving economic activity in the US. This is inferred from the estimated positive short-run response of US industrial production to global activity shocks and is argued – in line with Kilian’s findings regarding GDP – to be relevant in explaining the prolonged resilience of the US economy in face of the recent oil price increases. The results concerning industrial production and producer prices are consistent with those in Lippi and Nobili (2009) although a different empirical approach is employed and an additional oil demand innovation is identified. This conclusion thus appears to be robust to alternative identification strategies. Such a response to global activity shocks may be understood in light of two opposite signed effects: a stimulating effect working mainly through increased export demand and a negative effect working through the higher price of oil. Similar results have been found for a set of other countries including Portugal, Spain, the United Kingdom and Germany. Since these results would not add to the conceptual analysis, they were left out of the text in order to avoid excess length. A more detailed international comparison of the effects of crude oil market innovations on the macroeconomy may be subject of future empirical work based on this paper’s framework. Third and finally, the relevance of Blanchard and Galí’s hypothesis of structural change is supported by parameter constancy tests, variance decompositions analysis, and impulse analysis that shows more muted responses to oil price increases in the post-1984 period. The line of research on the structural change hypothesis should

thus continue to be pursued although empirical evidence suggests that it should take into account the arguments from the strand of literature that has focused on disentangling structural shocks in the crude oil market.

References

- Apergis, Nicholas, and Stephen M. Miller. 2009. "Do Structural Oil-Market Shocks Affect Stock Prices?" *Energy Economics*, doi:10.1016/j.eneco.2009.03.001
- Atkeson, Andrew, and Patrick J. Kehoe. 1999. "Models of Energy Use: Putty-Putty vs. PuttyClay." *American Economic Review* 89 (September), pp. 1028-43.
- Balke, Nathan S., Stephen P. Brown, and Mine K. Yücel. 2002. "Oil Price Shocks and the U.S. Economy: Where Does the Asymmetry Originate?" *The Energy Journal* 23(3), pp. 27-52.
- Barsky, Robert, and Lutz Killian. 2002. "Do We Really Know that Oil Caused the Great Stagflation? A Monetary Alternative." *NBER Macroeconomics Annual 2001*, May, 137-183.
- Bernanke, Ben, Mark Gertler, and Mark Watson. 1997. "Systematic Monetary Policy and the Effects of Oil Shocks." *Brookings Papers on Economic Activity*, 1997-1, 91-157.
- Blanchard, Olivier, and John Simon. 2001. "The Long and Large Decline in U.S. Output Volatility." *Brookings Papers on Economic Activity*, 2001-1, 135-174.
- Blanchard, Olivier, and Jordi Galí. 2008. "The Macroeconomic Effects of Oil Shocks: Why are the 2000s so Different from the 1970s?" *CEPR Discussion Paper No. DP663*.
- Bohi, Douglas R. 1989. "Energy Price Shocks and Macroeconomic Performance." *Resources for the Future*, Washington, D.C.
- Bohi, Douglas R. 1991. "On the Macroeconomic Effects of Energy Price Shocks." *Resources and Energy*, 13, pp. 145-162
- Candelon, B., and Helmut Lutkepohl. 2001. "On the Reliability of Chow-type Parameter Constancy in Multivariate Dynamic Systems." *Economics Letters*, No. 73, pp. 155-160.
- Canova, F., and Gianni De Nicolò. 2002. "Monetary disturbances matter for business cycle fluctuations in the G7." *Journal of Monetary Economics* 49 (6), pp. 1131-1159.
- Davis, Steven J. 1987a. "Fluctuations in the Pace of Labor Reallocation," *Empirical Studies of Velocity, Real Exchange Rates, Unemployment and Productivity*." Carnegie-Rochester Conference Series on Public Policy, 24, Amsterdam: North Holland.
- Davis, Steven J. 1987b. "Allocative Disturbances and Specific Capital in Real Business Cycle Theories." *American Economic Review Papers and Proceedings*, 77, No. 2, pp. 326-332.
- Dedola, Luca, and Stefano Neri. 2006. "What Does a Technology Shock Do? A VAR Analysis with Model-Based Sign Restrictions." *European Central Bank Working Paper Series No. 705*

- Enders, Walter. 2004. *“Applied Econometric Time Series.”* 2nd ed. John Wiley & Sons.
- Ferderer, J. Peter. 1996. “Oil Price Volatility and the Macroeconomy: A Solution to the Asymmetry Puzzle.” *Journal of Macroeconomics*, 18, pp. 1-16.
- Gisser, Micha, and Thomas H. Goodwin. 1986. “Crude Oil and the Macroeconomy: Tests of Some Popular Notions,” *Journal of Money, Credit, and Banking*, 18, pp. 95-103.
- Hamilton, James D. 1983. “Oil and the Macroeconomy since World War II.” *Journal of Political Economy*, April 1983, 228-248.
- Hamilton, James D. 1988. “Are the Macroeconomic Effects of Oil-Price Changes Symmetric? A Comment” *Carnegie-Rochester Conference Series on Public Policy* 28, 369-378.
- Hamilton, James D. 1996. “This is What Happened to the Oil Price Macroeconomy Relationship.” *Journal of Monetary Economics*, vol. 38, No. 2, October, 215-220.
- Hamilton, James D. 2003. “What is an Oil Shock?” *Journal of Econometrics*, 113, pp. 363-398.
- Hamilton, James D. 2005. “Oil and the Macroeconomy.” *The New Palgrave Dictionary of Economics*, 2nd Edition. Macmillan, London.
- Hamilton, James D. 2009. “Understanding Crude Oil Prices.” *Energy Journal* 2009, vol 30, no. 2, pp. 179-206.
- Hamilton, James D., and Ana María Herrera. 2004. "Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy.” *Journal of Money, Credit, and Banking*, vol. 36, pp. 265-286
- Herrera, Ana María, and Elena Pesavento. 2009. “Oil Price Shocks, Systematic Monetary Policy and the Great Moderation.” *Macroeconomic Dynamics*, Cambridge University Press, 13, pp. 107-137.
- Hooker, Mark A. 1996. “What Happened to the Oil Price Macroeconomy Relationship?” *Journal of Monetary Economics*, 38, pp. 195-213.
- Hooker, Mark A. 2002. “Are Oil Shocks Inflationary? Asymmetric and Nonlinear Specifications versus Changes in Regime.” *Journal of Money, Credit and Banking*, vol. 34, No. 2, pp. 540-561.
- Huntington, Hillard G. 1998. "Crude Oil Prices and U.S. Economic Performance: Where Does the Asymmetry Reside?" *The Energy Journal* 19(4), pp. 107-132.
- Ivanov, V., and Lutz Kilian. 2005. "A Practitioner's Guide to Lag Order Selection For VAR Impulse Response Analysis." *Studies in Nonlinear Dynamics & Econometrics*. Vol. 9: No. 1, Article 2.

- Jones, D., Paul N. Leiby, and Inja K. Paik. 2003. "Oil Price Shocks and the Macroeconomy: What Has Been Learned since 1996." *The Energy Journal*, vol. 25, No. 2.
- Kilian, Lutz .2001. "Impulse Response Analysis in Vector Autoregressions with Unknown Lag Order." *Journal of Forecasting* 20(3), pp. 161-179.
- Kilian, Lutz. 2008. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market." *CEPR Discussion Paper No. 5994*.
- Kilian, Lutz, and Cheolbeom Park. 2008. "The Impact of Oil Price Shocks on the U.S. Stock Market." *CEPR Discussion Paper No. DP6166*.
- Lee, Kiseok., Shawn Ni, and R. A. Ratti. 1995. "Oil Shocks and the Macroeconomy: the Role of Price Volatility." *Energy Journal*, 16, pp. 39–56.
- Lippi, Francesco, and Andrea Nobili. 2009. "Oil and the Macroeconomy: A Structural VAR Analysis with Sign Restrictions." *CEPR Discussion Paper No. 6830*.
- Loungani, Prakash. 1986. "Oil Price Shocks and the Dispersion Hypothesis." *Review of Economics and Statistics*, 58, pp. 536-539.
- McConnell, Margaret M., and Gabriel Perez-Quiros. 2000. "Output Fluctuations in the United States: What Has Changed Since the Early 1980s?" *The American Economic Review*, Vol. 90, No. 5, pp. 1464-1476
- Mork, Knut A. 1989. "Oil and the Macroeconomy When Prices Go Up and Down: An Extension of Hamilton's Results." *Journal of Political Economy*, 91, pp. 740-744.
- Rasche, Robert H. and John A. Tatom. 1977. "Energy Resources and Potential GNP." *Federal Reserve Bank of St. Louis Review*, 59, pp. 10-24.
- Rasche, Robert H. and John. A. Tatom. 1981. "Energy Price Shocks, Aggregate Supply, and Monetary Policy: The Theory and International Evidence." *Supply Shocks, Incentives, and National Wealth, Carnegie-Rochester Conference Series on Public Policy*, vol. 14, Amsterdam: North-Holland.
- Rubio-Ramirez, J. F., Waggoner, D., and Zha, T. 2005. "Markov Switching Structural Vector Autoregressions: Theory and application." *Federal Reserve Bank of Atlanta Working Paper No. 27*.
- Sims, Christopher A. 1980. "Macroeconomics and Reality." *Econometrica*, Vol. 48, No. 1, pp. 1-48
- Sims, Christopher A., James H. Stock, and Mark W. Watson. 1990. "Inference in Linear Time Series Models with some Unit Roots." *Econometrica*, Vol. 58, No. 1, pp. 113-144
- Stock, James, and Mark Watson. 2003. "Understanding Changes in International Business Cycle Dynamics." *Journal of the European Economic Association*, Vol. 3, No. 5, pp. 968-1006.

Uhlig, Harald. 2005. "What Are the Effects of Monetary Policy on Output? Results from an agnostic identification procedure." *Journal of Monetary Economics* 52, pp. 381–419.

Verbeek, M. 2008. "A Guide to Modern Econometrics." 3rd ed, *John Wiley and Sons*