Oil Demand and Supply Shocks: an Analysis in an Estimated DSGE-Model [*]

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Abstract

This paper develops and estimates a structural model of the US and Oil Producing countries including a well-specified oil market in which oil prices are endogenously determined. We not only distinct oil demand from oil supply disturbances, but also identify different kinds of oil supply and demand shocks. Investigating the dynamics induced by the various oil shocks, we first find that different sources of oil price changes entail different macro-economic effects. Second, the results show that real oil price fluctuations are mostly exogenous with respect to US macro-economic developments. Disturbances on the supply side of the oil market explain at least half of the observed oil price variability and are mainly caused by inefficient changes in the market power of oil companies, rather than by exogenous shifts in the oil sector's productive capacity. Oil-specific demand shocks are the second most important driving forces of the oil price and explain the bulk of the more recent oil price hikes. Finally, we report a small contribution of the various oil shocks to US real economic variables.

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1 Introduction

Recent advances in the empirical literature show that the effects of oil shocks on the real oil price and economic activity depend critically on the source of the disturbance, e.g. Kilian (2009) and Peersman and Van Robays (2009). As a consequence, policymakers should identify the deeper causes of oil price fluctuations and respond to the underlying fundamentals. However, the current class of structural models, used by policy makers, does typically not model an oil sector. Instead oil prices enter the model as a random disturbance and not as a result of optimizing behavior to economic fundamentals. To overcome this shortcoming, it requires economic modelling to abandon the assumption of exogeneity of oil prices, and instead treat the oil market endogenously. This paper is an attempt into this direction and seeks to develop and estimate a dynamic stochastic general equilibrium (DSGE) model of the US and the Oil Producing countries including a well-specified oil market. We think that a convincing structural model, that can be used to determine policy in a world characterized by oil price fluctuations, must have two features. First, the model must include the real and nominal frictions which are shown to be necessary to capture the empirical persistence in the main macro-economic data series. Second, the structure of the oil market must be rich enough to identify different 'kinds' of oil demand and supply shocks. For example, from a welfare perspective exogenous shifts in the oil price mark-up are in contrast to disturbances to oil capacity inefficient oil supply shocks and therefore require different policy responses. Estimating the model with Bayesian estimation techniques, for the period following the structural break in the oil market in 1986, we investigate the relative importance of these various types of oil demand and supply shocks in explaining the evolution of the oil price as well as analyze the dynamics these shocks trigger.

Oil price movements are mostly treated as exogenous supply disturbances, that are unrelated to any economic fundamentals. This view also dominates the structural oil literature, which dates back to Kim and Loungani (1992).[1] However, some recent theoretical contributions model an endogenous oil market and investigate the sources of oil price fluctuations and their economic effects in greater detail. In calibration experiments Elekdag et al. (2008) ascribe the 2003 oil price increase mainly to demand factors and to a much lesser extent to oil supply shocks, and Jacquinot et al. (2009) and Nakov and

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[1] Recent examples of structural models treating oil as an exogenous variable include Rotemberg and Woodford (1996) and Finn (2000) who try to assess the impact of oil supply shocks on the US economy, Leduc and Sill (2004) and Medina and Soto (2005) who examine the role of monetary policy as a transmission channel of oil shocks, and Bodenstein et al. (2007) who investigate the effects of oil price shocks on the trade balance and the terms of trade.

Pescatori (2009a) demonstrate that different oil shocks matter for the monetary policy reaction.[2] The structural analyses of Nakov and Pescatori (2009b) and Balke et al. (2009) use Bayesian estimation techniques to disentangle oil demand and supply shocks and analyze their economic effects.[3] Our paper contributes to the latter strand of the literature in that it endogenizes oil prices in a structural set-up which is richer, mainly in the sense that it allows the identification of a larger set of oil shocks.

In contrast to the small but emerging class of structural business cycle models that endogenize the oil market, our modelling approach is richer along several dimensions. First, oil is not only included in the consumption basket of households and the production process of firms, but is also part of the investment portfolio. This gives rise to an additional transmission mechanism of oil shocks to the macro-economy. Second, we do not only make a distinction between disruptions in oil demand and supply, but identify different kinds of oil supply and demand shocks in more detail. Concerning the demand side of the oil market we follow the empirical literature and disentangle oil demand shocks driven by economic activity and oil-specific demand shocks which could be the result of speculative or precautionary motives. The latter shock is identified by the exogenous deviations from the arbitrage condition of oil inventories linking the oil price evolution to the rate of return on other assets. On the supply side of the oil market we disentangle three types of shocks. Following the work by Balke et al. (2009) we identify shocks to investments in oil-bearing reservoirs, which represent shifts in the success of striking oil or the efficiency of oil drilling. We further make a distinction between oil mark-up and oil capacity shocks, which respectively capture exogenous shifts in market power and productive capacity of the oil-producing sector. Finally, the model includes real and nominal frictions standard in the recent generation of new Keynesian models as proposed by Smets and Wouters (2003, 2007).

Our findings corroborate that '*not all oil price shocks are alike*' (Kilian 2009, p.16). Not only is there a difference between the dynamic effects of oil supply and oil demand shocks, but also the kind of oil supply shock matters for economic behavior. We find that unfavorable oil mark-up and oil investment shocks always imply a negative output gap, while negative oil capacity shocks entail a positive output gap in the very short run. The most striking difference concerns the inflation effects. Negative oil capacity shocks raise headline inflation. In contrast, oil mark-up shocks cause inflation to increase on impact

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[2] Another notable example can be found in Backus and Crucini (2000). These authors model an endogenous non-OPEC oil firm, while assuming an exogenous supply curve for the OPEC countries.

[3] More precisely, both Nakov and Pescatori (2009b) and Balke et al. (2009) investigate the role of changes in the oil market as an explanation for the Great Moderation.

but to decrease after about 3 quarters; and following an unfavorable oil investment shock, negative output effects depress core inflation in such a way that they offset the direct effects of the oil price increase on headline inflation. As a result, in contrast to oil capacity and oil mark up shocks, oil investment shocks never burden the central banker with a trade-off between output gap and inflation stabilization. Second, the results show that movements in the real oil price are mostly exogenous with respect to US macro-economic developments. Disruptions on the supply side of the oil market explain at least half of the observed oil price fluctuations and are mainly caused by inefficient mark-up shocks. The Gulf War in 1991 is a rare example during which unfavorable disturbances to oil capacity create important upward pressure on the real oil price. Shifts in precautionary or speculative holdings of oil inventories also significantly contribute to the oil price variability and explain the bulk of the recent oil price hikes. Finally, we report a small contribution of the various oil shocks to US real GDP. Only following the Gulf War and during the '2003-2006' oil price hike US real GDP was significantly lower due to respectively unfavorable oil capacity and oil-specific demand shocks. In contrast, oil mark-up and inventory shocks are important drivers of US headline inflation.

The remainder of this paper is organized as follows. Section 2 presents the DSGE-model. Subsequently, we estimate the model by Bayesian techniques, which is reported in Section 3. In Section 4, we perform an impulse response analysis in order to investigate the dynamic effects of the various oil shocks. Sections 5 and 6 turn to evaluating the relative importance of the different oil shocks in explaining variability in US economic activity and fluctuations in the oil market. Finally, Section 7 offers some concluding remarks.

2 The Model

We follow Nakov and Pescatori (2009a) (henceforth, NP) by assuming that there are two large regions or countries in the world. The first - home - country is an oil-importing country, representing the net oil-importing developed world. In the empirical analysis we assume, for simplicity, that this country is approximated by the United Sates.[4] The second - foreign - country is an oil-producing country and represents the aggregate of the net oil-exporting countries.[5] Trade between the two countries is carried out in a common

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[4] Although simplifying, this assumption can be motivated by two observations over the past four decades. First, the share of US oil consumption in total world oil production amounts to a more or less stable 23 percent. Second, the linearly detrended series of world oil production and US oil consumption have a correlation of 85 percent.

[5] In contrast to NP (2007a) we do not make an explicit distinction between the OPEC-countries, which set the oil price, and a fringe of small 'rest-of-the-world'-oil producers, which act competitively.

world currency, namely the dollar.[6]

The oil-importing country is a standard new Keynesian economy. The structure of the economy is closely related to the closed economy models of Christiano et al. (2005) (henceforth, CEE) and Smets and Wouters (2003, 2007) (henceforth, SW). In line with these models different types of real and nominal frictions are included. Among the real frictions we distinguish: external habit formation in consumption, investment adjustment costs, variable capital utilization and monopolistic competition in both the labor and goods market. Nominal rigidities are introduced by assuming that wage and price decisions are subject to Calvo staggering (Calvo 1983). The main difference to CEE (2005) and SW (2003, 2007) is the introduction of oil in the economy. Since domestic firms produce only non-oil goods (core goods) the country is a gross oil importer. Imported oil is used for three different purposes. First, intermediate goods producers combine oil with other input factors in the production process of core goods. Second, consumers buy oil to e.g. heat their houses and drive their cars. Finally, oil is a storable commodity. There are two reasons why economic agents may decide to store oil. The first reason is that oil inventories provide a service to consumers by supporting liquidity in the oil market. Second, like every other commodity, oil can be treated as an asset in the investment portfolio.

Following the model of Balke et al. (2009) (henceforth, BBY) the production process of crude oil passes through two sectors. At the upstream of the manufacture a competitive drilling firm constructs exploitable oil fields. Downstream, the oil-producing sector rents these fields and extracts the oil from the ground. In contrast to BBY (2009) both sectors have only one factor of production, namely capital, and hence do not demand labor. Instead, we allow for a variable utilization rate of the capital stock in both sectors.

In the rest of this section the various economic agents and their optimization programmes are outlined.[7] We present the log-linearized optimal equilibrium conditions, in which variables presented as deviations from steady state are denoted with a superscript '$\hat{}$'. Unless otherwise noted, foreign region parameters and variables are denoted by a superscript '*'. Prices are deflated by US CPI, represented by P.

Domestic Firms The home country produces a continuum of intermediate core-goods, indexed by $i \in [0, 1]$. Each of these differentiated types of goods, Y_t^i, is produced by a single firm, which faces monopolistic competition. Production is carried out by means of three input factors: capital services, $K_t^{S,i}$, labor, L_t^i, and oil, O_{gt}^i. $K_t^{S,i} = z_t K_{t-1}^i$,

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[6] Assuming one common currency is identical to stating that the oil-producing countries set a fixed exchange rate peg with respect to the dollar and part with their own monetary policy.

[7] A more detailed description of the model, including all our derivations, is available on request.

where z_t denotes the utilization rate which depends positively on the rental rate of capital r_t^k: $\hat{z}_t = \frac{1}{\chi}\left(\hat{r}_t^k - \hat{p}_t^g\right)$, $\chi \geqslant 0$, and K_{t-1}^i represents the effective capital stock. The value added output, VA_t, of the domestic production factors is produced by a Cobb-Douglas production function. Subsequently, this value added is aggregated with oil by means of a constant elasticity of substitution (CES) technology.[8] Hence, the technology of the intermediate firm i is given by $Y_t^i = \left(\eta^{\frac{1}{\alpha}}\left(VA_t^i\right)^{\frac{\alpha-1}{\alpha}} + (1-\eta)^{\frac{1}{\alpha}}\left(O_{gt}^i\right)^{\frac{\alpha-1}{\alpha}}\right)^{\frac{\alpha}{\alpha-1}} - \Phi$, with $VA_t^i = \varepsilon_t^{TFP}\left(L_t^i\right)^{\theta}\left(K_t^{S,i}\right)^{1-\theta}$. $\alpha > 0$ defines the elasticity of substitution between value-added and oil in production and Φ is a fixed cost. θ captures the share of labor in GDP, while η represents the share of the domestic production factors in gross output. Total factor productivity, ε_t^{TFP}, is assumed to follow an exogenous process.

Cost minimization implies the following demand curves for labor and oil:

$$\hat{L}_t = -\left(\hat{w}_t - \hat{r}_t^k\right) + \hat{K}_t^S \tag{1}$$

$$\hat{O}_{gt} = -\alpha\left(\hat{p}_t^o - \hat{s}_t\right) + \widehat{VA}_t \qquad \text{with: } \hat{s}_t = (1-\theta)\,\hat{r}_t^k + \theta\hat{w}_t - \hat{\varepsilon}_t^{TFP} \tag{2}$$

which are equal across firms; and where $\hat{p}_t^o$ denotes the real oil price and $\hat{w}_t$ represents the real wage rate. Real marginal costs equal:

$$\widehat{mc}_t = \eta\hat{s}_t + (1-\eta)\,\hat{p}_t^o \tag{3}$$

Following the recent tradition of new Keynesian models, core-goods producers set prices according to the Calvo model augmented with a partial indexation rule to past core inflation rates for firms that do not receive a price signal. If $\left(1-\xi_p\right) \in [0,1]$ is the Calvo probability of being allowed to optimize one's price, $\gamma_p \in (0,1)$ denotes the degree of price indexation and $\beta \in (0,1)$ represents the discount factor, the Phillips curve for core goods is given by:

$$\hat{\pi}_t^g = \frac{\gamma_p}{1+\beta\gamma_p}\hat{\pi}_{t-1}^g + \frac{\beta}{1+\beta\gamma_p}\mathbf{E}_t\hat{\pi}_{t+1}^g + \frac{\left(1-\beta\xi_p\right)\left(1-\xi_p\right)}{\left(1+\beta\gamma_p\right)\xi_p}\left(\widehat{mc}_t - \hat{p}_t^g\right) + \hat{\varepsilon}_t^{PM} \tag{4}$$

where $\hat{\varepsilon}_t^{PM}$ denotes a shock to the mark-up of core prices, $\hat{p}_t^g$, over marginal costs, $\widehat{mc}_t$ (henceforth, '*price mark-up shock*').

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[8] The technology for gross output reflects the presumption that "*the relationship between physical inputs of oil and other factors of production would be closer to Leontief than Cobb-Douglas*" (Backus and Cruchini, 2000, p.196). Kim and Loungani (1992) were the first to formalize this by defining a Cobb-Douglas production function combining labour and a CES-aggregate of capital and oil. However, to estimate the model, it is easier to have a clearly defined technology for Value Added (GDP). Therefore we follow e.g. de Walque et al. (2005) and Medina and Soto (2005) and nest labour and capital as a CD-aggregate in a CES-function combining Value Added and Oil.

Foreign Firms Since oil-producing firms are situated all around the world, each of them produces a type of oil that is differentiated from the other oil producers' output in terms of geographical distance. Therefore, we assume that the market conditions of the crude oil producers are characterized by monopolistic competition.[9] Defining a continuum of oil-producing firms, indexed by $j \in [0,1]$, oil type $O_t^{j,*}$ is produced with the technology $O_t^{j,*} = \varepsilon_t^{OC} D_t^{S,,j}$. In contrast to the technology of core-goods, the production of oil, $O_t^{j,*}$, requires only the use of capital services, $D_t^{S,j}$, which are defined as the product of the utilization rate u_t and the capital stock D_{t-1}^{j}. This capital stock should be interpreted as a combination of exploitable oil fields and the installed machinery on these fields. Oil firm j produces at normal capacity, $OCAP_t^{j,*}$, if $u_t = 1$, so that: $OCAP_t^{j,*} = \varepsilon_t^{OC} D_{t-1}^{j}$. Accordingly, we label exogenous shifts in the total factor productivity of the oil sector, ε_t^{OC}, as '*oil capacity shocks*'. Military conflicts or natural disasters are examples of such exogenous oil supply events.

Real marginal costs of oil-producers, $\widehat{mc}_t^*$, are equal across firms and given by:

$$\widehat{mc}_t^* = \hat{r}_t^d - \hat{\varepsilon}_t^{OC} \tag{5}$$

where $\hat{r}_t^d$ represents the rental rate of oil fields. Instead of assuming flexible oil prices we employ the same price-setting model as for the core-goods producers and estimate the degree of oil price stickiness, $\xi_o \in [0,1]$, and indexation , $\gamma_o \in (0,1)$, in the Phillips curve for crude oil:

$$\hat{\pi}_t^o = \frac{\gamma_o}{1+\beta\gamma_o}\hat{\pi}_{t-1}^o + \frac{\beta}{1+\beta\gamma_o}\mathbf{E}_t\hat{\pi}_{t+1}^o + \frac{(1-\beta\xi_o)(1-\xi_o)}{(1+\beta\gamma_o)\,\xi_o}\left(\widehat{mc}_t^* - \hat{p}_t^o\right) + \hat{\varepsilon}_t^{OM} \tag{6}$$

We assume that the mark-up is subject to a shock $\hat{\varepsilon}_t^{OM}$. This '*oil mark-up shock*' represents exogenous shifts in the market power of oil producers and captures, among other things, shifts in the degree by which cartel agreements are observed by its members.

The total stock of exploitable oil fields, D_t, is owned by a representative drilling firm which produces new fields, DN_t, according to a simple AK-technology. Given the development of new fields and the extraction from existing ones, the evolution of the total amount of utilizable oil fields is represented by:

$$\hat{D}_t = \hat{D}_{t-1} + \mu\widehat{DN}_t - \mu\hat{O}_t^* \qquad \text{with} \qquad \widehat{DN}_t = \hat{\varepsilon}_t^{OI} + K_t^{S*} \tag{7}$$

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[9] In the literature there is no clear consensus about the structure of the oil market. OPEC is often considered as a powerful cartel acting like a monopolistic price setter. Others claim that OPEC has no market power whatsoever, implying a perfect competitive oil market. An overview of different viewpoints can be found in Crémer and Salehi-Isfahani (1991).

where $\hat{K}_t^{S*}$ are the capital services (drilling rigs) rented from the foreign households at the rental rate $\hat{r}_t^{k*}$, while $\mu(= O^*/D)$ denotes the steady-state depletion rate of oil fields. $\hat{\varepsilon}_t^{OI}$ represents a disturbances to the productivity of the drilling activities, which could be the result of technological changes as well as shifts in the success of discovering oil. Since this shock appears at the upstream of the oil manufacture, we refer to it as the '*oil investment shock*'. The drilling firm rents out the exploitable oil fields, D_{t-1}, to the various oil-producing companies at the rental rate r_t^d. It also decides about the utilization rate of the fields of which a level of u_t incurs a utilization cost of $\vartheta(u_t)$ core goods.[10] Profit maximization implies:

$$\hat{r}_t^d = \hat{p}_t^g + \vartheta \hat{u}_t \quad \text{with} \quad \vartheta \equiv \vartheta''(1)/\vartheta'(1) \tag{8}$$

$$\hat{Q}_t^d = -\left(\hat{R}_t^* - \mathbf{E}_t \hat{\pi}_{t+1}\right) + (1-\beta)\,\mathbf{E}_t \hat{r}_{t+1}^d + \beta \mathbf{E}_t \hat{Q}_{t+1}^d \quad \text{with} \quad \hat{r}_t^{k*} = \hat{Q}_t^d + \hat{\varepsilon}_t^{OI} \tag{9}$$

Eq (8) states that the drilling firm increases the utilization rate, u_t, up to the point were the marginal revenue equals the marginal cost of the extra oil exploitation. An increase in oil production, O_t^*, for given normal capacity levels, $OCAP_t^*$, can only be reached by raising the utilization rate and therefore puts upward pressure on the rental rate for the oil fields, r_t^d (eq.(8)), which in turn raises the oil-producing firms' marginal costs, mc_t^* (eq.(5)) as well as oil prices (eq.(6)). Equation (9) constitutes an intertemporal condition between the real rental price r_t^d, which the drilling firm receives for renting out the exploitable oil fields, and the real rental price r_t^{k*}, which is the rent for the drills.

Domestic Households The home economy is populated by a continuum of households, indexed by $\tau \in [0,1]$, which seek to maximize lifetime utility $E_0 \sum_{t=0}^{\infty} \beta^t \bar{\varepsilon}_t^{TI} U_t^\tau$. $\bar{\varepsilon}_t^{TI}$ is a disturbance that can be interpreted as a '*time-impatience shock*' to the subjective discount factor β. Period utility is given by $U_t^\tau = \frac{1}{1-\sigma_c}\left(C_t^\tau - hC_{t-1}\right)^{1-\sigma_c} - \frac{1}{1+\sigma_l}\left(L_t^\tau\right)^{1+\sigma_l} + \bar{\varepsilon}_t^{OS} \ln\left(OS_{t-1}^\tau\right)$. First, households derive utility from consumption, C_t^τ, where the curvature parameter $\sigma_c > 0$ and the external habit coefficient $h \in [0,1)$ govern the inter-temporal elasticity of substitution. Second, utility depends negatively on hours worked, L_t^τ, with $\sigma_l \geqslant 0$ denoting the reciprocal of the Frisch elasticity of labor. Third, domestic households can stockpile oil, the size of which is given by OS_t^τ. Besides being an investment option, we treat oil inventories as a source of household utility, in that these stocks support liquidity in the oil market.[11] Inventories built up in the previous period can be used to bridge the lead time in oil delivery, originating from the distant oil-producing countries, in the current

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[10] We make the standard assumption that $\vartheta(u_t)$ is an increasing convex function, with $\vartheta(1) = 0$.

[11] A critique worth mentioning to modelling inventories as a source of household utility is that this approach "*relies on reduced-form analysis rather than on the microfoundations of inventory behavior*" (Wen, 2008, p.4). However, deriving inventory behavior from micro foundations in general-equilibrium

period. $\bar{\varepsilon}_t^{OS}$ denotes an oil-specific demand shock to the desired level of oil inventories and is henceforth called the '*oil inventory shock'*. Shifts in precautionary or speculative holdings of oil inventories are captured by this shock.

The aggregate consumption basket, C_t, is produced by a competitive retailer combining imported oil, O_{ct}, and domestically produced core consumption goods, Z_t, via a Dixit-Stiglitz aggregator. Demand for oil and core goods in the consumption basket are respectively given by:

$$\hat{O}_{ct} = -\psi \hat{p}_t^o + \hat{C}_t \qquad \qquad \hat{Z}_t = -\psi \hat{p}_t^g + \hat{C}_t \tag{10}$$

where $\psi > 0$ defines the elasticity of substitution between oil and core consumption. Profit maximization also implies that headline inflation is a weighted sum of oil and core inflation rates, $\hat{\pi}_t = \delta \hat{\pi}_t^o + (1-\delta)\,\hat{\pi}_t^g$, with δ representing the share of oil in the consumption basket.

Domestic households have access to several types of assets to facilitate the intertemporal transfer of wealth. First, they can purchase one-period domestic bonds for which the gross nominal interest rate is given by R_t. There also exists a one-period international bond which can be subscribed to by both the domestic and foreign households and which pays a gross nominal interest rate of R_t^*. The optimal conditions for these asset holdings are the usual Euler equation and an arbitrage condition for home and foreign bonds:

$$\hat{C}_t = \frac{h}{1+h}\hat{C}_{t-1} + \frac{1}{1+h}\mathbf{E}_t\hat{C}_{t+1} - \frac{(1-h)}{(1+h)\,\sigma_c}\left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{t+1}\right) + \hat{\varepsilon}_t^{TI} \tag{11}$$

$$\hat{R}_t^* = \hat{R}_t - \kappa \widehat{NFL}_t \tag{12}$$

Following Jacob and Peersman (2008), consumers incur quadratic adjustment costs in accumulating foreign debt, NFL_t, the size of which is measured by κ.[12]

In addition to financial securities, households can build positions in physical assets. They can either invest (I_t) in the capital stock of the intermediate goods sector, K_t, or invest (I_t^o) in oil inventories, OS_t. The investment accumulation equations of these two assets are given by:

$$\hat{K}_t = (1-\tau)\hat{K}_{t-1} + \tau\hat{I}_t + \tau\,(1+\beta)\,S\hat{\varepsilon}_t^{INV} \qquad \qquad \widehat{OS}_t = (1-\tau^o)\,\widehat{OS}_{t-1} + \tau^o\hat{I}_t^o \tag{13}$$

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models is a recent research area on itself, and beyond the scope of this paper. Instead, we follow earlier attempts in the literature and include inventories into the households' utility function, e.g. Kahn et al. (2002).

[12] Since the model is characterized by incomplete financial markets, the deterministic steady-state would not be unique and the linear solution would be non-stationary if the quadratic adjustment costs in accumulating foreign debt were not included. See Boileau and Normandin (2008) for a discussion of restoring stationarity in open economy DSGE-models containing incomplete financial markets.

where parameters τ and τ^o represent the depreciation rates in the respective asset accumulation equations.[13] ε_t^{INV} is a shock to the domestic investment-specific technology process. The first order conditions with respect to K_t and OS_t yield the following two asset-pricing conditions that determine the values, Q, of the respective capital stocks:

$$\begin{aligned}
\hat{Q}_t &= -\left(\hat{R}_t - \mathbf{E}_t \hat{\pi}_{t+1}\right) + \left(1 - \beta\left(1-\tau\right)\right)\mathbf{E}_t \hat{r}_{t+1}^k + \beta\left(1-\tau\right)\mathbf{E}_t \hat{Q}_{t+1} \qquad (14) \\
\hat{Q}_t^o &= -\left(\hat{R}_t - \mathbf{E}_t \hat{\pi}_{t+1}\right) + \left(1 - \beta\left(1-\tau\right)\right)\left\{\widehat{U_{OS_t}} - \widehat{U_{C_{t+1}}}\right\} + \beta\left(1-\tau\right)\mathbf{E}_t \hat{Q}_{t+1}^o + \hat{\varepsilon}_t^{OS} \qquad (15)
\end{aligned}$$

$\left\{\widehat{U_{OS_t}} - \widehat{U_{C_{t+1}}}\right\}$ represents the marginal rate of substitution of oil inventories for consumption, where $\widehat{U_{OS_t}} = \left(\frac{\sigma_c}{1-h}\left(E_t\hat{C}_{t+1} - h\hat{C}_t\right)\right)$ and $\widehat{U_{OS_t}} = -\widehat{OS}_t$. We allow for investment adjustment costs in both the capital stock K_t and the oil inventories OS_t, which are measured by respectively S and S^o, both > 0. As a result, the market value of both stocks can differ from their replacement cost and investments evolve according to:

$$\begin{aligned}
\hat{I}_t &= \frac{1}{(1+\beta)}\hat{I}_{t-1} + \frac{\beta}{(1+\beta)}\mathbf{E}_t\hat{I}_{t+1} + \frac{1}{(1+\beta)S}\left(\hat{Q}_t - \hat{p}_t^g\right) + \varepsilon_t^{INV} \qquad (16) \\
\hat{I}_t^o &= \frac{1}{(1+\beta)}\hat{I}_{t-1}^o + \frac{\beta}{(1+\beta)}\mathbf{E}_t\hat{I}_{t+1}^o + \frac{1}{(1+\beta)S^o}\left(\hat{Q}_t^o - \hat{p}_t^o\right) \qquad (17)
\end{aligned}$$

The arbitrage condition for the value of oil stocks Q_t^o (eq.(15)), bears close resemblance to the one Hamilton (2009) presents in his overview of theories describing the time path of crude oil prices, which is: $\hat{p}_t^o = -\left(\hat{R}_t - \hat{\pi}_{t+1}\right) + \beta\hat{p}_{t+1}^o + \left(1-\beta\right)\hat{C}_t^y - d\hat{C}_t^{\#}/p^o$. This condition states that in principle arbitrage equates the gross return on bonds, $\hat{R}_t - \hat{\pi}_{t+1}$, with the expected oil price increase, $\beta\hat{p}_{t+1}^o - \hat{p}_t^o$. However, oil storage also entails costs $\hat{C}_t^{\#}$ to be taken into account. We model these costs as a function of the change in investment rather than investment levels, which gives rise to a real market value of oil stocks $\hat{Q}_t^o$ that differs from the real oil price $\hat{p}_t^o$. On the other hand oil storage implies benefits, such as the ability to keep a production process running. Hamilton (2009) refers to these benefits as the convenience yield $\hat{C}_t^y$. In our model this convenience yield is structurally derived and given by the marginal rate of substitution of oil inventories for consumption. Higher economic activity induces an increase in $\hat{C}_t^y$ through its effect on consumption, while higher oil inventory levels reduce $\hat{C}_t^y$. The oil inventory disturbance, $\hat{\varepsilon}_t^{OS}$, can also be interpreted as a shock to the convenience yield.

Finally, we assume that L_t^τ is a differentiated labor service, giving household τ some monopoly power over wages. This wage-setting power is subject to nominal rigidities à la Calvo (Erceg et al., 2003) enriched with a partial indexation rule (SW, 2003) to inflation

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[13] τ^o is introduced in the model to obtain a well-defined steady state. As will be presented in section 3.1, we assign a low value to it.

for households that do not receive a ‘wage-change signal’. The resulting wage equation is given by:

$$\begin{aligned}\hat{w}_t \quad = \quad & \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}\mathbf{E}_t\hat{w}_{t+1} + \frac{\beta}{1+\beta}\mathbf{E}_t\hat{\pi}_{t+1} - \frac{1+\beta\gamma_w}{1+\beta}\hat{\pi}_t + \frac{\gamma_w}{1+\beta}\hat{\pi}_{t-1} \qquad (18) \\ & - \frac{(1-\beta\xi_w)(1-\xi_w)}{\xi_w\left(1+\sigma_l\frac{(1+\lambda_w)}{\lambda_w}\right)(1+\beta)}\left[\hat{w}_t - \sigma_l\hat{L}_t - \frac{\sigma_c}{1-h}\left(\hat{C}_t - h\hat{C}_{t-1}\right)\right] + \hat{\varepsilon}_t^{WM}\end{aligned}$$

$\gamma_w \in [0,1]$ represents the degree of indexation to lagged inflation and $\xi_w \in (0,1)$ denotes the Calvo probability. $\hat{\varepsilon}_t^{WM}$ is a shock to the mark-up, λ_w, of the real wage over the marginal rate of substitution between consumption and leisure.

Foreign Households The lifetime utility function of each foreign household γ, with $\gamma \in [0,1]$, is given by $E_0\sum_{t=0}^{\infty}\beta^t\left(\frac{1}{1-\sigma_c^*}\left(Z_t^{\gamma*} - h^* Z_{t-1}^*\right)^{1-\sigma_c^*}\right)$, which reflects several asymmetries between the home and foreign households. First, we assume that foreign households are endowed with a fixed amount of oil. As a consequence, household γ’s consumption bundle only contains domestically produced core goods, $Z_t^{\gamma*}$, and oil is not being stockpiled. Second, foreign households are not only the owners, but also the entrepreneurs of the oil companies. In their capacity as entrepreneurs foreign households do not offer any labor efforts in addition to the entrepreneurial tasks, which require a fixed amount of time and which are not rewarded with a wage in addition to profit. Accordingly, in contrast to domestic households, total income consists of only two components. Households are the owners of the drilling rigs, K_t^*, and hence receive the rent. Furthermore, households receive the dividends derived from the imperfect competitive intermediate oil firms. Financial wealth is hold in the form of international bonds. Savings can also be invested (I_t^*) in the physical capital stock of the drilling sector, K_t^*, according to $\hat{K}_t^* = (1-\tau^*)\hat{K}_{t-1}^* + \tau^*\hat{I}_t^*$.

Utility maximization yields an Euler equation similar to eq.(11) and an asset-pricing equation that determines the behavior of Tobin’s Q for drilling rigs which looks like eq.(14). The investment accumulation equation, I_t^*, resembles eq.(16).

National Income Accounts Aggregating the budget constraints of all domestic households τ, and taking into account the profits of the domestic firms as well as the fact that total nominal oil demand is given by $P_t^o O_t^d = P_t^o O_{gt} + P_t^o O_{ct} + P_t^o I_t^o$, provides the national income account of the oil-importing country. If c_y, i_y, z_y and o_y denote the steady-state shares of consumption, investment, capacity utilization and oil demand in gross output, the linearized version of this equilibrium condition is given by:

$$\hat{Y}_t = c_y\hat{Z}_t + i_y\hat{I}_t + o_y\left(\hat{p}_t^o + \hat{O}_t^d - \hat{p}_t^g\right) + z_y\hat{z}_t - \left(\widehat{NFL}_t - \frac{1}{\beta}\widehat{NFL}_{t-1}\right) + \hat{\varepsilon}_t^{ES} \qquad (19)$$

where ε_t^{ES} represents exogenous spending, such as shifts in government consumption and the non-oil trade balance.

As mentioned before, in the empirical analysis we assume that the world economy is driven by the US and therefore approximate the oil-importing country by the US. Although the correlation between US oil consumption and world oil production is high, evolutions in US oil consumption often differ from those in the rest-of-the-world (RoW).[14] To take this into account, we introduce the following RoW oil demand schedule: $O_t^{d,RW} = f\varepsilon_t^{RW} O_t^d$, with O_t^d denoting US oil demand. Neglecting ε_t^{RW}, this schedule expresses the assumption of the US driving the world economy, as represented by the constant ratio $O_t^{d,RW}/O_t^d$. However, the introduction of ε_t^{RW} implies that this ratio is only constant on average (f). Events which create a wedge between US and RoW oil consumption patterns shift ε_t^{RW} and change the ratio $O_t^{d,RW}/O_t^d$ accordingly. In our model such events are exogenous and therefore we refer to ε_t^{RW} as the '*RoW oil demand shock'*. Consequently, the oil market clears when:

$$\hat{O}_t^* = \hat{O}_t^d + \frac{f}{1+f}\hat{\varepsilon}_t^{RW} \tag{20}$$

The introduction of a RoW-economy does not change the foreign agents' optimization problems as long as we assume that these agents pay, irrespective of the country of origin, the same dollar price, P_t^g, for each import good.[15] In this case, imports from the US, $M_t^{*,US}$, and the RoW, $M_t^{*,RW}$, evolve equally:

$$\hat{M}_t^{*,US} = \hat{M}_t^{*,RW} = c_o^* \hat{Z}_t^* + i_o^* \hat{I}_t^* + u_o \hat{u}_t + z_o^* \hat{z}_t^* \tag{21}$$

Equilibrium on the balance of payments between the US and the oil-producing country requires that $\hat{p}_t^o + \hat{O}_t^d = \hat{p}_t^g + \hat{M}_t^{*,US} + \frac{1}{o_y}\left(\widehat{NFL}_t - \frac{1}{\beta}\widehat{NFL}_{t-1}\right)$. Substituting this expression in the oil market equilibrium condition (20) and taking into account equation (21), gives the national income account of the oil-producing country:

$$\hat{O}_t^* = (\hat{p}_t^g - \hat{p}_t^o) + c_o^* \hat{Z}_t^* + i_o^* \hat{I}_t^* + u_o \hat{u}_t + z_o^* \hat{z}_t^* + \frac{1}{o_y}\left(\widehat{NFL}_t - \frac{1}{\beta}\widehat{NFL}_{t-1}\right) + \frac{f}{1+f}\hat{\varepsilon}_t^{RW} \tag{22}$$

Monetary Policy In order to close the model, we assume that the monetary authority follows a simple empirical Taylor-type rule to set nominal interest rate, R_t, given by:

$$\begin{aligned} \hat{R}_t \;=\; & \rho \hat{R}_{t-1} + (1-\rho)\left\{ r_\pi \hat{\pi}_t + r_y \left(\widehat{VA}_t - \widehat{VA}_t^p\right)\right\} \\ & + r_{dy}\left\{\left(\widehat{VA}_t - \widehat{VA}_t^p\right) - \left(\widehat{VA}_{t-1} - \widehat{VA}_{t-1}^p\right)\right\} + \hat{\varepsilon}_t^R \end{aligned} \tag{23}$$

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[14] As mentioned before, over the past four decades the linearly detrended series of world oil production and US oil consumption have a correlation of 85 percent.

[15] This assumption implies that there is no home bias in trade between the US and the RoW, nor do firms follow a local-currency pricing strategy. Under these conditions the law of one price holds.

The central bank targets both inflation and the output gap.[16] However, the interest rate is only gradually adjusted which gives rise to a certain degree of interest rate smoothing ρ. In addition, there is also a short-run feedback from the change in the output gap. $\hat{\varepsilon}_t^R$ is a *'monetary policy shock'* that corresponds to a deviation from the policy rule.

Shock Processes Finally, we need to define the various shock processes. Except for the exogenous spending and mark-up shocks, all disturbances follow an AR(1) process in logarithmic terms. Following SW (2007), exogenous spending is also affected by the productivity shock and disturbances in market power are assumed to follow an ARMA(1,1) process.[17] Table 1 summarizes the various structural shocks and their functional form.

3 Estimation

In this section we solve the model presented in Section 2 and estimate the different parameters. We split the parameter set $\digamma$ into two subsets Ξ and Θ ($\digamma = (\Xi, \Theta)$). The subset Ξ contains the parameters which are calibrated (Section 3.1). Following the work of SW (2003, 2007), Fernandez-Villaverde and Rubio-Ramirez (2004) and Lubik and Schorfheide (2005) the parameters in set Θ are estimated with Bayesian methods (Section 3.2).

3.1 Calibrated Parameters

The discount factor, β, is fixed at 0.99 and the quarterly depreciation rates τ and τ^* are set at 0.025. Following SW (2007), the labour cost share in value added at steady-state, θ, is calibrated to be 0.76, the steady-state consumption share in value added, $\frac{PC}{P^{va}VA}$, is set equal to 0.65 and the steady-state wage mark-up, λ_w, is assigned a value of 0.5. The parameter κ governing the adjustment costs in accumulating foreign debt is assumed to be small and equal to 0.001 (Jacob and Peersman, 2008). Using data about energy consumption by different sectors within the US, the steady-state ratio of oil used in the consumption basket over oil used in the production process, $\frac{P^oO_c}{P^oO_g}$, is calibrated to be 0.84. The empirical short term effect of oil-inflation on US headline inflation, implies a steady-state share of oil in the consumption basket, δ, which is equal to 0.01. Using data

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[16] The output gap is defined as the difference between actual output and the level of output that would prevail under flexible prices and wages in the abscence of mark-up shocks.

[17] SW (2007) motivate the exogenous spending process by the fact that '*in estimation exogenous spending also include net exports, which may be affected by the domestic productivity developments*' (SW 2007, p.11).

about the level of and changes in US crude oil stocks, we obtain a steady-state share of oil-inventory investments in total US oil consumption, $\frac{P^o I^o}{P^o O_t^{d,US}}$, which equals 0.002 and a depreciation rate on oil-inventories, τ^o, which is 0.001. Following BBY (2009) the steady-state depletion rate of exploitable oil fields, μ, is set at 0.0065.

3.2 Estimated Parameters

Next we turn to the parameter set Θ, the elements of which are estimated using a Bayesian approach. For this estimation exercise we use thirteen quarterly economic time series: nine US data series, of which two oil-data series, and four global oil-data series. Among the US data we distinguish: real GDP, real consumption, real investments, real wages, hours worked, headline inflation, Fed funds rate, US real oil inventories and US real oil consumption. The observed global oil-data series are: global real oil production, world real oil price, global active drilling rigs and the global oil capacity utilization rate.[18,19]

As the oil literature widely documents a weakened relationship between oil prices and the macro-economy since the mid 1980s, we restrict our sample to the period 1986Q1-2007Q1.[20] Predominantly the break is found to be the result of structural changes, e.g. Bernanke et al. (1997) and Blanchard and Gali (2007a). In contrast, recent discussions stress that shifts in the relative importance of oil demand and supply shocks driving the oil price help explain the changed oil macro-economy relationship, e.g. Barsky and Kilian (2001, 2004), Rotemberg (2007), Hamilton (2008) and BBY (2009). However, Baumeister and Peersman (2008) find a considerable break in the first quarter of 1986 even after allowing oil prices to change endogenously, and hence emphasize the importance of structural shifts. Since this discussion is beyond the scope of the paper, we focus our analysis on the most recent '*oil era*' and take 1986Q1 as the starting point of the sample.

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[18] In order to make the data series consistent with the variables of the linearized model several data transformations are required. The logs of real oil price and oil capacity utilization are demeaned. Other real variables, of which the aggregate ones are first expressed in per capita terms, are detrended by a linear trend. Finally, inflation and the nominal interest rate are demeaned with their respective sample averages. See appendix 2 for a more thorough description of the raw data and different data transformations.

[19] During estimation we allow for a measurement error in US oil consumption, η_t^{mes1}, to grasp shifts in energy efficiency, US oil inventories, η_t^{mes2}, to correct for the '*crude oil adjustments*' that are reported in the oil accounting tables and are often huge, and the oil capacity utilization rate, η_t^{mes3}, to take into account errors induced by interpolating annual data to quarterly frequencies. Measurement errors are assumed to be white noise.

[20] Mork (1989) and Hooker (1996) were the first to find a breakpoint in the oil-macroeconomy relationship. More recent evidence is provided by Hooker (2002), Jiménez-Rodriguez and Sánchez (2005), Blanchard and Gali (2007a), Edelstein and Kilian (2007) and Herrera and Pesavento (2009).

Prior Distribution Tables 2 and 3 present an overview of all priors that we set. Diffuse priors are chosen for the shock parameters. The AR- and MA-parameter of the stochastic processes are given a beta distribution with a mean of 0.5 and a standard deviation of 0.15. The standard errors of the shocks are assumed to be inverse gamma distributed with mean 0.25 and standard deviation 2.

Based on empirical evidence, reporting small values for the price elasticity of oil demand, we assume a low degree of substitution of oil in both the consumption basket and the production process.[21] In particular, it is assumed that ψ and α follow an inverse-gamma distribution with mean 0.07 and a standard error of 4.[22] The steady-state price elasticity of oil supply is represented by the elasticity of capital utilization with respect to the rental rate of capital in the oil sector ($1/\vartheta$). Assuming similar price elasticities for oil demand and supply, ϑ is given a normal distribution with mean 15 and standard error 3. The adjustment cost parameters, S and S^*, for investments in the capital stock of respectively the core-goods sector and the drilling sector are assumed to fluctuate around 4 (based on CEE 2005). It is reasonable to assume that stockpiling commodities, such as oil, is considerable less subject to adjustment problems than transforming physical goods into capital goods. Therefore, S^o is assigned an inverse-gamma distribution with mean 0.25 and standard deviation 4.

Rather than defining a prior on the Calvo probabilities we follow Rabanal and Rubio-Ramirez (2005) and impose our prior beliefs directly on the duration. We use rather lose priors and assume that the average duration of both US price and wage contracts follow a normal distribution with a mean of 3 (quarters) and a standard deviation of 1.[23] We also allow for rigid oil prices and assume a prior mean of 2 quarters for the duration of oil price contracts.[24] The prior mean and standard error for the degree of indexation to past inflation are respectively set at 0.5 and 0.15 for core prices, wages as well as oil prices.

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[21] Krichene (2002) finds a price elasticity of crude oil demand ranging from -0.02 to -0.08. Reviews of the literature estimating the price elasticity of energy demand by Dahl and Sterner (1991) and Atkins and Jazayeri (2004) also point to a very low short run elasticity, ranging between 0 to -0.11. There is less evidence about the steepness of the oil supply curve: e.g. Krichene (2002) who finds a short-run price elasticity of 0.01 and a long-run elasticity of 0.1.

[22] The highest calibrated value for comparable substitution elasticities in the production process, α, are reported in Kim and Loungani (1992) (0.7) and Rotemberg and Woodford (1996) (0.69). However, Backus and Crucini (2000) state that such high values can only be motivated for analyses of the secular changes in energy use and consider lower values (< 0.1) more appropriate if the focus lies on the business cycle.

[23] Concerning prices, this prior belief lies in the middle of the '*8-11 months*' range found in the '*micro-economic-data*' based study of Nakamura and Steinsson (2008).

[24] The main results are robust to alternative specifications of the oil price contract's prior distribution, such as the specification of the prior assigned to the duration of US price and wage contracts.

For the remaining parameters we use priors as imposed by SW (2007) for the US (see table 1). Note that the parameters of the utility function are assumed to be symmetric across the two countries.

Posterior Estimates Tables 2 and 3 also report the results of the Monte Carlo simulation.[25] We present the mode, the mean and the 5 and 95 percentiles of the posterior distribution.[26] In what follows we comment on the mean value. Regarding the shock variables, the productivity, the exogenous spending, the oil capacity and price mark-up processes are estimated to be the most persistent with an AR(1) coefficient of 0.93, 0.93, 0.95 and 0.85. All other processes have an AR(1) coefficient smaller than 0.8, indicating that the model is able to explain an important part of the persistence of the data.

The posterior estimates of the parameters encompassing the price elasticity of oil demand and supply confirm our prior beliefs. The coefficients describing the elasticity of substitution for oil in consumption and production are respectively equal to 0.04 and 0.03. Compared to similar structural analyses, these values are lower than the estimates for the Chilean economy found by Medina and Soto (2005) ($\psi = 0.66$ and $\alpha = 0.51$), and the results for the US found by BBY (2009) ($\alpha = 0.129$). For the price elasticity of oil supply we obtain an estimate fluctuating around 0.08.

The results for the policy-rule coefficients tend to confirm previous findings for the US (e.g. SW 2007 and Rabanal and Rubio-Ramirez 2005). The estimate of the elasticity of intertemporal substitution lies in the traditional range from half to unity. For the habit formation parameter we obtain a value of 0.52, which is at the low end of those reported in the literature.[27] Consistent with studies including staggered wage contracts, the posterior mean of the inverse of the intertemporal elasticity of labor supply is found to be high at 2.82.[28] In line with the DSGE-literature, the average length of US price contracts is somewhat more than one year and a half. Wage contracts are estimated to

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[25] Overall the data seems to be quite informative. Figures comparing the posterior and prior distributions are available upon request. The parameters for which the data is the least informative are: the degree of wage and oil price indexation, and the investment adjustment cost parameter in both the drilling sector and the oil inventories.

[26] The reported posterior moments are numerically approximated. Applying the random walk Metropolis-Heastings algorithm a sample of 900.000 draws was created (neglecting the first 36.000 draws).

[27] For a comparable sample SW (2007) report a habit formation parameter of 0.68. However, Medina and Soto (2005) note that because of the explicit inclusion of oil in the consumption basket, the persistence of oil shocks by itself generate persistence in aggregate consumption, without having to rely on habit formation.

[28] See Rabanal and Rubio-Ramirez (2005) for a comparison between estimates of σ_l in models with flexible wages and models with staggered wage contracts.

have an average duration of about 1 year. Compared to US core prices, oil prices are rather flexible, characterized by an average contract duration between 2 and 2.5 quarters. In accordance with the results for the US found by SW (2007), the posterior mean of the degree of price indexation is less than 0.5. On the other hand, the degree of oil price and wage indexation are both close to the mean of the prior assumptions. Among the various investment adjustment cost parameters, only the elasticity of the cost of changing investments in the core goods sector differs significantly from our prior beliefs. Similar to SW (2007) this coefficient is found to be high at 6.01. Finally, the elasticity of capital utilization with respect to the rental rate of capital in the core-goods sector and the drilling sector are respectively found to be low at 0.35 and high at 1.08.

4 The Dynamic Effects Of Various Types Of Oil Shocks

In order to analyze the dynamic effects of the various oil shocks, graphs 1 to 5 present the estimated impulse responses of these shocks on the main endogenous variables of our model. Based on a selection of 1000 random draws out of the posterior distribution, each graph depicts the median response as well as the 5 and 95 percent error bands. As presented in Section 2, we distinguish three types of oil supply shocks, namely oil capacity, oil mark-up and oil investment shocks. On the demand side, the model identifies oil inventory shocks, oil demand shocks originating from the RoW and a collection of US macro-economic driven oil demand shocks (henceforth, '*US ME oil demand shocks*'). We mainly focus on the IRFs of the first five shocks (figures 1-4) and discuss only briefly the dynamic effects of one of the US ME oil demand shocks, in particular the US TFP shock.[29]

Oil Supply Shocks Among the oil supply shocks we can make a distinction between shocks hitting oil productive capacity (oil capacity and oil investment shocks) and shifts in the market power of oil producers. Negative disturbances in both types of shocks cause oil prices to increase, but through a different transmission channel creating different effects on drilling activity (see figure 1). Following an exogenous decline in productive oil capacity, oil fields need to be utilized more intensively in order to meet demand. This creates upward pressure on the oil fields' rental rate, which stimulates the development of exploitable oil

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[29] Except for the time-impatience shock, all shocks to the US non-oil aggregates (the US ME oil demand shocks) are identical to the ones identified in the closed-economy model for the US of SW (2007). The estimated IRFs of these shocks on the main US variables are shown to be qualitatively similar in both models. Figures of impulse responses to these shocks are available upon request.

fields and drives up marginal costs and oil prices.[30] Negative oil mark-up shocks, on the other hand, depress drilling activity. If oil producers' market power increase, they impose a higher price given a certain productive capacity. This induces a decline in oil demand which in turn mitigates the utilization rate of exploitable oil fields. As a result, the rental rate of these fields declines and with it the development of oil reserves.

Turning to the consequences for the US economy, figure 2 shows that all three oil supply shocks cause output, consumption, investments, real wages and hours worked to decline. However, concerning the output gap and inflation effects as well as the persistence of the dynamics, the various types of oil supply shocks are not alike. Before turning to analyze these differences, we first discuss the key transmission channels. The rise in real oil prices, following each of the supply shocks, implies a negative income effect on US consumption. However, there is also a substitution effect that tends to substitute core consumption for oil. Since the elasticity of substitution between the two types of consumption goods is very low, the income effect dominates and the demand for both falls. Higher oil prices also entail a negative income effect on GDP. Owing to staggered price contracts, this negative effect is partly counteracted by an endogenous decrease in the price mark-up. Furthermore, firms hire more domestic input factors to substitute for the more expensive oil. However, given the small degree of substitution between oil and the domestic inputs and the decrease in the demand for core goods, there is a negative net effect on GDP. As a result labor demand as well as capacity utilization (not shown) and investment fall. Since consumption levels drop, the decline in labour demand is accompanied by an increase in labour supply depressing real wages even further. However, demand effects dominate and hours worked go down. The real oil price increase also induces investors to cut down on their oil inventories and to shift their portfolio to more lucrative investment opportunities. This leads to a gradual decrease in the amount of oil inventories and hence an increased supply of oil on the market (reflected in the negative wedge between oil production and US oil consumption, see figure 1) which mitigates the negative supply effects.

Although the three oil supply shocks imply similar dynamics on the real side of the economy, the persistence of these dynamics differ considerably. Since the oil capacity process is more persistent than the oil mark-up process, the former naturally generates longer lasting effects. Because of the small oil depletion rate, real oil prices increase very sluggishly following a negative oil investment shock. While domestic consumption and investments adjust accordingly, the oil producers' lower investment needs significantly

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[30] Note that following a negative disturbance to oil investments the direct incidence of the shock on drilling activity exceeds the positive effects induced by the increase in the utilization rate and therefore drilling activity decreases.

push down domestic exports, output and hours worked on impact.

Positive oil mark-up shocks are assumed not to affect the output level that is targeted by monetary policy and therefore lead to a negative output gap. Following unfavorable shocks to oil productive capacity, the price and wage stickiness induce two opposite effects on the output gap. First, these nominal frictions buffer the economy from the oil price increase, implying a positive output gap. Second, declining consumption levels and falling real wages enlarge the wage and price mark-ups, reinforcing the negative output effects. Only in the very short run, up to 2 quarters, the first effect dominates the dynamics of the oil capacity shock. The sluggish effect of the oil investments shock on the real oil price induces the negative output gap effect of this shock to dominate at all horizons.

The most striking difference between the various oil supply shocks concerns their impact on inflation. Following an adverse oil capacity shock, headline inflation increases on impact and then gradually returns to target after four quarters. This inflation effect is mainly explained by the direct incidence of oil in the consumption basket; although core inflation rates (not shown) increase as well. The trade-off between output gap and inflation stabilization causes real interest rates to rise after only three quarters. Similarly, positive oil mark-up shocks cause total inflation to increase on impact. However, due to the short-lived character of the oil price hike, oil inflation quickly recedes bringing about a decrease in headline inflation under its target level in the third quarter after the shock. Finally, negative disturbances to oil investments induce decreasing core inflation rates (due to a decline in both real wages and the rental rate of capital) which completely offset the direct effects of the oil price increase on headline inflation. This implies that, given the negative output gap, the central banker faces no trade-off and real interest rates drop.

Oil Demand Shocks The dynamic responses to RoW oil demand shocks and, to a lesser extent, to positive oil inventory shocks (figures 3 and 4) are quite similar to the ones following, respectively, unfavorable shifts in oil productive capacity and oil producers' market power. Generally, higher oil demand, caused by the RoW or the oil inventory shock, can only be satisfied by utilizing the oil productive capacity more intensively. This raises the oil sector's marginal costs which in turn feeds into higher real oil prices. Since the degree of substitution of oil is estimated to be small in both the consumption basket of households and the production process of firms, income effects dominate and put downward pressures on domestic consumption, investments, GDP, hours worked and real wages.

Although similar, there are some notable differences between the dynamics of the oil inventory and oil mark-up shock. First, the oil inventory shock pushes up the level of oil stocks. Second, compared to oil mark-up shocks, unfavorable oil inventory shocks induce a less severe and almost insignificant negative output gap and a more sluggish inflation response. As a result, for a similar oil price increase, oil inventory shocks imply stronger and more persistent interest rate responses and accordingly also stronger and more persistent investment effects. The third difference concerns the effects on the drilling activity. On the one hand, the rental rate for exploitable oil fields increases, which stimulates investments in these fields. On the other hand, the Fed raises the interest rate in order to stem inflation. This policy leads to an increase in the real interest rate after about 6 quarters, which curbs investments in both the domestic and foreign economy.[31] On impact, the net effect is similar to the one following a negative oil capacity shock and oil investments increase. However, after about two years the strain of the higher real interest rate dominates and oil investments fall. Finally, in line with other oil demand shifters, unfavorable oil inventory shocks entail an increase in world oil production.

A key finding from the previous results is that US economic activity does not expand after rising real oil prices which have been caused by unfavorable oil supply and oil-specific demand shocks. The impulse response functions in figure 5, however, show that not all oil price hikes are accompanied by a slowdown in economic activity. Indeed, an increase in economic activity, stemming from e.g. a positive TFP shock, leads to a positive co-movement between US GDP and oil prices.[32]

5 Variance Decompositions

In this section we address two questions. First, what is the relative importance of the various oil shocks in explaining US macro-economic variability? More specifically, we track the sources of the volatility of US GDP, headline inflation and the federal funds rate. Second, what are the most important determinants of fluctuations in the oil market? In order to answer these questions we generate, using 750 random draws from the posterior, distributions of forecast error variance decompositions of the variables of interest. To summarize these distributions, we report the 5 and 95 percentiles as well as the median value.

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[31] Note that the relevant real interest rate for investment decisions is the nominal interest rate minus the core inflation rate. The latter is not shown in the figures.

[32] It is interesting to note that these observations are consistent with the sign restrictions Baumeister and Peersman (2008) and Peersman and Van Robays (2008) impose in order to disentangle different oil shocks in a VAR set-up. In this respect our structural model offers a useful theoretical underpinning to the empirical literature.

5.1 How important are oil shocks in explaining macro-economic variability in the US?

Tables 4-6 present the forecast error variance decomposition of US real GDP, US headline inflation and the federal funds rate at various horizons.

As shown in table 4, the contribution of oil shocks to the variability in US real GDP is quite modest: their combined median contribution barely amounts to 5 percent at all horizons. In the short run (within a year), the oil investment shock accounts for the bulk of this contribution. Over longer horizons, the oil inventory shock becomes the dominant driving force among the oil shocks. In line with the results of SW (2007) for the US, unexpected short-run output fluctuations are mainly explained by domestic ME demand shocks, which are the time-impatience shock, the investment-specific technology shock and the exogenous spending shock. In the medium to long run, the three domestic supply shocks (productivity, wage mark-up and price mark-up) account for more than half of the variation in real GDP.

In contrast to the real-side of the US economy, oil shocks are important drivers of US headline inflation (see table 5). Their combined median contribution makes up between 28 percent of the variance in the very short run and a minimal 25 percent in the long run. Among these oil shocks, disturbances in the oil mark-up are by far the most important. Of the domestic shocks, those arising from the price and wage mark-up contribute the biggest fraction of the forecast error variance of headline inflation at all horizons.[33]

Next we turn to the forecast error variance decomposition of the nominal interest rate, presented in table 6. Since the Fed responds quite aggressively to inflation and emerging output gaps, monetary policy mainly reacts to shocks not involving a trade-off problem, that is to the domestic ME demand and productivity shocks. Due to their muted effect on real GDP and significant contribution to headline inflation, oil shocks account for about 20 percent of variations in the nominal interest rate in the short run. Their contribution decreases over time and amounts to about 15 percent over the long horizon of 10 years.

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[33] In contrast to SW (2007) price mark-up shocks have a higher contribution to the forecast error variance of the real variables than wage mark-up shocks and stay the dominant driving force of inflation at all horizons. This is probably due to our lower and higer estimates of respectively the persistence in the wage and price mark-up processes.

5.2 Sources of oil market fluctuations?

Table 7 presents the variance decomposition of the main oil variables. Note that we summarize the combined contribution of the US ME oil demand shocks, rather than presenting the individual contribution of each of these shocks.

A key finding from our estimation results is the predominant role of the oil mark-up shock for oil prices. The median contribution amounts to about 80 percent in the very short run and its role decreases over time to some 45 percent over the longer run. With hardly 3 to 5 percent the oil capacity shock, on the other hand, does not contribute much to the forecast error variance of the real oil price. As a consequence, oil price movements caused by supply disturbances in the oil market are rather the result from shifting market power than from exogenous changes in productive capacity. Due to the small oil depletion rate, the contribution of the oil investment shock to the oil price variability is completely negligible. The second most important driver of real oil prices is the oil inventory shock. Its median contribution slightly increases from around 20 percent within one year to about 30 percent in the long run. With 2 to 5 percent the contributions of the US ME oil demand shocks are not important and equal about one third of the role of the RoW oil demand shock. Consequently, these results support strongly the case of oil price fluctuations which are exogenous with respect to US macro-economic developments. The predominant role of oil supply shocks as a source of oil price fluctuations is consistent with evidence provided in the structural work of NP (2009b) and BBY (2009). Among the limited number of empirical contributions, using reduced-form models, there is less consensus about the relative importance of oil supply shocks. Kilian (2009) finds that only a small fraction of the observed oil price movements can be attributed to oil supply shocks. On the other hand, Peersman and Van Robays (2009) report an equal contribution of oil supply and demand shocks to oil price volatility, which resembles our results at the business cycle frequency. Concerning the most relevant oil demand shock, our conclusions are more in line with Kilian (2009) who assigns a big role to oil-specific demand shocks.

In line with the forecast error variance of the real oil price, the oil mark-up and oil inventory shocks account for more than 50 percent of the variability in both world oil production and US oil consumption at all horizons. They play, however, a less predominant role. Regarding the variation in world oil production, the oil mark-up shock loses significance in favour of the RoW oil demand shock in the short run, but also the shocks hitting oil productive capacity (oil capacity and oil investment shock) in the long run. On the other hand, an important part of US oil consumption variability is due to shifts in the US ME oil demand shocks (28 percent in the short run and 60 percent in the long run).

The question arises as to why US ME and RoW oil demand shocks are important drivers of respectively US oil consumption and world oil production but at the same time do not significantly contribute to neither the real oil price nor respectively world oil production and US oil consumption. The key is that arbitrage elicits trading in oil inventories which counteracts disturbances in the oil market (see IRFs, Section 4). In case of e.g. positive US ME oil demand shocks (see figure 5), the increase in US oil consumption puts upward pressure on both world oil production and the real oil price. The subsequent gradual return of oil prices to the lower steady-state, turns investments in oil commodities into an unprofitable activity. Therefore, investors shift the portfolio to more lucrative investments and sell the expensive oil inventories on the oil market. This implies that, given a certain crude oil production level, oil supply increases, which in turn puts downward pressure on both the oil price and oil production levels and further stimulates US oil consumption. A positive oil demand shock in the RoW causes world oil production and real oil price to rise on impact and hence crowds out US oil consumption (see figure 3). Again increasing oil prices induces investors to cut down on their oil inventory positions. The resulting higher oil supply mitigates the oil price increase as well as the negative crowding out effects on US oil consumption.

Given the long lags needed to adjust capacity in the oil-producing sector, changes in the oil production levels can only be realized by adapting the utilization rate of exploitable oil fields accordingly. As a consequence, the variance decomposition of the oil capacity utilization rate is quite similar to that of world oil production. However, whereas the importance of shocks to oil capacity (oil capacity and oil investment shocks) in explaining the variation of world oil production increases over the forecast horizon, these shocks have a comparably low contribution to the variance of the utilization rate in both the short and long run. This is because alterations in oil production caused by changes in productive capacity do not require the utilization rate to adjust.

Finally, we turn to the variance decomposition of oil investments (active drilling rigs) and oil inventories. In short, the model seems to perform poor in explaining these two variables. At all horizons the oil investment shock itself is the main driving force of investments in the oil sector. In the long run, the median contribution of the US ME oil demand shocks increases, through their influence on the nominal interest rate, to about 50 percent. Most of the variations in oil inventories are due to exogenous precautionary or speculative reasons rather than to endogenous shifts in the investment portfolio. This is especially true in the short run, where the oil inventory shock accounts for about 75 percent of the variations in oil inventories, against roughly 40 percent in the long run.

6 An Analysis Of Important Oil Episodes Since 1986

We proceed to evaluate the role played by the various oil shocks as driving forces behind real oil price and US GDP fluctuations, by analyzing their importance for specific episodes. Specifically, we summarize the historical decomposition, at the mode of the posterior, of the two linearly detrended variables in figures 6 and 7.

Between the oil price collapse in late 1985, of which the end marks the beginning of our sample, and the beginning of the Gulf War in August 1990 real oil price evolutions were mainly the consequence of changes in oil producers' market power. Following the outbreak of hospitalities in August 1990 real oil prices reached a short-lived but significant peak in the fourth quarter of 1990. About 40 percent of this peak was caused by capacity-induced supply shortfalls. The other big half can be ascribed to an exogenous increase in the market power of oil-producing countries. As reflected by the positive contribution of the RoW oil demand shock, the US share in world demand for newly extracted crude oil declined relatively to the RoW during the war. Part of this decline can be explained by the sale of US strategic oil reserves. However, it could also indicate the US economy to have suffered more than the RoW. The upward pressure on the real oil price induced by the decline in oil productive capacity following the Gulf War not only reached a peak about 3 quarters after the end of war activities, but was also very long lasting.

During the first half of the nineties varying success of the OPEC countries to set prices explains the bulk of the oil price evolutions. About half of the decline in real oil prices in the years 1997 and 1998 were due to favorable oil supply shocks reducing OPEC's market power. The RoW oil demand shock provides some evidence that part of this decline can also be attributed to the Asian Crisis. An important observation concerns the negative pressure of the oil inventory shock on the real oil price following these events. One plausible explanation is that abundant oil supply induced a decline in precautionary or speculative holdings of oil inventories. In 1999, there came an abrupt end to the decline in real oil prices as OPEC and non-OPEC countries jointly decided to cut output in order to raise prices. Soon afterwards, exogenous demand for oil stocks rose again.

In the course of the early millennium slowdown both the US and the RoW ME shocks put downward pressure on the real oil price. The damaged oil production capacity during the Iraq war in 2003 was greatly offset by restraining market power of oil producers and hence oil prices remained relatively stable. Although the 2000s are characterized by big shifts in oil producers's market power, the bulk of the real oil price hike since 2002 is attributed to unfavorable disturbances in the desired level of oil inventories.[34] As a result

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[34] This is in contrast to Kilian's findings (2009), which attribute the biggest fraction of the real oil price

our estimation results provide strong evidence for precautionary or speculative induced oil price increases during this recent oil episode.

Turning to figure 7 one notices that the bulk of US real GDP episodes is explained by the domestic ME shocks. The decline in the oil sector's productive capacity following the Gulf War in late 1991, however, accounted for about one fifth in the drop of real GDP under steady-state levels during the beginning of the 90s. A second interesting observation is that, if unfavorable oil inventory shocks would have failed to appear, US real GDP levels would have been higher during the last couple of years.

7 Conclusions

In this paper, we have developed an endogenous oil sector in an estimated structural model of the US and the Oil Producing countries. Having estimated the model with Bayesian techniques for the more recent '*oil era*', starting in 1986, we investigated the relative importance of different kinds of oil demand and supply shocks in explaining the evolution of the oil price as well as analyzed the dynamics these shocks trigger. Recent advances in the empirical literature show that it is important for policy makers to identify the sources of oil price fluctuations so as to understand the macro-economic effects these disturbances induce. This, however, requires a new class of structural models that explain crude oil production levels and prices endogenously within the model, instead of treating them as random disturbances. In our modelling approach we took into account two features that we think such a model must include. First, the model must display the real and nominal frictions which are shown to be necessary to capture the persistence in the data. Second, to uncover the origin of shocks driving the real oil price, the structure of the oil market must be rich enough. The model must be able to identify at least those shocks that in the empirical literature have been found to be important drivers of the oil price; such as shifts in oil demand due to precautionary or speculative reasons. Next to this, we also made a distinction between supply shocks hitting oil productive capacity and inefficient shifts in the market power of oil producers.

A key finding of the paper is that oil price fluctuations are mostly exogenous with respect to US macro-economic developments. Exogenous shifts in the market power of oil producers and the level of oil inventories (most likely driven by precautionary or speculative motives) are predominant in driving the real oil price. A historical decomposition of the real oil price suggests that only during the Gulf War, in 1991, shocks to oil capacity

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increase since 2002 to a surge in real economic activity.

played a central role in understanding oil price fluctuations. One reason as to why macroeconomic developments in the US, and to a lesser extent in the RoW, hardly affects crude oil prices, is that arbitrage elicits trading in oil inventories which acts as a counteractive force against these demand shocks.

Our analysis also assesses the importance of the oil shocks in explaining variability of US economic activity. It turns out that the combined contribution of oil shocks to fluctuations in US real GDP is quite modest. They are, however, important drivers of US headline inflation. At the business cycle frequency, their combined contribution is about one fourth of the variance in US inflation. Historical decompositions show that only following the Gulf War and during the '2003-2006' oil price hike oil market disturbances significantly affected US real GDP.

Finally, our findings corroborate that '*not all oil price shocks are alike*' (Kilian 2009, p.16). First, the macro-economic effects of the various oil supply shocks exhibit some important differences. For example, negative oil capacity shocks raise inflation, oil mark-up shocks cause inflation to increase on impact but to decrease afterwards, and unfavorable oil investment shocks entail no significant inflation effects. Second, there are also some notable differences between the effects of the two main drivers of crude oil prices, i.e. the oil mark-up and inventory shock. For example, compared to market power shifts, oil inventory shocks induce a more sluggish inflation response and a less severe and almost insignificant output gap effect. As a result, for a similar oil price increase, oil inventory shocks imply stronger and more persistent interest rate responses and accordingly also stronger and more persistent investment effects.

Our results provide some preliminary insights into the conduct of monetary policy in a world characterized by oil price fluctuations. First, although fluctuations in the oil market are mostly exogenous with respect to US macro-economic developments, disturbances that are specific to the oil market have different effects which policy makers should take into account. Second, disruptions on the supply side of the oil market are mainly the consequence of inefficient mark-up shocks which always burden the central banker with a difficult trade-off between inflation and output gap stabilization. Even if wages and oil prices were completely flexible, this entails the breakdown of the "divine coincidence" (Blanchard and Gali, 2007b), in that a policy that stabilizes prices does not automatically stabilizes the distance of output from first best. This result is closely related to the conclusions of NP (2009a), who model a variable oil mark-up under flexible prices, and suggests that, apart from the output gap and headline inflation, optimal policy should directly focus on the oil price itself. We leave these issues as an interesting topic for future research.

A Data appendix

Quarterly series for US real GDP, US nominal consumption and US nominal investments are obtained from the US Department of Commerce: Bureau of Economic Analysis (BEA). Monthly data for US hours and nominal wages have been retrieved from the US Department of Labor - Bureau of Labor statistics (BLS). Following Chang et al. (2002), who point to the limited coverage of the NFB sector compared to GDP, we multiply the index of average hours for the NFB sector (all persons) with the civilian employment (16 years and over). The interest rate is the federal reserve rate which is taken from the Board of Governors of the Federal Reserve System. US headline inflation is measured by the first difference of the log of the implicit price deflator of the personal consumption expenditures (PCE) (available at the BEA). Nominal variables are deflated with the PCE-deflator.

Monthly series for US crude oil refinery inputs - oil consumption -, US crude oil stocks and world oil production are retrieved from the US Department of Energy (DoE): Energy Information Administration (EIA). The world oil price is represented by the refiner acquisition cost of imported crude oil which have been obtained from the EIA-database.[35] Real oil prices are obtained by deflating the nominal price with the US PCE-deflator. The rig counts database of the oilfield services company Baker Hughes offers a monthly census of active drilling rigs exploring for or developing oil or natural gas worldwide (the Worldwide Rig Count).[36] Yearly OPEC-spare capacity data are obtained from the IMF World Economic Outlook (August 2006) and the DoE Short-Term Energy Outlook (January 2009).[37] Quadratic interpolation techniques, matching averages to the source data, have been used to generate quarterly data points. Potential world oil production levels are calculated as the sum of OPEC spare capacity and world oil production, and the global oil capacity utilization rate is expressed as a percentage of this potential production level.

Monthly series have been converted to quarterly frequency by taking monthly averages. The log of the real oil price and the oil capacity utilization rate have been demeaned. Data for aggregate real variables have been seasonally adjusted, expressed per capita by dividing with the Civilian Noninstitutional Population over 16 (BLS-database) and linearly detrended in logarithmic terms.[38] Finally, the inflation rate and the nominal interest rate

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[35] The refiner acquisition cost of imported crude oil is a volume-weighted average price of all kinds of crude oil imported into the US over a specific period. Since the US imports more types of crude oil than any other country, it may represent the best proxy for a true world oil price.

[36] In contrast to other rotary rig counts, the Baker Hughes Rig Count only includes rigs that are actually working and not those rigs which are available or contracted but not actively drilling.

[37] Spare capacity equals production capacity that can be brought online within 30 days and sustained for 90 days.

[38] It is assumed that the US and the oil producing countries have equal population growth rates. Therefore

are demeaned with their respective sample averages.

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we can express the aggregate real variables of both regions in per capita terms by dividing them through the US civilian noninstitutional population.

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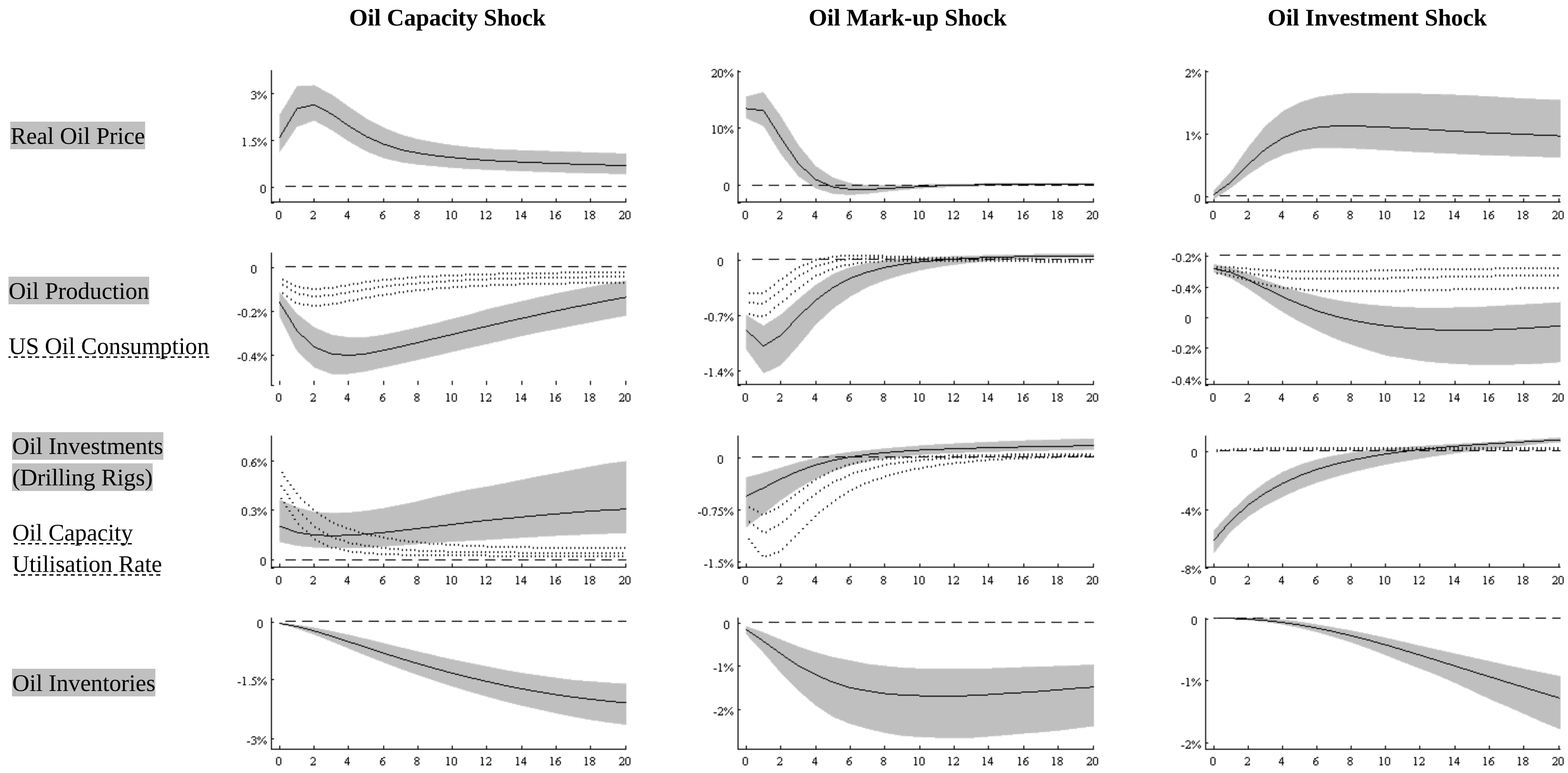
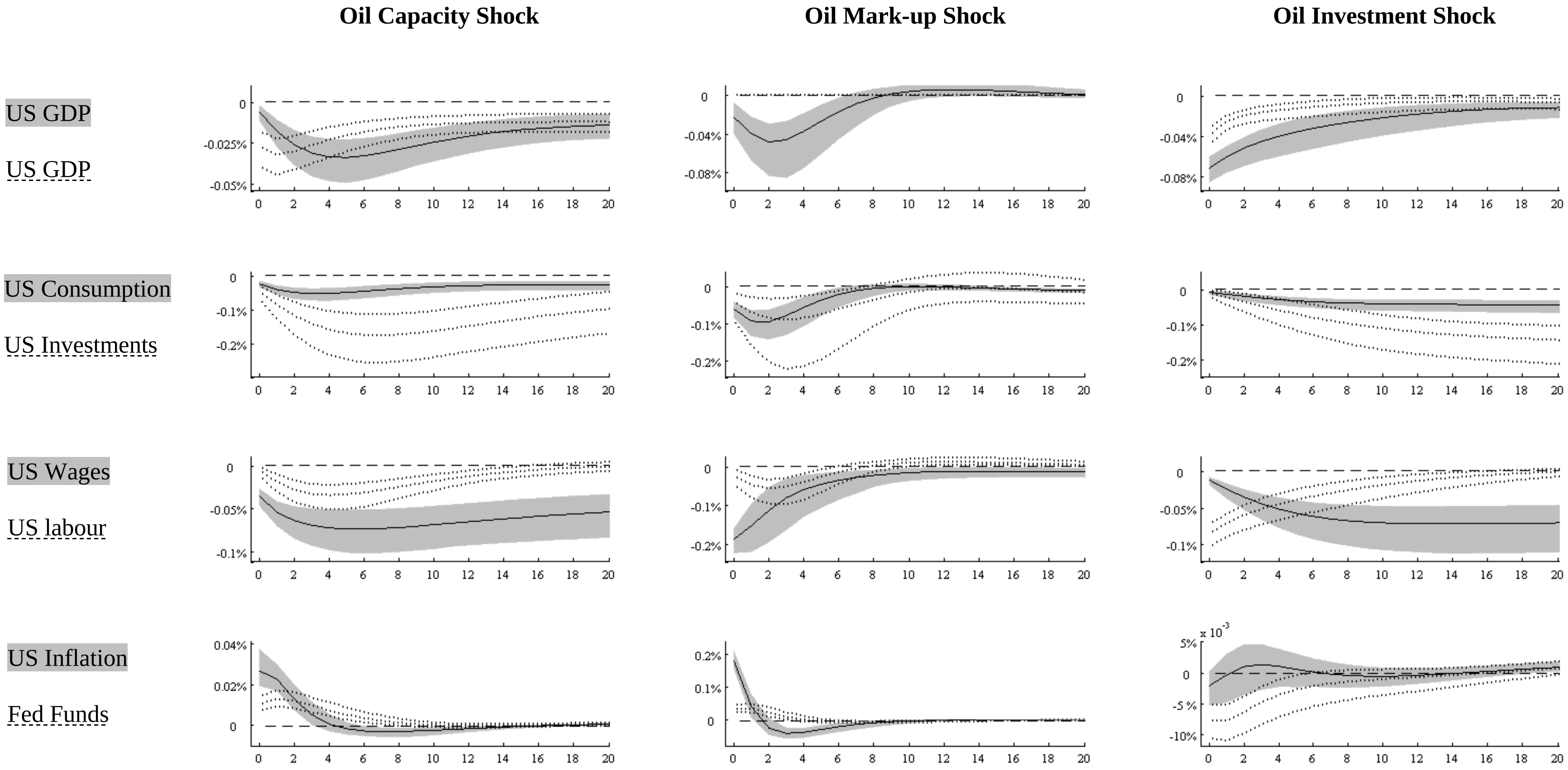
Figure 1: Impulse response functions of oil variables to oil supply shocks



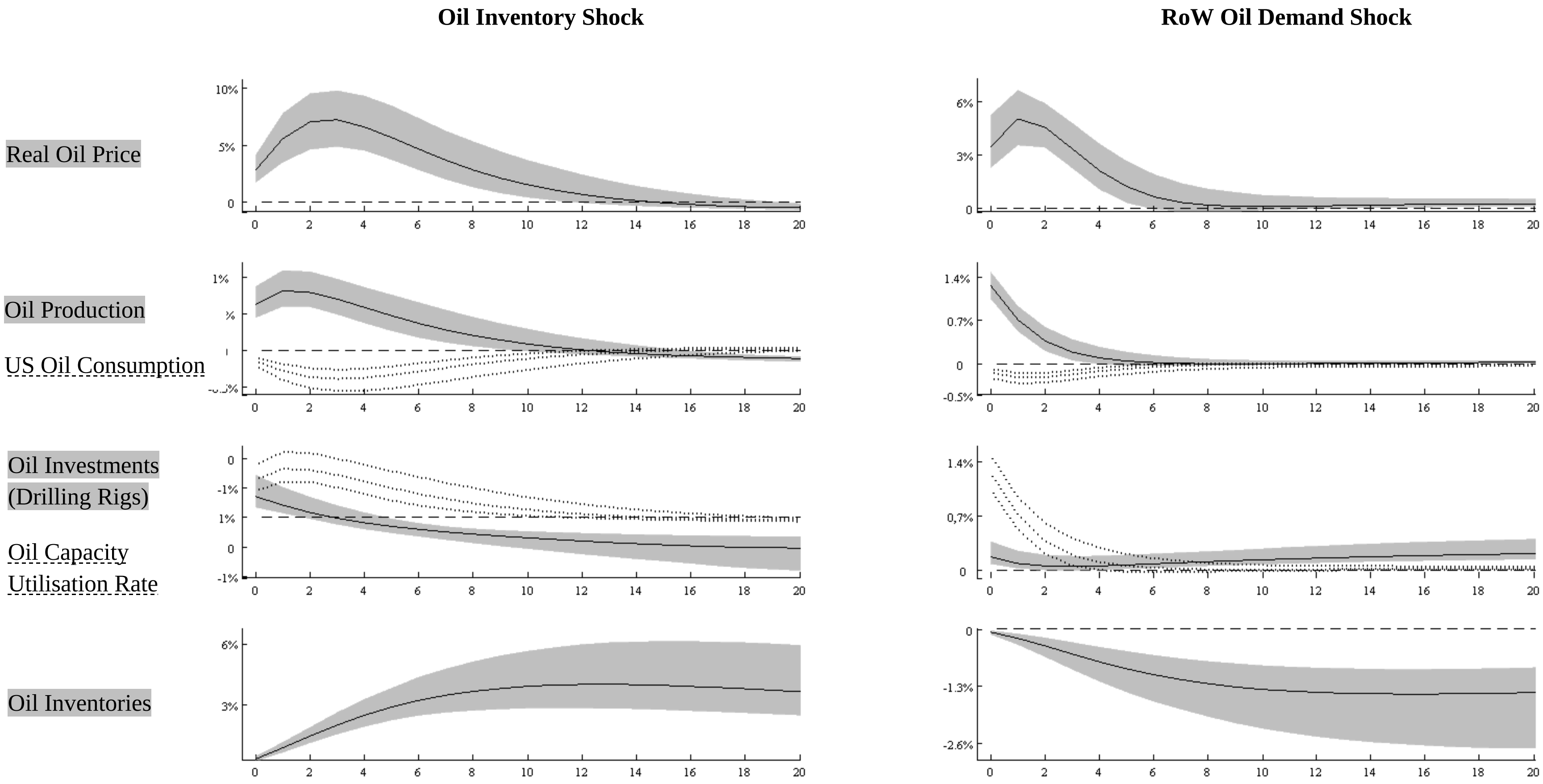
Note: The median IRF and the 5th and 95th percentiles are based on 1000 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Figure 2: Impulse response functions of US variables to oil supply shocks



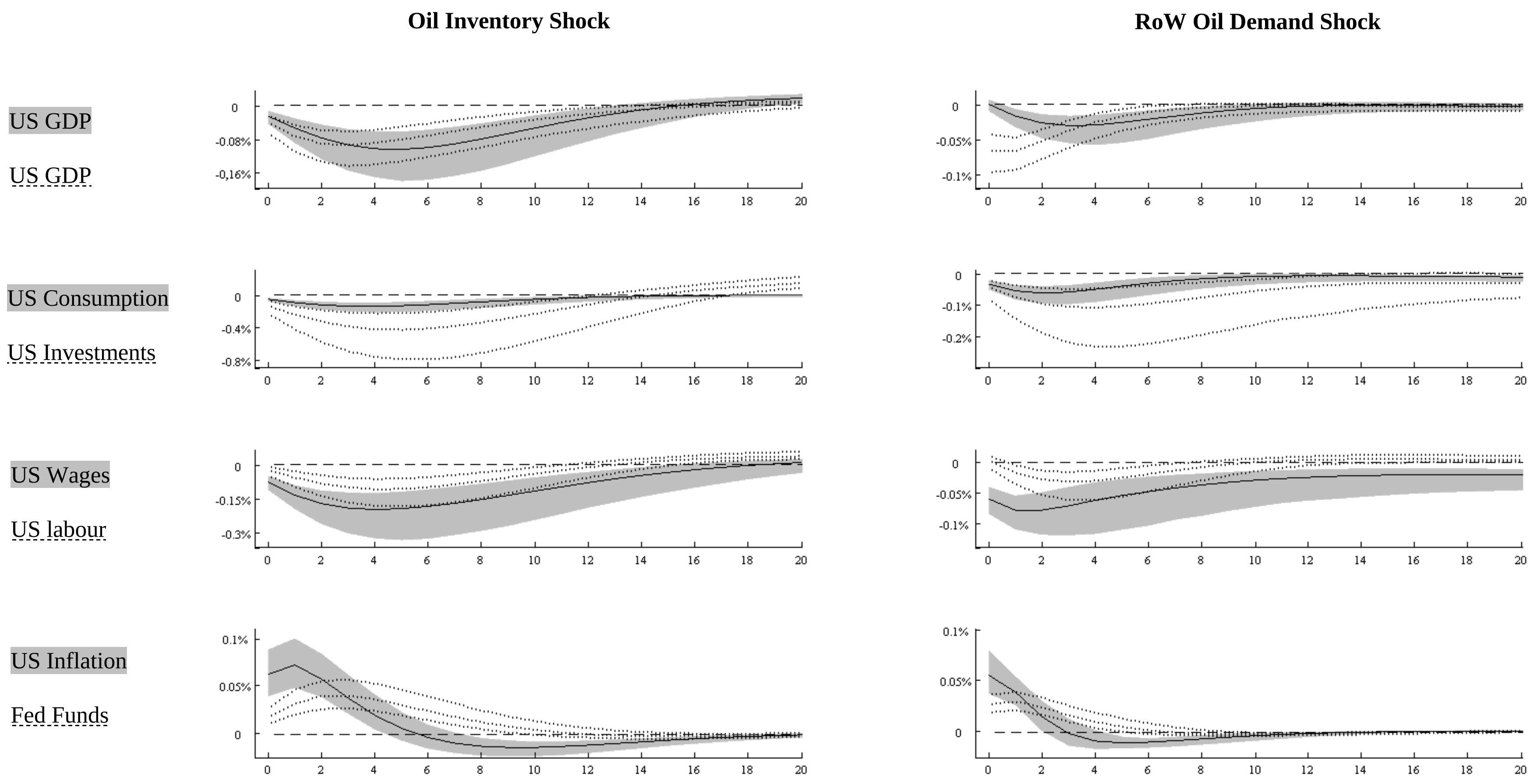
Note: The median IRF and the 5th and 95th percentiles are based on 1000 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Figure 3: Impulse response functions of oil variables to oil demand shocks



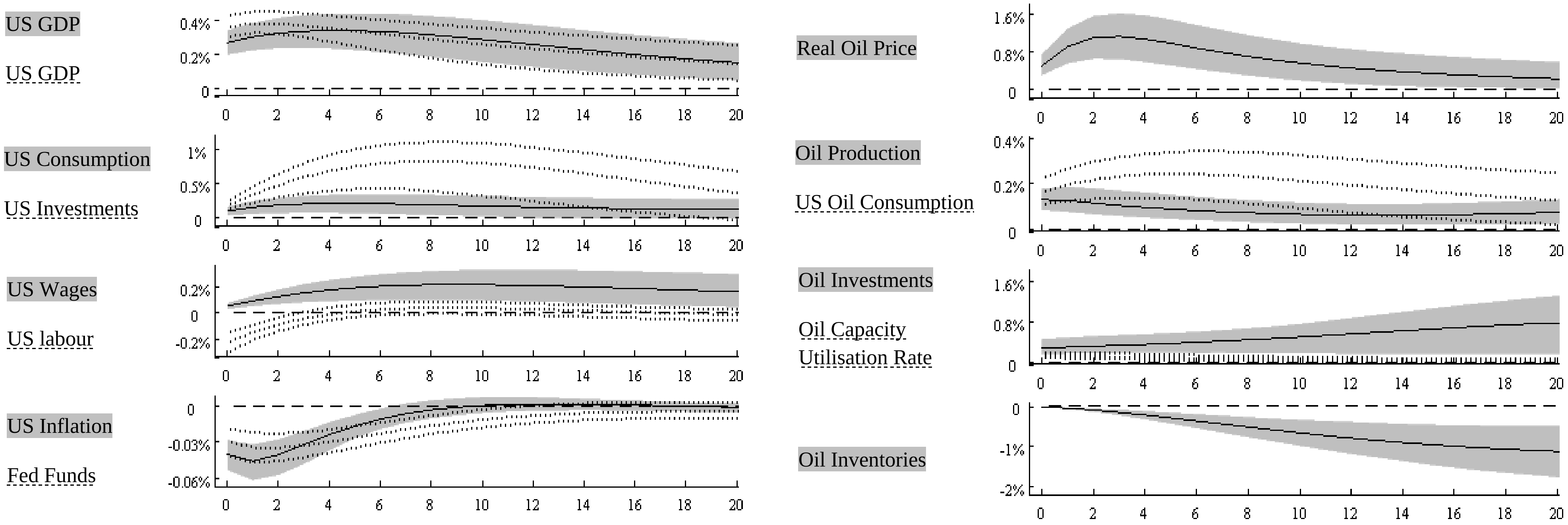
Note: The median IRF and the 5th and 95th percentiles are based on 1000 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Figure 4: Impulse response functions of US variables to oil demand shocks



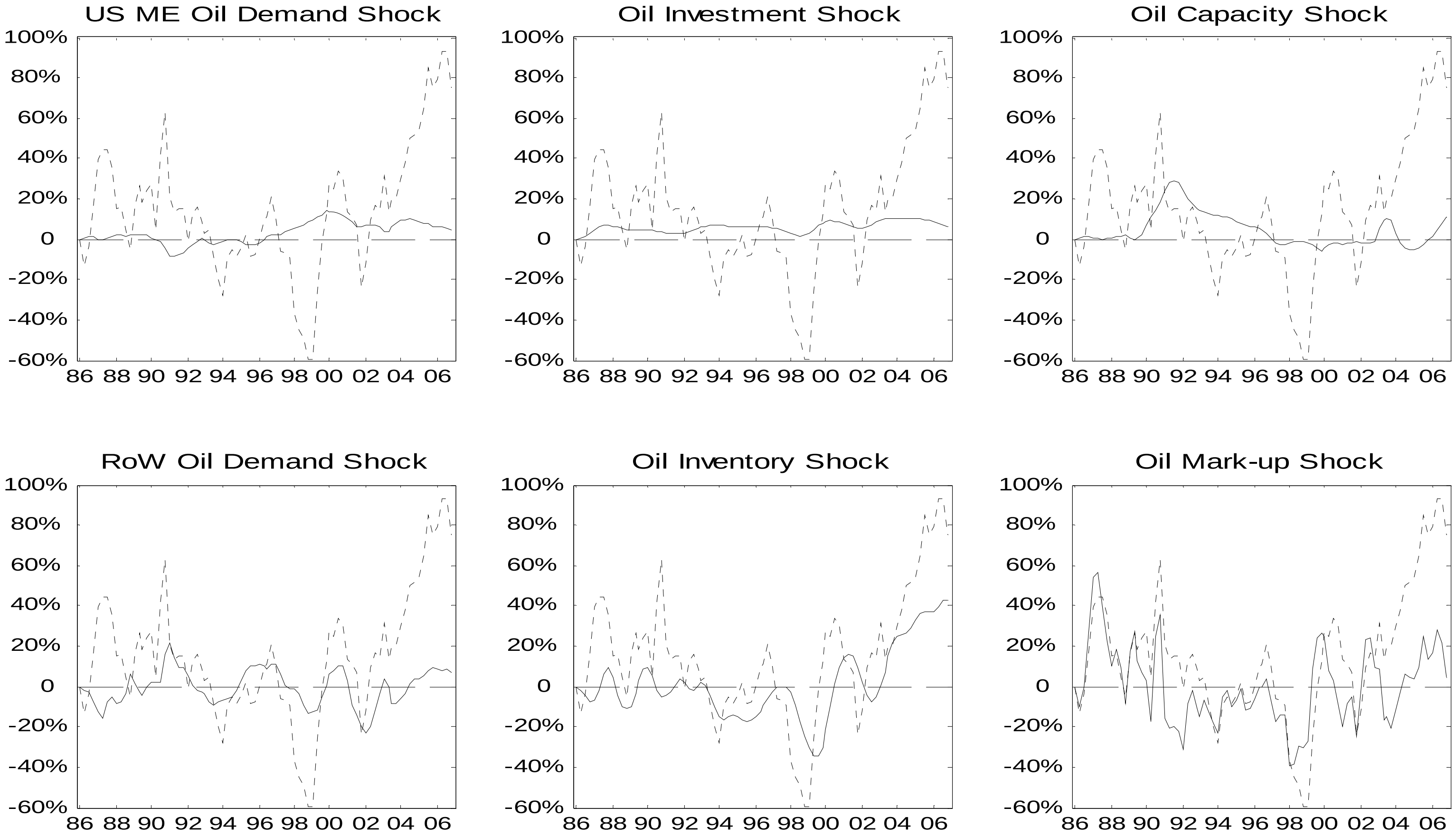
Note: The median IRF and the 5th and 95th percentiles are based on 1000 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Figure 5: Impulse response functions to the US TFP shock



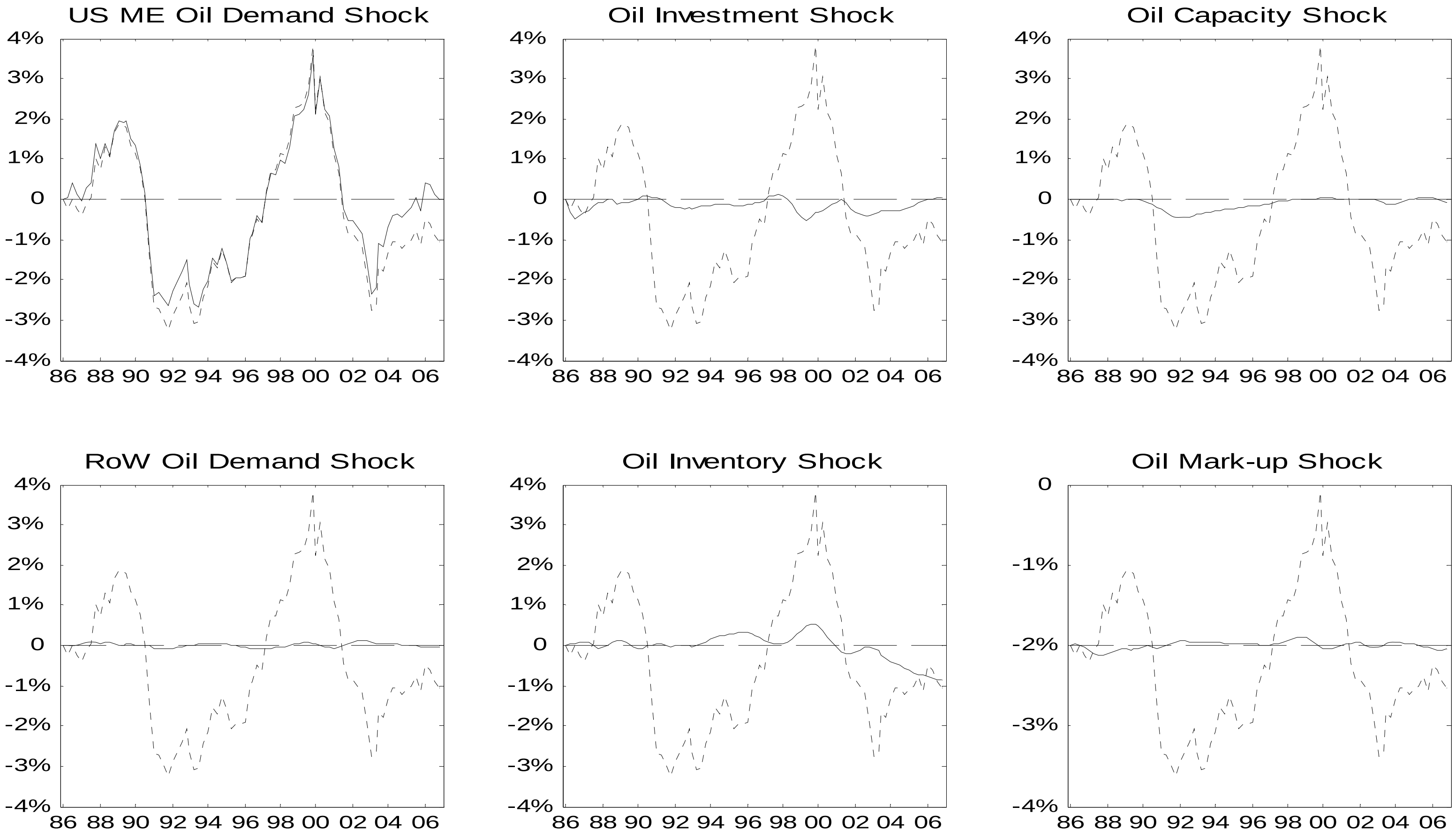
Note: The median IRF and the 5th and 95th percentiles are based on 1000 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Figure 6: Historical decomposition of real oil prices (percentage deviations from linear trend)



Note: Figures present the historical decomposition at the mode of the posterior. The solid line plots the contribution of each shock to the linearly detrended series, represented by the dotted line.

Figure 7: Historical decomposition of US real GDP (percentage deviations from linear trend)



Note: Figures present the historical decomposition at the mode of the posterior. The solid line plots the contribution of each shock to the linearly detrended series, represented by the dotted line.

Table 1: Overview structural shocks

Disturbances to:	**Denotation**	**Shock Process**
Factor productivity	$\hat{\varepsilon}_t^{TFP}$	$\hat{\varepsilon}_t^{TFP} = \rho_{TFP}\hat{\varepsilon}_{t-1}^{TFP} + \eta_t^{TFP}$
Investment -specific technology	$\hat{\varepsilon}_t^{INV}$	$\hat{\varepsilon}_t^{INV} = \rho_{INV}\hat{\varepsilon}_{t-1}^{INV} + \eta_t^{INV}$
General preferences	$\hat{\varepsilon}_t^{TI}$	$\hat{\varepsilon}_t^{TI} = \rho_{TI}\hat{\varepsilon}_{t-1}^{TI} + \eta_t^{TI}$
Monetary policy	$\hat{\varepsilon}_t^{R}$	$\hat{\varepsilon}_t^{R} = \rho_{R}\hat{\varepsilon}_{t-1}^{R} + \eta_t^{R}$
Exogenous spending	$\hat{\varepsilon}_t^{ES}$	$\hat{\varepsilon}_t^{ES} = \rho_{ES}\hat{\varepsilon}_{t-1}^{ES} + \eta_t^{ES} + \rho_{EA}\eta_t^{ES}$
Oil inventories	$\hat{\varepsilon}_t^{OS}$	$\hat{\varepsilon}_t^{OS} = \rho_{OS}\hat{\varepsilon}_{t-1}^{OS} + \eta_t^{OS}$
RoW oil demand	$\hat{\varepsilon}_t^{RW}$	$\hat{\varepsilon}_t^{RW} = \rho_{RW}\hat{\varepsilon}_{t-1}^{RW} + \eta_t^{RW}$
Oil capacity	$\hat{\varepsilon}_t^{OC}$	$\hat{\varepsilon}_t^{OC} = \rho_{OC}\hat{\varepsilon}_{t-1}^{OC} + \eta_t^{OC}$
Oil investments	$\hat{\varepsilon}_t^{OI}$	$\hat{\varepsilon}_t^{OI} = \rho_{OI}\hat{\varepsilon}_{t-1}^{OI} + \eta_t^{OI}$
Core price mark-up	$\hat{\varepsilon}_t^{PM}$	$\hat{\varepsilon}_t^{PM} = \rho_{PM}\hat{\varepsilon}_{t-1}^{PM} + \eta_t^{PM} - \mu_{PM}\eta_{t-1}^{PM}$
Wage mark-up	$\hat{\varepsilon}_t^{WM}$	$\hat{\varepsilon}_t^{WM} = \rho_{WM}\hat{\varepsilon}_{t-1}^{WM} + \eta_t^{WM} - \mu_{WM}\eta_{t-1}^{WM}$
Oil mark-up	$\hat{\varepsilon}_t^{OM}$	$\hat{\varepsilon}_t^{OM} = \rho_{OM}\hat{\varepsilon}_{t-1}^{OM} + \eta_t^{OM} - \mu_{OM}\eta_{t-1}^{OM}$

Table 2: Prior and posterior distribution of shock parameters

	Prior Distribution			**Posterior Distribution**			
	Distr	mean	st error	mode	mean	5%	95%
St. Dev of Shocks							
stdev η_t^{TI}	inv gamma	0.25	2.00	0.25	0.37	0.16	0.55
stdev η_t^{INV}	inv gamma	0.25	2.00	0.32	0.35	0.27	0.43
stdev η_t^{TFP}	inv gamma	0.25	2.00	0.44	0.45	0.39	0.50
stdev η_t^{ES}	inv gamma	0.25	2.00	0.45	0.48	0.40	0.55
stdev η_t^{OS}	inv gamma	0.25	2.00	0.27	1.04	0.13	3.04
stdev η_t^{OC}	inv gamma	0.25	2.00	0.61	0.63	0.55	0.71
stdev η_t^{OI}	inv gamma	0.25	2.00	5.20	6.48	3.44	9.39
stdev η_t^{RW}	inv gamma	0.25	2.00	1.57	1.57	1.33	1.79
stdev η_t^{PM}	inv gamma	0.25	2.00	0.13	0.13	0.10	0.16
stdev η_t^{WM}	inv gamma	0.25	2.00	0.33	0.34	0.28	0.41
stdev η_t^{R}	inv gamma	0.25	2.00	0.10	0.10	0.09	0.12
stdev η_t^{OM}	inv gamma	0.25	2.00	0.98	1.00	0.71	1.27
stdev η_t^{mes1} [1]	inv gamma	0.25	2.00	1.58	1.60	1.40	1.80
stdev η_t^{mes2} [1]	inv gamma	0.25	2.00	0.70	0.74	0.60	0.87
stdev η_t^{mes3} [1]	inv gamma	0.25	2.00	0.09	0.11	0.06	0.15
Process Parameters							
ρ_{TI}	beta	0.50	0.15	0.85	0.80	0.72	0.89
ρ_{INV}	beta	0.50	0.15	0.73	0.70	0.59	0.82
ρ_{TFP}	beta	0.50	0.15	0.95	0.93	0.88	0.97
ρ_{ES}	beta	0.50	0.15	0.93	0.93	0.89	0.96
ρ_{EA}	beta	0.50	0.15	0.65	0.64	0.48	0.80
ρ_{OS}	beta	0.50	0.15	0.80	0.67	0.45	0.85
ρ_{OC}	beta	0.50	0.15	0.96	0.95	0.93	0.98
ρ_{OI}	beta	0.50	0.15	0.80	0.79	0.72	0.86
ρ_{RW}	beta	0.50	0.15	0.77	0.78	0.69	0.87
ρ_{R}	beta	0.50	0.15	0.29	0.31	0.18	0.43
ρ_{PM}	beta	0.50	0.15	0.88	0.85	0.77	0.94
ρ_{WM}	beta	0.50	0.15	0.60	0.57	0.39	0.75
ρ_{OM}	beta	0.50	0.15	0.65	0.63	0.47	0.79
μ_{PM}	beta	0.50	0.15	0.61	0.56	0.37	0.76
μ_{WM}	beta	0.50	0.15	0.50	0.46	0.26	0.65
μ_{OM}	beta	0.50	0.15	0.41	0.40	0.20	0.59

Notes: [1] During estimation we allow for a measurement error in:

a) US oil consumption, η_t^{mes1}, to grasp shifts in energy efficiency,

b) US oil inventories, η_t^{mes2}, to correct for the *crude oil adjustments* reported in oil accounting tables and which are often huge,

c) The oil capacity utilization rate, η_t^{mes3}, to take into account errors induced by interpolating annual data to quarterly frequencies.

Our main findings are robust to alternative assumptions concerning these shocks, e.g. not taking into account η_t^{mes2} and η_t^{mes3}, or modelling shifts in energy efficiency as structural disturbances within the model.

Table 3: Prior and posterior distribution of structural parameters

	Prior Distribution			**Posterior Distribution**			
	Distr.	Mean	St error	Mode	Mean	5%	95%
Structural Parameter							
h consumption habit (home & foreign)	beta	0.70	0.10	0.47	0.52	0.39	0.65
σ_c consumption utility (home & foreign)	normal	1.50	0.375	1.74	1.71	1.25	2.18
σ_l consumption labor	normal	2.00	0.75	2.79	2.82	1.83	3.79
S capital-stock invest cost (home)	normal	4.00	1.50	5.67	6.01	4.04	8.06
S^o oil-inventory invest cost	inv gamma	0.25	4.00	0.11	0.22	0.07	0.41
S^* capital-stock invest cost (foreign)	normal	4.00	1.50	3.89	4.18	2.10	6.12
ψ elast of sub oil & core cons	inv gamma	0.07	4.00	0.04	0.04	0.02	0.06
α elast of sub oil & VA	inv gamma	0.07	4.00	0.03	0.03	0.02	0.05
γ_p indexation core prices	beta	0.50	0.15	0.39	0.42	0.19	0.64
$\frac{1}{1-\xi_p} - 1$ duration US price contracts-1 [1]	normal	2.00	1.00	5.11	5.20	4.09	6.31
γ_w indexation wages	beta	0.50	0.15	0.43	0.43	0.20	0.66
$\frac{1}{1-\xi_w} - 1$ duration US wage contracts-1 [1]	normal	2.00	1.00	2.96	2.96	1.95	4.01
γ_o indexation oil prices	beta	0.50	0.15	0.49	0.49	0.26	0.72
$\frac{1}{1-\xi_o} - 1$ duration oil price contracts-1 [1]	normal	1.00	0.50	1.23	1.35	0.72	2.00
$\frac{\chi}{1+\chi}$ $(\equiv \bar{\chi})$ cap util adj cost core-goods sector [2]	beta	0.50	0.075	0.79	0.74	0.60	0.90
$\frac{\chi^*}{1+\chi^*}$ $(\equiv \bar{\chi}^*)$ cap util adj cost drilling sector [2]	beta	0.50	0.075	0.45	0.48	0.36	0.61
ϑ cap util adj cost oil sector	normal	15.00	3.00	11.97	11.52	7.21	15.52
ϕ fixed costs	normal	1.25	0.125	1.39	1.40	1.26	1.55
ρ policy lagged interest rate	beta	0.75	0.10	0.87	0.87	0.83	0.90
r_π policy inflation	normal	1.50	0.25	1.67	1.69	1.40	1.98
r_y policy output	normal	0.50	0.20	0.07	0.09	0.01	0.17
r_{dy} policy lagged output	normal	0.50	0.20	0.22	0.21	0.15	0.27

Notes: [1] As in Rabanal and Rubio-Ramirez (2005), we impose our prior beliefs on the duration of the price and wage contracts minus one.

[2] As in SW (2007), we define $\frac{1}{\chi} = \frac{1-\bar{\chi}}{\bar{\chi}}$ and $\frac{1}{\chi^*} = \frac{1-\bar{\chi}^*}{\bar{\chi}^*}$, where $\bar{\chi}$ and $\bar{\chi}^*$ are normalized to be between zero and one.

Table 4: Contribution of the various shocks to the forecast error variance of US real GDP, at various horizons

	US Real GDP				**US Real GDP**				**US Real GDP**		
	med	5%	95%		med	5%	95%		med	5%	95%
1				**4**				**40**			
US productivity shock	27.49	16.34	39.96	US productivity shock	27.78	15.17	40.62	US productivity shock	34.84	14.68	56.53
US time-impatience shock	9.41	5.54	15.78	US time-impatience shock	5.75	2.90	10.78	US time-impatience shock	2.78	1.39	5.62
US exog. spending shock	27.14	19.71	37.09	US exog. spending shock	14.46	9.54	21.64	US exog. spending shock	6.63	3.71	12.11
US investment shock	14.82	10.89	20.11	US investment shock	18.65	12.72	26.68	US investment shock	15.27	8.11	26.47
Oil investment shock	1.52	1.07	2.09	Oil investment shock	0.85	0.55	1.35	Oil investment shock	0.54	0.27	1.19
Oil capacity shock	0.06	0.02	0.15	Oil capacity shock	0.17	0.08	0.35	Oil capacity shock	0.30	0.13	0.68
RoW oil demand shock	0.05	0.01	0.19	RoW oil demand shock	0.16	0.04	0.47	RoW oil demand shock	0.10	0.03	0.46
Oil inventory shock	0.60	0.17	1.59	Oil inventory shock	1.63	0.60	3.99	Oil inventory shock	1.83	0.61	5.31
Oil mark-up shock	0.38	0.11	1.03	Oil mark-up shock	0.46	0.18	1.36	Oil mark-up shock	0.20	0.08	0.68
US price mark-up shock	6.78	2.95	14.24	US price mark-up shock	15.87	7.49	27.94	US price mark-up shock	20.39	8.90	41.32
US interest rate shock	8.40	5.17	13.58	US interest rate shock	8.48	5.09	13.96	US interest rate shock	5.03	2.59	9.55
US wage mark-up shock	0.38	0.07	1.57	US wage mark-up shock	2.49	0.86	6.04	US wage mark-up shock	6.82	3.05	14.81
2				**10**				**100**			
US productivity shock	27.56	15.85	39.50	US productivity shock	30.24	15.02	45.35	US productivity shock	34.93	14.61	58.36
US time-impatience shock	8.29	4.61	14.47	US time-impatience shock	2.99	1.52	6.12	US time-impatience shock	2.78	1.35	5.67
US exog. spending shock	20.90	14.75	29.49	US exog. spending shock	8.61	5.10	13.73	US exog. spending shock	6.57	3.63	12.09
US investment shock	17.04	12.26	23.65	US investment shock	17.23	10.01	27.84	US investment shock	15.13	7.96	26.42
Oil investment shock	1.19	0.83	1.71	Oil investment shock	0.56	0.32	1.07	Oil investment shock	0.66	0.31	1.49
Oil capacity shock	0.11	0.05	0.24	Oil capacity shock	0.23	0.11	0.46	Oil capacity shock	0.33	0.13	0.75
RoW oil demand shock	0.10	0.03	0.33	RoW oil demand shock	0.12	0.03	0.48	RoW oil demand shock	0.11	0.03	0.47
Oil inventory shock	0.99	0.32	2.49	Oil inventory shock	2.02	0.69	5.79	Oil inventory shock	1.82	0.61	5.43
Oil mark-up shock	0.47	0.17	1.30	Oil mark-up shock	0.26	0.11	0.84	Oil mark-up shock	0.21	0.08	0.69
US price mark-up shock	10.29	4.59	19.71	US price mark-up shock	21.60	10.41	38.21	US price mark-up shock	20.10	8.73	41.13
US interest rate shock	8.92	5.62	14.05	US interest rate shock	6.38	3.41	11.41	US interest rate shock	5.00	2.52	9.50
US wage mark-up shock	0.97	0.25	2.96	US wage mark-up shock	5.86	2.58	12.30	US wage mark-up shock	6.72	3.01	14.79

Note: Distributions of forecast error variance decompositions are generated on the basis of 750 random draws from the posterior.

Table 5: Contribution of the various shocks to the forecast error variance of US headline inflation, at various horizons

	US Inflation				US Inflation				US Inflation		
	med	5%	95%		med	5%	95%		med	5%	95%
1				**4**				**40**			
US productivity shock	2.04	1.09	3.29	US productivity shock	2.85	1.51	4.67	US productivity shock	2.88	1.56	4.78
US time-impatience shock	1.92	0.98	3.80	US time-impatience shock	2.82	1.28	5.89	US time-impatience shock	2.96	1.29	6.46
US exog. spending shock	0.48	0.27	0.91	US exog. spending shock	0.72	0.37	1.33	US exog. spending shock	0.95	0.47	1.84
US investment shock	0.71	0.20	1.99	US investment shock	1.15	0.25	3.71	US investment shock	1.79	0.65	4.84
Oil investment shock	0.00	0.00	0.03	Oil investment shock	0.01	0.00	0.04	Oil investment shock	0.04	0.01	0.11
Oil capacity shock	0.72	0.41	1.22	Oil capacity shock	0.62	0.35	1.05	Oil capacity shock	0.60	0.34	1.00
RoW oil demand shock	2.61	1.34	4.64	RoW oil demand shock	2.06	1.07	3.81	RoW oil demand shock	2.04	1.03	3.71
Oil inventory shock	5.19	2.19	9.38	Oil inventory shock	6.12	2.71	10.90	Oil inventory shock	6.14	2.65	11.03
Oil mark-up shock	19.56	13.32	27.78	Oil mark-up shock	15.98	9.91	23.57	Oil mark-up shock	15.21	9.12	22.65
US price mark-up shock	53.34	42.65	65.72	US price mark-up shock	47.49	36.52	62.18	US price mark-up shock	46.04	35.02	60.22
US interest rate shock	2.68	1.24	6.01	US interest rate shock	4.90	2.26	10.87	US interest rate shock	6.02	2.72	12.73
US wage mark-up shock	8.64	5.15	13.96	US wage mark-up shock	12.14	6.93	20.25	US wage mark-up shock	12.18	6.82	20.78
2				**10**				**100**			
US productivity shock	2.45	1.34	3.95	US productivity shock	2.84	1.51	4.68	US productivity shock	2.98	1.59	5.08
US time-impatience shock	2.41	1.17	4.80	US time-impatience shock	3.00	1.30	6.53	US time-impatience shock	2.96	1.28	6.46
US exog. spending shock	0.58	0.31	1.10	US exog. spending shock	0.87	0.45	1.68	US exog. spending shock	0.98	0.48	1.92
US investment shock	0.93	0.24	2.76	US investment shock	1.20	0.28	4.03	US investment shock	1.91	0.71	5.02
Oil investment shock	0.01	0.00	0.03	Oil investment shock	0.01	0.00	0.05	Oil investment shock	0.06	0.02	0.19
Oil capacity shock	0.69	0.39	1.15	Oil capacity shock	0.60	0.34	1.01	Oil capacity shock	0.60	0.34	1.01
RoW oil demand shock	2.31	1.19	4.09	RoW oil demand shock	2.08	1.07	3.79	RoW oil demand shock	2.02	1.03	3.69
Oil inventory shock	6.01	2.66	10.70	Oil inventory shock	6.11	2.62	10.86	Oil inventory shock	6.10	2.65	10.97
Oil mark-up shock	16.87	11.09	24.02	Oil mark-up shock	15.69	9.50	23.34	Oil mark-up shock	15.13	9.09	22.42
US price mark-up shock	51.25	40.31	65.06	US price mark-up shock	46.09	35.22	60.50	US price mark-up shock	45.84	34.95	59.80
US interest rate shock	3.65	1.68	7.91	US interest rate shock	6.11	2.71	12.79	US interest rate shock	6.00	2.73	12.66
US wage mark-up shock	10.64	6.27	16.98	US wage mark-up shock	12.05	6.80	20.75	US wage mark-up shock	12.15	6.78	20.79

Note: Distributions of forecast error variance decompositions are generated on the basis of 750 random draws from the posterior.

Table 6: Contribution of the various shocks to the forecast error variance of US short run nominal interest rate, at various horizons

	Fed Funds				**Fed Funds**				**Fed Funds**		
	med	5%	95%		med	5%	95%		med	5%	95%
1				**4**				**40**			
US productivity shock	6.18	2.92	11.04	US productivity shock	6.54	3.26	10.79	US productivity shock	7.54	4.28	11.92
US time-impatience shock	24.93	16.39	35.18	US time-impatience shock	25.88	16.49	37.15	US time-impatience shock	23.79	14.00	36.41
US exog. spending shock	4.12	2.00	8.03	US exog. spending shock	4.12	2.18	7.70	US exog. spending shock	5.83	3.54	9.48
US investment shock	5.28	2.65	9.25	US investment shock	9.75	4.40	18.44	US investment shock	14.87	7.00	28.51
Oil investment shock	0.36	0.16	0.72	Oil investment shock	0.25	0.10	0.57	Oil investment shock	0.30	0.13	0.71
Oil capacity shock	0.90	0.54	1.45	Oil capacity shock	0.77	0.47	1.26	Oil capacity shock	0.65	0.40	1.09
RoW oil demand shock	5.02	2.83	7.96	RoW oil demand shock	3.38	1.96	5.35	RoW oil demand shock	2.40	1.30	4.04
Oil inventory shock	4.18	1.71	7.99	Oil inventory shock	7.62	3.62	13.36	Oil inventory shock	7.34	3.28	13.30
Oil mark-up shock	8.00	4.10	12.93	Oil mark-up shock	4.21	1.98	7.80	Oil mark-up shock	2.97	1.43	5.79
US price mark-up shock	12.22	6.26	20.64	US price mark-up shock	14.50	6.21	26.44	US price mark-up shock	12.99	6.53	25.21
US interest rate shock	23.22	15.46	31.87	US interest rate shock	13.58	8.38	21.16	US interest rate shock	9.59	5.95	15.29
US wage mark-up shock	2.95	1.45	5.33	US wage mark-up shock	5.68	2.71	10.44	US wage mark-up shock	6.99	2.83	14.33
2				**10**				**100**			
US productivity shock	6.27	3.08	10.92	US productivity shock	7.09	3.52	11.27	US productivity shock	8.24	4.65	13.68
US time-impatience shock	25.81	17.09	36.31	US time-impatience shock	25.50	14.98	38.68	US time-impatience shock	22.84	13.12	35.21
US exog. spending shock	4.05	2.04	7.86	US exog. spending shock	4.95	2.78	8.63	US exog. spending shock	5.89	3.58	9.66
US investment shock	7.05	3.46	12.75	US investment shock	12.20	4.95	25.11	US investment shock	15.45	7.49	28.81
Oil investment shock	0.30	0.13	0.64	Oil investment shock	0.21	0.07	0.55	Oil investment shock	0.51	0.22	1.28
Oil capacity shock	0.86	0.53	1.40	Oil capacity shock	0.65	0.38	1.10	Oil capacity shock	0.69	0.42	1.13
RoW oil demand shock	4.37	2.52	6.82	RoW oil demand shock	2.62	1.45	4.27	RoW oil demand shock	2.27	1.24	3.92
Oil inventory shock	5.81	2.58	10.42	Oil inventory shock	8.00	3.64	14.37	Oil inventory shock	6.99	3.09	12.76
Oil mark-up shock	6.20	3.01	10.78	Oil mark-up shock	3.25	1.55	6.19	Oil mark-up shock	2.85	1.39	5.56
US price mark-up shock	13.75	6.74	23.95	US price mark-up shock	13.14	5.47	26.41	US price mark-up shock	13.19	6.82	25.74
US interest rate shock	18.50	11.96	27.09	US interest rate shock	10.41	6.46	16.83	US interest rate shock	9.20	5.79	14.81
US wage mark-up shock	4.03	2.05	7.30	US wage mark-up shock	7.25	2.90	14.38	US wage mark-up shock	7.04	2.98	14.25

Note: Distributions of forecast error variance decompositions are generated on the basis of 750 random draws from the posterior.

Table 7: Contribution of the various shocks to the forecast error variance of the oil variables, at various horizons

	Real oil price			**Oil production**			**US oil consumption**			**Oil capacity util**			**Oil investments**			**Oil inventories**		
	med	5%	95%	med	5%	95%	med	5%	95%	med	5%	95%	med	5%	95%	med	5%	95%
1																		
US ME oil demand shocks	1.11	0.61	1.86	3.01	1.90	4.85	28.24	19.12	39.64	2.90	1.87	4.58	1.96	0.77	4.73	1.03	0.47	1.95
Oil investment shock	0.01	0.00	0.04	0.09	0.04	0.17	0.38	0.23	0.67	0.04	0.03	0.07	96.57	91.77	98.69	0.00	0.00	0.03
Oil capacity shock	1.95	1.05	3.46	1.97	1.01	3.96	1.82	1.04	3.24	5.34	3.41	8.28	0.11	0.03	0.36	1.28	0.60	2.45
RoW oil demand shock	8.03	3.69	15.58	38.15	25.24	51.78	6.08	2.83	12.07	36.84	25.10	49.09	0.06	0.01	0.30	3.66	1.32	8.72
Oil inventory shock	8.78	3.25	17.50	19.22	11.21	31.01	8.72	3.51	17.11	18.61	10.80	29.29	0.25	0.05	1.21	77.07	58.87	90.04
Oil mark-up shock	80.00	64.26	89.91	36.00	23.76	50.40	52.71	40.56	65.77	34.69	22.35	50.06	0.80	0.21	2.70	16.34	6.42	31.32
2																		
US ME oil demand shocks	1.69	1.00	2.71	3.10	1.79	5.23	31.32	21.31	43.51	3.03	1.80	5.02	2.37	1.00	5.62	1.34	0.61	2.46
Oil investment shock	0.05	0.02	0.14	0.15	0.07	0.30	0.45	0.26	0.83	0.09	0.05	0.16	96.21	90.98	98.53	0.01	0.00	0.04
Oil capacity shock	2.60	1.52	4.33	3.19	1.67	6.10	2.31	1.37	3.77	4.53	2.77	7.36	0.11	0.03	0.40	1.61	0.77	3.02
RoW oil demand shock	9.39	4.77	16.21	29.96	19.36	43.40	6.69	3.43	12.14	29.69	19.37	41.80	0.05	0.01	0.30	4.36	1.57	9.83
Oil inventory shock	14.85	5.90	27.59	23.02	13.95	34.63	13.70	5.63	24.90	22.63	13.78	33.94	0.21	0.04	1.15	75.62	57.57	89.30
Oil mark-up shock	71.00	53.37	84.42	39.06	26.60	53.71	43.61	31.33	57.99	38.67	25.57	54.25	0.77	0.20	2.67	16.80	6.68	31.05
4																		
US ME oil demand shocks	2.58	1.58	4.19	3.25	1.76	6.15	37.56	25.73	50.83	3.24	1.79	5.84	3.35	1.41	7.52	2.06	0.95	3.74
Oil investment shock	0.23	0.11	0.53	0.42	0.21	0.86	0.66	0.36	1.30	0.24	0.13	0.47	95.29	89.27	98.05	0.03	0.00	0.10
Oil capacity shock	3.30	2.07	5.04	5.67	3.10	10.01	2.68	1.65	4.21	3.89	2.30	6.56	0.14	0.04	0.50	2.39	1.16	4.19
RoW oil demand shock	9.63	5.36	15.67	23.48	14.74	35.35	6.13	3.20	11.02	24.35	15.21	35.39	0.05	0.01	0.32	5.51	1.95	11.75
Oil inventory shock	24.84	10.94	41.59	26.42	16.80	39.20	20.13	9.64	35.04	27.01	17.25	39.71	0.20	0.05	1.08	73.13	55.29	87.91
Oil mark-up shock	58.22	41.77	75.41	38.54	25.52	53.74	30.63	19.83	45.52	39.51	25.41	56.00	0.72	0.18	2.49	16.35	6.58	29.95
10																		
US ME oil demand shocks	3.52	2.00	6.15	3.68	1.95	7.45	49.09	34.03	64.61	3.68	1.94	7.16	7.27	3.51	13.58	4.60	2.10	8.46
Oil investment shock	0.99	0.48	2.28	2.36	1.17	4.90	1.24	0.62	2.62	0.76	0.32	1.82	90.59	82.69	95.38	0.36	0.15	0.81
Oil capacity shock	3.79	2.38	5.88	11.01	6.53	17.51	2.62	1.53	4.61	3.69	2.14	6.35	0.30	0.08	1.11	4.91	2.42	8.60
RoW oil demand shock	8.52	4.65	14.32	19.43	12.27	29.53	4.23	2.04	8.37	21.57	13.50	30.95	0.11	0.03	0.59	6.93	2.45	15.51
Oil inventory shock	31.12	15.32	51.22	26.35	16.28	41.70	21.01	10.09	37.83	30.01	19.04	44.78	0.64	0.25	1.63	68.08	48.54	84.89
Oil mark-up shock	50.37	33.16	67.41	34.17	20.95	49.63	19.57	11.24	31.64	38.04	22.38	55.41	0.66	0.16	2.21	13.60	5.30	26.90
40																		
US ME oil demand shocks	4.02	2.39	6.94	8.91	5.00	16.00	58.10	41.41	72.86	4.04	2.18	7.78	34.61	19.67	51.33	12.29	5.62	22.63
Oil investment shock	3.48	1.51	9.00	9.36	4.17	20.01	2.96	1.23	6.98	2.50	0.90	6.89	58.20	41.97	74.38	8.92	3.93	18.99
Oil capacity shock	4.80	2.85	8.05	12.08	7.10	19.12	2.93	1.52	5.88	3.93	2.33	6.58	1.17	0.31	4.95	13.82	6.92	24.10
RoW oil demand shock	8.17	4.44	13.60	15.20	9.61	23.63	3.24	1.51	6.68	20.88	13.16	29.84	0.66	0.28	2.35	6.23	2.17	18.87
Oil inventory shock	30.12	15.13	49.59	23.43	13.53	37.75	15.95	7.16	31.34	29.42	18.65	44.55	3.18	1.25	9.31	46.33	24.61	69.90
Oil mark-up shock	47.17	30.83	63.69	26.82	16.06	40.66	14.43	7.72	24.34	36.82	21.03	53.90	0.63	0.22	1.93	7.74	2.74	16.75
100																		
US ME oil demand shocks	6.78	4.12	11.21	22.09	11.96	37.78	60.94	43.81	75.43	5.98	3.10	11.34	40.17	22.14	58.49	18.27	9.56	31.40
Oil investment shock	3.97	1.68	10.71	8.37	3.75	18.45	3.45	1.35	8.67	2.87	1.03	8.15	51.55	34.53	71.05	17.14	7.10	36.99
Oil capacity shock	4.71	2.80	8.21	10.36	6.15	16.83	2.81	1.38	5.95	3.87	2.31	6.42	1.58	0.42	5.93	13.55	6.29	25.34
RoW oil demand shock	7.84	4.27	13.16	12.43	7.56	19.66	2.93	1.31	6.13	20.15	12.94	28.92	0.60	0.26	2.09	4.94	1.67	15.72
Oil inventory shock	28.85	14.49	47.93	20.63	11.57	35.50	14.59	6.09	29.54	28.46	18.11	43.37	3.65	1.47	10.40	33.57	16.39	58.89
Oil mark-up shock	45.26	29.65	61.91	21.12	12.30	33.73	13.00	6.85	22.42	35.83	20.08	53.10	0.54	0.19	1.66	5.62	2.12	12.87

Note: Distributions of forecast error variance decompositions are generated on the basis of 750 random draws from the posterior.