BANCA D'ITALIA
EUROSISTEMA

Temi di discussione
(Working papers)

Oil and the macroeconomy:
a quantitative structural analysis

by Francesco Lippi and Andrea Nobili

The purpose of the Temi di discussione *series is to promote the circulation of working papers prepared within the Bank of Italy or presented in Bank seminars by outside economists with the aim of stimulating comments and suggestions.*

The views expressed in the articles are those of the authors and do not involve the responsibility of the Bank.

OIL AND THE MACROECONOMY:
A QUANTITATIVE STRUCTURAL ANALYSIS

by Francesco Lippi* and Andrea Nobili**

Abstract

We consider an economy in which the oil costs, industrial production, and other macroeconomic variables fluctuate in response to fundamental domestic and external demand and supply shocks. We estimate the effects of these structural shocks on US monthly data for the 1973.1-2007.12 period using robust sign restrictions suggested by theory. The interplay between the oil market and the US economy goes in both directions. About 20% of changes in the cost of oil come in response to US aggregate demand shocks, while shocks originating in the oil market also affect the US economy, the impact depending on the nature of the shock: a negative oil supply shock reduces US output, whereas a positive oil demand shock has a positive and persistent effect on GDP.

Contents

* University of Sassari, EIEF and CEPR.

** Bank of Italy, Economic Outlook and Monetary Policy Department.

1 Introduction[*]

Large fluctuations in oil prices are a recurrent feature of the macroeconomic environment. Despite of oil's relatively small share as a proportion of total production costs, such dynamics raise the specter of the seventies, worrying consumers, producers and policy makers. This view is supported by some empirical evidence that large and persistent oil price upswings lead to economic recessions and higher inflation rates. Hamilton (1983) pointed out that nine out of ten of the U.S. recessions since World War II were preceded by a spike in oil prices. The reduced-form relation between oil prices and US macroeconomic variables, however, has not been stable over time. The evidence available since the mid eighties detects smaller real effects of oil prices on the US economy.[1]

Barsky and Kilian (2002) and Barsky and Kilian (2004) call for a structural interpretation of the reduced form correlations mentioned above. These authors challenge the view that oil price shocks tend to be driven mainly by exogenous factors in the Middle East and claim that the OPEC decisions usually respond to global macroeconomic conditions affecting the demand for oil.[2] Following this view Kilian (forthcoming b) uses a VAR model to identify 3 structural shocks in the oil market by means of "short-run restrictions". Assuming a recursive (Choleski) scheme, he identifies oil supply shocks, world aggregate demand shocks and specific oil demand innovations, interpreted as reflecting fluctuations in precautionary demand for oil driven by fears about the availability of future oil supplies. One important message

[1]See Hooker (1996) and Hamilton (2008). Similar conclusions are reached for European countries by Mork, Olsen and Mysen (1994) and Cunado and Perez de Gracia (2003).

[2]Blanchard and Gali (2007) also conjecture the possibility that the time varying effect of "oil shocks" on US production may reflect shocks of different nature. Given their partial identification strategy, however, they do not explore this hypothesis quantitatively.

is that oil price changes have different effects on the US economy depending on the underlying shock that caused them.[3]

Disentangling the source of oil price changes is also the question studied in this paper. We use the three-country model of Backus and Crucini (2000) to identify four fundamental shocks, using some robust predictions (sign restrictions) of the model in a parsimonious VAR. The VAR includes (relative) prices and quantities in the oil market and in the US economy. A novelty of this approach is that the interplay between the oil market and the US economy is managed within a unified framework. This differs from the analysis in Kilian (forthcoming b), which assumes that shocks originated in the US do not affect the oil market.[4] By allowing for the simultaneous interaction between the oil market and the US economy our analysis casts light on the assumption, often used in the empirical analysis, that oil-price shocks are exogenous to the US business cycle.[5] Another feature of our approach is that we study the impact of shocks on the US industrial production, instead of GDP. This provides a control for the change in the GDP composition over time (increasing role of services), that may in itself affect how the economy responds to energy price shocks. It is interesting however that even the analysis that take this composition effect into account, such as Edelstein and Kilian (2007) detect that the (negative) correlation between US production and oil-price changes is smaller in more recent years. Our analysis will study the effect of different fundamental shocks on the (real) price of oil and the US industrial production and account for the time-series changes

---

[3]In a number of related papers, this scheme was used by the author to address the effects of oil price shocks on several US macroeconomic variables, see e.g. Kilian (fortcoming a) for a survey.

[4]His paper first estimates a monthly VAR model for the oil market that does not include US macro aggregates. The fundamental shocks are identified by assuming a recursive scheme. Under the assumption that the fundamental shocks of this VAR are predetermined with respect to US macroeconomic aggregates, an OLS regression is used to study the effect of these shocks on the US GDP.

[5]The recent papers by Anzuini, Pagano and Pisani (2007) and Baumeister and Peersman (2008) study the effect of oil-supply shocks on the US output abandoning the recursiveness assumption. Compared to these papers our study also considers oil-demand shocks and shocks to the US business cycle.

in the production vs. oil-price correlation.

The paper is organized as follows. The next section presents a simple theoretical framework to be used as a reference in the empirical analysis. Section 3 describes the estimation approach, whose results are presented in Section 4. The literature on the macroeconomic effects of energy prices is huge: Section 5 discusses three recent contributions that are related to the topics discussed here. Section 6 summarizes the main findings.

2 Theoretical frame

We present a three-country theoretical economy that is useful to organize ideas about the US macroeconomy and its interaction with the oil market. The model is taken from Backus and Crucini (2000) who extend the two-good two-country economy of Backus, Kehoe and Kydland (1994) and incorporate a country that produces oil. The model features supply shocks z_j in each country j. We enrich the model by introducing stochastic preference shocks. Below we present the essential ingredients of the theoretical economy and discuss the implications that will be used in the empirical analysis. More information on the model solution and calibration is given in the Online Appendix A.

Two industrialized countries, the US and RoW (rest of the industrial world), produce imperfectly substitutable consumption goods, a and b, using capital (k), labor (n) and oil (o). The US produce good a using the technology

$$y_t = z_t n_t^\alpha [\eta k_t^{1-\nu} (1-\eta) o_t^{1-\nu}]^{(1-\alpha)/(1-\nu)} \tag{1}$$

where z is an AR(1) stochastic productivity shock $z_t = \rho_z z_{t-1} + \tilde{z}_t$ with iid innovation $\tilde{z}_t$. An analogous technology is used for the production of b by RoW. The oil supply, y^o, is determined according to $y_t^o = z_t^o + (n_t^o)^\alpha$ where z_t^o is an AR(1)

7

exogenous stochastic oil supply component and $(n_t^o)^\alpha$ the endogenous supply by the third country, which one can think of as the union of OPEC and other (non US) oil producing countries. Goods a and b are aggregated into final consumption (c) and investment (i) goods using the CES aggregator

$$x(a,b) = [\psi_t a^{1-\mu} + (1-\psi_t)b^{1-\mu}]^{1/(1-\mu)} \tag{2}$$

The consumption bundle is subject to stochastic AR(1) preference shocks, such that $\psi_t \equiv s_t \cdot \psi$ with $s_t = (1-\rho_s) + \rho_s s_{t-1} + \tilde{s}_t$ and $\tilde{s}_t$ is i.i.d.[6] Capital obeys the accumulation equation $k_{t+1} = (1-\delta)k_t + k_t \, \phi(i_t/k_t)$, where $\phi(\cdot)$ is a concave function positing adjustment costs in capital formation as in Baxter and Crucini (1993). Consumers in each country maximize the expected value of lifetime utility

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \, U\left(c_t, 1-n_t\right) \tag{3}$$

where $\beta < 1$ is the intertemporal discount and $U(c_t, 1-n_t)$ is a CES function defined in Online Appendix A.

The model allows us to examine the effects of supply side (productivity) and demand (preference) shocks in each economy. The solid lines in Figure 1 report impulse responses produced using the benchmark parametrization based on Backus and Crucini (2000), see Appendix A. Each column of the figure reports (from top to bottom) the impulse response functions of oil prices, oil production, the price of output and the output level to the structural shock shown below the column. All prices are expressed relative to the US consumption deflator, i.e. the US consumption price index is chosen as the numeraire, as done later in the empirical analysis.

The first column describes the effect of a positive oil supply shock ($z^o > 0$). The shock moves oil price and quantities in opposite directions. As the relative price of

---

[6]Similar effects are obtained by considering shocks to the intertemporal discount factor.

the energy input falls, production in the US increases (see the bottom panel in the first column). This represents the prototype textbook case of an exogenous oil supply shock. Innovations to productivity ($z^* > 0$) or preferences ($s^* > 0$) in the RoW also affect the market for oil and that for US goods. As shown in the second and third columns of Figure 1, the sign of the response of the oil price and of oil quantity to each of these shocks is the same, i.e. these shocks appear to an observer of the oil market as typical "demand shocks" causing oil prices and quantities to move in the same direction (solid lines). The bottom panels of columns two and three show that US production increases following these shocks. The fourth and fifth columns describe the effects of shocks originated in the US. A positive productivity shock ($z > 0$) raises US production and reduces its price (relative to the CPI). The ensuing increase in oil demand ultimately leads to higher oil prices and output, though the latter is small in the benchmark parametrization. Finally, a US demand shock ($s > 0$) increases US production and its price (relative to the CPI). The increased demand spills over to the oil market, where the energy cost and production increase (solid lines).

The quantitative features of the effects described above depend on the parameterization but some qualitative features of this model are robust across parametrizations. Four properties in particular will be used in the empirical analysis. First, the US production and its price respond with opposite signs to US productivity shocks and, second, they respond with the same sign to US demand shocks. Third, oil-supply shocks always cause the oil price to move with a sign that is opposite to that of the oil production. Fourth, supply shocks in the RoW appear on the oil market as demand shocks, moving oil prices and quantities in the same direction. Other predictions of the model are not robust across parametrizations, for instance the response of US production to shocks that occur in the RoW depends on the degree of substitutability between domestic and foreign goods. The benchmark case

9

(solid lines) assumes a low substitutability $1/\mu < 1$, a case where the income effect dominates the substitution effect. Results for the case with high substitutability $1/\mu > 1$ are shown by the dashed lines. It appears that following a positive supply shock in the rest of the world (second column) the US supply increases when the substitutability between the goods is small, and falls otherwise. As the sign of some responses crucially hinge on parametrization chosen, the identification of the structural shocks presented below will restrict attention to the four robust features just discussed.

We conclude by noting that the model economy shows that the expected change of US production conditional on an oil price increase depends on the underlying fundamental shock. For instance, while the oil price hike caused by an oil supply shock is followed by a decrease of US production, the oil price hike caused by a US demand shock or a foreign supply shock is followed by an increase of US output. Therefore, it should not be surprising that over a long sample period the unconditional correlation between oil prices and US GDP appears tenuous, as it blurs conditional correlations with different signs. The empirical analysis will allow us to cast light on this conjecture.

3   The Empirical Analysis

The empirical analysis aims to identify a set of structural shocks affecting the oil market and the US business cycle and analyze their effects on the oil prices and US output. The identification method is based on sign restrictions, following the approach pioneered by Davis and Haltiwanger (1999), Canova and Nicolo (2002) and Uhlig (2005). The idea is to identify structural shocks using some robust properties of the model, such as the sign of impulse responses discussed in the previous section, without imposing on the data the whole structure of the theoretical model i.e.

allowing for some degree of "model uncertainty". This is convenient when, as in our case, the model economy is stylized and one is reluctant to assume that the model is the true data generating process and/or e.g. the magnitude of the substitution elasticity. We first briefly describe the identification method and then discuss the sign restrictions that are used, relating them to the theory of Section 2.

The analysis is based on the vector autoregression (VAR)

$$y_t = B(L) \, y_{t-1} + \epsilon_t \qquad \epsilon_t \sim N(0, \Sigma), \tag{4}$$

where $B(L)$ is a lag polynomial of order p and y_t contains four variables describing the US and the oil market. The first two are the (log of) US industrial production and the (log of) consumer price index. This set of variables is similar to those used in previous studies, such as Bernanke, Gertler and Watson (1997) and Hamilton and Herrera (2004).[7] Two additional variables describe the oil market: the (log of) average oil spot nominal price and the (log of) global oil production.[8] Estimation of the VAR is based on monthly data spanning the period January 1973 - December 2007 (this uses the longest available production time series provided by the International Energy Agency). The period covers all the relevant episodes characterized by major oil price increases. We complete the specification by using a lag order of 6 months, as suggested by the Akaike Information Criteria (AIC).[9] The structural VAR approach sees (4) as a reduced form representation of the structural form

$$\mathcal{A}_0^{-1} y_t = A(L) \, y_{t-1} + e_t \qquad e_t \sim N(0, I) \tag{5}$$

---

[7]The VAR by Bernanke et al. (1997) also included the non-energy commodity price index the short-term and long-term interest rates. The effect of including these variables in our VAR model is discussed in Section 5.

[8]Production is in barrels per day, the spot price is from the International Monetary Fund.

[9]The appropriate lag length was debated in previous literature, see Hamilton and Herrera (2004). Our results remain virtually unchanged if 12 lags are used.

where $A(L)$ is a lag polynomial of order p and the vector e includes the four structural innovations discussed above, assumed to be orthogonal. Identification of the structural shocks thus amounts to select a matrix $\mathcal{A}_0$ (i.e. a set of restrictions) that uniquely solves −up to an orthonormal transformation− for the following decomposition of the estimated covariance matrix $\mathcal{A}_0\mathcal{A}_0' = \Sigma$. The j-th column of the identification matrix $\mathcal{A}_0$, a_j, maps the structural innovations of the j-th structural component of e into the contemporaneous vector of responses of the endogenous variables y, $\Psi_0 = a_j$. The structural impulse responses of the endogenous variables up to the horizon k, Ψ_k, can then be computed using the $B(L)$ estimates from the reduced form VAR, B_1, B_2, ..., B_p, and the impulse vector a_j.[10]

The sign restriction approach identifies a set of structural models, the $\tilde{\mathcal{A}}_0 \in \tilde{\mathbf{A}}_0$, such that the impulse responses Ψs implied by each $\tilde{\mathcal{A}}_0$ over the first k horizons are consistent with the sign restrictions derived from the theory. The approach exploits the fact that given an arbitrary identification matrix $\mathcal{A}_0$ satisfying $\mathcal{A}_0\mathcal{A}_0' = \Sigma$, any other identification matrix $\hat{\mathcal{A}}_0$ can be expressed as the product of $\mathcal{A}_0$ and an orthonormal matrix H. The set of the theory-consistent models, $\tilde{\mathbf{A}}_0$, can be characterized as follows. For a given estimate of the reduced form VAR, $B(L)$ and Σ, take an arbitrary identification matrix $\mathcal{A}_0$ and compute the set of candidate structural models $\hat{\mathbf{A}}_0 = \{\mathcal{A}_0\, H \mid HH = I\}$ by spanning the space of the orthonormal matrices H. The set $\tilde{\mathbf{A}}_0$ is then obtained by removing from the set $\hat{\mathbf{A}}_0$ the models that violate the desired sign restrictions. The findings can then be summarized by the properties of the resulting distribution of $\tilde{\mathcal{A}}_0$ models. The set of orthonormal theory-consistent matrices $\tilde{\mathbf{A}}_0$ is computed using the efficient algorithm proposed by Rubio-Ramirez, Waggoner and Zha (2005).[11]

---

[10]As $\Psi_s = \sum_{i=0}^{s} B_{s-i}\Psi_i$ for $s \geq 1$ and $B_{s-i} = 0$ if $s - i > p$.

[11]Given the OLS estimates for $(B(L), \Sigma)$, the algorithm draws an arbitrary independent standard normal $(n \times n)$ matrix X and, using the QR decomposition of X (where Q is orthogonal and R triangular), generates impulse responses directly from A_0Q and $B(L)$. If these impulse responses do not satisfy the sign restrictions the algorithm generates a different draw for Q. Compared with

In the empirical analysis we restrict attention to 4 mutually orthogonal shocks: demand and supply shocks in the US economy and in the oil market, consistent with the model robust features discussed in Section 2. These restrictions are summarized in Table 1. A US demand shock is one that generates a response of the US industrial production and its deflator (relative to the CPI) of the same sign. A US supply shock is one that induces a negative correlation between the US industrial production and its deflator. These assumptions are consistent with the impulse responses reported in the fourth and fifth columns of Figure 1. The third one is an oil-supply shock, i.e. one that causes the oil production and its price (CPI deflated) to move in opposite directions, as in the first column of Figure 1. Finally we define the oil demand shock as one that, upon occurring, moves the price and the quantity of oil in the same direction. As discussed in the previous section this captures shocks to the oil market that originate from e.g. supply shocks in the rest of the world (second column in Figure 1).[12] The sign restrictions for the shocks in Table 1 are not mutually exclusive. By construction, however, each of the models in $\tilde{\mathbf{A}}_{\mathbf{0}}$ generates orthogonal structural shocks.

In practice we also have to decide on for how long the sign restrictions should hold. We start by imposing they hold for a period of 6 months. Similar findings are obtained when the restrictions are imposed for a period of 12 months. In all of these cases the resulting posterior distribution is made of 5,000 $\tilde{\mathcal{A}}_0$ models.

_____

Uhlig's procedure, this algorithm directly draws from a uniform distribution instead of involving a recursive column-by-column search procedure.

[12]For low values of the substitution elasticity between the US and the RoW goods the oil demand restrictions are also consistent with demand shocks originating in the RoW. However, our analysis does not attempt to distinguish supply and demand shocks in the RoW, due to the lack of a sufficiently long time series for prices and output in a country group for RoW that includes China and India.

Table 1: Sign restrictions used for identification

| | Structural shocks | | | |
VAR Variables	oil-supply	oil-demand	US demand	US supply
oil production	−	+		
oil price[a]	+	+		
US industrial production			+	+
US producer's price[a]			+	−

Note: A "+" (or "−") sign indicates that the impulse response of the variable in question is restricted to be positive (negative) for 6 months after the shock. A blank entry indicates that no restrictions is imposed on the response. −[a]Price is deflated by the US CPI.

4 The estimated effects of structural shocks

This section reports summary measures from the distribution of impulse responses of the structural models in $\tilde{\mathbf{A}}_0$. The distribution reflects the model uncertainty inherent to the sign restriction approach, providing a description of the range of possible outcomes consistent with the set of theoretical restrictions. In particular, in this exercise we freeze the VAR coefficients for $B(L)$ and Σ at their estimated OLS values. Therefore the distribution reflects the model uncertainty but not the sampling uncertainty that underlies the coefficient estimates. Appendix B presents the results for the case when both sampling and model uncertainty are accounted for.

4.1 Impulse responses

We follow Dedola and Neri (2007) and Uhlig (2005) and report the median (solid line), the 16th and the 84th percentiles (the dashed lines) of the distribution of impulse responses produced by the $\tilde{\mathcal{A}}_0$ models for each variable over the first 36 months.

The effects of an oil supply shock, normalized to yield a 1 per cent reduction in oil production, are displayed in Figure 2. The shock lowers the US industrial

production, that reaches a through after about 12 months. The figure shows that after one year the response is negative for 76% of the models. In Table 2 we follow the terminology of Dedola and Neri (2007) and interpret this fraction as a probability. The price of US production (CPI deflated) increases slightly in the short run, but not in the long run. The persistence of the oil-supply shock is high, well above the 6 month restriction imposed by the model selection. The effect on industrial production is also persistent.

The effects of an oil demand shock, normalized to yield a 1 per cent increase in oil production, are displayed in Figure 3. The oil price increase is highly persistent. The key finding from this figure is that the response of the US industrial production differs markedly from the case of the oil-supply shock. For most models, production 12 months after the shock is above the baseline. Table 2 shows that the fraction of models in which the US industrial production increases conditional on a positive oil demand shock is about 70 per cent after 12 months, and is greater than 60 per cent at all horizons.

Table 2: US output response to oil market shocks

	Probability of a negative response of US output[a]				
At Horizon:	1	6	12	18	24
Oil-supply shock	0.65	0.74	0.76	0.76	0.75
Oil-demand shock	0.38	0.34	0.33	0.34	0.35

Note: $-^a$Fraction of models $\tilde{\mathcal{A}}_0 \in \tilde{\mathbf{A}}_\mathbf{0}$ that yield a negative response at the given horizon.

These results show that in order to predict the dynamics of US business cycle conditional on observing an oil-price increase it is key to identify the fundamental shock underlying the oil-price hike. Higher oil prices are associated to an expected reduction of production conditional on a negative oil-supply shock, and to an expected rise of production conditional on a positive oil-demand shock. The fact that US industrial production increases following a positive oil-demand shock can

be reproduced by the theoretical model of Section 2 under the assumption that the substitution elasticity between US and RoW goods is small, so that the higher demand in the RoW countries increases expenditure on US goods.

Figure 4 illustrates the extent to which the oil market is affected by the US shocks. An aggregate demand shock that raises the US industrial production causes a rise in oil prices. The effect on oil production is smaller, and it is centered about zero 12 months after the shock. Figure 5 shows the effects of a positive US aggregate supply shock: the response of oil quantity is positive, while the response of the oil price is small and centered about zero over the first 18 months.

4.2 Variance decomposition

What is the contribution of the different structural shocks on aggregate fluctuations and oil prices? We assess this issue by computing the percentage of the variance of the k-step ahead forecast error that is accounted for by the identified structural shocks. Table 3 reports the variance decomposition at horizons up to 24 months for the spot oil price and the US industrial production. To ensure orthogonality of the structural shocks the table entries are computed from a unique $\tilde{\mathcal{A}}_0$, chosen so as to minimize a minimum distance criterion from the median responses displayed in the previous subsection (see Appendix C for the details).[13]

The first panel of table 3 shows that oil-demand shocks explain a large fraction of the oil price variance, between 40 and 70 per cent, over the horizons considered. Oil-supply shocks explain a large portion of the variance within the one year horizon. Another sizeable fraction of the oil-price variance, accounting for about 20 to 30 percent, is due to US aggregate demand shocks. The US supply shocks have a negligible impact on oil prices. The historical decomposition of the oil price time

---

[13]Qualitatively the results are similar to those produced by the median of the forecast variance posterior distribution implied by the set of $\tilde{\mathcal{A}}_0$ models (available upon request).

Table 3: Variance decomposition

	Oil		US	
k	supply	demand	supply	demand
	Spot oil price (CPI deflated)			
1	51.8	42.7	2.2	3.3
6	51.1	38.6	0.0	10.2
12	18.8	58.5	2.7	20.0
18	0.0	70.0	2.1	27.9
24	7.9	68.6	1.1	22.4
	US industrial production			
1	7.2	9.7	41.3	41.7
6	14.2	14.3	45.4	26.1
12	15.7	13.7	54.6	16.0
18	15.4	12.2	62.4	10.0
24	13.7	9.2	71.1	5.9

Notes: Entries computed by the $\tilde{\mathcal{A}}_0$ model that minimizes the distance from the median impulse response (see Online Appendix C). k denotes the forecast horizon (in months).

series, displayed in Figure A.1 of the Appendix, shows that oil-demand shocks were a key factor underlying the drop of oil prices following the Asian crisis of 1997-1998 and the strong price hike that started in 2003.

The second panel of Table 3 presents the variance decomposition of the US industrial production at horizons of up to two years. The US aggregate supply shock explains the largest share, in line with the real business cycle hypothesis and the recent contributions of Dedola and Neri (2007), and Francis and Ramey (2005). The role of US aggregate demand shocks is largest at short horizons (1 to 6 months), and smaller than the role of US supply shocks at all subsequent horizons. Concerning the role of the oil market variables on US production, both the oil-supply and the oil-demand shocks appear important, as each one explains a proportion of about 10 percent. Figure A.1 presents the time-series decomposition of the US production.

4.3 Robustness

The robustness of the findings was tested along several dimensions. First, we considered whether the quantitative findings on the effects of the oil market shocks changed

if we used a scheme that identifies only 2, as opposed to 4, structural shocks. This corresponds to identifying $\tilde{\mathcal{A}}_0$ matrices using the restrictions of the first two columns only of Table 1. The estimated effects of the oil market shocks on the US industrial production are virtually unchanged, as shown in Figure A.2.

Second, we estimated the effects of structural shocks accounting for both model and sample uncertainty (the latter was ignored above). We also explored the critique, raised by Fry and Pagan (2007), that the sign restriction approach is flawed because the impulse response functions it generates likely violate the assumption that structural innovations are orthogonal. Details on each of these analysis are given in the Appendices B and C. Altogether, these analyses produce impulse response functions that are not significantly different from the benchmark case analyzed above.

The next section studies how the results are affected by extending the VAR to include a role for the monetary policy rule, for precautionary oil demand shocks, and considering the possibility that other structural changes in the economy occurred between the seventies and the last part of the century.

5   Related hypotheses in recent literature

Some recent contributions −that maintain the assumption that oil prices are exogenous to the US economy− discuss complementary mechanisms that may explain the smaller effects of oil prices on the US macroeconomy observed in recent years. Below, we explore some of them in the context of our framework.

5.1   Precautionary demand for oil

One hypothesis concerns the possibility that oil demand shocks of different nature have different effects on the US economy. For instance, the model of Section 2 shows that demand and supply shocks in the rest of the world cause an oil demand shock

(comovement of oil cost and quantity), whose consequences on US production can be different in size and persistence depending on the substitution elasticity between domestic and foreign goods. Here, we analyze the possibility of oil-demand shocks of a different nature that may have an impact of opposite sign on the US output. To this end, we follow Kilian (forthcoming a) who decomposes oil price dynamics into oil-supply shocks, world aggregate demand shocks and precautionary oil-demand shocks (due to e.g. fears about future oil supply availability).[14] Kilian's shocks are identified by a recursive scheme based on short-run restrictions. His findings show that precautionary oil-demand shocks have a negative effect on production that is more persistent than the one implied by oil-supply shocks. To explore the hypothesis that the oil-demand shocks described in Figure 3 may also reflect shocks to the precautionary demand for oil discussed by Kilian, we set up a 5-variable VAR that includes a non-energy commodity price index. The oil-demand shock is now identified by assuming that the shock simultaneously increases the demand for oil quantity, as well as the demand for other non-energy commodities, thus resulting in an increase of both the oil price and the commodity price index (both CPI deflated). The impulse responses, reported in Figure A.3, show that the median responses obtained with our benchmark 4-variable VAR are extremely similar to those produced by the new identification scheme.[15]

---

[14]The measure of global real economic activity is based on a global index of dry cargo single voyage freight rates. Increase in freight rates may be used as indicators of cumulative global demand pressures.

[15]Regarding oil-supply shocks in Kilian's work the hike in oil price is small and transitory, smaller than indicated by our impulse response. His estimates of world aggregate-demand shocks produce effects on US real GDP qualitatively very similar to the oil-demand shocks described in Figure 3 in the short-run, but diverging in sign at the longer horizons (negative in his framework, positive in ours).

5.2 Structural change

Blanchard and Gali (2007) argue that the smaller effect of oil shocks on the US economy in the recent years can be ascribed to structural changes, such as changes in real and nominal wage rigidity, or the energy share of production.[16] These authors also discuss the possibility that other shocks had an offsetting impact on the US economy. The last hypothesis is aligned with our view that the reduced form correlation between US macro variables and oil prices reflect a variety of shocks, and the evidence presented above supports this view and shows that it is quantitatively important.

To address the hypothesis that important structural changes have occurred, we analyze the effects of identified oil-supply and oil-demand shocks over different sample periods. A warning is due: as our approach assumes the presence of different structural shocks, splitting the sample may lead to the selection of observations (subperiods) in which some of the shocks considered were not present. For this reason we avoid cutting the sample in very short periods. The sample splits that are considered were suggested by previous studies: 1981 as the date in which the Federal Reserve changed operating procedures, 1984 as the conventional date used in the Great Moderation literature (Blanchard and Gali (2007)), 1987 as the beginning of the post-OPEC period in the oil market (Backus and Crucini (2000)), 1991 as the date before which major oil price shocks were caused by (exogenous) political disruptions in the Middle East (Hamilton (1983); Hamilton (1996); Bernanke, Gertler and Watson (2004)). The estimated effects of oil supply and demand shock on US variables in each subsample are summarized in Table 4.

The table shows that the probability of a negative output response to an oil supply shock is slightly larger in the post 1987 sample. The estimated effects of the

---

[16]As mentioned in the Introduction the last hypothesis is explored quantitatively by Edelstein and Kilian (2007).

Table 4: US output response to oil shocks in different sample periods

At Horizon:	Probability of a negative response to oil-supply shock[a]				
	1	6	12	18	24
1981-2007	0.56	0.63	0.56	0.49	0.46
1984-2007	0.52	0.57	0.61	0.59	0.57
1987-2007	0.70	0.78	0.77	0.75	0.71
1991-2007	0.64	0.61	0.78	0.89	0.93
At Horizon:	Probability of a negative response to oil-demand shock[a]				
	1	6	12	18	24
1981-2007	0.34	0.37	0.36	0.37	0.38
1984-2007	0.32	0.39	0.42	0.46	0.50
1987-2007	0.29	0.37	0.40	0.44	0.49
1991-2007	0.28	0.31	0.32	0.35	0.39

Notes: $-^{a}$Fraction of models $\tilde{\mathcal{A}}_0 \in \tilde{\mathbf{A}}_0$ that yield a negative response at the given horizon.

oil-demand shock turns out to be very similar to the one obtained on the full sample. Overall, we no major structural breaks in the effects of structural shocks emerge from the analysis of the subsamples. One possible difference with other studies is that our analysis concentrates on the effects on industrial production rather than GDP. It may be that the decline in energy intensity recorded by the industrial sector was smaller than in the rest of the economy.

5.3 The monetary policy rule

Bernanke et al. (2004) and Leduc and Sill (2004) argue that a change of the monetary rule is key in explaining the time-varying effects of oil price shocks on the US economy. We focus here on the real side of the economy. Recently, Herrera and Pesavento (2007) have explored the contribution of the US monetary policy response to oil price shocks and its role in the Great Moderation. They find that the magnitude and the duration of the response of output to an oil price shock has diminished during the Volcker-Greenspan era. The contribution of systematic monetary policy to the dynamic response of most macro variables during the post-1984 period appears significantly smaller.

We attempt to study this issue by including the Federal Funds rate in the VAR. The restrictions used to identify the 4 structural shocks are as in Table 1, i.e. no restriction on the response of the Federal Funds rate is imposed. Figure A.4 shows the estimated effects of oil supply shocks for this new specification. The Fed Fund response to an oil supply shock is hardly different from zero, especially in the more recent sub-samples. A comparison with the estimates produced by the benchmark 4 variable VAR, suggests that the response of US industrial production is very similar for most of the sample periods considered. Overall, US monetary policy does not seem to have played a role in the transmission of oil supply shocks on the real side of the US economy. The lower panel of Figure A.4 describes the IRFs following oil demand shocks. Industrial production increases following the shock. The Federal Funds rate increases gradually and remains above the baseline for a three years. As a consequence of a tightening monetary policy, the response of the US industrial production remains positive in the short run but it is less persistent than in our benchmark case. This picture remains broadly unchanged in all the sample splits considered. The results also show that the response of the Federal Funds rate varies with the underlying shock: a stronger response is detected in response to oil demand shocks.[17]

6   Concluding remarks

We argued that identifying the shocks underlying oil price fluctuations is key to predict their effect on US production. This point was illustrated with a simple open economy model, adapted from Backus and Crucini (2000), where two industrial

---

[17]Similar results, available on request, are obtained when the VAR includes a long-term rate. The IRFs for the US structural shocks are also available. They show that after a US demand shock, the Federal Funds rate increase, consistently with much previous evidence. In line with the effects of technological innovation estimated by Dedola and Neri (2007), the US supply shock effect on the federal funds rate is tiny, with an almost equal probability of being either positive or negative.

countries produce and consume tradeable goods using energy supplied by a third oil-producing country. In the model the effects of an oil-demand shock are very different from those of an oil-supply shock. This prediction is tested on the data, where oil-demand and supply shocks are identified exploiting sign-restrictions suggested by the theory.

The estimates show that oil prices respond significantly to US business cycle fluctuations.[18] In particular, US aggregate demand shocks account for more than one-fifth of the variance of oil prices at horizons of 12 months or more. Thus the assumption that oil are predetermined with respect to the US production is not supported by our analysis. Reverse causality from the US economy to the energy cost appears clear in the data.

The estimated (negative and persistent) effect of the oil-supply shock on US production is very similar to the findings of Kilian (forthcoming b). Instead, our estimates of the effect of a positive oil-demand shock is different from his estimate of the effect of "global demand": while he finds that US production initially rises and then decreases (after 2 years), we find that the production increases persistently. Our finding is consistent with the model of Section 2 with a parameterization that assumes a low substitutability between domestic and foreign produced goods. Altogether, the estimates show that identifying the shocks underlying oil-price changes is key to understand the response of the US industrial production.

These findings provide a simple explanation of the unstable correlation between oil price fluctuations and the US economic activity documented in e.g. Hamilton (2008).[19] As the sign of this correlation depends on the type of shock that hits the economy, a negative correlation emerges in periods when oil-supply shocks domi-

---

[18]Interesting theoretical work by Bodenstein, Erceg and Guerrieri (2007) and Nakov and Pescatori (2008) present models where the price of oil is endogenously determined.

[19]Baumeister and Peersman (2008) also assess the changes in the response of US output after only an oil supply shock using sign restrictions in a time-varying Bayesian-VAR framework. Compared to our framework these authors focus on the time-varying effects of oil shocks, focusing exclusively on oil supply shocks.

nate, while a positive correlation emerges in periods of strong US demand shocks or benign supply shocks in RoW. The unconditional correlation detected by OLS estimates between oil prices and US production is tenuous because it blends conditional correlations with different signs.

References

Anzuini, A., Pagano, P. and Pisani, M. (2007), Oil supply news in a var: Information from financial markets, Temi di discussione (Economic working papers) 632, Bank of Italy, Economic Research Department.

Backus, D. K. and Crucini, M. J. (2000), 'Oil prices and the terms of trade', *Journal of International Economics* **50**(1), 185–213.

Backus, D. K., Kehoe, P. J. and Kydland, F. E. (1994), 'Dynamics of the trade balance and the terms of trade: The J-curve?', *American Economic Review* **84**(1), 84–103.

Barsky, R. B. and Kilian, L. (2002), 'Do we really know that oil caused the great stagflation? a monetary alternative,', *NBER Macroeconomics Annual 2001, B. Bernanke and K. Rogoff (eds.) Cambridge, Mit Press* pp. 137–183.

Barsky, R. B. and Kilian, L. (2004), 'Oil and the macroeconomy since the 1970s', *Journal of Economic Perspectives* **18**(4), 115–134.

Baumeister, C. and Peersman, G. (2008), Time-varying effects of oil supply shocks on the us economy, Ghent University, manuscript.

Baxter, M. and Crucini, M. J. (1993), 'Explaining saving-investment correlations', *American Economic Review* **83**(3), 416–36.

Bernanke, B. S., Gertler, M. and Watson, M. (1997), 'Systematic monetary policy and the effects of oil price shocks', *Brookings Papers on Economic Activity* pp. 91–157.

Bernanke, B. S., Gertler, M. and Watson, M. (2004), 'Oil shocks and aggregate macroeconomic behavior: The role of monetary policy: A reply', *Journal of Money, Credit and Banking* **36**(2), 286–91.

Blanchard, O. J. and Gali, J. (2007), The macroeconomic effects of oil shocks: Why are the 2000s so different from the 1970s?, NBER Working Papers # 13368.

Bodenstein, M., Erceg, C. J. and Guerrieri, L. (2007), Oil shocks and external adjustment, FRB International Finance Discussion Paper No. 897.

Canova, F. and Nicolo, G. D. (2002), 'Monetary disturbances matter for business fluctuations in the G-7', *Journal of Monetary Economics* **49**(6), 1131–1159.

Cunado, J. and Perez de Gracia, F. (2003), 'Do oil price shocks matter? evidence for some european countries', *Energy Economics* **25**(2), 137–154.

Davis, S. J. and Haltiwanger, J. (1999), 'On the driving forces behind cyclical movements in employment and job reallocation', *American Economic Review* **89**(5), 1234–1258.

Dedola, L. and Neri, S. (2007), 'What does a technology shock do? a VAR analysis with model-based sign restrictions', *Journal of Monetary Economics* **54**(2), 512–549.

Edelstein, P. and Kilian, L. (2007), Retail energy prices and consumer expenditures, CEPR Discussion Papers 6255, C.E.P.R. Discussion Papers.

Francis, N. and Ramey, V. A. (2005), 'Is the technology-driven real business cycle hypothesis dead? shocks and aggregate fluctuations revisited', *Journal of Monetary Economics* **52**(8), 1379–1399.

Fry, R. and Pagan, A. (2007), Some issues in using sign restrictions for identyfing structural VARs, NCER Working Paper Series # 14.

Hamilton, J. D. (1983), 'Oil and the macroeconomy since world war II', *Journal of Political Economy* **91**(2), 228–48.

Hamilton, J. D. (1996), 'This is what happened to the oil price-macroeconomy relationship', *Journal of Monetary Economics* **38**(2), 215–220.

Hamilton, J. D. (2008), 'Oil and the macroeconomy', *The New Palgrave Dictionary of Economics. Second Edition.* S. Durlauf and L. Blume (Eds), Palgrave MacMillan Ltd.

Hamilton, J. D. and Herrera, A. M. (2004), 'Oil shocks and aggregate macroeconomic behavior: The role of monetary policy: Comment', *Journal of Money, Credit and Banking* **36**(2), 265–86.

Herrera, A. M. and Pesavento, E. (2007), Oil price shocks, systematic monetary policy and the great moderation, Michigan State Univeristy, Emory Univeristy, mimeo.

Hooker, M. A. (1996), 'What happened to the oil price-macroeconomy relationship?', *Journal of Monetary Economics* **38**(2), 195–213.

Kilian, L. (forthcoming*a*), 'The economic effects of energy price shocks', *Journal of Economic Literature.*

Kilian, L. (forthcoming*b*), 'Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market', *The American Economic Review.*

Leduc, S. and Sill, K. (2004), 'A quantitative analysis of oil-price shocks, systematic monetary policy, and economic downturns', *Journal of Monetary Economics* **51**(4), 781–808.

Mork, K. A., Olsen, y. and Mysen, H. T. (1994), 'Macroeconomic responses to oil price increases and decreases in seven OECD countries', *Energy Journal* **15**(4), 19–35.

Nakov, A. and Pescatori, A. (2008), Oil and the great moderation, Federal Reserve Bank of Cleveland No. 0717.

Rubio-Ramirez, J. F., Waggoner, D. and Zha, T. (2005), Markov switching structural vector autoregressions: Theory and application, Federal Reserve Bank of Atlanta Working Paper # 27.

Uhlig, H. (2005), 'What are the effects of monetary policy on output? results from an agnostic identification procedure', *Journal of Monetary Economics* **52**(2), 381–419.

Figures

Figure 1: Structural shocks in the model economy

(% deviation from steady state)
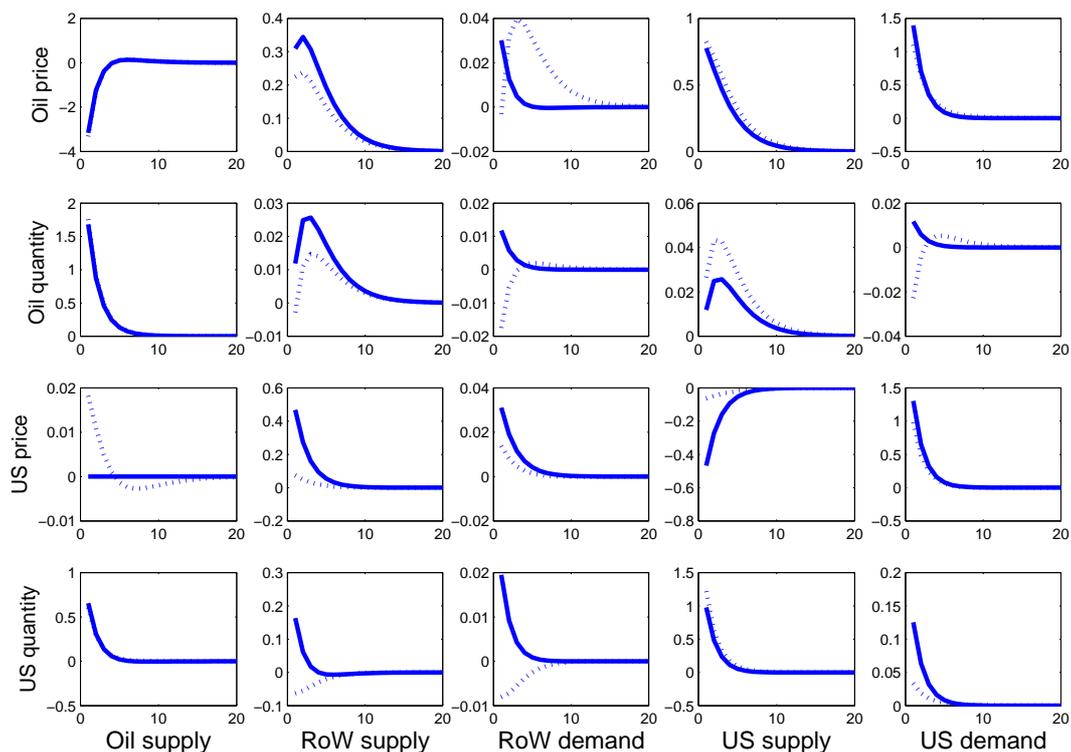
Note: Each column describes the effect of the structural shock indicated below the column. Each row corresponds to the variable indicated on the left vertical axis. All prices are expressed relative to the US consumption price index. The solid lines is the benchmark parametrization. The dashed lines show the responses under a parametrization with a high substitution elasticity between the goods of US and RoW ($\mu = 0.7$ instead of $\mu = 2$ in the benchmark case).

Figure 2: Effects of an oil-supply shock
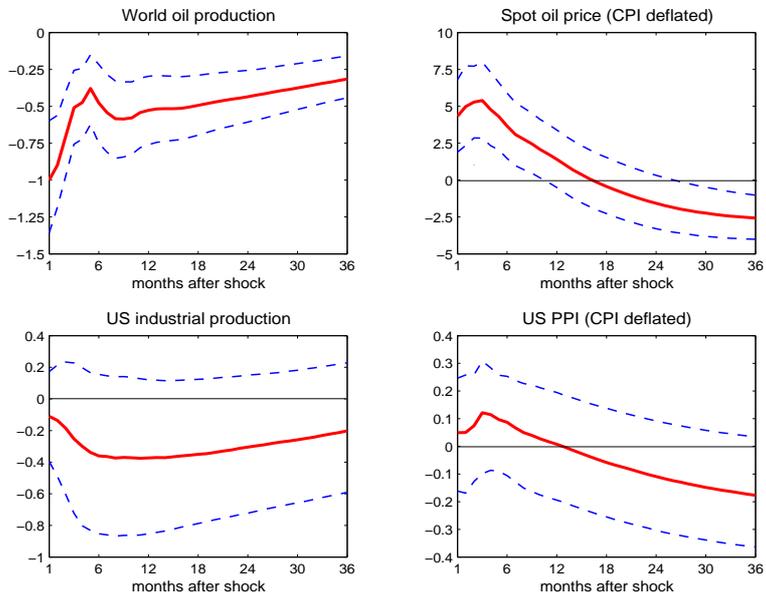
Figure 3: Effects of an oil-demand shock
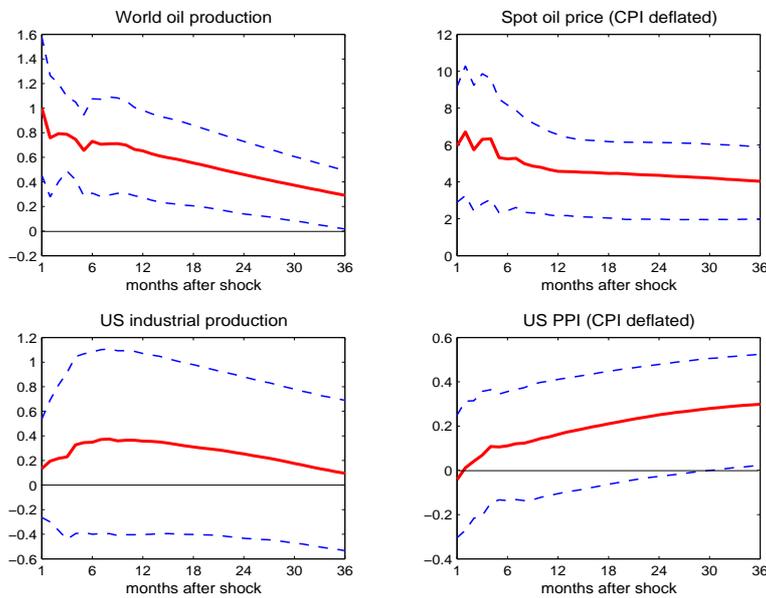
Note: The figures report the 16th, 50th and 84th percentiles of the IRFs distribution.

Figure 4: Effects of a US aggregate demand shock
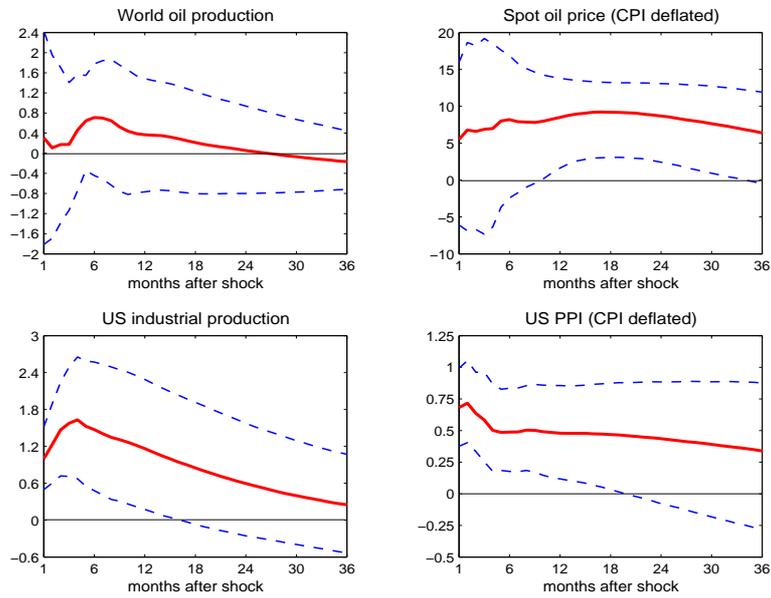
Figure 5: Effects of a US aggregate supply shock
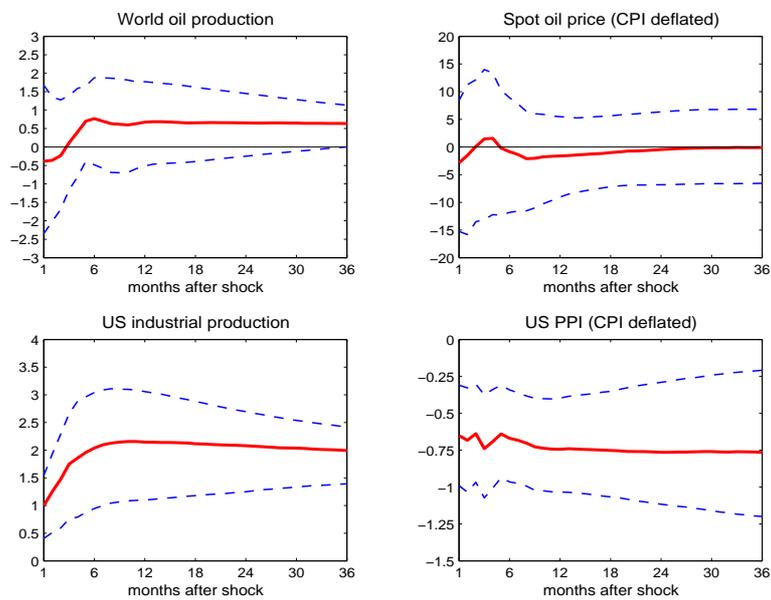
Note: The figures report the 16th, 50th and 84th percentiles of the IRFs distribution.

30

Appendices

A   The model economy

By the first welfare theorem the competitive equilibrium solves the planner's problem:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\left[c_t^{\theta}(1-n_t)^{1-\theta}\right]^{1-\gamma}}{1-\gamma} + \frac{\left[(c_t^*)^{\theta}(1-n_t^*)^{1-\theta}\right]^{1-\gamma}}{1-\gamma} + \left(\frac{(c_t^o)^{1-\gamma}}{1-\gamma} + \theta_L \frac{(1-n_t^o)^{1-\xi_L}}{1-\xi_L}\right) \right.$$

$$+ p_{c,t}\left[\left(s_t\psi(a_{c,t})^{1-\mu} + (1-s_t\psi)(b_{c,t})^{1-\mu}\right)^{\frac{1}{1-\mu}} - c_t\right]$$

$$+ p_{c^*,t}\left[\left(s_t^*\psi(b_{c,t}^*)^{1-\mu} + (1-s_t^*\psi)(a_{c,t}^*)^{1-\mu}\right)^{\frac{1}{1-\mu}} - c_t^*\right]$$

$$+ p_{c^o,t}\left[\left(\psi_o(a_{c,t}^o)^{1-\mu} + (1-\psi_o)(b_{c,t}^o)^{1-\mu}\right)^{\frac{1}{1-\mu}} - c_t^o\right]$$

$$+ p_{y,t}\left[z_t \, n_t^{\alpha}\left(\eta \, k_t^{1-\nu} + (1-\eta) \, o_t^{1-\nu}\right)^{\frac{1-\alpha}{1-\nu}} - a_{c,t} - a_{i,t} - a_{c,t}^* - a_{i,t}^* - a_{c,t}^o\right]$$

$$+ p_{y^*,t}\left[z_t^* \, n_t^{*\alpha}\left(\eta k_t^{*1-\nu} + (1-\eta) \, o_t^{*\,1-\nu}\right)^{\frac{1-\alpha}{1-\nu}} - b_{c,t} - b_{i,t} - b_{c,t}^* - b_{i,t}^* - b_{c,t}^o\right]$$

$$+ p_{o,t}\left[z^o + (n^o)^{\alpha} - o_t - o_t^*\right]$$

$$+ q_t\left[(1-\delta)k_t + \left(\frac{\left(\psi(a_{i,t})^{1-\mu} + (1-\psi)(b_{i,t})^{1-\mu}\right)^{\frac{1}{1-\mu}}}{k_t}\right)^{\phi} k_t - k_{t+1}\right]$$

$$\left. + q_t^*\left[(1-\delta)k_t^* + \left(\frac{\left(\psi(b_{i,t}^*)^{1-\mu} + (1-\psi)(a_{i,t}^*)^{1-\mu}\right)^{\frac{1}{1-\mu}}}{k_t^*}\right)^{\phi} k_t^* - k_{t+1}^*\right]\right\}$$

The AR(1) laws of motion (identical across countries) for the oil and preference shocks complete the model: $z_t = \rho_z z_{t-1} + \tilde{z}_t$ and $s_t = \rho_s s_{t-1} + \tilde{s}_t$. There are 20 choice variables (chosen at time t):

$$c \, , \, c^* , \, c^o , \, n \, , \, n^* , \, n^o , a_c \, , \, a_i \, , \, a_c^* \, , \, a_i^* \, , a_c^o , \, b_c \, , \, b_i \, , \, b_c^* \, , \, b_i^* \, , \, b_c^o , \, o \, , \, o^* , k_{t+1} \, , \, k_{t+1}^*$$

and 16 endogenous variables:

$$y \, , \, y^* , \, y^o , \, i \, , \, i^* \, , \, z , \, z^* , \, z^o , p_c \, , \, p_{c^*} , \, p_{c^o} , \, p_y \, , \, p_{y^*} , \, p_o , \, q^* \, , \, q$$

The parameters used in the benchmark IRFs of Figure 1 are reported in Table A.1.

Table A.1: Benchmark parametrization for the model economy

α	β	γ	δ	η	μ	ν	ψ	ϕ
0.64	0.99	1/0.5	0.025	0.9	2	11	0.8	0.99
ρ_z	ρ_{z^*}	ρ_{z^o}	θ	ψ^o	ξ_L	θ_L	ρ_s	
0.5	0.5	0.5	0.4	0.5	5	0.6	0.5	

B Analysis with sampling and model uncertainty

This Appendix describes how we derive impulse response analysis when the model is subject to both sampling and model uncertainty. In this case, the informativeness of the sign restriction method is also affected by the uncertainty around the OLS estimates regarding reduced form VAR coefficients and the covariance matrix of reduced form innovations.

The empirical distribution for the impulse responses are derived in a Bayesian framework. As shown by Uhlig (2005) under a standard diffuse prior for $(B(L), \Sigma)$ and a Gaussian likelihood for the data sample, the posterior density for the reduced-form VAR parameters with sign restrictions is proportional to a standard Normal-Wishart. Thus one can simply draw from the Normal-Wishart posterior for $(B(L), \Sigma)$, and then use the algorithm by Rubio-Ramirez et al. (2005) to find an orthonormal theory-consistent identification matrix.

Operationally, our simulation is based on a two-step procedure. In the first step, we derive 1,000 random draws from the posterior distribution of the reduced form VAR coefficients, $B(L)$ and the covariance matrix of disturbance, Σ. In the second step, the procedure runs a loop. It starts by randomly selecting one draw from the posterior distribution of the reduced form VAR and, conditionally on it, uses the QR decomposition by Rubio-Ramirez et al. (2005) to find an impulse matrix satisfying the sign restrictions. Then, it selects an alternative draw

The loop ends when we obtain 10,000 identification matrices.[20] We notice that the number of theory-consistent models we choose to shape impulse responses should be enough large to avoid an important drawback. First, for each draw of the reduced form VAR the simulation should finds at least one orthonormal impulse matrix satisfying the sign restrictions. This allows us to derive posterior distribution for impulse responses which are not too dependent from few selected candidate draws of the reduced form.

In Figure A.6 we report the resulting impulse responses of US output and CPI to both an oil supply and an oil demand shock allowing a comparison with the corresponding ones obtained by taking into account only the model uncertainty. The median estimated effects are almost identical, while the upper and lower confidence bands appear to be slightly wider. This evidence may suggest a relatively low uncertainty around OLS estimates of our parsimonious reduced form VAR.

---

[20]Our simulation works partly differently than those in Dedola and Neri (2007), and Uhlig (2005). In these papers the authors select a priori the number of draws for reduced form parameters and for each of them they draw a fixed number of impulse matrices. The resulting posterior distribution for impulse responses. Therefore, the number of accepted theory-consistent models is not fixed.

C Complying with Fry and Pagan's critique

Fry and Pagan (2007) argue that the sign restriction approach is in principle flawed because it ends up reporting impulse responses drawn from different $\tilde{\mathcal{A}}_0$ models, thus possibly violating the assumption that the structural innovations are orthogonal. These authors recommend to check the robustness of the results by comparing them with the impulse responses drawn from a single $\tilde{\mathcal{A}}_0$, chosen to e.g. minimize some distance criterion from the median response. Appendix C shows that the results displayed above remain virtually unchanged when this prescription is followed.

This appendix explores the sensitivity of the impulse responses reported in Section 4 to the critique raised by Fry and Pagan (2007) to the sign restriction approach. These authors note that the practice of reporting selected statistics from the posterior distribution of, say, the magnitude of impulse responses is subject to a potential methodological flaw. While the model uncertainty captured by this distribution squares nicely with a Bayesian view of model uncertainty, it is important to realize that under this approach different models are used in representation of the e.g. median impulse response to a given shock. To see this consider the moving average representation for the VAR reduced form

$$y_t = C(L)e_t \tag{A.1}$$

where

$$C(L) = [I - B(L)L]^{-1}\tilde{\mathcal{A}}_0 \tag{A.2}$$

where $C(L)$ contains the matrices of the estimated impulse responses to structural shocks. Let $C_{i,j,h}^{(k)}$ denote the response of variable i to shock j at horizon h, where k indexes the value of the estimated response in the set of the theory-consistent models. It is straightforward to notice that there is no guarantee that the median response of variable i with respect to shock j at two different horizons, h and h', $(med(C_{i,j,h}^{(k)}), med(C_{i,j,h'}^{(k)}))$ is generated by the same model $\hat{k}$. This issue also arises in comparison across all variables, shocks and for any quantile of the impulse response distribution. The ensuing violation of the shocks orthogonality may cast doubt on the results of the effects of structural shocks.

One way to tackle this problem, suggested by Fry and Pagan (2007), is to perform the structural analysis using a single structural model $\tilde{\mathcal{A}}_0 \in \tilde{\mathbf{A}}_0$, choosing the one whose impulse responses are "closest" to the median at all horizons. This strategy preserves the view that the median is an appealing way of summarizing the estimated effects of structural shocks at all horizons while ensuring the orthogonality of the shocks. Implementing this strategy requires us to define what we mean by "close". As impulse responses are not unit free, we first standardize them as

$$Z_{ij,h}^{(k)} = [C_{ij,h}^{(k)} - med(C_{ij,h}^{(k)})]/[stdev(C_{ij,h}^{(k)})] \tag{A.3}$$

The $Z_{ij,h}^{(k)}$ are then collected into a vector ϕ^k of dimension $(n \cdot h \cdot s \times 1)$, where n is the number of variables in the VAR, h the horizons over which the impulse responses is computed, and $s <= n$ the number of identified structural shocks. In our case we have $n = 6$ $h = 36$ and $s = 4$, therefore, ϕ^k is a vector (846×1). Finally, we choose the value of k that minimizes $\phi^k \phi^{k\,\prime}$, and use it to derive the estimated impulse responses.

Figure A.5 compares the median impulse responses of Figure 3 (dashed lines) with the one produced by the model satisfying the criterion describe above (solid lines). The

dynamic effects of structural shocks are very similar, even if there are some differences in the magnitude of the responses. In particular, after a supply oil shock the negative response of the US industrial production appears to be more pronounced. After an oil demand shock the hike in the oil price is even larger, leading to a magnified increase in the US industrial production.

Figure A.1: Historical decomposition

Oil Price (CPI deflated)
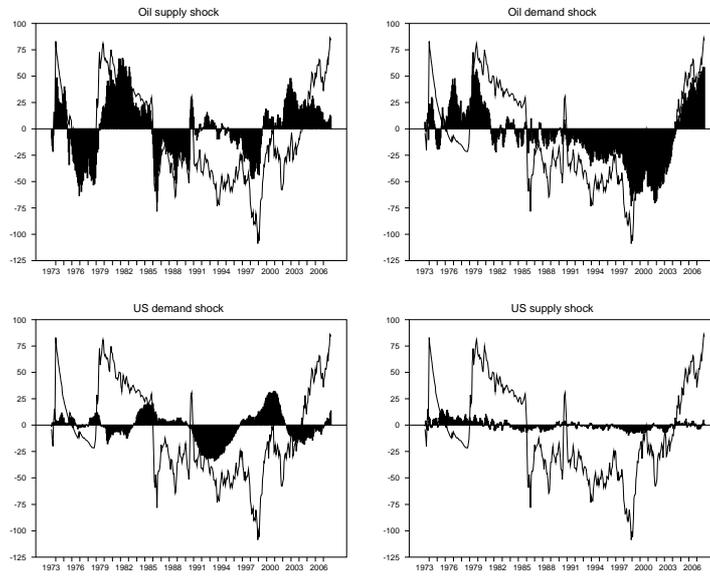
US industrial production
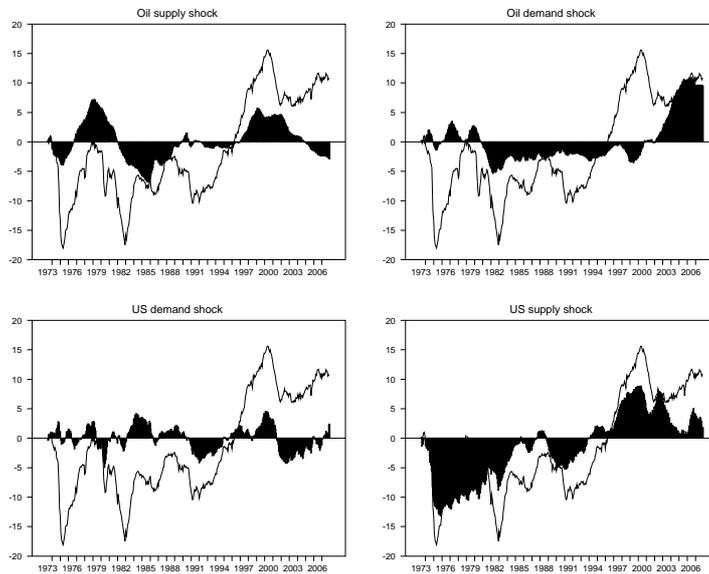
Note: The thin line denotes the oil price (or the US Industrial production), in deviation from the baseline. The black bars in each panel denote the component of the series accounted for by each structural shock.

Figure A.2: Robustness: Two vs. Four shocks

Oil supply shock
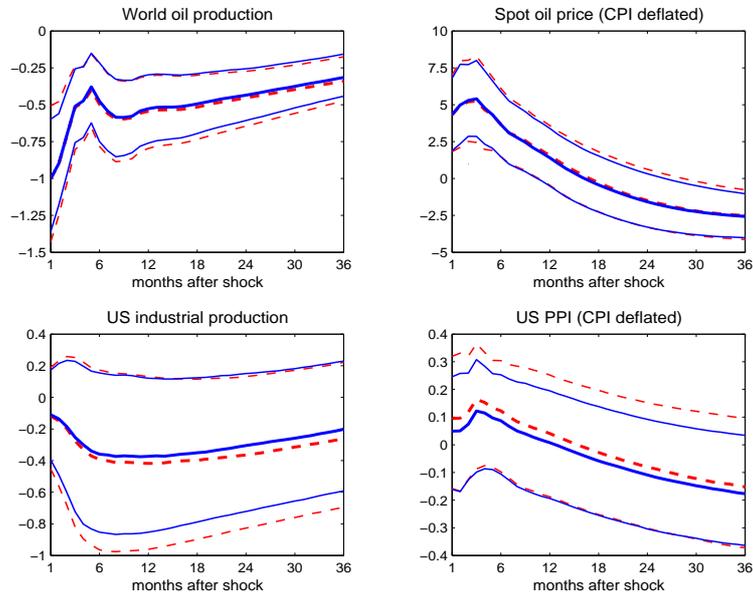
Oil demand shock
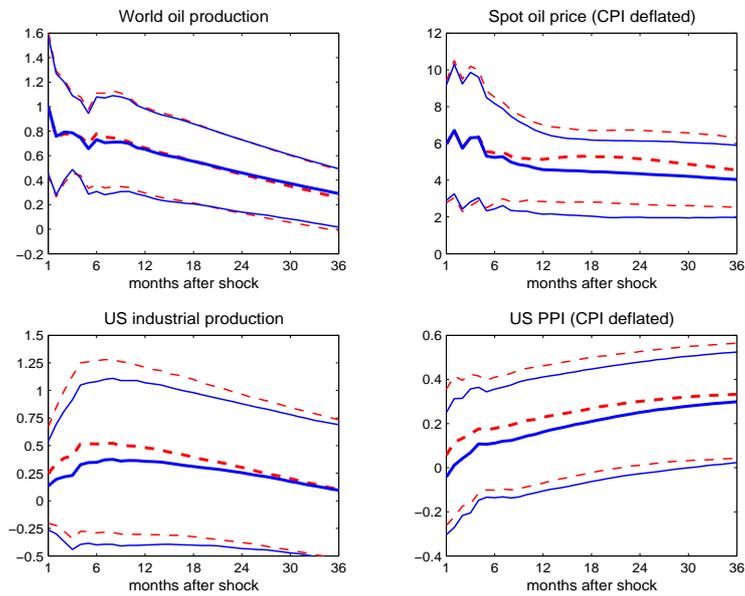
Note: The figure reports the 16th, 50th and 84th percentiles of the IRFs distribution. The solid lines are produced by the model with 2 identified shocks; the dashed lines are those of the benchmark model (with 4 identified shocks).

Figure A.3: Effects of an oil demand shock using Kilian's Hypothesis
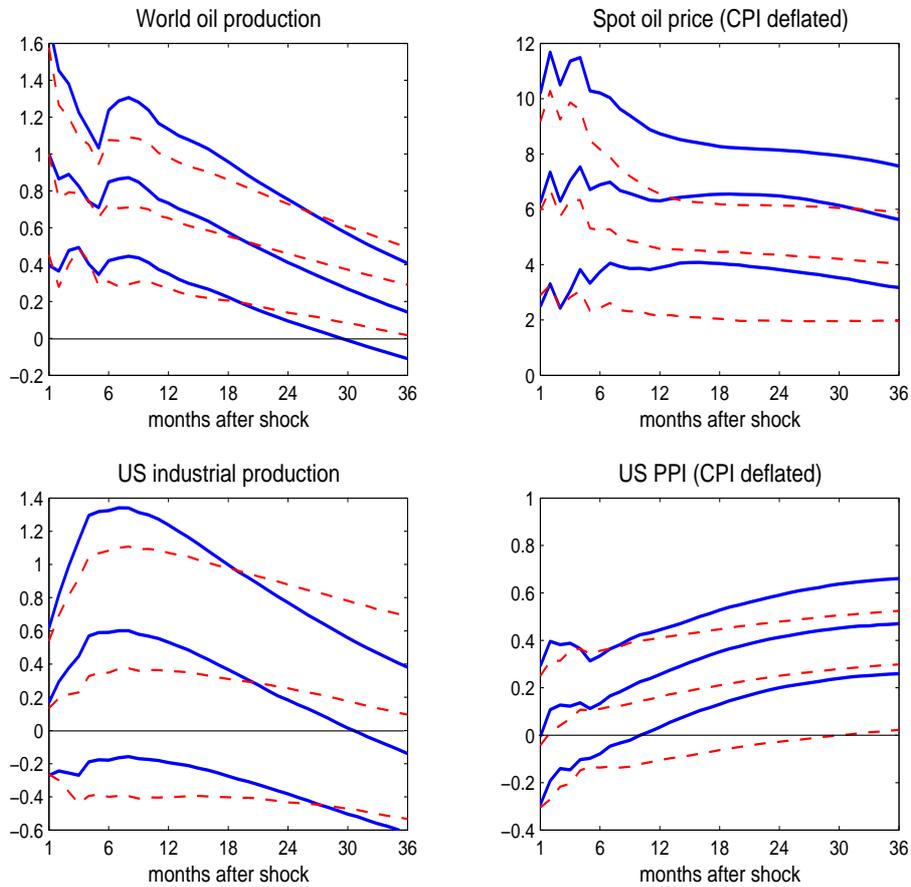
Note: The figure reports the 16th, 50th and 84th percentiles of the IRFs distribution. The solid lines are produced by the VAR including non-energy commodity price index; the dashed lines are those of the benchmark VAR (excluding non-energy commodity price index).

Figure A.4: Robustness: VAR with Fed Fund rate

Oil supply shock
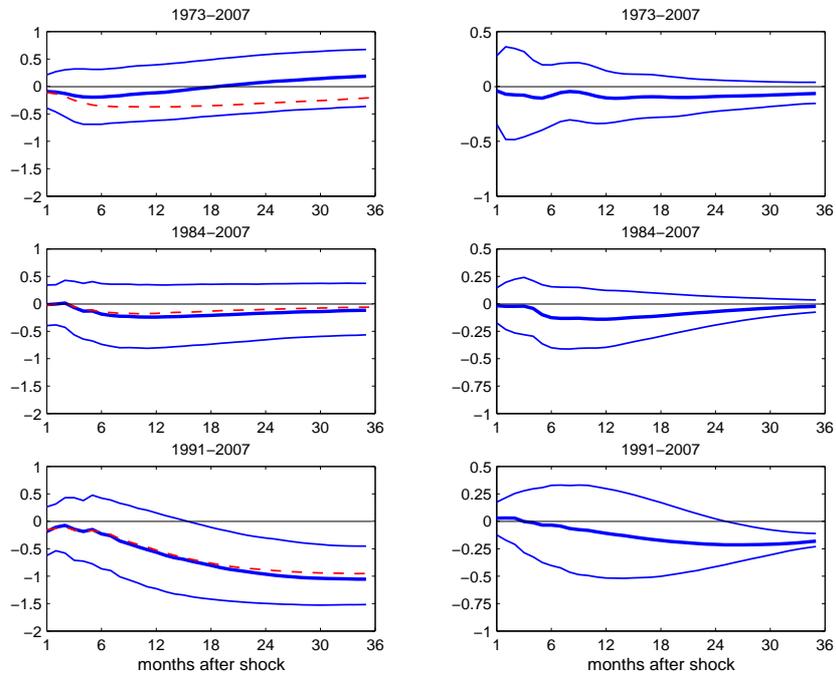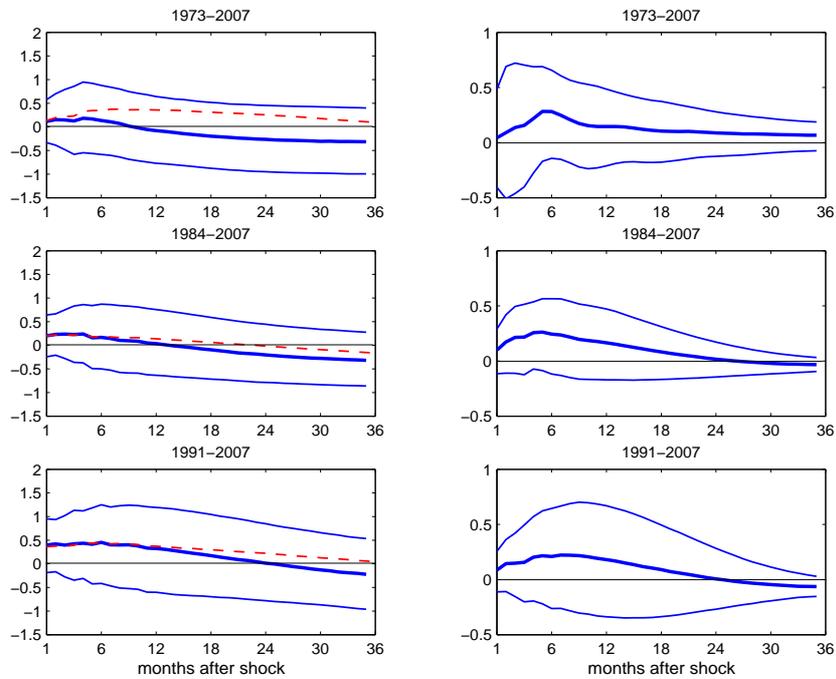
Oil demand shock

Note: The figure reports the 16th, 50th and 84th percentiles of the IRFs distribution. The solid lines are produced by the VAR including the Fed Fund rate; the dashed lines are those of the benchmark VAR.

Figure A.5: Robustness: Results based on Fry and Pagan method

Oil supply shock
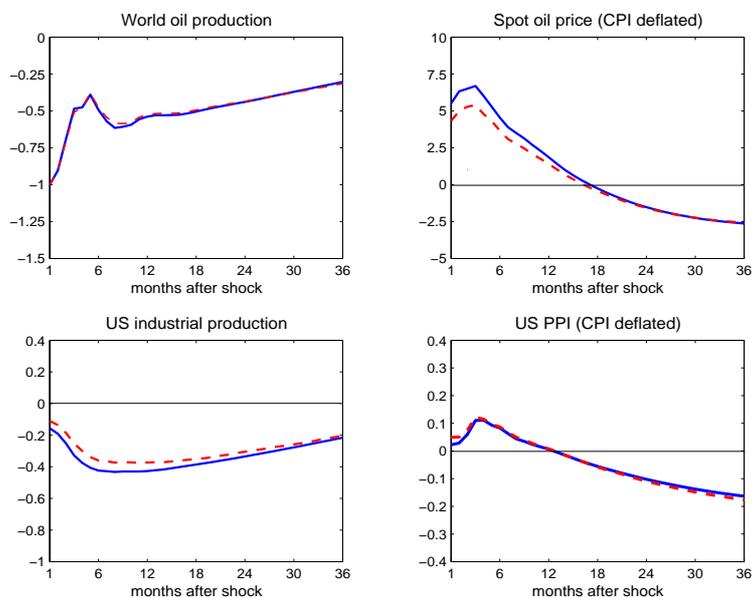
Oil demand shock
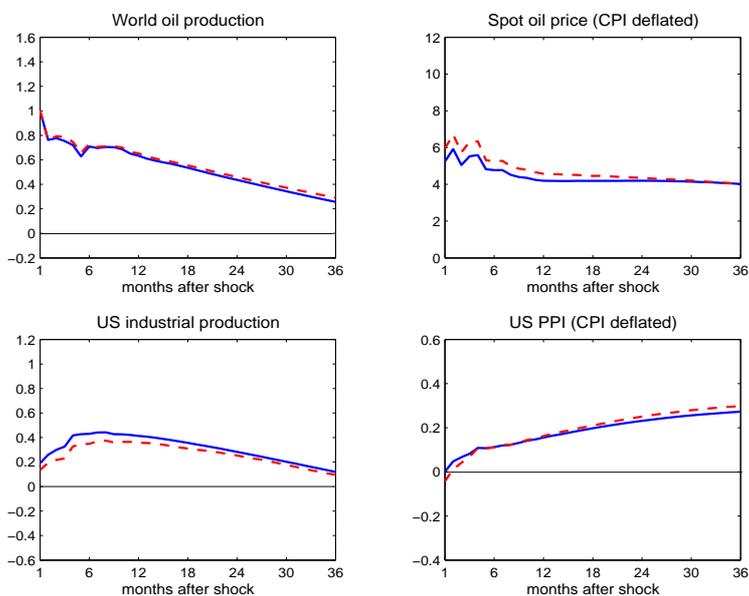
Note: The solid line is the response obtained applying the algorithm of Fry and Pagan (see Appendix C); the dashed line gives the median response of our benchmark VAR.

Figure A.6: Response of US production with model and sampling uncertainty
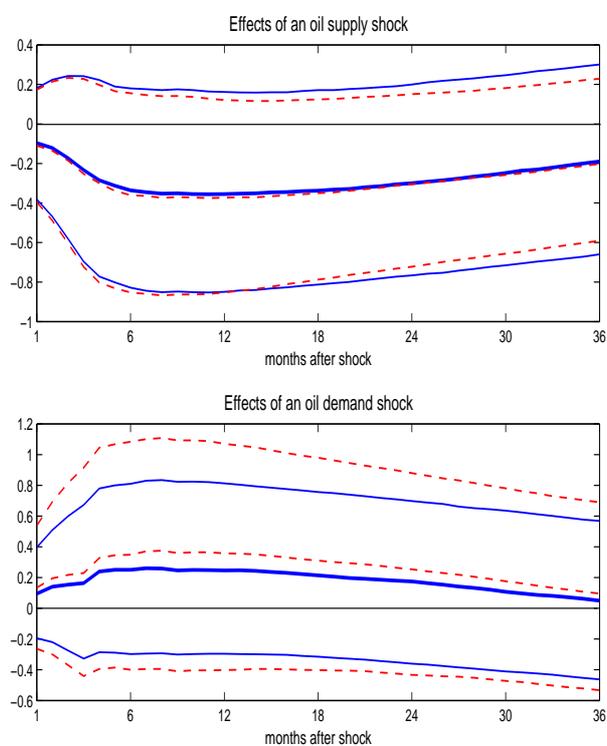
Note: The figure reports the 16th, 50th and 84th percentiles of the IRFs distribution. The solid lines are produced assuming model and sampling uncertainty; the dashed line assuming only model uncertainty.

RECENTLY PUBLISHED "TEMI" (*)

N. 680 – *Family succession and firm performance: Evidence from Italian family firms*, by Marco Cucculelli and Giacinto Micucci (June 2008).

N. 681 – *Short-term interest rate futures as monetary policy forecasts*, by Giuseppe Ferrero and Andrea Nobili (June 2008).

N. 682 – *Vertical specialisation in Europe: Evidence from the import content of exports*, by Emanuele Breda, Rita Cappariello and Roberta Zizza (August 2008).

N. 683 – *A likelihood-based analysis for relaxing the exclusion restriction in randomized experiments with imperfect compliance*, by Andrea Mercatanti (August 2008).

N. 684 – *Balancing work and family in Italy: New mothers' employment decisions after childbirth,* by Piero Casadio, Martina Lo Conte and Andrea Neri (August 2008).

N. 685 – *Temporal aggregation of univariate and multivariate time series models: A survey*, by Andrea Silvestrini and David Veredas (August 2008).

N. 686 – *Exploring agent-based methods for the analysis of payment systems: A crisis model for StarLogo TNG*, by Luca Arciero, Claudia Biancotti, Leandro D'Aurizio and Claudio Impenna (August 2008).

N. 687 – *The labor market impact of immigration in Western Germany in the 1990's*, by Francesco D'Amuri, Gianmarco I. P. Ottaviano and Giovanni Peri (August 2008).

N. 688 – *Agglomeration and growth: the effects of commuting costs*, by Antonio Accetturo (September 2008).

N. 689 – *A beta based framework for (lower) bond risk premia*, by Stefano Nobili and Gerardo Palazzo (September 2008).

N. 690 – *Nonlinearities in the dynamics of the euro area demand for M1*, by Alessandro Calza and Andrea Zaghini (September 2008).

N. 691 – *Educational choices and the selection process before and after compulsory schooling*, by Sauro Mocetti (September 2008).

N. 692 – *Investors' risk attitude and risky behavior: a Bayesian approach with imperfect information*, by Stefano Iezzi (September 2008).

N. 693 – *Competing influence*, by Enrico Sette (September 2008).

N. 694 – *La relazione tra gettito tributario e quadro macroeconomico in Italia*, by Alberto Locarno and Alessandra Staderini (December 2008).

N. 695 – *Immigrant earnings in the Italian labour market*, by Antonio Accetturo and Luigi Infante (December 2008).

N. 696 – *Reservation wages: explaining some puzzling regional patterns*, by Paolo Sestito and Eliana Viviano (December 2008).

N. 697 – *Technological change and the demand for currency: an analysis with household data*, by Francesco Lippi and Alessandro Secchi (December 2008).

N. 698 – *Immigration and crime: an empirical analysis*, by Milo Bianchi, Paolo Buonanno and Paolo Pinotti (December 2008).

N. 699 – *Bond risk premia, macroeconomic fundamentals and the exchange rate*, by Marcello Pericoli and Marco Taboga (January 2009).

N. 700 – *What determines debt intolerance? The role of political and monetary institutions*, by Raffaela Giordano and Pietro Tommasino (January 2009).

N. 701 – *On analysing the world distribution of income*, by Anthony B. Atkinson and Andrea Brandolini (January 2009).

N. 702 – *Dropping the books and working off the books*, by Rita Cappariello and Roberta Zizza (January 2009).

N. 703 – *Measuring wealth mobility*, by Andrea Neri (January 2009).

2006

F. BUSETTI, *Tests of seasonal integration and cointegration in multivariate unobserved component models*, Journal of Applied Econometrics, Vol. 21, 4, pp. 419-438, **TD No. 476 (June 2003).**

C. BIANCOTTI, *A polarization of inequality? The distribution of national Gini coefficients 1970-1996*, Journal of Economic Inequality, Vol. 4, 1, pp. 1-32, **TD No. 487 (March 2004).**

L. CANNARI and S. CHIRI, *La bilancia dei pagamenti di parte corrente Nord-Sud (1998-2000)*, in L. Cannari, F. Panetta (a cura di), Il sistema finanziario e il Mezzogiorno: squilibri strutturali e divari finanziari, Bari, Cacucci, **TD No. 490 (March 2004).**

M. BOFONDI and G. GOBBI, *Information barriers to entry into credit markets,* Review of Finance, Vol. 10, 1, pp. 39-67, **TD No. 509 (July 2004).**

W. FUCHS and LIPPI F., *Monetary union with voluntary participation,* Review of Economic Studies, Vol. 73, pp. 437-457 **TD No. 512 (July 2004).**

E. GAIOTTI and A. SECCHI, *Is there a cost channel of monetary transmission? An investigation into the pricing behaviour of 2000 firms*, Journal of Money, Credit and Banking, Vol. 38, 8, pp. 2013-2038 **TD No. 525 (December 2004).**

A. BRANDOLINI, P. CIPOLLONE and E. VIVIANO, *Does the ILO definition capture all unemployment?,* Journal of the European Economic Association, Vol. 4, 1, pp. 153-179, **TD No. 529 (December 2004).**

A. BRANDOLINI, L. CANNARI, G. D'ALESSIO and I. FAIELLA, *Household wealth distribution in Italy in the 1990s,* in E. N. Wolff (ed.) International Perspectives on Household Wealth, Cheltenham, Edward Elgar, **TD No. 530 (December 2004).**

P. DEL GIOVANE and R. SABBATINI, *Perceived and measured inflation after the launch of the Euro: Explaining the gap in Italy*, Giornale degli economisti e annali di economia, Vol. 65, 2 , pp. 155-192, **TD No. 532 (December 2004).**

M. CARUSO, *Monetary policy impulses, local output and the transmission mechanism*, Giornale degli economisti e annali di economia, Vol. 65, 1, pp. 1-30, **TD No. 537 (December 2004).**

L. GUISO and M. PAIELLA, *The role of risk aversion in predicting individual behavior, In P. A. Chiappori e C. Gollier (eds.) Competitive Failures in Insurance Markets: Theory and Policy Implications, Monaco, CESifo*, **TD No. 546 (February 2005).**

G. M. TOMAT, *Prices product differentiation and quality measurement: A comparison between hedonic and matched model methods*, Research in Economics, Vol. 60, 1, pp. 54-68, **TD No. 547 (February 2005).**

L. GUISO, M. PAIELLA and I. VISCO, *Do capital gains affect consumption? Estimates of wealth effects from Italian household's behavior*, in L. Klein (ed), Long Run Growth and Short Run Stabilization: Essays in Memory of Albert Ando (1929-2002), Cheltenham, Elgar, **TD No. 555 (June 2005).**

F. BUSETTI, S. FABIANI and A. HARVEY, *Convergence of prices and rates of inflation*, Oxford Bulletin of Economics and Statistics, Vol. 68, 1, pp. 863-878, **TD No. 575 (February 2006).**

M. CARUSO, *Stock market fluctuations and money demand in Italy, 1913 - 2003*, Economic Notes, Vol. 35, 1, pp. 1-47, **TD No. 576 (February 2006).**

R. BRONZINI and G. DE BLASIO, *Evaluating the impact of investment incentives: The case of Italy's Law 488/92.* Journal of Urban Economics, Vol. 60, 2, pp. 327-349, **TD No. 582 (March 2006).**

R. BRONZINI and G. DE BLASIO, *Una valutazione degli incentivi pubblici agli investimenti,* Rivista Italiana degli Economisti , Vol. 11, 3, pp. 331-362, **TD No. 582 (March 2006).**

A. DI CESARE, *Do market-based indicators anticipate rating agencies? Evidence for international banks*, Economic Notes, Vol. 35, pp. 121-150, **TD No. 593 (May 2006).**

R. GOLINELLI and S. MOMIGLIANO, *Real-time determinants of fiscal policies in the euro area*, Journal of Policy Modeling, Vol. 28, 9, pp. 943-964, **TD No. 609 (December 2006).**

2007

S. SIVIERO and D. TERLIZZESE, *Macroeconomic forecasting: Debunking a few old wives' tales,* Journal of Business Cycle Measurement and Analysis , v. 3, 3, pp. 287-316, **TD No. 395 (February 2001).**

S. MAGRI, *Italian households' debt: The participation to the debt market and the size of the loan*, Empirical Economics, v. 33, 3, pp. 401-426, **TD No. 454 (October 2002).**

L. CASOLARO. and G. GOBBI, *Information technology and productivity changes in the banking industry*, Economic Notes, Vol. 36, 1, pp. 43-76, **TD No. 489 (March 2004).**

G. FERRERO, *Monetary policy, learning and the speed of convergence,* Journal of Economic Dynamics and Control, v. 31, 9, pp. 3006-3041, **TD No. 499 (June 2004).**

M. PAIELLA, *Does wealth affect consumption? Evidence for Italy*, Journal of Macroeconomics, Vol. 29, 1, pp. 189-205, **TD No. 510 (July 2004).**

F. LIPPI. and S. NERI, *Information variables for monetary policy in a small structural model of the euro area*, Journal of Monetary Economics, Vol. 54, 4, pp. 1256-1270, **TD No. 511 (July 2004).**

A. ANZUINI and A. LEVY, *Monetary policy shocks in the new EU members: A VAR approach*, Applied Economics, Vol. 39, 9, pp. 1147-1161, **TD No. 514 (July 2004).**

D. JR. MARCHETTI and F. Nucci, *Pricing behavior and the response of hours to productivity shocks*, Journal of Money Credit and Banking, v. 39, 7, pp. 1587-1611, **TD No. 524 (December 2004).**

R. BRONZINI, *FDI Inflows, agglomeration and host country firms' size: Evidence from Italy*, Regional Studies, Vol. 41, 7, pp. 963-978, **TD No. 526 (December 2004).**

L. MONTEFORTE, *Aggregation bias in macro models: Does it matter for the euro area?*, Economic Modelling, 24, pp. 236-261, **TD No. 534 (December 2004).**

A. NOBILI, *Assessing the predictive power of financial spreads in the euro area: does parameters instability matter?,* Empirical Economics, Vol. 31, 1, pp. 177-195, **TD No. 544 (February 2005).**

A. DALMAZZO and G. DE BLASIO, *Production and consumption externalities of human capital: An empirical study for Italy,* Journal of Population Economics, Vol. 20, 2, pp. 359-382, **TD No. 554 (June 2005).**

M. BUGAMELLI and R. TEDESCHI, *Le strategie di prezzo delle imprese esportatrici italiane*, Politica Economica, v. 23, 3, pp. 321-350, **TD No. 563 (November 2005).**

L. GAMBACORTA and S. IANNOTTI, *Are there asymmetries in the response of bank interest rates to monetary shocks?,* Applied Economics, v. 39, 19, pp. 2503-2517, **TD No. 566 (November 2005).**

P. ANGELINI and F. LIPPI, *Did prices really soar after the euro cash changeover? Evidence from ATM withdrawals,* International Journal of Central Banking, Vol. 3, 4, pp. 1-22, **TD No. 581 (March 2006).**

A. LOCARNO, *Imperfect knowledge, adaptive learning and the bias against activist monetary policies*, International Journal of Central Banking, v. 3, 3, pp. 47-85, **TD No. 590 (May 2006).**

F. LOTTI and J. MARCUCCI, *Revisiting the empirical evidence on firms' money demand*, Journal of Economics and Business, Vol. 59, 1, pp. 51-73, **TD No. 595 (May 2006).**

P. CIPOLLONE and A. ROSOLIA, *Social interactions in high school: Lessons from an earthquake*, American Economic Review, Vol. 97, 3, pp. 948-965, **TD No. 596 (September 2006).**

L. DEDOLA and S. NERI, *What does a technology shock do? A VAR analysis with model-based sign restrictions*, Journal of Monetary Economics, Vol. 54, 2, pp. 512-549, **TD No. 607 (December 2006).**

F. VERGARA CAFFARELLI, *Merge and compete: strategic incentives for vertical integration*, Rivista di politica economica, v. 97, 9-10, serie 3, pp. 203-243, **TD No. 608 (December 2006).**

A. BRANDOLINI, *Measurement of income distribution in supranational entities: The case of the European Union*, in S. P. Jenkins e J. Micklewright (eds.), Inequality and Poverty Re-examined, Oxford, Oxford University Press, **TD No. 623 (April 2007).**

M. PAIELLA, *The foregone gains of incomplete portfolios*, Review of Financial Studies, Vol. 20, 5, pp. 1623-1646, **TD No. 625 (April 2007).**

K. BEHRENS, A. R. LAMORGESE, G.I.P. OTTAVIANO and T. TABUCHI, *Changes in transport and non transport costs: local vs. global impacts in a spatial network*, Regional Science and Urban Economics, Vol. 37, 6, pp. 625-648, **TD No. 628 (April 2007).**

M. BUGAMELLI, *Prezzi delle esportazioni, qualità dei prodotti e caratteristiche di impresa: analisi su un campione di imprese italiane,* v. 34, 3, pp. 71-103, Economia e Politica Industriale, **TD No. 634 (June 2007).**

G. ASCARI and T. ROPELE, *Optimal monetary policy under low trend inflation*, Journal of Monetary Economics, v. 54, 8, pp. 2568-2583, **TD No. 647 (November 2007).**

R. GIORDANO, S. MOMIGLIANO, S. NERI and R. PEROTTI, *The Effects of Fiscal Policy in Italy: Evidence from a VAR Model*, European Journal of Political Economy, Vol. 23, 3, pp. 707-733, **TD No. 656 (January 2008).**

B. ROFFIA and A. ZAGHINI, *Excess money growth and inflation dynamics,* International Finance, v. 10, 3, pp. 241-280, **TD No. 657 (January 2008).**

G. BARBIERI, P. CIPOLLONE and P. SESTITO, *Labour market for teachers: demographic characteristics and allocative mechanisms*, Giornale degli economisti e annali di economia, v. 66, 3, pp. 335-373, **TD No. 672 (June 2008).**

E. BREDA, R. CAPPARIELLO and R. ZIZZA, *Vertical specialisation in Europe: evidence from the import content of exports*, Rivista di politica economica, numero monografico,**TD No. 682 (August 2008).**

2008

P. ANGELINI, *Liquidity and announcement effects in the euro area*, Giornale degli Economisti e Annali di Economia, v. 67, 1, pp. 1-20, **TD No. 451 (October 2002).**

P. ANGELINI, P. DEL GIOVANE, S. SIVIERO and D. TERLIZZESE, *Monetary policy in a monetary union: What role for regional information?*, International Journal of Central Banking, v. 4, 3, pp. 1-28, **TD No. 457 (December 2002).**

F. SCHIVARDI and R. TORRINI, *Identifying the effects of firing restrictions through size-contingent Differences in regulation,* Labour Economics, v. 15, 3, pp. 482-511, **TD No. 504 (June 2004).**

L. GUISO and M. PAIELLA,, *Risk aversion, wealth and background risk*, Journal of the European Economic Association, v. 6, 6, pp. 1109-1150, **TD No. 483 (September 2003).**

C. BIANCOTTI, G. D'ALESSIO and A. NERI, *Measurement errors in the Bank of Italy's survey of household income and wealth*, Review of Income and Wealth, v. 54, 3, pp. 466-493, **TD No. 520 (October 2004).**

S. MOMIGLIANO, J. HENRY and P. HERNÁNDEZ DE COS, *The impact of government budget on prices: Evidence from macroeconometric models*, Journal of Policy Modelling, v. 30, 1, pp. 123-143 **TD No. 523 (October 2004).**

L. GAMBACORTA, *How do banks set interest rates?,* European Economic Review, v. 52, 5, pp. 792-819, **TD No. 542 (February 2005).**

P. ANGELINI and A. GENERALE, *On the evolution of firm size distributions*, American Economic Review, v. 98, 1, pp. 426-438, **TD No. 549 (June 2005).**

R. FELICI and M. PAGNINI, *Distance, bank heterogeneity and entry in local banking markets*, The Journal of Industrial Economics, v. 56, 3, pp. 500-534, **No. 557 (June 2005).**

S. DI ADDARIO and E. PATACCHINI, *Wages and the city. Evidence from Italy*, Labour Economics, v.15, 5, pp. 1040-1061, **TD No. 570 (January 2006).**

M. PERICOLI and M. TABOGA, *Canonical term-structure models with observable factors and the dynamics of bond risk premia,* Journal of Money, Credit and Banking, v. 40, 7, pp. 1471-88, **TD No. 580 (February 2006).**

E. VIVIANO, *Entry regulations and labour market outcomes. Evidence from the Italian retail trade sector*, Labour Economics, v. 15, 6, pp. 1200-1222, **TD No. 594 (May 2006).**

S. FEDERICO and G. A. MINERVA, *Outward FDI and local employment growth in Italy,* Review of World Economics, Journal of Money, Credit and Banking, v. 144, 2, pp. 295-324, **TD No. 613 (February 2007).**

F. BUSETTI and A. HARVEY, *Testing for trend*, Econometric Theory, v. 24, 1, pp. 72-87, **TD No. 614 (February 2007).**

V. CESTARI, P. DEL GIOVANE and C. ROSSI-ARNAUD, *Memory for prices and the Euro cash changeover: an analysis for cinema prices in Italy*, In P. Del Giovane e R. Sabbatini (eds.), The Euro Inflation and Consumers' Perceptions. Lessons from Italy, Berlin-Heidelberg, Springer, **TD No. 619 (February 2007).**

H. BRONWYN, F. LOTTI and J. MAIRESSE, *Employment, innovation and productivity: evidence from Italian manufacturing microdata*, Industrial and Corporate Change, v. 17, 4, pp. 813-839, **TD No. 622 (April 2007).**

J. SOUSA and A. ZAGHINI, *Monetary policy shocks in the Euro Area and global liquidity spillovers,* International Journal of Finance and Economics, v.13, 3, pp. 205-218, **TD No. 629 (June 2007).**

M. Del Gatto, Gianmarco I. P. Ottaviano and M. Pagnini, *Openness to trade and industry cost dispersion: Evidence from a panel of Italian firms,* Journal of Regional Science, v. 48, 1, pp. 97-129, **TD No. 635 (June 2007).**

P. Del Giovane, S. Fabiani and R. Sabbatini, *What's behind "inflation perceptions"? A survey-based analysis of Italian consumers,* in P. Del Giovane e R. Sabbatini (eds.), *The Euro Inflation and Consumers' Perceptions. Lessons from Italy*, Berlin-Heidelberg, Springer, **TD No. 655 (January 2008).**

B. Bortolotti, and P. Pinotti, *Delayed privatization,* Public Choice, v. 136, 3-4, pp. 331-351, **TD No. 663 (April 2008).**

R. Bonci and F. Columba, *Monetary policy effects: New evidence from the Italian flow of funds,* Applied Economics , v. 40, 21, pp. 2803-2818, **TD No. 678 (June 2008).**

M. Cucculelli, and G. Micucci, *Family Succession and firm performance: evidence from Italian family firms,* Journal of Corporate Finance, v. 14, 1, pp. 17-31, **TD No. 680 (June 2008).**

2009

S. Magri, *The financing of small innovative firms: The Italian case*, Economics of Innovation and New Technology, v. 18, 2, pp. 181-204, **TD No. 640 (September 2007).**

L. Arciero, C. Biancotti, L. D'Aurizio and C. Impenna, *Exploring agent-based methods for the analysis of payment systems: A crisis model for StarLogo TNG,* Journal of Artificial Societies and Social Simulation, v. 12, 1, **TD No. 686 (August 2008).**

A. Calza and A. Zaghini, *Nonlinearities in the dynamics of the euro area demand for M1*, Macroeconomic Dynamics, v. 13, 1, pp. 1-19, **TD No. 690 (September 2008).**

FORTHCOMING

L. Monteforte and S. Siviero, *The Economic Consequences of Euro Area Modelling Shortcuts*, Applied Economics, **TD No. 458 (December 2002).**

M. Bugamelli and A. Rosolia, *Produttività e concorrenza estera*, Rivista di politica economica, **TD No. 578 (February 2006).**

R. Bronzini and P. Piselli, *Determinants of long-run regional productivity with geographical spillovers: the role of R&D, human capital and public infrastructure,* Regional Science and Urban Economics, **TD No. 597 (September 2006).**

U. Albertazzi and L. Gambacorta, *Bank profitability and the business cycle,* Journal of Financial Stability, **TD No. 601 (September 2006).**

A. Ciarlone, P. Piselli and G. Trebeschi, *Emerging Markets' Spreads and Global Financial Conditions*, Journal of International Financial Markets, Institutions & Money, **TD No. 637 (June 2007).**

L. Forni, L. Monteforte and L. Sessa, *The general equilibrium effects of fiscal policy: Estimates for the euro area,* Journal of Public Economics, **TD No. 652 (November 2007).**

R. Golinelli and S. Momigliano, *The cyclical reaction of fiscal policies in the Euro Area. A critical survey of empirical research*, Fiscal Studies, **TD No. 654 (January 2008).**

A. Accetturo, *Agglomeration and growth: the effects of commuting costs,* Regional Science, **TD No. 688 (September 2008).**