Disentangling the effects of oil shocks: the role of rigidities and monetary policy♣

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Abstract

Using a new Keynesian, stochastic, dynamic model of a small open monetary economy that imports oil and applying it to the Spanish economy, this paper addresses the question of why the effects of oil shocks from the mid-1980's on output and inflation were smaller. We depart from the previous literature on this topic by simulating a theoretical model whose parameters are estimated using Kalman Filter techniques. The paper is particularly appealing to study the effects of high energy prices, which would be associated to climate change policies, and to the feedback effects of those policies on the economy. The results of the paper support the hypothesis of smaller macroeconomic effects of oil shocks from the mid-1980's. The results emerge from the different features of the economy: both labor market rigidities and the oil share have decreased over time and the monetary policy has changed in that it is more focused on controlling inflation.

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1.- Introduction

To guide climate change mitigation efforts after 2012, the end of the Kyoto Protocol commitment period, a redefinition of energy policies will be necessary. In the new scenario, those policies will drastically impact prices in international energy markets. Thus, there is a renewed interest in analyzing the impact of energy prices on economic activity, particularly fossil fuels, given the crucial role they have played in developed economies during the last decades.

Since the 1970's, oil shocks have received a great deal of attention from economists. There has been an extensive literature studying the macroeconomic effects of oil shocks, whose interest starts with the oil crises of 1973 and 1979. In particular, many authors have cited oil shocks as the main factor behind the episode of stagflation in the 1970's, analyzing the impact of oil shocks on output and inflation.

Starting with Hamilton (1983), there is a large branch of the literature reporting a correlation between oil price shocks and economic downturns, as well as many papers that theoretically address the question of whether standard models can account for the observed effects of oil price shocks. Those papers include Kim and Loungani (1992), Finn (2000), Rotemberg and Woodford (1996), Backus and Crucini (2000) and De Miguel, Manzano and Martín-Moreno (2003, 2006).

By the mid-1980's, it was believed that the macroeconomic effects of oil shocks had changed over time. Thus emerged a literature on the so-called "Great Moderation," which refers to the decrease in GDP volatility over the previous three decades. In this analysis, the lower effects of oil shocks on the economy are pointed out as a potential explanation. Bohi (1989, 1991) and Bernanke, Gertler and Watson (1997) show that the effects of an oil shock would depend on the response of monetary policy in mitigating it. Huang (2008) takes into account the effects of oil price shocks on the economy, considering the differences in economic development, energy dependence and the efficiency of energy use in each country. Papers by Herrera and Pesavento (2009) and Blanchard and Gali (2008) examine several hypotheses for explaining the weaker effects of oil shocks from the mid-1980's. Both papers consider changes in monetary policy, finding that changes in monetary rule can explain some of the lesser effects of oil shocks on output and inflation. In particular, Blanchard and Gali (2008) also consider other hypotheses, including more flexible labor markets and a smaller share of oil in production. All those papers follow a VAR methodology, although Blanchard and Gali also consider a new Keynesian model, only for the purpose of illustrating the empirical VAR results.

In this paper, we also address the question of why the effects of oil shocks on output and inflation were smaller during the mid-1980's. We differ from the previous literature in several ways:

1) We analyze the case for the Spanish economy, which is different in many ways from the U.S. economy. The Spanish economy is less flexible in both the labor and goods market, so considering an imperfect competition framework is important. Spain's economy also needs to be modeled as a small open economy that imports oil and has a negligible impact on oil prices and international interest rates.

2) Methodologically, we depart from the empirical VAR analysis present in the literature. The VAR methodology has an important limitation in the sense that the estimated shocks cannot be interpreted directly in economic terms, because they arise from a reduced form. Those shocks are a function of the structural shocks, and identification assumptions are needed to understand the economic meaning of the estimated shocks. Recent developments of econometric and numerical techniques allow for estimating structural parameters and structural shocks in the framework of Dynamic Stochastic General Equilibrium Models (DSGE). Those techniques overcome the identification assumption problem of the VAR methodology, making DSGE models a more appealing alternative for our purpose.

   Thus, we specify, estimate and simulate a new Keynesian DSGE model of a small open economy hit by three kinds of shocks: productivity, monetary and oil shocks. The monetary authority follows a Taylor rule, adjusting interest rates for the steady state deviations of inflation and output and the difference between domestic and international interest rates. The parameters of the model are estimated using Kalman filter techniques. We have different sets of estimated parameters depending on the sample considered. Finally, the model is simulated in order to obtain impulse response and variance decomposition of the different shocks.

The results of the paper support the hypothesis of smaller macroeconomic effects of oil shocks from the mid-1980's. Those results emerge from the different features of the economy: both labor market rigidities and the oil share have decreased over time and the monetary policy has changed in that it is more focused on controlling inflation.

The paper is organized as follows. Section 2 describes the theoretical model and derives the conditions of the equilibrium. In Section 3 we discuss the estimation of the model parameters. Section 4 presents the numerical simulation of the model and the results. Finally, Section 5 concludes.

2.- The model

Here we depart from Ireland's (2004) monetary model, modified to assume a small open economy that uses imported oil to produce and that is subject to rigidities in both the goods and the labor markets. The model consists of a representative household with real balances in the utility function *à la* Sidrauski, a representative firm that produces the final good, a continuum of intermediate goods-producing firms and a monetary authority. Since intermediate commodities are imperfect substitutes in the production of the final good, the representative firm producing intermediate commodities sells its production in a monopolistic competition market at a price that depends on the demand by the firm producing the final good. We assume that the firm producing intermediate commodities faces quadratic costs for adjusting nominal prices between periods, and these costs are responsible for the price rigidity in this model.

The representative household

The representative household starts each period t with a stock of nominal debt B_t traded internationally and a money stock M_t. At the beginning of the period, the household receives a nominal lump-sum transfer T_t from the monetary authority. After receiving this transfer, bonds mature, providing the household with B_t additional units of money. These monetary units are used in part to purchase new bonds B_{t+1}, at a nominal cost $B_{t+1}/(1+i_t)$, where i_t denotes the nominal rate of interest.

The household supplies $h_t(j)$ units of labor to each intermediate goods-producing firm. Since there is a continuum of intermediate firms, we have:

$$h_t = \int_0^1 h_t(j)dj, \;\; j \in [0,1].$$

The household is paid at the real wage w_t. and consumes the final good c_t purchased at a nominal price P_t. At the end of the period, the household receives a nominal dividend $D_t(j)$ from each intermediate goods-producing firm.

$$D_t = \int_0^1 D_t(j)dj,\ j \in [0,1].$$

The representative household chooses c_t, M_{t+1}, B_{t+1} and h_t to maximize its expected lifetime utility subject to the budget constraint. The optimization problem is:

$$\max\ E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\left[c_t \left(\frac{M_{t+1}}{P_t} \right)^{\theta} \right]^{1-\sigma} - 1}{1-\sigma} - \psi h_t \right\}$$

s.t.:

$$c_t + \frac{M_{t+1}}{P_t} + \frac{B_{t+1}}{P_t(1+i_t)} \leq \frac{M_t}{P_t} + \frac{B_t}{P_t} + \frac{T_t}{P_t} + w_t h_t + \frac{D_t}{P_t}\ ,$$

given M_0 and B_0 , where $0<\beta<1$ is the subjective rate of intertemporal discount, $\sigma>0$ is the parameter of relative risk aversion and ψ and θ are positive preference parameters.

First-order conditions for this problem are:

$$c_t^{-\sigma} m_t^{\theta(1-\sigma)} = \lambda_t\ , \tag{1}$$

$$\theta c_t^{1-\sigma} m_t^{\theta(1-\sigma)-1} = \lambda_t - \beta E_t \left[\lambda_{t+1} \frac{1}{1+\pi_{t+1}} \right], \tag{2}$$

$$\psi = \lambda_t w_t\ , \tag{3}$$

$$\frac{1}{P_t(1+i_t)} \lambda_t = \beta E_t \left(\lambda_{t+1} \frac{1}{P_{t+1}} \right), \tag{4}$$

together with the budget constraint written as an equality, and the transversality condition:

$$\lim_{T\to\infty} E_t \left[\beta^{t+T} \lambda_{t+T} \left(\frac{M_{t+T+1}}{P_{t+T}} + \frac{B_{t+T+1}}{P_{t+T}(1+i_{t+T})} \right) \right] = 0,$$

where λ is the Lagrange multiplier and $m_t = \frac{M_{t+1}}{P_t}$ and $\pi_{t+1} = \frac{P_{t+1}}{P_t} - 1$ are, respectively, the real balances and the inflation rate.

From (1) and (3), we obtain:

$$\frac{\psi}{c_t^{-\sigma} m_t^{\theta(1-\sigma)}} = w_t$$

We assume real wage rigidities by modifying *ad hoc* the previous equation:

$$\frac{(1+\eta)\psi}{c_t^{-\sigma} m_t^{\theta(1-\sigma)}} = w_t , \qquad (5)$$

where η represents an index of the degree of real wage rigidities, that is, η could be interpreted as the markup charged by unions. Thus, real wages are set as a markup over the marginal rate of substitution between labor and consumption as if the economy had a representative union that, when setting its wage, faces a downward-sloping demand for its type of labor, assuming that there is an aggregate of the differentiated types of labor. Equation (5) allows us to analyze the role of rigidities in the labor market when analyzing the macroeconomic effects of the different shocks considered[1].

From (1), (2) and (4):

$$\theta \frac{c_t}{m_t} = \frac{i_t}{1+i_t} . \qquad (6)$$

And finally, from (1) and (4), we obtain:

$$c_t^{-\sigma} m_t^{\theta(1-\sigma)} = \beta(1+i_t) E_t \left[c_{t+1}^{-\sigma} m_{t+1}^{\theta(1-\sigma)} \frac{1}{1+\pi_{t+1}} \right] . \qquad (7)$$

The representative finished goods-producing firm

During each period t=0,1,2,…, this firm produces y_t units of the final good by using as inputs $y_t(j)$ units of each intermediate good for $j \in [0,1]$, purchased at price $P_t(j)$. The firm uses a constant return to scale technology described by:

$$\left[\int_0^1 y_t(j)^{(\varepsilon-1)/\varepsilon} dj \right]^{\frac{\varepsilon}{\varepsilon-1}} \geq y_t , \quad \varepsilon > 1 .$$

[1] See Chari, Kehoe and McGrattan (2009) for a complete foundation of equation (5).

And it solves the following problem subject to its technology,

$$\max\ \Pi_t = P_t y_t - \int_0^1 P_t(j) y_t(j) dj .$$

The first-order condition of this problem is:

$$y_t(j) = \left[P_t(j)/P_t \right]^{-\varepsilon} y_t, \quad \forall j \in [0,1],$$

where ε represents the constant price elasticity of demand for each intermediate good.

Competition among firms in the market for the final good leads to zero profits in equilibrium, determining P_t as:

$$P_t = \left[\int_0^1 P_t(j)^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}} .$$

The representative intermediate goods-producing firm

In each period, the *j*-th firm uses labor $h_t(j)$ and oil (e_t) to produce the intermediate good, $y_t(j)$. The *j*-th firm exhibits the technology:

$$z_t h_t(j)^{\alpha_1} e_t(j)^{\alpha_2} \geq y_t(j), \quad \alpha_1 + \alpha_2 \in (0,1],$$

where z_t is an aggregate technological shock, common to all firms, that follows the autoregressive process,

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \varepsilon_{zt}, \quad |\rho_z| < 1, \quad \varepsilon_{zt} \underset{iid}{\sim} N(0, \sigma_z^2).$$

Oil is purchased in an international oil market at a real price p_t^e that we assume to be exogenous and following a stochastic process:

$$\ln(p_t^e) = \overline{p^e} + \varphi_{p^e} \ln(p_{t-1}^e) + \varepsilon_{p^e,t}, \quad \left|\varphi_{p^e}\right| < 1, \quad \varepsilon_{p^e,t} \underset{iid}{\sim} N(0, \sigma_{p^e}^2).$$

Intermediate goods substitute imperfectly to produce the final good. Thus, the representative intermediate good-producing firm sells its production in a monopolistic competition market at a price that depends on the demand by the firm producing the final good and facing a quadratic cost of changing nominal price as specified in Rotemberg (1982):

$$\frac{\phi}{2}\left[\frac{P_t(j)}{(1+\pi_{ss})P_{t-1}(j)}-1\right]^2 y_t,$$

where $\phi \geq 0$ and π_{ss} denotes the steady state rate of inflation.

The market value maximization problem of the representative j-th firm producing intermediate commodities becomes dynamic as a result of this adjustment cost:

$$\max\ E_0\sum_{t=0}^{\infty}\beta^t\lambda_t\left[\frac{D_t(j)}{P_t}\right],$$

s.t.:

$$y_t(j)=\left[P_t(j)/P_t\right]^{-\varepsilon}y_t,\quad \forall j\in[0,1]$$

$$z_t h_t(j)^{\alpha_1}e_t(j)^{\alpha_2}\geq y_t(j),\quad \alpha_1+\alpha_2\in(0,1]$$

where $\dfrac{D_t(j)}{P_t}=\dfrac{P_t(j)}{P_t}y_t(j)-w_t h_t(j)-p_t^e e_t(j)-\dfrac{\phi}{2}\left[\dfrac{P_t(j)}{(1+\pi_{ss})P_{t-1}(j)}-1\right]^2 y_t$ and $\beta^t\lambda_t/P_t$ represents for the representative household the value of the marginal utility of an additional monetary unit received as dividends in period t.

Finally, the representative j-th firm's problem of choosing $h_t(j)$, $e_t(j)$ and $P_t(j)$ can be written as follows:

$$\max\ E_0\sum_{t=0}^{\infty}\beta^t\lambda_t\left[\left(\frac{P_t(j)}{P_t}\right)^{1-\varepsilon}y_t-w_t h_t(j)-p_t^e e_t(j)-\frac{\phi}{2}\left[\frac{P_t(j)}{(1+\pi_{ss})P_{t-1}(j)}-1\right]^2 y_t\right]+$$
$$E_0\sum_{t=0}^{\infty}\beta^t\zeta_t\left[z_t h_t(j)^{\alpha_1}e_t(j)^{\alpha_2}-\left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon}y_t\right],$$

where ζ_t is the Lagrange multiplier.

The first-order conditions are:

$$\lambda_t w_t h_t(j)=\xi_t\alpha_1 z_t h_t(j)^{\alpha_1}e_t(j)^{\alpha_2}, \qquad (8)$$

$$\lambda_t p_t^e e_t(j)=\xi_t\alpha_2 z_t h_t(j)^{\alpha_1}e_t(j)^{\alpha_2}, \qquad (9)$$

$$\phi\lambda_t\left(\frac{P_t(j)}{P_{t-1}(j)(1+\pi_{ss})}-1\right)\frac{P_t}{P_{t-1}(j)(1+\pi_{ss})}=\lambda_t(1-\varepsilon)\left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon}+\xi_t\varepsilon\left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon-1}+ \beta E_t\left[\lambda_{t+1}\phi\left(\frac{P_{t+1}(j)}{P_t(j)(1+\pi_{ss})}-1\right)\right]\frac{y_{t+1}}{y_t}\frac{P_{t+1}(j)}{P_t(j)^2(1+\pi_{ss})}. \quad (10)$$

The monetary authority

The monetary authority implements policy by adjusting the nominal rate of interest, i_t, in response to deviations of the final output, y_t, the inflation π_t, and an exogenous international interest rate, i_t^*, with respect to their respective steady-state values $\{y_{ss},\pi_{ss},i_{ss}^*\}$:

$$\ln(1+i_t)=\ln(1+i_t^*)+\rho_i\ln\left(\frac{1+i_{t-1}}{1+i_{ss}^*}\right)+\rho_\pi\ln\left(\frac{1+\pi_t}{1+\pi_{ss}}\right)+\rho_y\ln\left(\frac{y_t}{y_{ss}}\right)+\varepsilon_{i,t},$$

where $\varepsilon_{i,t}\underset{iid}{\sim}N(0,\sigma_i^2)$.

Notice that the specified Taylor rule for the Spanish economy would correspond to the time before the Euro Area was set up (until 1999:4). In practice, as Burriel, Fernández-Villaverde and Rubio-Ramírez (2009) point out, it is difficult to solve a DSGE model with a Taylor rule for the period 2000:1-2007:2, given the small weight of Spain in the Euro Area aggregate (10%). The reason is that such a rule produces a large indeterminacy region of equilibria and a smaller degree of freedom for parameter estimation.

One way to solve the problem is to assume that, for the entire sample, the domestic economy has an independent monetary policy that sets the nominal interest rate. This assumption, as Burriel, Fernández-Villaverde and Rubio-Ramírez (2009) mention, would be valid if the goal is not policy evaluation but estimating the model parameters and computing variance decomposition, as it is in our case.

Finally, the monetary authority finances the lump-sum transfers:

$$\frac{T_t}{P_t}=\frac{M_{t+1}}{P_t}-\frac{M_t}{P_t}=m_t-m_{t-1}\frac{1}{1+\pi_t}.$$

The equilibrium

We consider a symmetric equilibrium in which all intermediate commodity-producing firms make the same decisions:

$y_t(j) = y(t),\ h_t(j) = h_t,\ P_t(j) = P_t$ and $D_t(j)/P_t = D_t/P_t$.

Net exports in this model include oil purchases as well as purchases of bonds. In equilibrium we assume that net exports are zero at each period so that oil purchases are financed by varying the net holding bonds:

$[B_{t+1}/P_t(1+i_t)] - [B_t/P_t] = -p_t^e e_t$.

With these conditions, equilibrium is summarized in the following system, whose first equation is the global constraint of resources.

$$y_t = c_t + \frac{\phi}{2}\left[\frac{\pi_t - \pi_{ss}}{1+\pi_{ss}}\right]^2 y_t, \qquad (11)$$

$$\frac{(1+\eta)\psi}{c_t^{-\sigma} m_t^{\theta(1-\sigma)}} = \frac{\alpha_1}{\alpha_2}\frac{p_t^e e_t}{h_t}, \qquad (12)$$

$$\theta\frac{c_t}{m_t} = \frac{i_t}{1+i_t}, \qquad (13)$$

$$c_t^{-\sigma} m_t^{\theta(1-\sigma)} = \beta(1+i_t)E_t\left[c_{t+1}^{-\sigma} m_{t+1}^{\theta(1-\sigma)}\frac{1}{1+\pi_{t+1}}\right], \qquad (14)$$

$$y_t = z_t h_t^{\alpha_1} e_t^{\alpha_2}, \qquad (15)$$

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \varepsilon_{z,t}, \qquad (16)$$

$$\begin{aligned}\phi\left(\frac{\pi_t - \pi_{ss}}{1+\pi_{ss}}\right)\frac{1+\pi_t}{1+\pi_{ss}} &= (1-\varepsilon) + \varepsilon\frac{p_t^e}{\alpha_2 z_t h_t^{\alpha_1} e_t^{\alpha_2 - 1}} + \ldots \\ &\beta E_t\left[\frac{c_{t+1}^{-\sigma} m_{t+1}^{\theta(1-\sigma)}}{c_t^{-\sigma} m_t^{\theta(1-\sigma)}}\phi\left(\frac{\pi_{t+1}-\pi_{ss}}{1+\pi_{ss}}\right)\frac{z_{t+1}h_{t+1}^{\alpha_1}e_{t+1}^{\alpha_2}}{z_t h_t^{\alpha_1} e_t^{\alpha_2}}\frac{1+\pi_{t+1}}{1+\pi_{ss}}\right],\end{aligned} \qquad (17)$$

$$\ln(1+i_t) = \ln(1+i_t^*) + \rho_i \ln\left(\frac{1+i_{t-1}}{1+i_{ss}^*}\right) + \rho_\pi \ln\left(\frac{1+\pi_t}{1+\pi_{ss}}\right) + \rho_y \ln\left(\frac{y_t}{y_{ss}}\right) + \varepsilon_{i,t}, \qquad (18)$$

These eight equations determine the equilibrium values for: $\{c_t, y_t, \pi_t, m_t, e_t, h_t, i_t, z_t\}$, given $\{i_t^*, p_t^e, \varepsilon_t\}$.

A log-linear approximation around the steady state and the solution of the model through the Blanchard-Kahn (1980) procedure is showed in the appendix.

3. Estimation results

The first-order conditions (11)-(18) can be log-linearized around the steady state. Applying the method of Blanchard and Kahn (1980), we can obtain a solution of the form of a state-space econometric model. The empirical model takes the form:

$$\xi_{t+1} = F\xi_t + Bx_t + D\upsilon_{t+1}$$
$$d_t = A'x_t + H'\xi_t$$

where $\xi_{t+1} \equiv [\hat{i}_t, \hat{z}_{t+1}, \varepsilon_{i,t+1}]'$,

$$d_t \equiv [\hat{c}_t, \hat{\pi}_t]', x_t \equiv [\hat{p}_t^e, \hat{i}_t^*]', \upsilon_{t+1} \equiv [\varepsilon_{z,t+1}, \varepsilon_{i,t+1}]', D \equiv \begin{bmatrix} 0_{(1\times 2)} \\ I_{(2\times 2)} \end{bmatrix},$$

with $\hat{f}_t = \ln(f_t / f_{ss})$, for $f = i, z, c, \pi, p^e, i^*$.

When applied to this state-space system, the Kalman filter delivers forecasts of the three unobserved states, $[\hat{i}_t, \hat{z}_{t+1}, \varepsilon_{i,t+1}]'$, conditional on all observed values of $[\hat{c}_t, \hat{\pi}_t]'$ and $[\hat{p}_t^e, \hat{i}_t^*]'$. These forecasts can be recursively obtained as follows:

$$\hat{\xi}_{t+1|t} = F\hat{\xi}_{t|t-1} + K_t(d_t - A'x_t - H'\hat{\xi}_{t|t-1}) + Bx_t,$$
$$P_{t+1|t} = FP_{t|t-1}F' - K_t H' P_{t|t-1}F' + \tilde{Q}',$$
$$K_t = FP_{t|t-1}H(H'P_{t|t-1}H)^{-1},$$
$$\tilde{Q} = D\left(\text{cov}(\upsilon_{t+1})\right)D',$$
$$\text{cov}(\upsilon_{t+1}) = \begin{bmatrix} \sigma_z^2 & 0 \\ 0 & \sigma_{p^e}^2 \end{bmatrix},$$

where

$$\hat{\xi}_{t+1|t} \equiv \hat{E}(\xi_{t+1} \mid \Omega_t), \Omega_t \equiv (d_t', d_{t-1}', \ldots d_1', x_t', x_{t-1}', \ldots, x_1')',$$
$$P_{t+1|t} \equiv \hat{E}\left[(\xi_{t+1|} - \hat{\xi}_{t+1|t})(\xi_{t+1} - \hat{\xi}_{t+1|t})'\right],$$

given $\hat{\xi}_{1|0}$ and $P_{1|0}$.

Following Ireland (2004), the parameters of the empirical model can be estimated via maximum likelihood using methods described by Hamilton (1994, Ch. 13), given the time series $\{p_t^e, i_t^*\}$ as exogenous variables and using Spanish quarterly time series of consumption and inflation $\{c_t, \pi_t\}$ as observed variables. [2] The likelihood function for $\{d_t\}_{t=1}^{T}$ is:

$$f_{d_t|x_t,\Omega_{t-1}} = (2\pi)^{-1} | H'P_{t|t-1}H |^{-1/2} \exp\left[-\frac{1}{2}(d_t - A'x_t - H'\hat{\xi}_{t|t-1})'(H'P_{t|t-1}H)^{-1}(d_t - A'x_t - H'\hat{\xi}_{t|t-1}) \right],$$

for $t = 1, 2, ..., T$.

Thus, the sample log likelihood is

$$\sum_{t=1}^{T} \log f_{d_t|x_t,\Omega_{t-1}}. \tag{19}$$

The expression (19) can then be maximized numerically with respect to the structural parameters of the model.

Parameters θ and ψ are calibrated to be consistent with the ratio of real money holdings to the GDP in the data (0.35) and assuming that the fraction of hours worked in the steady state is equal to the average fraction of the data (0.31), respectively. Thus, the estimation of the rest of the model parameters is conditional on those calibrated values.

We provide three different sets of estimations depending on the sample considered, one taking the whole sample (1971:1-2007:2) and two more estimations splitting up the sample in 1988:2, in order to check the hypothesis of the different effects of oil shocks from the mid-1980's. Table 1 gives the estimated parameter values.

From this table, we can extract important differences in some parameters that will drive the model simulation results. As a matter of fact, many of those differences correspond to the explanations suggested by the literature that oil shocks have had less macroeconomic impact since the OPEC collapse in 1986 [see Herrera and Pesavento (2009) and Blanchard and Gali (2008), among others]. Those explanations are supported by our parameter estimations by suggesting a more flexible labor market, changes in monetary policy, a lower oil share in the economy and smaller oil shocks.

[2] Consumption corresponds to private consumption from Spanish National Accounts and inflation is the annual growth rate of CPI. The real oil price is constructed from the ratio between nominal oil prices and the GDP deflator and normalized to unity. The annual international interest rate is assumed to be constant and equal to 4%. The data sample is 1971:1-2007:2.

Parameter η changes from 0.0016 in the period 1971:1-1988:2 to 0.0010 from mid-1988, reporting a reduction in labor market rigidities. Regarding monetary policy, we find that the central bank is more committed to a stronger control of inflation, as the parameter ρ_π increases significantly from 0.21 to 0.33. The importance of oil in production has declined over time, thus α_2 has been reduced from 0.15 to 0.09, contributing to explaining the lower macroeconomic effects of an oil shock. Finally, oil shocks from the mid-1980's are smaller, as can be seen in the reduction of both the unconditional mean and the standard deviation of real oil prices.

In Table 1, the correlation between the observed output in data and the estimated output in the model is included as a measure of how well our model fit the data. As can be observed, the goodness of fit is very high.

4.- Simulation results.

Given the previously estimated parameter values and the symmetric equilibrium defined in Section 2, this section analyzes the contributions of the several shocks considered in the model to output, inflation, hours worked and real money holdings fluctuations. For that purpose, we simulate the model to obtain the variance decompositions of these variables and the impulse responses of productivity, monetary and oil price shocks. In particular, we will carry out the simulation with the three different sets of estimated parameters.

4.1 Variance Decomposition

Tables 2-5 provide statistics for the role of the different shocks as a source of fluctuations, including their percent contribution to the volatility of each variable.

With regard to the fluctuations in output, as we can see in Table 2, monetary policy explains a large part of the variance of the output (40%) in the first part of the sample(1971:1-1988:2), with this figure diminishing over time as the effect of the policy disappears. However, this does not happen in the second part of the sample (1988:3-2007:2), where the importance of the monetary policy is greatly reduced, 4.7% in the first period and close to zero in the long term. We can find the explanation in the different role played by the monetary policy in both periods. As such, there is a certain consensus on the stabilizing role of monetary policy in the 1970's with respect to the recent period in which monetary policy is clearly set to control inflation and the monetary authority enjoys greater credibility, which would imply a more active role for the monetary policy in the first subsample, and with it, a greater contribution to the output fluctuations. This argument is supported by our estimation of the weights of the target inflation and target output in the Taylor rule that the monetary authority follows. This is how we find that the parameter ρ_π is greater in the second part of the sample while ρ_y is considerably reduced in this second part, when monetary policy plays a less active role in the output fluctuations.

Real oil prices also explain a large percentage of the variance of the output in the first part of the sample, while in the second part, its weight is reduced to nearly a third of this percentage. We must remember that the second subsample is characterized by a lower oil share in the output (α_2 is smaller) and by a lower degree of real wage rigidities, which softens the effects of the oil price shocks on output and with this contributes less to explaining their fluctuations.

Finally, technological shock is especially important in the second subsample when it comes to explaining the variance of the output (80% in the first period), owing to the lesser weight of the monetary policy and the smaller effect of oil price shocks. Moreover, as Table 1 shows, the estimated parameters of the production functions α_1 and α_2 are smaller in the second part of the sample. As a consequence of this, technological shocks are crucial for explaining the variance of the output.

Inflation (see Table 3) is an essentially monetary phenomenon, such that monetary policy explains almost all the variance of inflation, having a weight of over 95% in the first part and close to 90% in the second part, in which technological shocks take on a more important role.

Table 4 represents the weight of the different shocks in the fluctuations of hours worked. In the first subsample, their variance is explained mainly by the oil price shocks, while in the second part, it is the technological shocks that explain almost 90% of these fluctuations. Monetary policy plays no role in either case. Keep in mind that the first part of the sample is characterized by a greater degree of real wage rigidities (larger estimated value of η), which contributes to a higher adjustment in hours worked when there are shocks in oil prices.

Finally, Table 5 presents the decomposition of the variance of real money holdings. As in the case of inflation, monetary policy plays a fundamental role in explaining their fluctuations, with a weight of 93% in the first subsample and over 50% in the second. In both cases, its effect diminishes over time as the effects of the monetary policy disappear. Also as in the previous cases, oil prices are, in general, more important in the first part of the sample and technological shocks are more important in the second.

4.2 Impulse Response Analysis

Figures 1-3 show the impulse response functions for the main variables to a productivity shock, a monetary shock and an oil price shock, respectively. Estimations are reported for three different sample periods: the total sample 1971:1-2007:2 and the subsamples 1971:1-1988:2 and 1988:3-2007:2. The first subsample includes the two great oil crises of the 1970's, which were characterized by important oil price increases and the significant drop in oil prices at the beginning of 1986. The second corresponds to the so-called "Great Moderation." The size of each shock is normalized to one standard deviation.

Figure 1 shows how a positive technological shock produces an increase in output and also reduces inflation, contributing to an increase in real money holdings. Given that the international price of oil remains constant, firms increase the amount of energy used and individuals reduce hours worked. Furthermore, we see that the response of all these variables is greater in the second part of the sample, which indicates that technological shocks are more important in this period.

When there is a positive shock in the domestic interest rate (see Figure 2), which is equivalent to a negative monetary shock, there is a drop in output and inflation. The global effect on real money holdings is also negative. In this case, individuals reduce the number of hours worked and firms reduce the use of oil. Furthermore, Figure 2 shows how the effect of a monetary policy is instantaneous, quickly returning to the steady state. In addition, the effect on the variables is greater in the first part of the sample, highlighting the fact that monetary policy had a greater effect in the 1970’s and part of the 1980’s than it has had in recent years.

Finally, Figure 3 shows how a positive shock in oil prices reduces output and causes higher inflation, which reduces real money holdings. In this case, firms reduce the amount of oil they use in production and individuals increase the number of hours worked. As we can observe in Figure 3, the response of the main variables in the second part of the sample is considerably more muted, thus suggesting a weaker impact of oil price shocks on the economy.

5. Conclusions

In this paper, we analyze the nature of the apparent changes in the macroeconomic effects of oil shocks, as well as some of their possible causes. The paper is particularly appealing to study the effects of high energy prices, which would be associated to climate change policies, and to the feedback effects of those policies on the economy. We depart from the previous literature on this topic by simulating a theoretical model whose parameters are estimated using Kalman Filter techniques.

We use a new Keynesian, stochastic, dynamic model of a small open monetary economy that imports oil and apply it to the Spanish economy. We consider three different sets of estimated parameters depending on the sample considered: the total sample 1971:1-2007:2 and the subsamples 1971:1-1988:2 and 1988:3-2007:2. The first subsample includes the two great oil crises of the 1970’s, and the significant drop in oil prices at the beginning of 1986. The second part of the sample corresponds to the so-called “Great Moderation.”

The main result is that the effects of oil price shocks have changed over time. We find the effects on output, inflation, hours worked and real money holdings are higher during the sample that includes the first two oil crises.

Furthermore, we find that, in general, monetary policy is more important in the first part of the sample when it comes to explaining fluctuations in output, inflation and real money holdings. This corresponds to the more stabilizing role that monetary policy had in the 1970's compared to recent years, in which monetary policy is clearly designed to control inflation.

Finally, productivity shocks are more important in the second subsample when explaining output, hours worked and real money holding fluctuations, due to the lower weight of monetary policy and the lesser effect of oil price shocks.

For future research, we would like to specify a more detailed foreign sector, which would allow for the existence of domestic and foreign consumer goods.

References

Backus, D. and M. Crucini (2000). "Oil Prices and the Terms of Trade." *Journal of International Economics* 50(1): 185–213

Bernanke, B., M. Gertler and M.Watson (1997). "Systematic Monetary Policy and the Effects of Oil Shocks." *Brookings Papers on Economic Activity* 1997-1: 91-157.

Blanchard, O and J. Gali (2008). "The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s so Different from the 1970s?." In J. Galí and M. Gertler (eds.). *International Dimensions of Monetary Policy*. University of Chicago Press (Chicago, IL).

Blanchard, O. and C. M. Kahn (1980). "The Solution of Linear Difference Models under Rational Expectations." *Econometrica* 48: 1305–1311.

Bohi, D. R (1989). *Energy Price Shocks and Macroeconomics Performance*. Washington D.C. Resources for the Future.

Bohi, D. R. (1991). "On the Macroeconomic Effects of Energy Price Shocks." *Resources and Energy* 13(2): 145-162.

Burriel, P., Jesús Fernández-Villaverde, and Juan F. Rubio-Ramírez (2009), "MEDEA: a DSGE Model for the Spanish Economy", mimeo. http://www.bde.es/doctrab/confere/confe_20/MEDEA_a_GDSE_model.pdf

Chari, V.V., P. J. Kehoe and E.R. McGrattan (2009). "The New Keynesian Models: Not Yet Useful for Policy Analysis." *American Economic Journal: Macroeconomics* 1: 242-266.

De Miguel C., B. Manzano and J.M. Martin-Moreno (2003). "Oil Price Shocks and Aggregate Fluctuations." *The Energy Journal* 24(2): 47-61.

De Miguel, C., B. Manzano and J. M. Martín-Moreno (2006): "Oil Shocks and the Business Cycle in Europe." In C. de Miguel, X. Labandeira and B. Manzano (eds.). *Economic Modelling of Climate Change and Energy Policies*. Edward Elgar, Cheltenham (UK).

Finn, M. G. (2000). "Perfect Competition and the Effects of Energy Price Increases on Economic Activity." *Journal of Money Credit and Banking* 32(3): 400-416.

Hamilton, J.D. (1983). "Oil and the Macroeconomy since World War II." *Journal of Political Economy* 91(2): 228-248

Hamilton, J.D. (1994). *Time Series Analysis*. Princeton, NJ: Princeton University Press.

Herrera, A.M. and E. Pesavento (2009):"Oil Price Shocks, Systematic Monetary Policy, and the Great Moderation." *Macroeconomic Dynamics* 13: 107-137.

Huang B.N. (2008). "Factors Affecting an Economy's Tolerance and Delay of Response to the Impact of a Positive Oil Price Shock." The Energy Journal 29(4): 1-34.

Ireland, P. N. (2004). "A method for taking models to the data", *Journal of Economic Dynamics and Control* 28(6):1205-1226.

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

Rotemberg, J.J. (1982). "Sticky Prices in the United States." *Journal of Political Economy* 90:1187–1211.

Rotemberg, J.J. and M. Woodford (1996). "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity." *Journal of Money, Credit and Banking* 28(4): 549-577.

Appendix. Log-linear approximation and estimation method

- *Deterministic Steady State*

The deterministic steady state is a trajectory along which:

i) $z_t = 1,\ i_t = i_t^* = i^*,\ p_t^e = \overline{p}^e, \forall t$, that is, $\varepsilon_t = \varepsilon_{i,t} = \varepsilon_{p^e,t} = 0,\ \forall t$,

ii) $y_t = y,\ c_t = c,\ m_t = m,\ e_t = e,\ h_t = h,\ \pi_t = \pi,\ \forall t$.

Given $\{ i^*, \overline{p}^e \}$ and solving equations (11)-(15) and (17) for $\{ y, c, m, \pi, e, h \}$, the following is obtained:

$$h = \left(\frac{A_2^{\frac{1+\alpha_2(\sigma-\theta(1-\sigma))}{1-\alpha_2}}}{A_1} \right)^{\frac{1}{1-\frac{\alpha_1(\sigma-\theta(1-\sigma)+1}{1-\alpha_2}}},$$

$$e = A_2^{\frac{1}{1-\alpha_2}} h^{\frac{\alpha_1}{1-\alpha_2}},$$
$$c = e / A_2,$$
$$y = c,$$
$$m = \theta\left(\frac{1+i^*}{i^*}\right)c,$$
$$\pi = \beta(1+i^*) - 1,$$

where

$$A_1 = (1+\eta)\psi\left(\frac{1+i^*}{i^*}\right)^{\theta(1-\sigma)} \frac{\alpha_2}{\alpha_1 \overline{p}^e},$$
$$A_2 = \frac{\varepsilon - 1}{\varepsilon}\frac{\alpha_2}{\overline{p}^e}.$$

- *Log-linear Approximation*

Let $\hat{b}_t = \ln(b_t / b)$, for $b = c,\ y,\ e,\ h,\ m,\ z,\ 1+i,\ 1+i^*,\ 1+\pi$. The first-order Taylor approximation to (11)-(18) yields

$(a.1)$ $\hat{c}_t = \hat{y}_t$,

$(a.2)$ $\hat{h}_t + \sigma\hat{c}_t - \theta(1-\sigma)\hat{m}_t - \hat{p}_t^e - \hat{E}_t = 0$,

$(a.3)$ $i^*(\hat{c}_t - \hat{m}_t) - \hat{i}_t = 0$,

$(a.4)$ $\sigma(\hat{c}_t - E_t\hat{c}_{t+1}) - \theta(1-\sigma)(\hat{m}_t - E_t\hat{m}_{t+1}) + \hat{i}_t - E_t\hat{\pi}_{t+1} = 0$,

$(a.5)$ $\hat{y}_t = \hat{z}_t + \alpha_1\hat{h}_t + \alpha_2\hat{e}_t$,

$(a.6)$ $\hat{z}_t = \rho_z\hat{z}_{t-1} + \varepsilon_{z,t}$,

$(a.7)$ $-\phi\hat{\pi}_t + \beta\phi E_t\hat{\pi}_{t+1} + (\varepsilon-1)\hat{p}_t^e - (\varepsilon-1)\hat{y}_t + (\varepsilon-1)\hat{e}_t = 0$,

$(a.8)$ $\hat{i}_t = \hat{i}_t^* + \rho_i\hat{i}_{t-1} + \rho_\pi\hat{\pi}_t + \rho_y\hat{y}_t + \varepsilon_{i,t}$.

From (a.1)-(a.3) and (a.5), we obtain

$$(a.9) \qquad \hat{h}_t\left(1+\frac{\alpha_1}{\alpha_2}\right)+\left[\sigma-\theta(1-\sigma)-\frac{1}{\alpha_2}\right]\hat{c}_t-\frac{\theta(1-\sigma)}{i^*}\hat{i}_t-\hat{p}_t^e+\frac{1}{\alpha_2}\hat{z}_t=0.$$

From (a.3) and (a.4)

$$(a.10) \qquad \left[\sigma-\theta(1-\sigma)\right](\hat{c}_t-E_t\hat{c}_{t+1})+\left[\frac{\theta(1-\sigma)}{i^*}+1\right]\hat{i}_t-\frac{\theta(1-\sigma)}{i^*}E_t\hat{i}_{t+1}-E_t\hat{\pi}_{t+1}=0.$$

From (a.1), (a.3) and (a.7)

$$(a.11) \qquad -\phi\hat{\pi}_t+\beta\phi E_t\hat{\pi}_{t+1}+(\varepsilon-1)\,\hat{p}_t^e+(\varepsilon-1)\left(\frac{1-\alpha_2}{\alpha_2}\right)\hat{c}_t-\frac{\varepsilon-1}{\alpha_2}\hat{z}_t-\frac{(\varepsilon-1)\alpha_1}{\alpha_2}\hat{h}_t=0.$$

The equations (a.6), (a.8), (a.9), (a.10) and (a.11) show the model's dynamic on the variables $\{\hat{c}_t, \hat{h}_t, \hat{\pi}_t, \hat{i}_t, \hat{z}_t\}$, given the paths for the exogenous variables $\{\hat{p}_t^e, \hat{i}_t^*\}$.

- *Solving the Model*

From (a.8) and (a.9):

$$(a.12) \qquad f_t^0=-A^{-1}\tilde{B}s_t^0-A^{-1}\tilde{D}x_t-A^{-1}Fa_t$$

where

$$f_t^0=\begin{bmatrix}\hat{h}_t\\ \hat{i}_t\end{bmatrix};\quad s_t^0=\begin{bmatrix}\hat{c}_t\\ \hat{\pi}_t\\ \hat{i}_{t-1}\end{bmatrix};\quad x_t=\begin{bmatrix}\hat{p}_t^e\\ \hat{i}_t^*\end{bmatrix};\quad a_t=\begin{bmatrix}\hat{z}_t\\ \hat{\varepsilon}_{i,t}\end{bmatrix}$$

$$\tilde{A}=\begin{bmatrix}1+\alpha_1/\alpha_2 & -\dfrac{\theta(1-\sigma)}{c}\\ 0 & 1\end{bmatrix};\quad \tilde{B}=\begin{bmatrix}\left[\sigma-\theta(1-\sigma)-\dfrac{1}{\alpha_2}\right] & 0 & 0\\ -\rho_y & -\rho_\pi & -\rho_i\end{bmatrix};$$

$$\tilde{D}=\begin{bmatrix}-1 & 0\\ 0 & -1\end{bmatrix};\quad \tilde{F}=\begin{bmatrix}1/\alpha_2 & 0\\ 0 & -1\end{bmatrix}.$$

Note that

$$(a.13) \qquad E_tf_{t+1}^0=-\tilde{A}^{-1}\tilde{B}E_ts_{t+1}^0-A^{-1}\tilde{D}\Phi_xx_t-A^{-1}\tilde{F}\Phi_aa_t,$$

where

$$\Phi_x=\begin{bmatrix}\varphi_{p^e} & 0\\ 0 & \rho_{i^*}\end{bmatrix};\ \Phi_a=\begin{bmatrix}\rho_z & 0\\ 0 & 0\end{bmatrix};$$

$$\ln(1+i_t^*)=(1-\rho_{i^*})\ln(1+i^*)+\rho_{i^*}\ln(1+i_{t-1}^*)+\varepsilon_{i^*,t},\ |\rho_{i^*}|<1,\ \varepsilon_{i^*,t}\underset{iid}{\sim}N(0,\sigma_{i^*}^2).$$

From (a.10)-(a.13):

$$(a.14) \qquad E_ts_{t+1}^0=\Gamma_1s_t^0+\Gamma_2x_t+\Gamma_3a_t,$$

where

$$\Gamma_1 = -(\tilde{H} - G\tilde{A}^{-1}\tilde{B})^{-1}(L - J\tilde{A}^{-1}\tilde{B}),$$
$$\Gamma_2 = -(\tilde{H} - G\tilde{A}^{-1}\tilde{B})^{-1}(M - GA^{-1}\tilde{D}\Phi_x - JA^{-1}\tilde{D}),$$
$$\Gamma_3 = -(\tilde{H} - G\tilde{A}^{-1}\tilde{B})^{-1}(N - GA^{-1}\tilde{D}\Phi_a - JA^{-1}\tilde{F}),$$

$$G = \begin{bmatrix} 0 & -\frac{\theta(1-\sigma)}{i^*} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}; \tilde{H} = \begin{bmatrix} -\left[\sigma - \theta(1-\sigma)\right] & -1 & 1+\frac{\theta(1-\sigma)}{i^*} \\ 0 & \beta\phi & 0 \\ 0 & 0 & 1 \end{bmatrix};$$

$$J = \begin{bmatrix} 0 & 0 \\ -(\varepsilon-1)\alpha_1/\alpha_2 & 0 \\ 0 & -1 \end{bmatrix}; L = \begin{bmatrix} \left[\sigma - \theta(1-\sigma)\right] & 0 & 0 \\ (\varepsilon-1)(1-\alpha_2)/\alpha_2 & -\phi & 0 \\ 0 & 0 & 0 \end{bmatrix};$$

$$M = \begin{bmatrix} 0 & 0 \\ \varepsilon-1 & 0 \\ 0 & 0 \end{bmatrix}; N = \begin{bmatrix} 0 & 0 \\ -\frac{\varepsilon-1}{\alpha_2} & 0 \\ 0 & 0 \end{bmatrix}.$$

The matrix Γ_1 has three eigenvalues. Since there are two control variables ($\hat{c}_t, \hat{\pi}_t$) in s_t^0, we would need two relationships between control and state variables to be able to solve the model. Thus, one of the eigenvalues must be stable and the other two unstable. Without loss of generality, let us assume that $|\mu_1| < 1$, and $|\mu_2| > 1, |\mu_3| > 1$. From (a.14):

$$(a.15) \qquad R^{-1}E_t s_{t+1}^0 = \Lambda R^{-1} s_t^0 + Qx_t + Ua_t,$$

where

$$\Gamma_1 = R\Lambda R^{-1}, Q = R^{-1}\Gamma_2, U = R^{-1}\Gamma_3,$$

$$\Lambda = \begin{bmatrix} \mu_1 & 0 & 0 \\ 0 & \mu_2 & 0 \\ 0 & 0 & \mu_3 \end{bmatrix}, \quad R^{-1} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix},$$

Λ being a diagonal matrix having the eigenvalues of Γ_1 as elements, and R^{-1} the matrix having the left eigenvectors of Γ_1 as rows.

Solving forwards the unstable equations of system (a.15), we obtain the stability condition or the **observation equation**:

$$(a.16) \qquad \underbrace{\begin{bmatrix} \hat{c}_t \\ \hat{\pi}_t \end{bmatrix}}_{d_t} = \underbrace{[\Phi_1 \;\; \Phi_3]}_{H'} \underbrace{\begin{bmatrix} \hat{i}_{t-1} \\ \hat{z}_t \\ \varepsilon_{i,t} \end{bmatrix}}_{\xi_t} + \underbrace{\Phi_2}_{A'} x_t,$$

where

$$\Phi_1 = -\begin{bmatrix} r_{21} & r_{22} \\ r_{31} & r_{32} \end{bmatrix}^{-1} \begin{bmatrix} r_{23} \\ r_{33} \end{bmatrix}; \Phi_2 = \begin{bmatrix} r_{21} & r_{22} \\ r_{31} & r_{32} \end{bmatrix}^{-1} \begin{bmatrix} \dfrac{Q_{21}}{\varphi_{p^e} - \mu_2} & \dfrac{Q_{22}}{\rho_{i^*} - \mu_2} \\ \dfrac{Q_{31}}{\varphi_{p^e} - \mu_3} & \dfrac{Q_{32}}{\rho_{i^*} - \mu_3} \end{bmatrix};$$

$$\Phi_3 = \begin{bmatrix} r_{21} & r_{22} \\ r_{31} & r_{32} \end{bmatrix}^{-1} \begin{bmatrix} \dfrac{U_{21}}{\rho_z - \mu_2} & -\dfrac{U_{22}}{\mu_2} \\ \dfrac{U_{31}}{\rho_z - \mu_3} & -\dfrac{U_{32}}{\mu_3} \end{bmatrix}.$$

Plugging (a.16) into the equation for the stable eigenvalue of (a.15), we get the **state equation**:

$$(a.17) \qquad \underbrace{\begin{bmatrix} \hat{i}_t \\ a_{t+1} \end{bmatrix}}_{\xi_{t+1}} = \underbrace{\begin{bmatrix} \mu_1 & \Psi_2 \\ 0_{(2\times1)} & \Phi_a \end{bmatrix}}_{F} \underbrace{\begin{bmatrix} \hat{i}_t \\ a_{t+1} \end{bmatrix}}_{\xi_t} + \underbrace{\begin{bmatrix} \Psi_1 \\ 0_{(2\times2)} \end{bmatrix}}_{B} x_t + \underbrace{\begin{bmatrix} 0_{(1\times2)} \\ I_{(2\times2)} \end{bmatrix}}_{D} \underbrace{\begin{bmatrix} \varepsilon_{z,t+1} \\ \varepsilon_{i,t+1} \end{bmatrix}}_{\upsilon_{t+1}},$$

where

$$\Psi_1 = \left[\frac{\left(\frac{r_{11}}{r_{13}}\Phi_{2,11} + \frac{r_{12}}{r_{13}}\Phi_{2,21}\right)\left(\mu_1 - \varphi_{p^e}\right) + \frac{Q_{11}}{r_{13}}}{1 + \frac{r_{11}}{r_{13}}\Phi_{1,1} + \frac{r_{12}}{r_{13}}\Phi_{1,2}}, \quad \frac{\left(\frac{r_{11}}{r_{13}}\Phi_{2,12} + \frac{r_{12}}{r_{13}}\Phi_{2,22}\right)\left(\mu_1 - \rho_{i^*}\right) + \frac{Q_{12}}{r_{13}}}{1 + \frac{r_{11}}{r_{13}}\Phi_{1,1} + \frac{r_{12}}{r_{13}}\Phi_{1,2}} \right],$$

$$\Psi_2 = \left[\frac{\left(\frac{r_{11}}{r_{13}}\Phi_{3,11} + \frac{r_{12}}{r_{13}}\Phi_{3,21}\right)\left(\mu_1 - \rho_z\right) + \frac{U_{11}}{r_{13}}}{1 + \frac{r_{11}}{r_{13}}\Phi_{1,1} + \frac{r_{12}}{r_{13}}\Phi_{1,2}}, \quad \frac{\left(\frac{r_{11}}{r_{13}}\Phi_{3,12} + \frac{r_{12}}{r_{13}}\Phi_{3,22}\right)\left(\mu_1\right) + \frac{U_{12}}{r_{13}}}{1 + \frac{r_{11}}{r_{13}}\Phi_{1,1} + \frac{r_{12}}{r_{13}}\Phi_{1,2}} \right].$$

Table 1. Parameters.

	1971:1-2007:2	1971:1-1988:2	1988:3-2007:2
PREFERENCES			
β	0.9918 (0.0056)	0.9898 (0.0052)	0.9893 (0.0016)
θ (calibrated parameter)	0.0132	0.0132	0.0132
σ	2.9120 (0.0035)	4.2667 (0.0125)	3.0901 (0.0086)
ψ (calibrated parameter)	0.0039	0.0039	0.0039
TECHNOLOGY			
ε	1.3481 (0.0195)	1.3666 (0.0144)	1.9873 (0.0594)
α_1	0.6674 (0.0689)	0.7089 (0.0735)	0.6782 (0.0034)
α_2	0.1026 (0.0412)	0.1506 (0.0409)	0.0932 (0.0294)
RIGIDITIES			
η	0.0016 (0.0000)	0.0016 (0.0000)	0.0010 (0.0000)
ϕ	0.2182 (0.0103)	0.3270 (0.0129)	0.5120 (0.0655)
TECHNOLOGICAL SHOCK			
ρ_z	0.9684 (0.0007)	0.9723 (0.0003)	0.9588 (0.0002)
σ_z	0.0255 (0.0021)	0.0215 (0.0027)	0.0307 (0.0034)
OIL PRICES (estimated AR(1) process)			
$\overline{p^e}$	1	1.3711	0.6954
φ_{p^e}	0.9434 (0.0269)	0.8956 (0.0491)	0.9231 (0.0487)
σ_{p^e}	0.1664 (0.0033)	0.1916 (0.0066)	0.1398 (0.0032)
TAYLOR RULE			
ρ_i	0.9775 (0.0020)	0.9889 (0.0010)	0.9862 (0.0010)
ρ_Π	0.3292 (0.0153)	0.2100 (0.0073)	0.3298 (0.0054)
ρ_y	0.0220 (0.0006)	0.0121 (0.0003)	0.0254 (0.0003)
σ_i	0.0191 (0.0016)	0.0173 (0.0022)	0.0095 (0.0012)
Log Likelihood	445.470	192.567	332.235
Correlation(y_t, $\hat{y}_{t\|t-1}$)	0.8938	0.9105	0.9965

Standard deviation of estimated parameters is in parentheses. The series of oil prices has been normalized so that its average is 1. **Correlation**(y_t, $\hat{y}_{t|t-1}$) represents a measure of how well our model fits the data.

Table 2. The contribution (%) of productivity shocks, monetary shocks and oil price shocks to output (y) fluctuations.

	1971:1-2007:2			1971:1-1988:2			1988:3-2007:2		
Periods	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock
1	53.80	22.78	23.42	22.26	40.07	37.67	80.88	4.73	14.39
4	65.14	7.68	27.18	31.45	16.61	51.94	84.08	1.38	14.54
8	68.94	4.49	26.57	35.67	10.15	54.19	85.17	0.80	14.03
12	71.08	3.44	25.48	38.36	7.97	53.67	85.83	0.62	13.55
20	73.79	2.64	23.57	42.17	6.31	51.52	86.70	0.48	12.81
40	76.79	2.14	21.06	47.10	5.29	47.61	87.61	0.41	11.98
Inf	78.05	2.01	19.94	49.70	4.99	45.31	87.89	0.40	11.71

Table 3. The contribution (%) of productivity shocks, monetary shocks and oil price shocks to inflation (π) fluctuations.

Periods	1971:1-2007:2 Productivity Shock	Monetary Shock	Oil Price Shock	1971:1-1988:2 Productivity Shock	Monetary Shock	Oil Price Shock	1988:3-2007:2 Productivity Shock	Monetary Shock	Oil Price Shock
1	1.35	97.60	1.04	0.55	97.24	2.21	9.28	88.45	2.26
4	1.53	97.37	1.10	0.59	97.21	2.20	10.02	87.63	2.35
8	1.62	97.27	1.11	0.60	97.19	2.20	10.33	87.30	2.38
12	1.68	97.19	1.12	0.61	97.19	2.20	10.53	87.08	2.39
20	1.77	97.09	1.13	0.62	97.18	2.20	10.79	86.81	2.40
40	1.87	96.99	1.14	0.63	97.16	2.20	11.00	86.59	2.40
Inf	1.91	96.95	1.14	0.64	97.16	2.20	11.05	86.54	2.40

Table 4. The contribution (%) of productivity shocks, monetary shocks and oil price shocks to hours worked (h) fluctuations.

	1971:1-2007:2			1971:1-1988:2			1988:3-2007:2		
Periods	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock
1	65.45	4.69	29.85	35.21	0.31	64.47	84.02	0.72	15.27
4	69.37	1.55	29.08	37.32	0.11	62.57	85.07	0.23	14.70
8	71.63	0.91	27.46	39.73	0.07	60.20	85.81	0.14	14.05
12	73.25	0.70	26.05	41.85	0.05	58.10	86.36	0.11	13.53
20	75.54	0.54	23.92	45.24	0.04	54.72	87.14	0.08	12.78
40	78.27	0.44	21.30	49.94	0.03	50.03	87.99	0.07	11.94
Inf	79.44	0.41	20.15	52.49	0.03	47.48	88.25	0.07	11.68

Table 5. The contribution (%) of productivity shocks, monetary shocks and oil price shocks to real money holdings (*m*) fluctuations.

	1971:1-2007:2			1971:1-1988:2			1988:3-2007:2		
Periods	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock	Productivity Shock	Monetary Shock	Oil Price Shock
1	7.07	87.78	5.16	1.46	93.42	5.11	38.18	52.71	9.10
4	23.79	59.59	16.62	6.16	72.87	20.97	65.89	18.89	15.23
8	34.07	44.00	21.92	10.22	58.04	31.75	72.79	11.21	15.99
12	39.43	37.02	23.55	12.74	50.98	36.29	75.42	8.73	15.85
20	45.17	30.85	23.97	15.92	44.72	39.36	77.81	6.90	15.29
40	50.46	26.64	22.90	19.59	40.64	39.77	79.66	5.90	14.44
Inf	52.43	25.46	22.11	21.43	39.49	39.07	80.13	5.72	14.14

Figure 1. Impulse response to a productivity shock

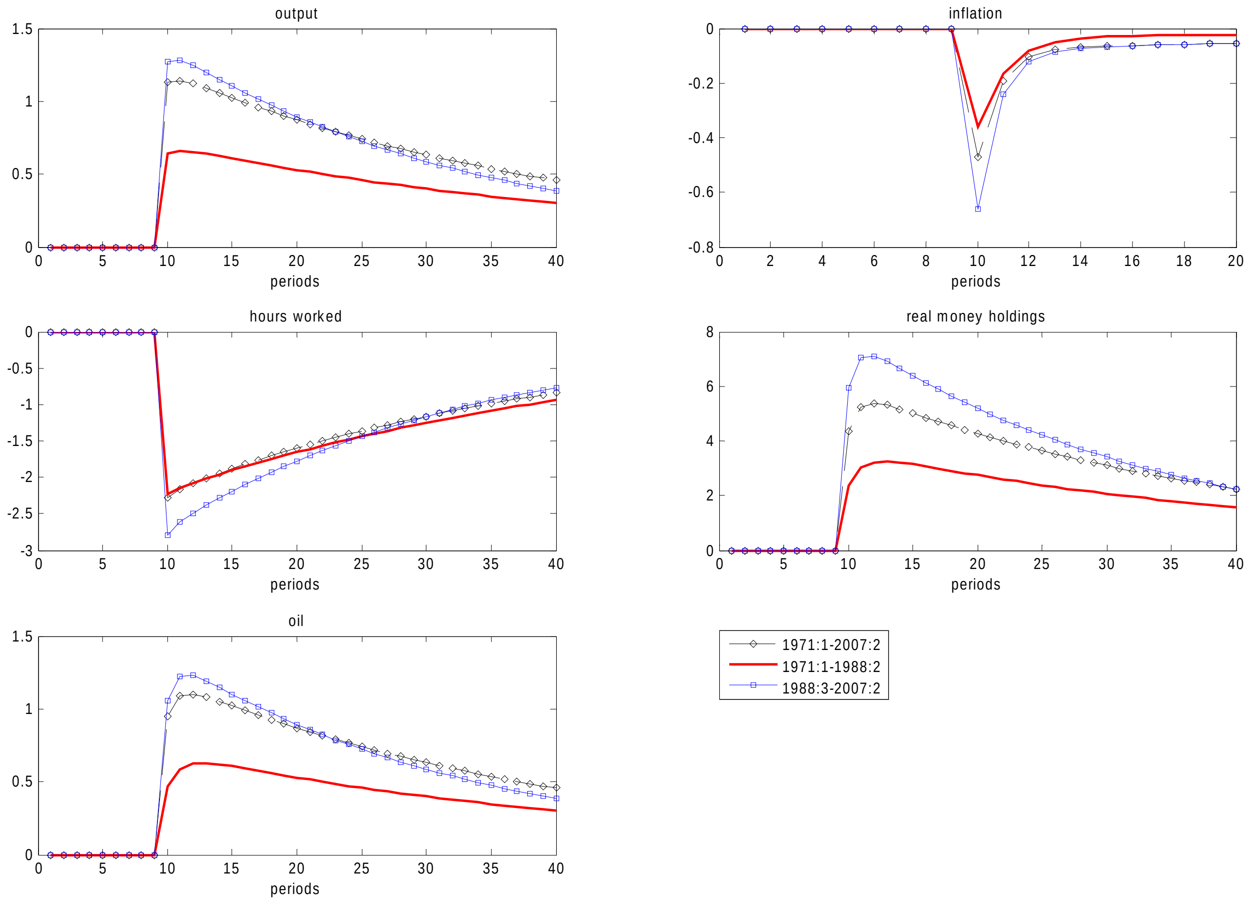

Figure 2. Impulse response to a monetary shock

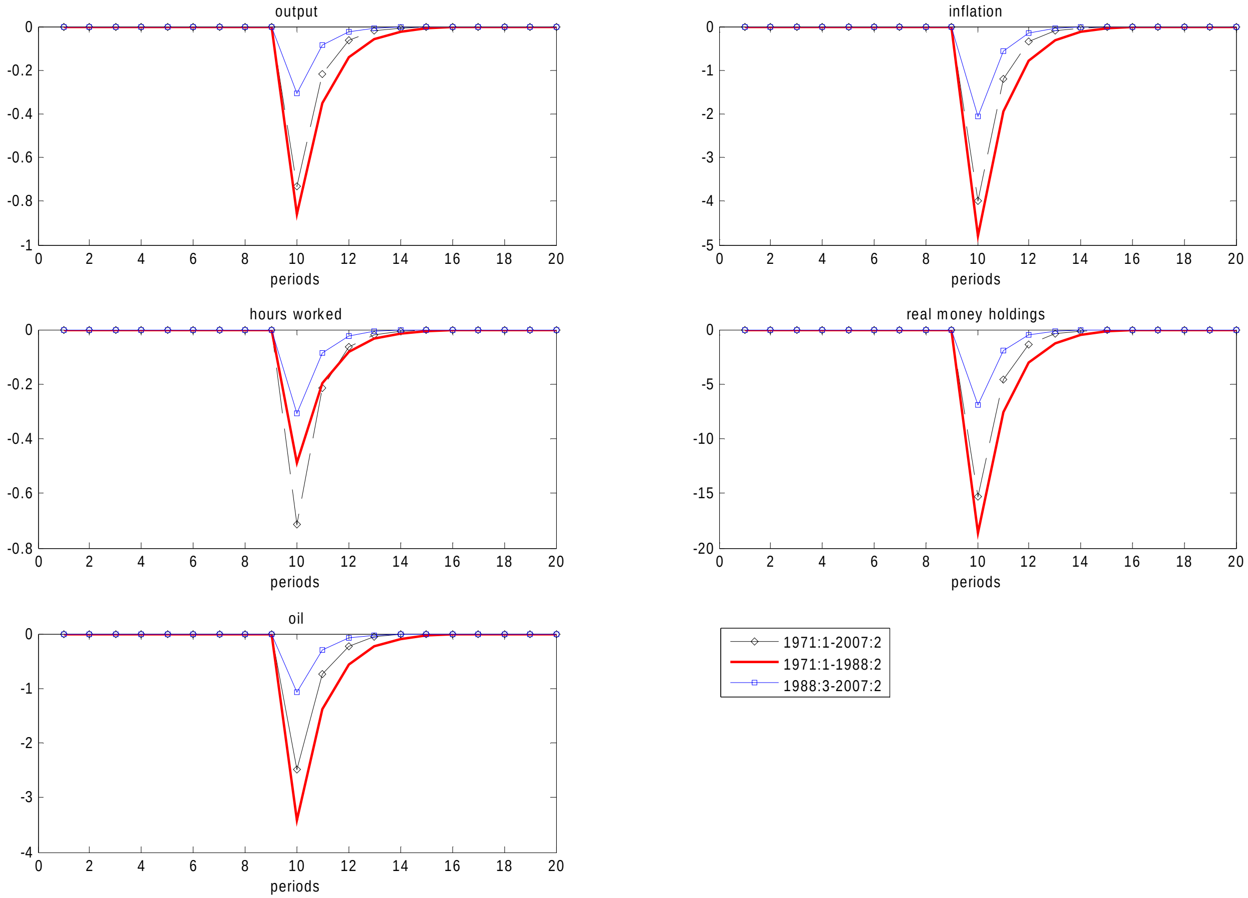

Figure 3. Impulse response to an oil price shock.