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On the Sources of Oil Price Fluctuations

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On the Sources of Oil Price Fluctuations

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Abstract

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Analyzing macroeconomic impacts of oil price changes requires first to investigate different sources of these changes and their distinct effects. Kilian (2009) analyzes the effects of an oil supply shock, an aggregate demand shock, and a precautionary oil demand shock. The paper's aim is to model macroeconomic consequences of these shocks within a new Keynesian DSGE framework. It models a small open economy and the rest of the world together to discover both accompanying effects of oil price changes and their international transmission mechanisms. Our results indicate that different sources of oil price fluctuations bring remarkably diverse outcomes for both economies.

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I. INTRODUCTION

The role of monetary policy and inflation dynamics in the wake of an oil price shock have motivated a large body of research, including Hamilton (1996), Bernanke, Gertler, and Watson (1997), Leduc and Sill (2004), and Bodenstein, Erceg, and Guerrieri (2008). However, less attention has been paid to the origins of oil price changes, for example, Kilian, Rebucci, and Spatafora (2007), Hamilton (2008) and Kilian (2008b). More prominently, Kilian (2009) argues that there are three main sources of oil price shocks that lead to oil price fluctuations: oil supply shocks; world aggregate demand shocks, and the shifts in the precautionary demand for oil due to uncertainties about future oil supply.

Our paper contributes to the literature by showing the impacts of oil price movements caused by various sources. We develop a sticky-price DSGE model through which we analyze the effects of various shocks studied in Kilian (2009), namely, the increase in aggregate demand, unexpected oil supply disruption and the precautionary oil demand on an (oil importing) small open economy (SOE) and on the rest of the world (ROW). In particular, we assume that the world economy is composed of a domestic SOE and a continuum of other small open economies. Effectively, an SOE has a negligible effect on the world economy. Hence, the ROW is regarded as a closed economy and oil demand and price are determined in the ROW. Oil supply is assumed to follow an exogenous process.[2]

We show that, although both productivity and fiscal policy shocks can be regarded as "demand" shocks for the oil market, leading to a rise in the world aggregate demand and a subsequent surge in the real price of oil, their impacts on inflation are different. In the case of a productivity increase, the marginal cost of the firms decline, which leads to lower CPI inflation. On the other hand, an increase in government spending directly creates additional demand for the consumption goods, while putting upward pressure on the marginal cost of the firms and the aggregate price level. We also compare the effects of expected and unexpected oil supply shocks. In the case of an expected future oil supply shortage, a precautionary oil demand raises the current real price of oil. Our results suggest that distinguishing between the causes of oil price shocks is very important, if not crucial, in both identifying the impact of oil price shocks on key macroeconomic variables and determining the appropriate policy responses to deal with them.

There are a few features of our model that are worth emphasizing. First, we incorporate oil demand in a relatively simple manner as in Blanchard and Gali (2008), while it is this simplicity that allows us to get analytical insights into both the causes and the international transmission mechanism of the oil price shocks. Contrary to their analysis, however, oil price is endogenously determined in our model. Since oil is included in the production function, oil

[2] Kilian (2009) argues that due to adjustment costs and uncertainty about the future oil demand, oil-producing countries do not revise their production level against short-term oil demand fluctuations. Backus and Crucini (2000) models oil supply partially endogenously, in a neoclassical setup.

demand and supply shocks in the ROW create oil price fluctuations. Given that oil price changes are not resilient to the global macroeconomic developments, it is more appropriate that oil prices are determined inside the model.

Second, we model the SOE and the ROW together, so that we are able to analyze the impacts of these shocks both in an SOE and a closed economy. In the SOE framework, ROW is traditionally modelled by a few exogenous processes, ignoring possible (and important) channels through which shocks affecting the ROW are transmitted to the SOE.[3] Although it is implicitly assumed in the existing literature that the effects of an oil shock can be analyzed by the introduction of an exogenous oil price process, this method is misleading as it does not consider the causes or effects of oil price changes, which eventually affects the SOE through real exchange rate and trade channels. Our results confirm the contribution of this detailed modelling exercise as each shock considered in the paper influences the real price of oil and the economies differently and has specific transmission channels.

Third, our model reveals that a precautionary oil demand shock is likely to cause sharp fluctuations in the price of oil. If there is an expectation of lower future oil supply, the current spot prices will adjust immediately, causing expectations-linked oil price volatility in the world oil market.

Recently, the rapid increases in the world oil prices have stimulated a renewed interest on the macroeconomic effects of oil price shocks. The fact that the oil price increases started in the early 2000s have led to very different outcomes than the 1970s in particular has received much attention. Nordhaus (2007) and Segal (2007) propose that the main reason for a smaller impact of oil shocks is the change in the transmission mechanism which helps to impede oil prices feed through to core inflation, and therefore enables a less aggressive monetary policy. Blanchard and Gali (2008) suggest that more flexible labor markets, more credible and stronger anti-inflationary stance of monetary policies and declining oil intensities in the major economies have helped to curb the effects of higher oil prices.

As Woodford (2007) argues, however, these explanations are not convincing enough as they ignore the endogenous responses of the real price of oil to the global economic conditions. In this line of thought, Elekdag and Laxton (2007) and Kilian (2008a, 2008b) argue that one of the reasons for the oil price increases of the 2000s is the increased world aggregate demand, possibly due to the world productivity increases, contrary to the oil price shocks mainly driven by supply side changes in the 1970s.[4] Relative to this literature, we take a step further by modelling different causes of oil price changes for domestic economy, as well as the world economy with a clear consideration of possible demand and supply side developments.

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[3] See, for example, Gali and Monacelli (2005) and Monacelli (2005).

[4] See also Barsky and Kilian (2004), Campolmi (2008), Elekdag and others (2008), and Unalmis, Unalmis, and Unsal (2008).

The remainder of the paper is organized as follows. In Section 2, the structure of the model is laid out. The oil market equilibrium and the equilibrium conditions are derived in Section 3. We discuss the findings in Section 4. The conclusions are outlined in Section 5.

II. THE SMALL OPEN ECONOMY MODEL

We develop an open economy sticky price DSGE model with a representative household, producers, a government and a monetary authority. The model shares its basic features with many new Keynesian SOE models, including the benchmark models of Gali and Monacelli (2005) and Clarida, Gali, and Gertler (2001), although several differences remain. In order to capture oil shocks, we follow Blanchard and Gali (2008) by introducing an oil input in the production function.

Oil market equilibrium is determined in the ROW. In order to highlight our interest on a SOE and its interlinkages with the foreign economy (ROW), variables without superscripts refer to the home economy, while variables with a star indicate the foreign economy variables. Small letters denote percentage deviations of the respective variables from their steady-state levels. We briefly sketch the model and present the log-linearized equations in Table 1, while the details of the model are provided in the Appendix.

Table 1. Model in Log-Linearized Form: Behavioral Equations for the SOE

$\pi_{H,t} = \beta E_t\left\{\pi_{H,t+1}\right\} + \lambda\widehat{mc}_t$	Phillips curve
$\widehat{mc}_t = \left[\frac{\eta\varphi}{1+(1-\eta)\varphi} + \frac{\Omega}{1-\alpha}\right] x_t$	Marginal cost
$y_t = E_t\left\{y_{t+1}\right\} - \frac{(1-G_y)}{\sigma}\left(r_t - E_t\left\{\pi_{t+1}\right\}\right)...$ $... - G_y E_t\left\{\Delta g_{t+1}\right\} - \psi E_t\left\{\Delta q_{t+1}\right\}$	IS curve
$\overline{y}_t = \frac{1}{\left[\Psi_3 + \frac{\Omega}{1-\alpha}\right]}\left(-\mu + \Psi_1 a_t + \Psi_4 b_t...\right.$ $\left.... - \left[\frac{\Psi_2}{1-G_y} - \frac{\Omega}{1-\alpha}\right]\left(y_t^* - G_y g_t^*\right) + \frac{\Omega}{1-\alpha}G_y g_t - \Psi_4 \widetilde{p}_{o,t}^*\right)$	Flexible price output
$x_t = y_t - \overline{y}_t$	Output gap
$q_t = \Omega(y_t - G_y g_t) - \Omega(y_t^* - G_y g_t^*)$	Real exchange rate
$r_t = \phi_\pi \pi_t + \phi_x x_t$	Monetary policy rule
$\pi_t = \pi_{H,t} + \frac{\alpha}{1-\alpha}\Delta q_t$	CPI inflation
$e_t = p_t - p_t^* + q_t$	Nominal exchange rate
$\widetilde{p}_{o,t} = \widetilde{p}_{o,t}^* + q_t.$	Real oil price

A. Households

A representative household is infinitely lived and seeks to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{1}$$

where $U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}$ is the period utility function, N_t denotes hours of work and C_t is a composite of domestically produced goods and imported foreign goods, defined by:

$$C_t = \left[(1-\alpha)^{\frac{1}{\gamma}} C_{H,t}^{(\gamma-1)/\gamma} + \alpha^{\frac{1}{\gamma}} C_{F,t}^{(\gamma-1)/\gamma} \right]^{\gamma/(\gamma-1)} \tag{2}$$

where $C_{H,t}$ and $C_{F,t}$ are CES indices of consumption of domestic and foreign goods, given by:

$$C_{H,t} = \left[\int_0^1 C_{H,t}(j)^{(\varepsilon-1)/\varepsilon} dj \right]^{\varepsilon/(\varepsilon-1)} ; C_{F,t} = \left[\int_0^1 (C_{i,t})^{(\gamma-1)/\gamma} di \right]^{\gamma/(\gamma-1)}$$

where $C_{i,t} = \left[\int_0^1 C_{i,t}(j)^{(\varepsilon-1)/\varepsilon} dj \right]^{\varepsilon/(\varepsilon-1)}$ is an index of the quantity of goods imported from country $i \in (0,1]$ and consumed by domestic households. $j \in (0,1]$ indicates the goods varieties and $\varepsilon > 1$ is the elasticity of substitution among goods produced within a country. $0 < \alpha < 1$ indicates the expenditure share of the imported goods in the consumption basket of households. We assume that the degree of substitutability between domestic and foreign goods ($\gamma > 0$) is the same as the degree of substitutability between goods produced in different foreign countries. The household's budget constraint in period t is:

$$P_t C_t + E\{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t \tag{3}$$

where $P_t = [(1-\alpha)P_{H,t}^{1-\gamma} + \alpha P_{F,t}^{1-\gamma}]^{1/(1-\gamma)}$ is the consumer price index (CPI) and the price indices for domestically produced and imported goods are:

$$P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{1-\varepsilon} dj \right]^{1/(1-\varepsilon)}; \quad P_{F,t} = \left[\int_0^1 P_{i,t}^{1-\gamma} di \right]^{1/(1-\gamma)}$$

where $P_{i,t} = \left[\int_0^1 P_{i,t}(j)^{1-\varepsilon} dj \right]^{1/(1-\varepsilon)}$ is a price index for goods imported from country i, $Q_{t,t+1}$ is the stochastic discount factor for the one period ahead nominal payoff, D_{t+1} is the nominal pay-off in period $t+1$ of the portfolio held at the end of period t including the shares in firms, W_t is the nominal wage and T_t is lump-sum transfers and/or taxes. Considering the

Ricardian nature of our model, it is analytically convenient to assume that T_t is set in each period so that the government budget is balanced. We further assume perfect international risk sharing, which implies that the household has full access to international financial markets. The representative household, therefore, maximizes the utility (1) subject to (3). The law of one price holds at the individual goods level at all times. Then, the bilateral real exchange rate $Q_{i,t}$ is defined as $Q_{i,t} = \frac{E_{i,t}P_t^i}{P_t}$, where $E_{i,t}$ is the bilateral nominal exchange rate (domestic currency price of country i's currency) and P_t^i is the aggregate price index for country i's consumption goods. We assume that households in the foreign economy face exactly the same optimization problem with identical preferences. Under complete international financial markets assumption and no-arbitrage, Euler equations from both countries can be combined to yield the conventional uncovered interest parity condition.

B. Firms

Each firm produces a differentiated good indexed by $j \in 0,1]$ with a production function

$$Y_t(j) = [A_t N_t(j)]^{\eta} [B_t O_t^d(j)]^{1-\eta} \tag{4}$$

where $O_t^d(j)$ is the amount of (imported) oil used in production by firm j, (log) labor productivity $a_t = \log(A_t)$ and (log) efficiency of oil use $b_t = \log(B_t)$ follow stationary $AR(1)$ processes[5]. Firm i faces a demand given by:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon} Y_t \tag{5}$$

Assuming that firms take the price of each input as given, cost minimization of the firm implies:

$$(1-\eta)(1-\tau)W_t N_t(j) = \eta O_t^d(j) P_{o,t} \tag{6}$$

which holds for each firm j. $P_{O,t}$ is the price of oil which is in fact determined endogenously in our model, as will be explored later. τ is an employment subsidy designed to allow the flexible price economy to be efficient. The nominal marginal cost is:

$$MC_t^n = \frac{(1-\tau)W_t}{\eta A_t^{\eta} N_t(j)^{\eta-1} B_t^{1-\eta} O_t^d(j)^{1-\eta}}. \tag{7}$$

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[5] In the next section, when we analyze the effects of the foreign productivity shocks, we also allow for spillover effects of foreign labor productivity on the SOE.

Equation (6) highlights the fact that the cost-minimizing input combination that each firm chooses depends on the relative factor price—that is, labor and oil are substitutes. Hence, higher oil prices brings the substitution of labor for oil, causing an upward adjustment in the real wages.[6]

We assume that firms set prices according to Calvo (1983) framework, in which only a randomly selected fraction $(1-\theta)$ of the firms can adjust their prices optimally. Thus, θ is the probability that firm j does not change its price in period t. When setting new price in period t, then, the firm chooses the price ($\widetilde{P}_{H,t}(j)$) so that it maximizes the stream of profits discounted by $Q_{t,t+1}$:

$$E_t \sum_{t=0}^{\infty} \theta^t \left\{ Q_{t,t+1} [Y_t(j)(\widetilde{P}_{H,t}(j) - TC_t^n)] \right\} \tag{8}$$

where TC_t^n refers to nominal total cost, subject to (4). Therefore, $\widetilde{P}_{H,t}(j)$ should satisfy the following first order condition:

$$\sum_{t=0}^{\infty} \theta^t E_t \left\{ Q_{t,t+1} Y_t(j)(\widetilde{P}_{H,t}(j) - \frac{\varepsilon}{\varepsilon - 1} MC_t^n) \right\}$$

As shown in Woodford (2003), the firm's optimal price setting strategy implies the following marginal cost-based (log-linearized) Phillips curve:

$$\pi_{H,t} = \beta E_t \left\{ \pi_{H,t+1} \right\} + \lambda \hat{mc}_t \tag{9}$$

C. Monetary and Fiscal Policy

The monetary policy reaction function is assumed to be a simple Taylor Rule:[7]

$$r_t = \phi_\pi \pi_t + \phi_x x_t \tag{10}$$

where π_t and x_t are (log-linearized) consumer price inflation and output gap.

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[6] We assume here that factor prices are flexible, but our results are robust to the alternative specification where real wages adjust sluggishly. Rigid labor markets, however, trigger second round effects and therefore make it harder to achieve stabilization objective. The results are available upon request.

[7] Our analysis ignores possible monetary policy coordination or related strategic interactions between the SOE and the ROW. Considering our assumption that the ROW consists of a continuum of other SOE's, all represented by a unit interval, this assumption is plausible.

We assume that the governments of both the SOE and the ROW are home-biased (i.e., $G_t = G_{H,t}$). The government spending index can be written as:

$$G_t = \left(\int_0^1 G_t(j)^{(\varepsilon-1)/\varepsilon} dj \right)^{\varepsilon/(\varepsilon-1)} \tag{11}$$

The government follows a balanced budget in each period and finances its expenditures by lump-sum taxation:

$$P_{H,t} G_t = T_t \tag{12}$$

Expenditure minimization leads to the following government demand function:

$$G_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\varepsilon} G_t \tag{13}$$

We assume a stationary AR(1) process for the government spending (G_t).

D. Equilibrium

The equilibrium condition in the home goods market requires that the production of domestic goods satisfies:

$$Y_t(j) = G_t(j) + C_{H,t}(j) + \int_0^1 C_{H,t}^i(j) di \tag{14}$$

where, $C_{H,t}^i(j)$ is country i's demand for good j produced in the home country. Using the optimal allocation of expenditures for the SOE and the ROW, the real exchange rate definition, the assumption of symmetric preferences and aggregating across goods, we obtain:

$$Y_t = G_t + \left(\frac{P_{H,t}}{P_t} \right)^{-\gamma} C_t \left[(1-\alpha) + \alpha \int_0^1 Q_{i,t}^{\gamma - \frac{1}{\sigma}} di \right]. \tag{15}$$

III. Rest of the World and the Oil Market

A. Equilibrium in the Rest of the World

Apart from being asymmetric in size, SOE and ROW share the same preferences, technology, market structure for the consumption goods sector, and same structures for the monetary and fiscal policies. The price of oil is determined according to the macroeconomic developments in the ROW, which is regarded as a closed economy. In Table 2, we present the log-linearized equations for the ROW.

Table 2. Model in Log-Linearized Form:Behavioural Equations for the ROW and the Oil Market

$\pi_t^* = \beta E_t\left\{\pi_{t+1}^*\right\} + \lambda \widehat{mc}_t^*$	Phillps curve
$\widehat{mc}_t^* = [(\frac{\sigma}{1-G_y}) + \frac{1+\varphi-\eta}{\eta}]x_t^*$	Marginal cost
$y_t^* = E_t\left\{y_{t+1}^*\right\} - \frac{(1-G_y)}{\sigma}(r_t^* - E_t\left\{\pi_{t+1}^*\right\})...$ $... - G_y E_t\left\{\Delta g_{t+1}^*\right\}$	IS curve
$\overline{y}_t^* = \frac{1}{\left[(\frac{\sigma}{1-G_y})+\frac{1+\varphi-\eta}{\eta}\right]}(-\mu + (1+\varphi)a_t^*...$ $... + \frac{(1-\eta)(1+\varphi)}{\eta}b_t^* + \frac{\sigma G_y}{1-G_y}g_t^* + \frac{(1-\eta)(1+\varphi)}{\eta}o_t^s$	Flexible price output
$x_t^* = y_t^* - \overline{y}_t^*$	Output gap
$r_t^* = \phi_\pi \pi_t^* + \phi_x x_t^*$	Monetary policy rule
$\widetilde{p}_{o,t}^* = \Gamma_1 y_t^* - \Gamma_2 g_t^* - \Gamma_3 a_t^* - \Gamma_4 b_t^* - \Gamma_5 o_t^s$	Real oil price

Table 3. Model in Log-Linearized Form: Parameters

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}$$
$$\psi = (1-G_y)\alpha[\frac{\gamma}{1-\alpha} + \gamma - \frac{1}{\sigma}]$$
$$\Omega = 1/\left(\frac{1-G_y}{\sigma} + \psi\right)$$
$$\Psi_1 = \frac{\eta(1+\varphi)}{1+(1-\eta)\varphi},\ \Psi_2 = \frac{\eta\sigma}{1+(1-\eta)\varphi}$$
$$\Psi_3 = \frac{\eta\varphi}{1+(1-\eta)\varphi},\ \Psi_4 = \frac{(1-\eta)(1+\varphi)}{1+(1-\eta)\varphi}$$
$$\Gamma_1 = \frac{\sigma}{1-G_y} + \frac{(1+\varphi)}{\eta},\ \Gamma_2 = \frac{\sigma G_y}{1-G_y}$$
$$\Gamma_3 = 1+\varphi,\ \Gamma_4 = \frac{(1+\varphi)(1-\eta)}{\eta}\ ,\ \Gamma_5 = \frac{1+(1-\eta)\varphi}{\eta}.$$

Table 4. Model in Log-Linearized Form: Exogenous Processes

Small open economy	
$a_t = \rho_a a_{t-1} + \varepsilon_{a,t}$	Labor productivity
$a_t = \rho_a a_{t-1} + \varepsilon_{a,t} + 0.3\varepsilon_{a^*,t}$	Labor productivity with spillover effects
$b_t = \rho_b b_{t-1} + \varepsilon_{b,t}$	Efficiency of oil use
$g_t = \rho_g g_{t-1} + \varepsilon_{g,t}$	Government spending
Rest of the world and oil market	
$a_t^* = \rho_{a^*} a_{t-1}^* + \varepsilon_{a^*,t}$	Labor productivity
$b_t^* = \rho_{b^*} b_{t-1}^* + \varepsilon_{b^*,t}$	Efficiency of oil use
$g_t^* = \rho_{g^*} g_{t-1}^* + \varepsilon_{g^*,t}$	Government spending
$o_t^s = \rho_o o_{t-1}^s + \varepsilon_{o,t}$	Oil supply

B. Oil Market Equilibrium

We assume that at each point in time there is a world oil endowment (O_t^s), which is subject to i.i.d. shocks.[8] The process for the (log) oil supply (o_t^s) is defined by a stationary AR(1) process. The market clearing condition in the oil market implies the equalization of the firms' aggregate oil demand in the ROW (O_t^{d*}) and the exogenous oil supply. In fact, using the (log-linearized) cost minimization condition for foreign firms, substituting the equilibrium level of employment and then equating the demand for oil to the supply of oil, $o_t^{d*} = o_t^s$, we can derive the optimum real price of oil (in log-linearized form) in the ROW as follows:

$$\tilde{p}_{o,t}^* = \Gamma_1 y_t^* - \Gamma_2 g_t^* - \Gamma_3 a_t^* - \Gamma_4 b_t^* - \Gamma_5 o_t^s \tag{16}$$

where $\Gamma_1 = \frac{\sigma}{1-G_y} + \frac{(1+\varphi)}{\eta}$, $\Gamma_2 = \frac{\sigma G_y}{1-G_y}$, $\Gamma_3 = 1+\varphi$, $\Gamma_4 = \frac{(1+\varphi)(1-\eta)}{\eta}$ and $\Gamma_5 = \frac{1+(1-\eta)\varphi}{\eta}$ respectively.

Oil market equilibrium with precautionary oil demand

We analyze the case where an expected decline in the world oil supply induces firms to build up oil reserves. Supposing that the oil shock is temporary and the expectations are for the next period ($t+1$), the new oil market equilibrium becomes:

$$o_t^{d*} + \Delta m_t = o_t^s. \tag{17}$$

[8] We assume that the profits from selling oil are distributed evenly among world consumers and are included in the lump-sum transfers in the budget constraints of both the SOE and the ROW. See also Campolmi (2008).

where $m_t = -E_t(o^s_{t+1})$ is the amount of reserve build-up in period t. Therefore, the magnitude of the oil reserve build up is the same as the expected future oil supply shortage. The oil reserves as a whole will be used up at the time when the shock is due. Notice that when we allow for the precautionary demand, the effect of the expected future oil supply decrease is observed today. The price of oil is then given by:

$$\widetilde{p}^*_{o,t} = \Gamma_1 y^*_t - \Gamma_2 g^*_t - \Gamma_3 a^*_t - \Gamma_4 b^*_t - \Gamma_5 o^s_t + \Gamma_5 \Delta m_t \quad (18)$$

A precautionary oil demand will push the oil prices up, and the use up of the oil reserves in the next period will have the opposite effect.[9] The dynamics in the next period will depend on whether the shock is actually observed or not.

IV. Impulse Response Analysis

Our main objective here is to investigate the channels which transmit the effect of the underlying causes of an oil price increase. We do not aim to match the impulse responses with the ones observed in the empirical literature for two reasons. First, despite the fact that our model is capable reasonably to approximate the behavior of macroeconomic variables of oil-importing small open economies in the wake of an oil price shock, the model dynamics should be enriched to incorporate, at least, habit persistence, wage indexation and financial frictions in order to replicate the historical responses. Neverthless, this may not be as illuminating as it seems at first sight as these additions make it much harder to grasp fully the inner working of the transmission mechanisms and the channels through which the foreign shocks are fed into the home country.

Second, this exercise would require employing some country-specific characteristics; such as whether the country mainly exports/imports raw materials or manufactured products, or whether the monetary authority intervenes in the exchange rate market. In line with our objective, however, we choose to calibrate the model with reasonable values, mostly as they are set in the literature, mainly following the baseline calibration used in Gali and Monacelli (2005) and Blanchard and Gali (2008) (see Table 5).

Time is measured in quarters. We set $\beta = 0.99$, implying a riskless annual return of approximately 4 percent in the steady state. The inverse of the elasticity of intertemporal substitution is taken as $\sigma = 1$, which corresponds to log utility. The inverse of the elasticity of labor supply φ is set to 3 since it is assumed that one-third of the time is spent on

[9] Expectation shock and therefore the stock build-up last only for one period. At period t, since $m_{t-1} = E_{t-1}(o^s_t) = 0$, $\Delta m_t = m_t$ is the stock build-up. On the other hand, at period $t+1$, $m_{t+1} = E_{t+1}(o^s_{t+2}) = 0$, hence $\Delta m_{t+1} = -m_t$, that is, the stock is completely depleted.

working. We set the degree of openness (α) to be 0.4. The share of labor in the production (η) is taken as 0.983, so that the share of oil in the production $(1-\eta)$ is 1.7 percent.[10] The Calvo probability (θ) is assumed to be 0.75 which implies an average period of one year between price adjustments. The elasticity of substitution between differentiated goods (of the same origin) ε is 6, implying a flexible price equilibrium mark-up of $\mu = 1.2$. We use the original Taylor estimates and set $\phi_\pi = 1.5$ and $\phi_y = 0.5$.

The persistence of the labor productivity shock (ρ_{a^*}), the shock to efficiency of oil use (ρ_{b^*}), the government spending shock (ρ_{g^o}) and the persistency of oil supply (ρ_o) shock are set to 0.9. Following Gali, Lopez-Salido, and Valles (2007), we set the share of government purchases in GDP as 20 percent.

Table 5. Parameter Values Used in Calibration

$\beta = 0.99$	Discount factor
$\sigma = 1$	Inverse of the intertemporal elasticity of substitution
$\varepsilon = 6$	Elasticity of substitution between domestic goods
$\gamma = 1$	Elasticity of substitution between domestic and foreign goods
$\alpha = 0.4$	Openness
$\varphi = 3$	Frisch elasticity of labor supply
$\eta = 0.983$	Share of labor in production
$\theta = 0.75$	Calvo parameter
$\phi_\pi = 1.5$	Coefficient of inflation in the policy rule
$\phi_y = 0.5$	Coefficient of output gap in the policy rule
$G_y = 0.2$	Share of government spending

A. Aggregate Demand Shocks

Our aim is to show that aggregate demand increases caused by different shocks affect the economies through different channels. We analyze two different shocks that lead to an increase in the world aggregate demand. In the first case, an unexpected rise of labor productivity is the cause of the surge in aggregate demand. In the second case, however,

[10] Blanchard and Gali (2008) set the share of oil in production as 1.7 percent, which corresponds to its value in 1997.

aggregate demand in the ROW increases in response to an unexpected rise in government spending.

Labor productivity shock

Responses of selected variables to a 1 percent shock to productivity of labor in the ROW are shown in Appendix Figure 1. Higher labor productivity creates a higher demand for oil since the increase in oil demand due to positive output growth dominates the decline in oil demand coming from the substitution effect. On the other hand, higher labor productivity implies lower marginal cost of production which spreads to the world as lower import prices. As a result, the increase in output growth is accompanied by low consumer price inflation, but higher oil prices in the global economy.

Following Backus, Kehoe, and Kydland (1992), we look at the effects of the foreign productivity shock on the SOE under two cases: with and without a spillover effect of labor productivity growth.[11] Without the spillover effect, a positive labor productivity shock in the ROW leads to a less persistent rise in the output of the SOE. However, with the spillover effect, the rise in the SOE's output is higher and more persistent. The rise in the real oil price is also higher in the SOE when there is a spillover effect due to the lesser appreciation of the SOE's currency. The behavior of CPI, on the other hand, is almost the same with and without spillover effects as the cost-increasing effect of the higher real oil price is offset by the cost-decreasing effect of the increase in labor productivity.

This exercise stresses an important point: higher oil prices do not necessarily lead to a conventional higher inflation-lower output scenario; instead, the positive effects of productivity increases on the inflation and output growth may well compensate the negative effects of the higher oil prices.

Government spending shock

Similar to a foreign labor productivity shock, a government spending shock that arises in the ROW increases the world aggregate demand and hence creates an upward adjustment in the price of oil, while it also pushes CPI inflation above the steady-state level as shown in Figure (2). In the ROW, the dynamic responses of output and real price of oil are persistent but smaller in magnitude in the wake of a shock to government spending than their responses under a labor productivity shock. Contrary to the latter, however, CPI inflation and the nominal interest rate increase above their steady-state levels.

After the government spending shock in the ROW, the output of the SOE declines below the steady-state level through two different channels. The first one is the decreased import

[11] Under spillover effects, we suppose that a 1 percent increase in the foreign productivity will be accompanied by a 0.3 percent increase in the domestic productivity.

demand by the ROW. Although a rise in the government spending causes aggregate output to increase, private consumption declines in the ROW.[12] This is due to the decrease in the present value of household's wealth after government increases lump-sum taxes in order to finance its higher spending. The decline in the consumer spending correspondingly reduces the import demand of the ROW, since government spending is assumed to be home-biased and it does not affect import demand accordingly. The second channel works through the real exchange rate. Typically, a government spending shock leads to a real appreciation of the real exchange rate of the country in which the shock is observed. Therefore, the real exchange rate of the SOE depreciates, stimulating the import demand of ROW contrary to the effect of the first channel. All in all, the latter impact outweighs that of the second channel in our case and the output in the SOE declines after the government spending shock in the ROW. CPI inflation of the SOE increases above the steady-state level, since the marginal cost of the firms in the SOE increases due to the real depreciation of the domestic currency.[13]

Therefore, despite a rise in the foreign labor productivity and in the foreign government spending which can both be regarded as global demand shocks increasing the world aggregate output and the price of oil, their implications for the other macroeconomic dynamics (such as inflation and exchange rate) can be divergent.

B. Oil Supply Shock

In Appendix Figure 3, we present the dynamic responses in a case where there is a 10 percent decline in the world oil supply which leads to an immediate, almost one-for-one, jump in the world real oil price.[14] In that case, output declines and inflation rises in the ROW for two reasons. First, the decline in the oil supply directly reduces world output through production function. Second, the increase in the oil price pushes up the CPI of the ROW above the steady-state level due to the rising marginal cost of production. Increasing consumer price inflation forces the monetary authority to raise interest rate according to the monetary policy rule and a higher real interest rate depresses world output further.

Under the baseline calibration, the oil supply shock is exogenous to both countries and the technologies are the same, hence the marginal costs of production in both countries are affected in the same way. Since the oil revenue is assumed to be distributed equally among the world consumers, an increase in the price of oil does not create asymmetric wealth effects in the SOE and the ROW. As a result, in case of an exogenous oil supply shock, the

[12] This is a typical result in many standard DSGE models. For a detailed analysis of the issue, see Gali, Lopez-Salido, and Valles (2007).

[13] These findings are consistent with the VAR estimates of Kilian (2009).

[14] For the ease of exposition, we analyze the effects of a 10 percent change in the oil supply instead of a 1 percent change.

responses of both countries are symmetric and the effect on the real exchange rate is negligible.

C. Precautionary Demand Shock

We assume that at time t economic agents learn that there might be an oil supply disruption in the next period (e.g., due to rising concerns about political stability in the OPEC countries or bad weather conditions). Because there is uncertainty about the future oil supply, it is also assumed that the producers in the ROW build up oil stocks in period t by the same amount as the expected oil supply reduction. We further assume that the oil supply shortage if realized will last only one period. Appendix Figure 4 shows the responses of variables when there is an expected oil supply disruption. The dashed lines are the paths of the responses of variables if the expectation is not realized and the solid lines show the paths if the expectation is realized.

As soon as the news about the possible future oil supply shortage arrives at period t, a precautionary demand arises, causing the real oil price to exceed its steady-state level. Output declines in the SOE and in the ROW because some of the oil supply is reserved for the future use in the latter. The increase in the real price of oil pushes CPI both in the SOE and in the ROW above the steady-state level in period t. The real exchange rate appreciates with the news about the possible future oil supply disruption but the effect is very small.

This sheds some light on the sharp expectations-driven fluctuations of the price of oil in the global markets. The fears about the future oil supply causes an oil-specific demand shock (contrary to the aggregate demand shocks presented previously) which generates an abrupt endogenous volatility in the oil market, even if the expectations do not come true in the following period. Nevertheless, in period $t+1$, the effects changes depending on whether the oil supply shock is realized or not. We now turn to these two cases.

The expectation about the oil supply is not realized

If the expectation is not realized, since the producers deplete their oil stocks, both the oil demand and the real price of oil fall sharply in period $t+1$. In period $t+2$, all the variables return back to their steady-state levels. In period $t+1$, the decline in the real price of oil stimulates output growth, hence, output increases above the steady-state level both in the ROW and in the SOE.

The expectation about the oil supply is realized

If the supply of oil declines in period $t+1$ as expected, the real oil price returns to the steady-state level since the decline in the oil supply is offset by the decline in the oil demand as firms in the ROW use their oil reserves. CPI inflation in the ROW and in the SOE decrease in period $t+1$.

V. Conclusions

This paper has investigated the origins and macroeconomic consequences of oil price fluctuations using a theoretical framework. Building on the work of Kilian (2009), real price of oil is endogenously determined in our model. We model a small open economy in order to analyze the effects of the oil price changes caused by the developments in the rest of the world. Modelling the small open economy and the rest of the world together enables us to identify the real exchange rate and the trade channels that transmit the direct and indirect effects of the global shocks to the small open economy. In order to capture the effects of the precautionary oil demand caused by uncertainties about the future oil supply, we add an oil stock variable in the model, which allows firms to build up temporary oil inventories.

Using our model, we focus on the following shocks that lead to higher oil prices: unanticipated productivity and government spending increases, an unexpected oil supply decrease and an expected oil supply disruption which lead to a precautionary oil demand. A key finding is that oil price shocks have significantly divergent impacts on economies depending on the nature of the shocks. It is striking to see that not all aggregate demand shocks produce CPI inflation. Although both productivity and government spending shocks lead to higher oil prices, they have opposite impacts on the firms' marginal costs and hence on CPI inflation.

It is widely known that expectations play an important role in the commodity markets, causing price volatility. We demonstrate that, when firms are allowed to hold oil inventories, expectations on future oil supply changes can create high oil price fluctuations, which cannot be explained by macroeconomic fundamentals.

Our results point out the importance of distinguishing between the causes of oil price increases. In the light of these results, we argue that macroeconomic policies dealing with oil price shocks must carefully consider the underlying causes in the first place. This is a crucial result for the operational conduct of monetary policy in terms of determining an appropriate accompanying path of the policy rate. This is because the dynamic responses of inflation and output gap, these being the variables in the objective function of the monetary authority, are substantially different in terms of both direction and magnitude depending on different oil price shocks.

This paper also gives an insight into the discussion regarding the choice of the inflation target. A direct monetary policy response to price of oil is probably not a good idea. The reason for this is twofold. First, by excluding oil prices whose movements show significant short run volatility, policy makers can get a better sense of underlying trends in consumer price inflation. As we illustrate, an expectation of lower oil supply in the future immediately creates an endogenous excess volatility in the global oil market due to the resulting precautionary demand. The second reason is the uncertainties about the origins of the oil price shocks. For example, if the origin of the oil price shock is an increase in the foreign productivity, simply raising interest rate following a policy rule which includes some measure of oil price inflation will contract output and bring future decrease in inflation, causing the economy to move further away from its steady state. Therefore, it is obvious that a stability oriented central bank may not afford to treat oil price shocks as if they take place in isolation.

This framework is indeed able to yield much more than what is presented here. The setting can be extended to perform welfare evaluation. Incorporating wage rigidity, which makes the stabilization objective of the monetary authority more complicated by triggering second round effects, allows for the analysis of optimal policy and normative policy conclusions, on which we are planning to focus next.

APPENDIX: EQUILIBRIUM CONDITIONS

A. Households and Goods Market Equilibrium in the SOE

Household's maximization of (1) subject to (3) yields the following (log-linearized) optimality conditions:

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{19}$$

$$c_t = -\frac{1}{\sigma}\left(r_t - E_t\{\pi_{t+1}\} - \rho\right) + E_t\{c_{t+1}\} \tag{20}$$

where $\rho = -\log\beta$, $\log R_t = \log(1+r_t) \approx r_t$ is the nominal interest rate and $\pi_{t+1} = \ p_t - p_{t-1}$ is the CPI inflation between t and $t+1$. CPI, domestic price level and real exchange rate ($q_t = \int_0^1 q_{i,t} di$) can be linked through the following equation:

$$p_t = p_{H,t} + \frac{\alpha}{1-\alpha} q_t. \tag{21}$$

Equations (19) and (20) hold also for the foreign economy with each variable replaced by a corresponding starred variable. Under the assumption of complete international financial markets and no-arbitrage, the following (log-linearized) risk sharing equation can be written:

$$c_t = c_t^* + \frac{1}{\sigma} q_t. \tag{22}$$

Aggregating the production function (4) over all firms and log-linearizing to first order yields:

$$y_t = \eta a_t + (1-\eta) b_t + \eta n_t + (1-\eta) o_t^d. \tag{23}$$

Then, log-linearization of good market equilibrium condition (15) around the symmetric steady state gives:

$$y_t = G_y g_t + (1-G_y) c_t + \psi q_t \tag{24}$$

where $G_y = \overline{G}/\overline{Y}$ is the steady-state share of government spending in GDP.[15] Equation (24) can be combined with the foreign goods market equilibrium $c_t^* = \frac{y_t^* - G_y g_t^*}{1-G_y}$ and equation (22) to yield:

$$q_t = \Omega(y_t - G_y g_t) - \Omega(y_t^* - G_y g_t^*) \tag{25}$$

Combining equation (24) with the Euler equation (20) gives (ignoring the constant):

$$y_t = E_t\{y_{t+1}\} - \frac{(1-G_y)}{\sigma}(r_t - E_t\{\pi_{t+1}\}) - G_y E_t\{\Delta g_{t+1}\} - \psi E_t\{\Delta q_{t+1}\}. \tag{26}$$

B. Marginal Cost and Inflation Dynamics

Utilizing equations (6), and (7), the (log) real marginal cost in terms of domestic prices mc_t, which is identical for each firm, can be derived as (ignoring a constant):

$$mc_t = -\eta a_t - (1-\eta)b_t + \eta(\sigma c_t + \varphi n_t) + (1-\eta)\widetilde{p}_{o,t} + (\frac{\alpha}{1-\alpha})q_t \tag{27}$$

where we make use of equations (19) and (21). $\widetilde{p}_{o,t} = p_{o,t} - p_t$ is the real price of oil (the relative price of oil with respect to CPI). Then using $\widetilde{p}_{o,t} = \widetilde{p}_{o,t}^* + q_t$, (23), cost minimization condition for firms, and finally (22), we can write:

$$mc_t = -\Psi_1 a_t - \Psi_4 b_t + \left[\Psi_2 - \frac{\Omega}{1-\alpha}\right](\frac{y_t^* - G_y g_t^*}{1-G_y}) + \left[\Psi_3 + \frac{\Omega}{1-\alpha}\right]y_t - \frac{\Omega}{1-\alpha}G_y g_t + \Psi_4 \widetilde{p}_{o,t}^* \tag{28}$$

Thus, one can get the flexible price level of output as follows:

$$\overline{y}_t = \frac{-\mu + \Psi_1 a_t + \Psi_4 b_t - \left[\Psi_2 - \frac{\Omega}{1-\alpha}\right](\frac{y_t^* - G_y g_t^*}{1-G_y}) + \frac{\Omega}{1-\alpha}G_y g_t - \Psi_4 \widetilde{p}_{o,t}^*}{\left[\Psi_3 + \frac{\Omega}{1-\alpha}\right]} \tag{29}$$

where $-\mu$ is the flexible price equilibrium level of the marginal cost. Defining the output gap as $x_t = y_t - \overline{y}_t$, we have $\hat{mc}_t = \left[\Psi_3 + \frac{\Omega}{1-\alpha}\right]x_t$. Hence, using equation (9), the new

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[15] $\overline{G}$ and $\overline{Y}$ denote the steady-state levels of the government expenditure and output, respectively.

Keynesian Phillips Curve can be written in terms of output gap as:

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda\left[\Psi_3 + \frac{\Omega}{1-\alpha}\right]x_t. \tag{30}$$

Moreover, using the definition of output gap, and equation (26), we can derive the new Keynesian IS curve as:

$$x_t = E_t\{x_{t+1}\} - \frac{(1-G_y)}{\sigma}(r_t - E_t\{\pi_{t+1}\}) - G_y E_t\{\Delta g_{t+1}\} - \psi E_t\{\Delta q_{t+1}\} + E_t\{\Delta \bar{y}_{t+1}\}. \tag{31}$$

C. Rest of the World and Oil Market Equilibrium

Using the (log-linearized) cost minimization condition for foreign firms ($w_t^* + n_t^* = p_{o,t}^* + o_t^{d*}$) and substituting the equilibrium level of employment yields:

$$\tilde{p}_{o,t}^* = \sigma c_t^* + (1+\phi)[\frac{y_t^* - \eta a_t^* - (1-\eta)b_t^* - (1-\eta)o_t^{d*}}{\eta}] - o_t^{d*}$$

Substituting $c_t^* = \frac{y_t^* - G_y g_t^*}{1-G_y}$ and equilibrium in the oil market condition $o_t^{d*} = o_t^s$ gives (16) in the text.

The foreign economy version of equation (28) is simply:

$$mc_t^* = -\eta a_t^* - (1-\eta)b_t^* + \eta(\sigma c_t^* + \varphi n_t^*) + (1-\eta)\tilde{p}_{o,t}^* \tag{32}$$

Using the corresponding equation for $\tilde{p}_{o,t}^*$ and then upon finding flexible price equilibrium level for the ROW, we can write $\hat{mc}_t^* = \Gamma_1 x_t^*$. *Q.E.D.*

Figure 1. Impulse Responses to 1 Percent Labour Productivity Shock
(Percent deviations from SS)

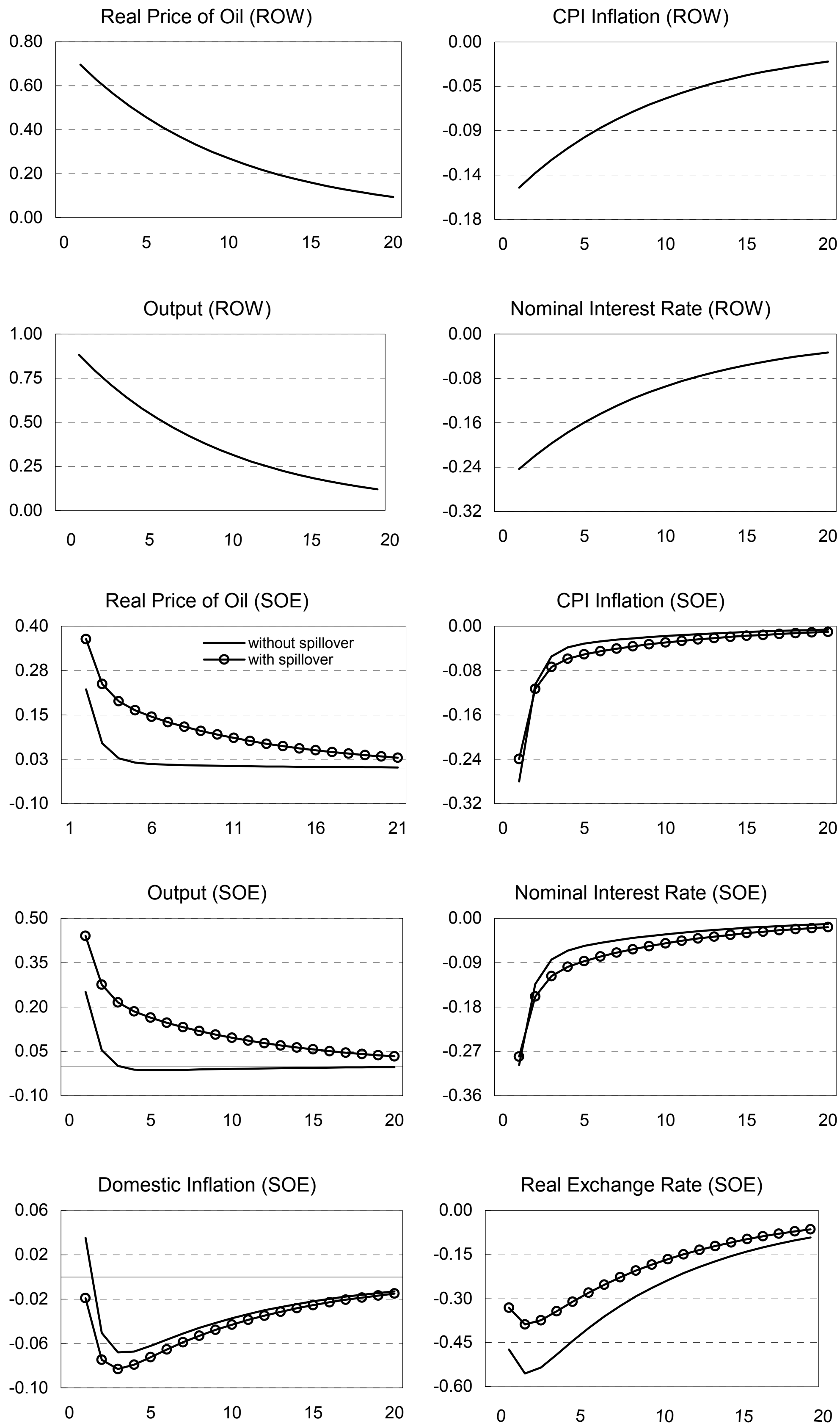


Figure 2. Impulse Responses to 1 Percent Government Spending Shock
(Percent deviations from SS)

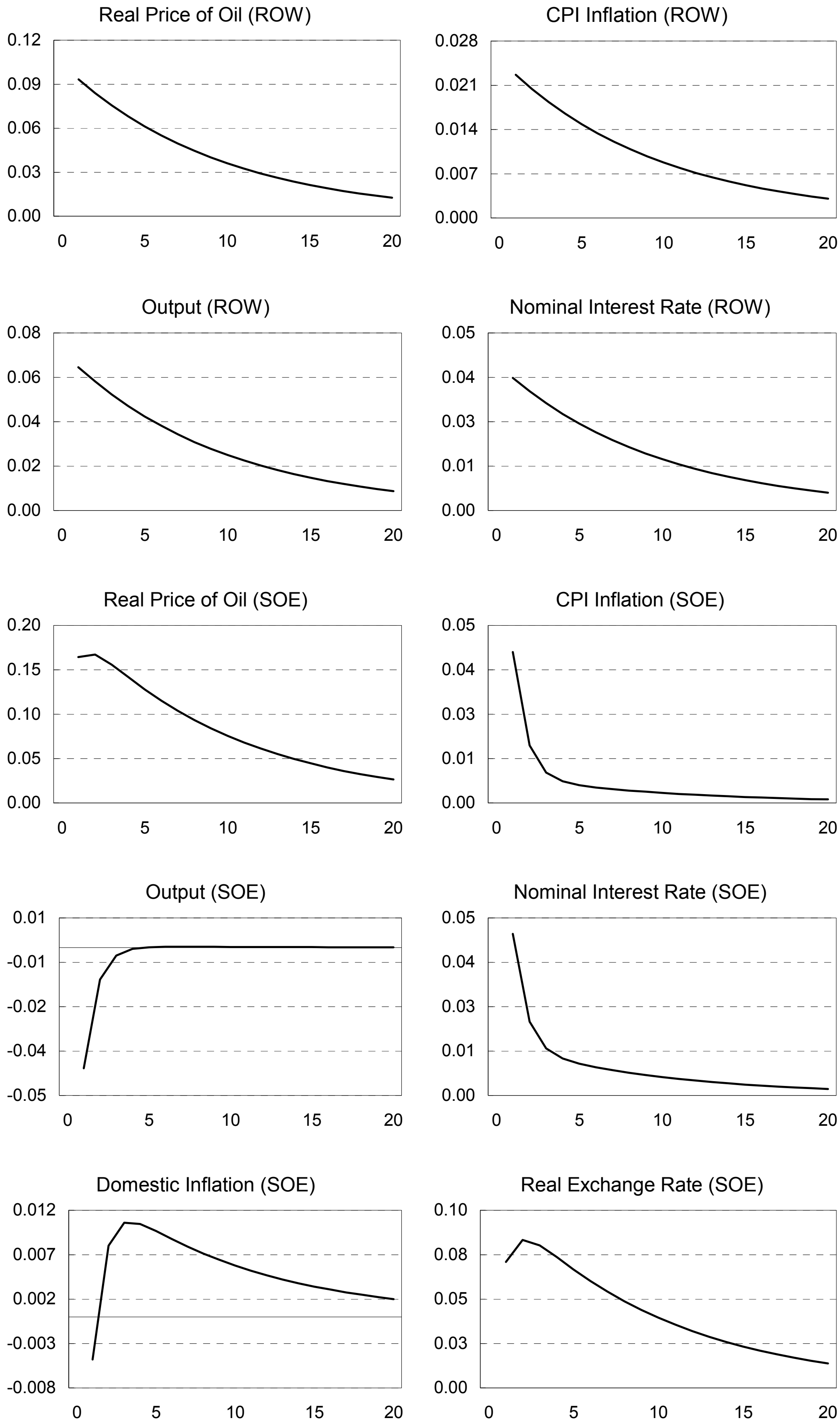


Figure 3. Impulse Responses to 10 Percent Negative Oil Supply Shock
(Percent deviations from SS)

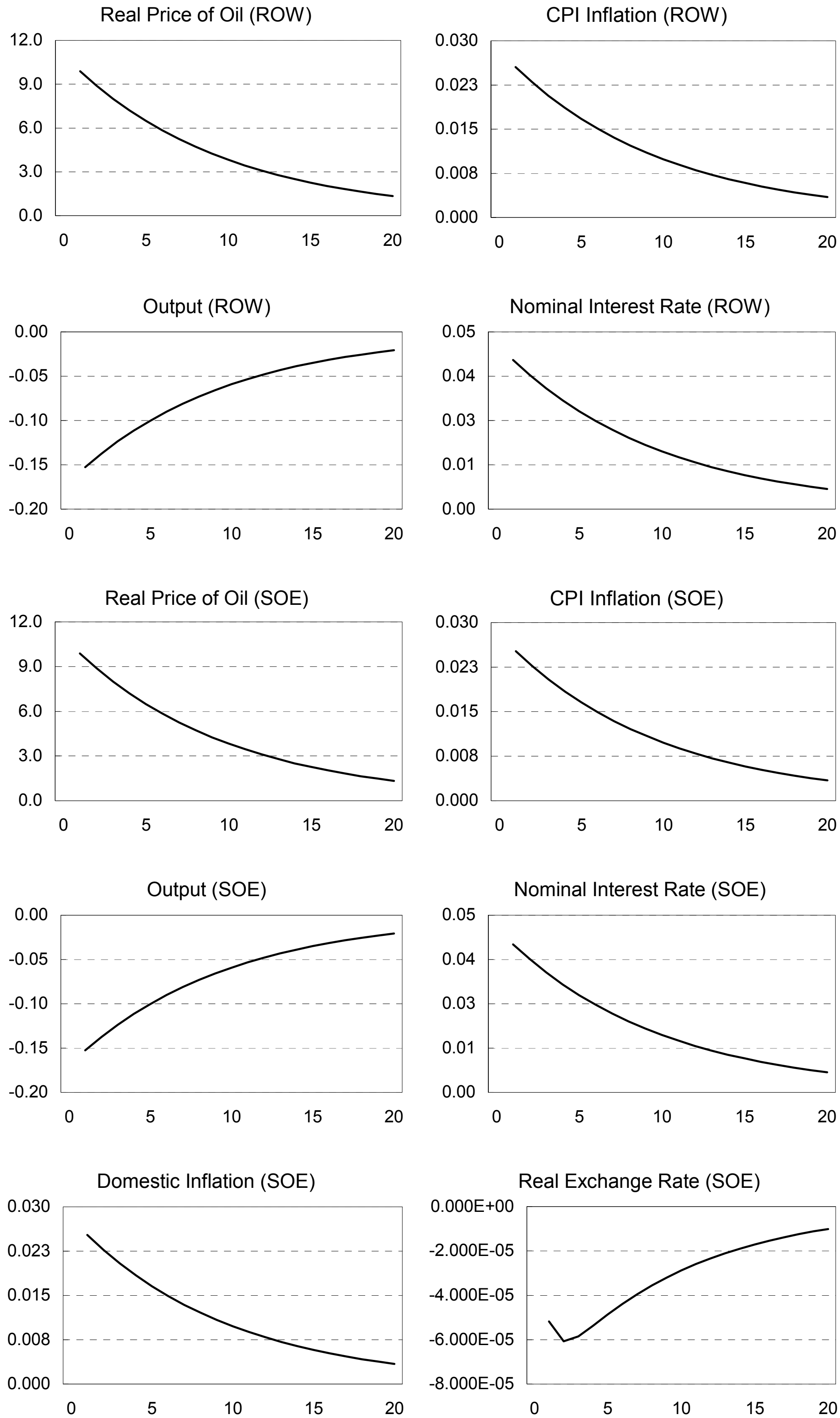
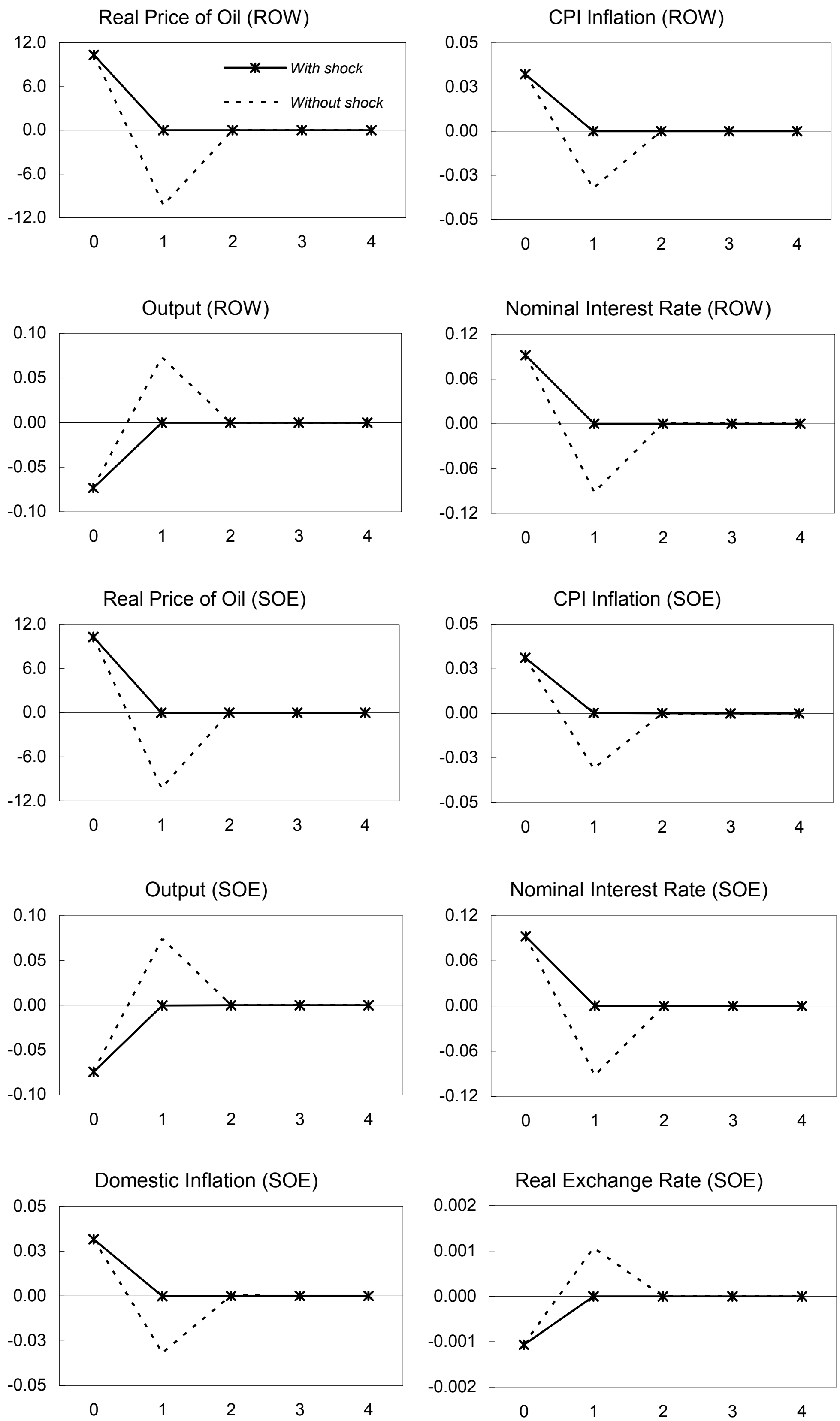


Figure 4. Impulse Responses to 10 Pecent Expected Negative Oil Supply Shock
(Percent deviations from SS)



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