Journal of Money and Economy
Vol. 9, No.2 Spring 2014

Oil Price Shocks and Economic Fluctuations in Iran as a Small Open Oil Exporting Economy

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Received: 5/19/2015   Approved: 5/24/2015

Abstract

Oil price shocks are the major source of economic instability in oil exporting developing countries, including Iran. In this paper a Multi Sector Dynamic Stochastic General Equilibrium model, with emphasis on optimization of oil sector as a producing sector is designed. Furthermore, an optimizing import sector is introduced into the model by considering the price rigidity in imported goods as a source of inefficiency in a New Keynesian open economy. The impact of oil price shocks on the dynamics of the economic variables is considered during 1988:1-2011:1. For this purpose, the Bayesian approach is used to estimate the model. The impulse response functions show that immediately after an oil price shock, output increases in the oil sector, while in the non-oil sector the result is reverse. Furthermore, GDP, consumption and inflation increase, while the employment and real exchange rate decreases immediately and finally, all the variables converge to their steady state values.

Keywords: *Impulse Response Functions, New Keynesian, MDSGE, Bayesian approach*

JEL Classification: *C61, D50, E12, Q43*

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1. Introduction

Oil price shocks, defined as unexpected changes in the price of oil, have considerable consequences on the macroeconomic variables in oil exporting developing countries, as well as Iran. In other words, significant contribution of value added in the oil sector to GDP, heavy reliance of the state budget on oil revenues, exogenous nature of oil price fluctuations and subsequent revenues obtained via oil exports have all caused the oil price fluctuations to affect macroeconomic variables in the form of an exogenous shock. It is therefore necessary to determine the effect of oil price fluctuations on macroeconomic variables so as to design appropriate policies to maintain economic stability. A macroeconomic model is required to study the effects of oil shocks on macroeconomic variables so as to demonstrate how and in what ways such shocks affect main variables of the country.

First, it is necessary to divide the countries into two groups based on their vulnerability against oil shocks. Oil shocks exert relatively different impacts on these two groups. The first group includes oil importers in which any severe increase in oil prices would result in reduction of economic growth and rise of inflation. This phenomenon can be explored from various aspects. For instance, rise of oil prices, as one of the main production factors for manufacturing firms leads to rise of production costs and fall of profits. Firms, therefore, will be unwilling to purchase new capital goods and this event will lead to reduction of production capacity in economic firms which explains the reduction in aggregate supply and rise of price levels. The second group includes oil exporting countries whose performance stability depends heavily on oil sector since they rely on their oil revenues and oil exports contributes to GDP to a large extent. As a result, oil is more than a production factor in these countries since an oil price shock will result in higher national income and the economy receives a positive wealth effect through better terms of trade; because of this channel of transmission, additional inflationary pressures may be present due to the effects on marginal costs and aggregate demand. In addition, wealth channel affects the inflation dynamism in such countries and the short-term relation between inflation and unemployment. Short-term dynamisms of inflation and unemployment in developing economies are affected not only by nominal stickiness in the price of domestic goods but also by inefficiencies of imported goods markets. Due to these features it is sheer naivety to explore developing oil-exporting economies in the framework of closed models.

Therefore, considering the role of oil both as a production factor and as the main source of export revenues, it is required to find out how positive shocks in oil prices can affect the key macroeconomic variables in Iran. For this purpose, a model of the mechanism of transferring impacts of oil price shocks on performance of economy has been introduced. Dynamic Stochastic General Equilibrium (DSGE) models have recently turned into a significant branch of macroeconomic studies and have been widely used by economists from various schools of thought to unravel the economic dynamism and to assess the consequences of economic policies. Therefore, this paper is designed in the framework of a Multi sector Dynamic Stochastic Model (MDSGE). It is multi sector since the manufacturing sector itself is divided into several sectors and oil rests beside non-oil, import, and final product sectors. This paper focuses on segregation of manufacturing sector into independent parts based on an optimization so that they simultaneously interact with other sectors. Such an approach mostly has been neglected in other New Keynesian DSGE articles about the economy of Iran. For instance, oil has not been modeled as a manufacturing sector that absorbs capital and labor and creates employment. In other words, oil revenues have merely been assumed as an exogenous auto regressive process while this paper puts this assumption aside. In addition, this model incorporates the specific characteristics of the economy of Iran as an oil-exporting country in which oil revenues go to the government and subsidies for fuel prices for manufacturing firms are common phenomena. Furthermore, a large body of Domestic New Keynesian studies views price stickiness for domestic products as sufficient enough whereas the current study pays special attention to lack of law of one price as a main source of inefficiency in developing open economies. This is done via modeling of import sector and including those importers who are capable to set their prices. Therefore, by using the Bayesian approach we estimate a MDSGE model for the economy of Iran according to New Keynesian standpoints to investigate the dynamic effects of oil price shocks. The impulse response functions of model variables against the defined shock is analyzed and assessed in accordance with the evidence provided by real data and theoretical expectations. The results can be useful in adopting suitable policies to minimize the negative effects of shocks and maximize their benefits.

The rest of the paper is organized as follows: Section 2 presents a literature review of the relevant studies that utilize various models particularly DSGE models for different countries. Section 3 presents the details of the model. Section 4 discusses the parameter calibration, data and the estimation results. Section 5 exhibits impulse response functions and analyzes these results. Concluding remarks are given in section 6.

2. Literature Review

The structural characteristic of oil exporting countries raises the question of whether there is a positive or negative effect on the key macroeconomic variables after hitting oil price shocks. For this purpose, Alotaibi (2006) uses Structural Vector Auto Regression (SVAR) to investigate the effects of oil price fluctuations on real exchange rate variables and price levels in GCC[1] countries. The results revealed that oil shocks exert a reverse effect on real exchange rate but directly change the inflation rate. Using a Vector Error

1. Gulf Cooperation Council

Correction model (VECM) in Iran, Hadian and Parsa (2006) concluded that oil price shocks are among the main factors which create fluctuations in macro-economic variables in a way that 20% of GDP fluctuations, 30% of unemployment fluctuations, and 60% of fluctuations of general level of prices can be attributed to oil-price changes. In addition, after a while, oil shocks have increased the fluctuations of those variables and created a divergence of actualized amounts of variables from their equilibrium level. Farzanegan and Markwardt (2009), using VAR method, investigated the dynamic relation between oil price shocks and main variables of the economy of Iran. Their findings implied a positive effect of oil shocks on inflation as well as a strong positive relation between oil shocks and growth of industrial products. It was also revealed that such shocks significantly strengthen the real exchange rate.

Despite this fact that oil exporting countries have experienced large and major fluctuations as a result of oil shocks, there have been a few recent models that analyze oil shocks in a new Keynesian DSGE framework. For instance, Medina and Soto (2005) analyze the effects of oil price shocks from a general equilibrium standpoint. They develop a DSGE model, estimated by Bayesian methods for the Chilean economy. The model explicitly includes oil in the consumption basket and also in the technology used by domestic firms. They show that a 13% increase in the real price of oil leads to a fall in output of about 0.5% and an increase in inflation of about 0.4%.

To investigate the dynamic effect of oil price shocks on an oil exporting economy, by using Bayesian approach, Allegret and Benkhodja (2011), have developed a DSGE model based on the features of the Algerian economy. Impulse Response functions show that non-oil production, investment and GDP increase after a positive oil price shock, but oil output can be relatively inelastic to price fluctuations. The reason for this weak response is difficult to interpret; it might be for this reason, Algeria as an OPEC member, cannot freely modify its oil supply according to oil price changes. Sticky prices due to the presence of subsidized and administrated prices explain the immediate responses of inflation: while the reaction is weak for CPI inflation, there's a negative response for core inflation. Neither inflation in the import sector, nor the real exchange rate reacts to the oil price shock. Both prices stickiness and the state control explain this response in the import sector. Furthermore, the response of real exchange rate is consistent with the real exchange rate stability target of the Algerian authorities.

Cologni and Manera (2013) used a DSGE model and calibration method to study the impact of oil price shocks in oil-exporting GCC countries. Their findings showed that increase of oil revenues had a negative impact on production and consumption due to the large size of the government. Motavaseli et al. (2011) developed a New Keynesian closed DSGE model to study the economy of Iran. In this model, like the other New Keynesian DSGE models, firms face two kinds of distortions, i.e., nominal rigidities and market power in the intermediate-good sector. Impulse response functions show that non-oil output and inflation increase in response to oil revenues shocks. By using the calibration method in the context of a New Keynesian open DSGE model, Jafari Samimi et al. (2014) showed that oil revenue shocks have an immediate positive effect on inflation and non-oil production.

Considering this background, oil price shocks play a significant role in macroeconomic fluctuations in oil exporting countries, therefore, using the models introduced by Medina and Soto (2005) and Allegret and Benkhodja (2011), this study aims at designing a New Keynesian DSGE model for Iran as an oil exporting economy so that it would be able to adopt appropriate policies after real oil price shocks to maintain economic stability.

3. The Model

In this section the model is designed in accordance with the features of the economy of Iran as a small[1] open oil-exporting economy. On this basis, we

1. It is assumed that the decisions of the country will not affect the global oil prices and oil price is an exogenous factor for domestic economy.

describe a DSGE model in which oil is included alongside non-oil, import, and final goods sectors where crude oil is exported and refined oil is used as an input for non-oil production. However the model pays special attention to dependency of the economy of Iran on oil, and oil revenues are considered both separately and as a finance resource for government budget. Furthermore the model assumes that in Iranian oil-exporting economy, the domestic price of oil is a weighted average of global and former domestic prices. This approach includes energy subsidies in the model as conventional phenomena in the economy of Iran.

This economy consists of households, representatives of firms (including oil, non-oil, imports, and final goods), government and the monetary authority (Central Bank). Households provide the oil and non-oil firms with labor and capital. The oil sector uses the technology, labor and capital to produce crude oil which is being exported at global prices. It is assumed that there are infinite production firms in non-oil sector which produce different goods in a monopolistic competitive market. Thus, firms producing non-oil goods set their prices following Calvo (1983) and Yun (1996) models. In the import sector, consumer goods are imported at the world prices and sold in the monopolistic domestic market by importers who follow Calvo and Yun price setting.

Conventional New Keynesian model assumes that imported goods are homogeneous and come from a perfectly competitive market. As a result, the law of one price applies to all imported goods. Since this assumption is not applicable to the economy of Iran, we assume that the imported goods are not homogeneous and the domestic market is monopolistically competitive. Therefore, the law of one price is not applicable. Meanwhile, the producers of final goods use a combination of domestic and imported products and work in a completely competitive environment. Besides, as the owner of the oil firm, the government exports crude oil and imports refined oil to be sold to non-oil producers at subsidized prices. Finally, monetary policy is conducted as a Taylor type rule that incorporates interest rate, GDP growth, inflation in the non-oil goods sector, CPI inflation and real exchange rate.

3.1. Household

The representative household derives utility from consumption (c_t) and leisure (1-h_t). The expected present value of the household utility is given by:

$$u_0 \cong E_t \sum_{t \cong 0}^{\clubsuit} \varepsilon^t [\frac{C_t^{10\varphi}}{10\varphi} 0 \frac{h_t^{1.\varpi}}{1.\varpi}] \quad (1)$$

Where E_t, denotes conditional expectation based on information set in period t. Parameter ε is the subjective discount factor. Parameter, φ is the inverse of the elasticity of inter-temporal substitution of consumption, ϖ represents the inverse of the wage elasticity of labor supply and h_t is labor supply.

The representative household has access to domestic and international financial markets. It enters in period t with holdings of domestic bonds, B_{t01}^d, and foreign bonds, B_{t01}^f. Following Medina and Soto (2005), buying foreign bonds entails paying a risk premium,ν, which the functional form is given by:

$$v_t \cong \exp(0\iota \frac{e_t B_t^{\,f}}{P_t y_t}) \quad (2)$$

Where ι denotes the parameter measuring the risk premium, e_t is the nominal exchange rate and $B_t^{\,f}$ is the net foreign asset. Note finally that y_t is the real GDP and P_t is the Consumer Price Index (CPI).

During period t, the household pays taxes on labor income, ψ to finance government spending and earns nominal wage, W_t for its labor supply. It also receives dividend payments from both non-oil, $D_{no,t}$, and import, $D_{I,t}$, sectors so that $D_t \cong D_{no,t} . D_{I,t}$.

At last, the household accumulates $K_{o,t}$ and $K_{no,t}$ units of capital stocks, used in the oil and non-oil sectors for nominal rental Q_t. The evolution of capital stock in each sector is given by:

$$k_{j,t.1} \cong (1 0 \gamma) k_{j,t} \,.\, i_{j,t} \; 0 \; \therefore_j (k_{j,t.1}, k_{j,t}) \tag{3}$$

Where $(0 ? \gamma ? 1)$ is the depreciation rate of all sectors and $\therefore_j (k_{j,t.1}, k_{j,t})$ is capital-adjustment cost paid by household. The functional form of $\therefore_{\mathrm{j}}$ is given, following Ireland (2003), by:

$$\therefore_{\mathrm{j,t}}(0) \cong \frac{|_{\mathrm{j}}}{2} (\frac{\mathrm{k}_{\mathrm{j,t.1}}}{\mathrm{k}_{\mathrm{j,t}}} 0 1)^2 \mathrm{k}_{\mathrm{j,t}} \tag{4}$$

Hence in the aggregate, household faces the budget constraint as:

$$P_t c_t \,.\, P_t i_t \,.\, \frac{B_t^d}{R_t} \,.\, \frac{e_t B_t^f}{R_t^f v_t} \infty (1 0 \psi) W_t h_t \,.\, B_{t01}^d \,.\, e_t B_{t01}^f \,.\, Q_t K_t \,.\, D_t \tag{5}$$

The representative household maximizes its lifetime utility function subject to capital accumulation equation and the budget constraint. Therefore, optimization problem yields the following FOCs:

$$\frac{\div \mathrm{L}}{\div \mathrm{c}_{\mathrm{t}}} \cong 0 \Diamond \quad \mathrm{o}_{\mathrm{t}} \cong \mathrm{C}_{\mathrm{t}}^{0\varphi} \tag{6}$$

$$\frac{\div L}{\div h_t} \cong 0 \Diamond \quad o_t \cong \frac{h_t^{\varpi}}{(1 0 \zeta) w_t} \tag{7}$$

$$\frac{\div \mathrm{L}}{\div \mathrm{k}_{\mathrm{t.1}}} \cong 0 \Diamond \quad \mathrm{o}_{\mathrm{t}} \cong \frac{\varepsilon \mathrm{E}_{\mathrm{t}} \left\{ \mathrm{o}_{\mathrm{t.1}} (\mathrm{q}_{\mathrm{t.1}} \,.\, (1 0 \gamma) 0 \frac{|_{\mathrm{j}}}{2} (\frac{\mathrm{k}_{\mathrm{j,t.2}}}{\mathrm{k}_{\mathrm{j,t.1}}} 0 1)^2 \,.\, |_{\mathrm{j}} (\frac{\mathrm{k}_{\mathrm{j,t.2}}}{\mathrm{k}_{\mathrm{j,t.1}}} 0 1)(\frac{\mathrm{k}_{\mathrm{j,t.2}}}{\mathrm{k}_{\mathrm{j,t.1}}}) \right\}}{1. |_{\mathrm{j}} (\frac{\mathrm{k}_{\mathrm{j,t.1}}}{\mathrm{k}_{\mathrm{j,t}}} 0 1)} \tag{8}$$

$$\frac{\div L}{\div(\frac{B_t^d}{P_t})} \cong 0 \lozenge \quad o_t \cong \varepsilon R_t E_t \left[\frac{o_{t.1}}{\sigma_{t.1}} \right] \tag{9}$$

$$\frac{\div L}{\div \left[\frac{B_t^f}{P_t^f} \right]} \cong 0 \lozenge \quad \frac{o_t S_t}{R_t^f \nu_t} \cong \varepsilon E_t \left[\frac{o_{t.1} S_{t.1}}{\sigma_{t.1}^f} \right] \tag{10}$$

By combing (10) and (11), it's possible to obtain an expression for the uncovered interest parity (UIP) condition given by:

$$\frac{R_t}{R_t^f \nu_t} \cong \frac{E_t(S_{t.1}) E_t(\sigma_{t.1})}{S_t E_t(\sigma_{t.1}^f)} \tag{11}$$

It means that, each time a domestic household borrows from abroad; it must pay a premium over the international price of external borrowings.

Where $\sigma_{t.1} \cong \frac{P_{t.1}}{P_t}$, $\sigma_{t.1}^f \cong \frac{P_{t.1}^f}{P_t^f}$, $w_t \cong \frac{W_t}{P_t}$, $q_t \cong \frac{Q_t}{P_t}$ and $S_t \cong e_t \frac{P_t^f}{p_t}$ represent the CPI inflation rate, the world inflation rate, the real wage, the real capital return and the real exchange rate respectively. Note that variables σ_t^f, R_t^f which represent the world inflation rate and the foreign interest rate evolve exogenously according to the following AR (1) process:

$$\log(\sigma_t^f) \cong (1 0 \upsilon_{\sigma^f}) \log(\sigma^f) . \ \upsilon_{\sigma^f} \log(\sigma_{t01}^f) . \ \eta_{\sigma^f,t} \tag{12}$$

$$\log(R_t^f) \cong (1 0 \upsilon_{R^f}) \log(R^f) . \ \upsilon_{R^f} \log(R_{t01}^f) . \ \eta_{R^f,t} \tag{13}$$

3.2. Oil sector

Oil firm uses technology, $A_{0,t}$, capital, $K_{0,t}$ and labor $h_{0,t}$ for producing crude oil and exporting abroad total oil output. The oil-producing firm maximizes profit by taking international oil price $p_{0,t}^{f}$ and Q_t, w_t. It operates under decreasing return to scale technology. The problem faced by the oil sector can therefore be summarized as:

$$Max(e_t p_{o,t}^{f}\, y_{o,t}\ 0\, Q_t\, k_{o,t}\ 0\, W_t\, h_{o,t}) \tag{14}$$

$$\text{S.T}\quad y_{o,t} \infty A_{o,t} k_{o,t}^{\delta_o} h_{o,t}^{\varepsilon_o} \tag{15}$$

Where δ_0, ε_0 €(0,1), denote respectively shares of capital and labor in the production of oil and $0 ?\ \delta_0 .\ \varepsilon_0 ?\ 1$

The First Order conditions imply:

$$k_{o,t} \cong \delta_o s_t\ p_{o,t}^{f} \frac{y_{o,t}}{q_t} \tag{16}$$

$$h_{o,t} \cong \varepsilon_o S_t\ p_{o,t}^{f} \frac{y_{o,t}}{w_t} \tag{17}$$

The two above equations determine respectively the capital and labor demand for the oil sector, and $p_{o,t}^{f} \cong \frac{P_{o,t}^{f}}{P_t^{f}}$ denotes the real oil price. Decreasing return to scale is assumed for the oil production to guarantee the existence of positive profit for the oil sector maximization problem.

Finally, the international oil price, $P_{0,t}^{f}$ and technology shock in the oil sector, $A_{0,t}$, following stochastic process:

$$\log(P_{o,t}^{f}) \cong (1\,0\,\upsilon_{p_o^f})\log(P_o^{f}) .\ \ \upsilon_{p_o^f}\ \log(p_{0o,t01}^{f}) .\ \ \eta_{p_{o,t}^f} \tag{18}$$

$$\log(A_{o,t}) \cong (1\,0\,\upsilon_{Ao})\log(A_o) .\ \ \upsilon_{Ao}\log(A_{o,t01}) .\ \ \eta_{A_{o,t}} \tag{19}$$

3.3. Non- oil sector

Firms producing non-oil goods operate in a monopolistic competitive market. They hire capital, $k_{no,t}(i)$ labor, $h_{no,t}(i)$ and refined oil $y^{I}_{o,t}(i)$ to produce the non-oil goods. Each firm indexed $i \angle \lfloor 0,1$ produces $y_{no,t}(i)$ units of differentiated non- oil goods using the following Cobb-Douglas production technology:

$$y_{no,t}(i) \infty A_{no,t} K_{no,t}^{\delta_{no}}(i) h_{no,t}^{\varepsilon_{no}}(i) y_{o,t}^{I\,\tau_{no}}(i) \tag{20}$$

Where $\delta_{no}, \varepsilon_{no}$ and τ_{no} donate respectively a share of capital, $k_{no,t}$, labor, $h_{no,t}$ and refined oil, $y^{I}_{0,t}$ in the production of non-oil goods. Note also that the technology shock specific to the non-oil sector is assumed to follow the AR(1) process given by:

$$\log(A_{no,t}) \cong (1 0 \upsilon_{A_{no}}) \log(A_{no}) .\ \upsilon_{A_{no}} \log(A_{no,t01}) .\ \eta_{A_{not}} \tag{21}$$

To maximize its profit, the producer i chooses $k_{no,t}(i)$, $h_{no,t(i)}$, $y^{I}_{o,t}(i)$ and set its price $p^{*}_{no,t}(i)$ by using Calvo-Yun type price setting. Following rule of Calvo (1983), the producer faces a constant probability of changing its price in each period. This probability is given by $(1 0 \iota_{no})$. As in Yun(1996), we assume that if non-oil goods producers are not able to change their prices, they index them to the steady state CPI inflation rate according to the following rule where σ is the long run average gross rate of inflation. The present discounted value of the flows of profit is obtained from the following problem:

$$\text{Max} \quad E_0 \Big|_{s\cong 0}^{\clubsuit} \left\{ (\varepsilon\iota_{no})^s o_{t.s} \frac{D_{no,t.s}(i)}{P_{t.s}} \right\} \tag{22}$$

$$y_{no,t.s}(i) \cong \left[\frac{\sigma^s P^{*}_{no,t}(i)}{P_{no,t.s}} \right]^{0v} y_{no,t.s} \tag{23}$$

Subject to the sequence of demand function:

Where $D_{no,t.s}(i)$ is the profit function:

(24)

$$D_{no,t.s}(i) \cong \sigma^s P^*_{no,t}(i) y_{no,t.s}(i)\, 0\, Q_{t.s} K_{no,t.s}(i)\, 0\, W_{t.s} h_{no,t.s}(i)\, 0\, P_{o,t} y^I_{o,t.s}(i)$$

The FOCs[1] of the maximization problem are:

$$k_{no,t}(i) \cong \delta_{no} \frac{y_{no,t}(i)}{q_t} mc_{no,t} \tag{25}$$

$$h_{no,t}(i) \cong \varepsilon_{no} \frac{y_{no,t}(i)}{w_t} mc_{no,t} \tag{26}$$

$$y^I_{o,t}(i) \cong \theta_{no} \frac{y_{no,t}(i)}{p_{o,t}} mc_{no,t} \tag{27}$$

Where equations (25) - (27) are the demand for capital, labor and oil by non-oil producer. Furthermore, $p_{o,t} \cong \frac{P_{o,t}}{P_t}$ and $\mathrm{mc}_{\mathrm{no,t}} \cong \frac{\mathrm{MC}_{\mathrm{no,t}}}{\mathrm{P_t}}$ denote respectively, the real domestic oil price and the real marginal cost.

The real marginal cost $\mathrm{mc}_{\mathrm{no,t}}$ can be obtained by replacing Equations (25)-(27) in (20):

$$mc_{no,t} \cong \frac{q_t^{\delta_{no}} w_t^{B_{no}} p_{o,t}^{\tau_{no}}}{\delta_{no}^{\delta_{no}} \varepsilon_{no}^{\varepsilon_{no}} \tau_{no}^{\tau_{no}}} \tag{28}$$

Now, if the optimization problem of non-oil firm is solved with respect to reset price control variable, the first order condition will be given by:

1. First order condition

(29)

$$p^{*}_{no,t}(i) \cong \left[\frac{v}{v\,0\,1}\right]\frac{E_0 \sum_{s\cong 0}^{♣} (\varepsilon\iota_{\ no})^{s}\, o_{t.\ s}\, y_{no,t.\ s}\, p^{v}_{no,t.\ s}\, mc_{no,t.\ s} \cdot \prod_{K\cong 1}^{S} \sigma^{0\,S\theta}\sigma^{\theta}_{t.\ K}}{E_0 \sum_{s\cong 0}^{♣} (\varepsilon\iota_{\ no})^{s}\, o_{t.\ s}\, y_{no,t.\ s}\, p^{v}_{no,t.\ s} \cdot \prod_{k\cong 1}^{S} \sigma^{s(1 0 v)}\sigma^{v01}_{t.\ k}}$$

Where $\mathrm{p}^{*}_{\mathrm{no,t.\ s}} \dfrac{\mathrm{P}_{\mathrm{no,t.\ s}}}{\mathrm{P}_{\mathrm{t.\ s}}}$ and $\sigma_{\mathrm{t.\ s}} \cong \dfrac{\mathrm{P}_{\mathrm{t.\ s}}}{\mathrm{P}_{\mathrm{t}}}$ denote the real optimized price for non-oil goods and the CPI inflation rate respectively.

The aggregate non-oil price index evolves according to the following recursive form:

$$(P_{no,t})^{1 0 v} \cong \iota_{\ no}(\sigma P_{no,t01})^{1 0 v} \ . \ (1 0\, \iota_{\ no})(P^{*}_{no,t})^{1 0 v} \tag{30}$$

This means that the aggregate price level in non-oil sector is a convex combination of the reset price and the previous price level, just as assumed earlier.

3.4. Import sector

In this sector, imported goods $y_{I,t}$ are imported at the world price P^{f}_{t} and sold by importers who follow Calvo and Yun price setting in domestic monopolistically competitive market at price $P_{I,t}(i)$. On this basis, the law of one price does not apply.

The maximization problem of importers can be written as follows:

$$\mathrm{Max}\quad \mathrm{E}_{\cdot} \sum_{\mathrm{s}\cong \cdot}^{♣} (\varepsilon\iota_{\ \mathrm{I}})^{\mathrm{s}}\, \mathrm{o}_{\mathrm{t.\ s}}(\sigma^{\mathrm{s}}\mathrm{P}^{*}_{\mathrm{I,t}}\ (\mathrm{i})\, 0\, \mathrm{e}_{\mathrm{t.\ s}}\mathrm{P}^{\mathrm{f}}_{\mathrm{t.\ s}})\mathrm{y}_{\mathrm{I,t.\ s}}(\mathrm{i}) \tag{31}$$

Subject to the sequence of demand function:

$$\mathrm{y}_{\mathrm{I,t.\ s}}(\mathrm{i}) \cong \left[\frac{\sigma^{\mathrm{s}}\mathrm{P}^{*(\mathrm{i})}_{\mathrm{I,t}}}{\mathrm{P}_{\mathrm{I,t.\ s}}}\right]^{0\mathrm{M}} \mathrm{y}_{\mathrm{I,t.\ s}} \tag{32}$$

Replacing (32) in (31) and following the same steps used for the non-oil sector, we get the optimal pricing condition which can be expressed as:

$$P^{*}_{I,t}(i)\cong\left[\frac{M}{M0\,1}\right]\frac{E_0\Big|_{s\cong0}^{\clubsuit}(\varepsilon\iota_{\,I})^{S}o_{t.\,s}p^{M}_{I,t.\,s}\quad mc_{I,t.\,s}\cdot\,_{k\cong1}^{S}\ \sigma^{0sM}\sigma^{M}_{t.\,k}}{E_0\Big|_{s\cong0}^{\clubsuit}(\varepsilon\iota_{\,I})^{s}o_{t.\,s}y_{I,t.\,s}p^{M}_{I,t.\,s}\cdot\,_{k\cong1}^{S}\ \sigma^{s(10M)}\sigma^{M01}_{t.\,k}} \tag{33}$$

Where $p_{I,t.\,s}\cong\dfrac{P_{I,t.\,s}}{P_{t.\,s}}$ is the relative price of imports, $mc_{I,t+s}=\frac{e_tP_t^f}{P_{I,t}}$ is the real marginal cost and $p^{*}_{I,t}(i)\cong\dfrac{P^{*}_{I,t}(i)}{P_t}$ is the optimized price in import sector.

Then the importer price index can be written as:

$$P_{I,t.\,s}\cong\left[\int\sigma^{s}P^{*}_{I,t}(i)^{\backslash0M}di\right]^{\frac{\backslash}{\backslash0M}} \tag{34}$$

The dynamic of the import price evolves according to the following recursive form:

$$(p_{I,t})^{10M}\cong\iota_{\,I}(\sigma P_{I,t01})^{10M}.\;(10\,\iota_{\,I})(P^{*}_{I,t})^{10M} \tag{35}$$

This means that the aggregate import price level is a convex combination of the reset import price and the previous import price level.

3.5. Final good producer

Final good is produced using the following CES[1] technology that includes non-oil output, $Y_{no,t}$, (which is domestically produced) and imports, $Y_{I,t}$ can be expressed as:

1. Constant elasticity substitution

$$Z_t \cong \left[X_{no}^{\frac{1}{\omega}} Y_{no,t}^{\frac{\omega 0 1}{\omega}} \;.\; X_{I}^{\frac{1}{\omega}} Y_{I,t}^{\frac{\omega 0 1}{\omega}} \right]^{\frac{\omega}{\omega 0 1}} \tag{36}$$

The parameter $\omega \text{A} 0$ is the elasticity of substitution between non-oil output and imported goods. X_{no}, X_I are the shares of non-oil and imported goods in the final good respectively, where $X_{no} \;.\; X_I \cong 1$. The final good is divided between consumption, investment and government expenditures. To maximize its profit, the final good producer chooses, $Y_{I,t}$ and $Y_{no,t}$. Resolving this problem, we get the following demand function for non-oil goods and imported goods.

$$\mathrm{Y}_{\mathrm{no,t}} \cong \mathrm{X}_{\mathrm{no}} \left[\frac{\mathrm{P}_{\mathrm{no,t}}}{\mathrm{P}_{\mathrm{t}}} \right]^{0\omega} \mathrm{Z}_{\mathrm{t}} \tag{37}$$

$$\mathrm{Y}_{\mathrm{I,t}} \cong \mathrm{X}_{\mathrm{I}} \left[\frac{\mathrm{P}_{\mathrm{I,t}}}{\mathrm{P}_{\mathrm{t}}} \right]^{0\omega} \mathrm{Z}_{\mathrm{t}} \tag{38}$$

We assume that the final good producer operates under perfect competition, and then the zero profit condition implies that the price of final good is given by:

$$P_t \cong \left[X_{no} P_{no,t}^{10\omega} \;.\; X_I P_{I,t}^{10\omega} \right]^{\frac{1}{10\omega}} \tag{39}$$

3.6. Government

In our model, we assume that the crude oil is exported abroad at the international price, $P_{0,t}^{f}$ (denominated in dollars) and also domestically used refined oil, $y_{0,t}^{I}$ is imported and sold to the domestic non-oil firms at price $P_{o,t}$ (which can be considered as the domestic fuel price). For this purpose, according to Bouakez (2008) and Benkhodja (2011), we assume that the domestic oil price $P_{o,t}$ is given by a convex combination of the current world price $P^{f}_{0,t}$, and last period's domestic prices. Therefore, it follows the following functional form:

$$P_{o,t} \cong (1 0 \vartheta) P_{o,t01} \cdot \vartheta_t P^{f}_{o,t} \tag{40}$$

Where ϑ denotes oil price rule parameter. Meanwhile, the government that owns the oil company exports crude oil and imports refined oil at the global price of $P^{f}_{0,t}$. Finally, the balanced government budget is:

$$\psi(w_t h_t) \cdot s_t p^{f}_{o,t} y_{o,t} \cong (S_t \; p^{f}_{o,t} \; 0 \; p_{o,t}) y^{I}_{o,t} \cdot w_t h_{o,t} \cdot q_t k_{o,t} \tag{41}$$

The government can finance its spending g_t, through taxes on labor income $\psi(w_t h_t)$ and from selling oil $(S_t p^{f}_{o,t} y_{o,t})$. On the other hand, government spending include payment both wages and capital return $(w_t h_{o,t} \cdot q_t k_{o,t})$ in the oil sector and the amount of oil's subsidies $(S_t p^{f}_{o,t} \; 0 \; p_{o,t}) y^{I}_{o,t}$.

3.7. Monetary Policy

We assume that the central bank adjusts the short-term nominal interest rate, i_t in response to fluctuation in inflation in the non-oil good sector (PPI[1] inflation) $\sigma_{no,t}$, CPI inflation σ_t, GDP gap y_t and real exchange rate s_t. The general functional form of the monetary policy rule in this economy can be written as the following Taylor-type relationship:

$$\frac{1 \cdot i_t}{1 \cdot \bar{i}} \cong \left(\frac{1 \cdot i_{t01}}{1 \cdot \bar{i}}\right)^{\rho_i} \left(\frac{y_t}{\bar{y}}\right)^{(10\rho_i)\pi_y} \left(\frac{\sigma_{no,t}}{\bar{\sigma}_{no}}\right)^{(10\rho_i)\pi_{\sigma no}} \left(\frac{\sigma_t}{\bar{\sigma}}\right)^{(10\rho_i)\pi_\sigma} \left(\frac{s_t}{\bar{s}}\right)^{(10\rho_i)\pi_s} \tag{42}$$

Where the variables $\bar{\imath}, \bar{Y}, \bar{\pi}_{no}, \bar{\pi}$ *and* $\bar{s}$ denote the steady-state values of

1. Producer price inflation

the corresponding variables. The first factor on the right hand side of equation (42) models the degree of interest rate smoothing. The second factor shows that the central bank responds to deviations of GDP from the steady-state level of economy. Similarly, the third and fourth factors respect the fact that the monetary authority reacts to changes in inflation in the non-oil goods sector and CPI inflation. The last factor is the reaction of the real exchange rate fluctuations.

3.8. Equilibrium

Aggregate equilibrium condition in each market is as follows:

GDP is:

$$p_t Y_t \cong P_{no} Y_{no}^{va} \;.\; e_t P_{o,t}^{f} Y_{o,t} \tag{43}$$

Where Y_t and $Y_{no,t}^{va}$ are the GDP and value added output in non-oil goods sector respectively. The value added of goods in non-oil sector is obtained as:

$$p_{no,t} Y_{no,t}^{va} \cong P_{no,t} Y_{no,t} \; 0 \; e_t P_{o,t}^{f} Y_{o,t}^{I} \tag{44}$$

$$\frac{p_{no,t} Y_{no,t}^{va}}{p_t} \;.\; \frac{e_t p_{o,t}^{f} Y_{o,t}}{p_t} \cong c_t \;.\; i_t \;.\; g_t \;.\; \frac{P_{x,t} X_t}{p_t} \; 0 \; \frac{p_{M,t} M_t}{p_t} \tag{45}$$

$$\frac{p_{no,t} Y_{no,t}^{va}}{p_t} \;.\; \frac{e_t p_{o,t}^{f} Y_{o,t}}{p_t} \cong c_t \;.\; i_t \;.\; g_t \;.\; \frac{e_t P_{o,t}^{f} Y_{o,t}}{p_t} \; 0 \; \frac{e_t p_{o,t}^{f} Y_{o,t}^{I}}{p_t} \; 0 \; \frac{e_t p_t^{f} Y_{I,t}}{p_t} \tag{46}$$

Based on these relationships, it can be concluded that real GDP value is given by:

$$Y_t \cong c_t \; . \; i_t \; . \; g_t \; . \; \frac{e_t P_{o,t}^f Y_{o,t}}{P_t} \, 0 \, \frac{e_t p_{o,t}^f Y_{o,t}^I}{P_t} \, 0 \, \frac{e_t p_t^f Y_{I,t}}{P_t} \tag{47}$$

The capital market:

$$K_t \cong K_{o,t} \; . \; K_{no,t} \tag{48}$$

The labor market:

$$h_t \cong h_{o,t} \; . \; h_{no,t} \tag{49}$$

From the budget constraint and the rest of aggregate equilibrium conditions, current account can be obtained as:

$$\frac{e_t B_t^f}{R_t^f \kappa_t} \, 0 \, e_t B_{t0\,1}^f \cong P_{X,t} X_t \, 0 \, P_{M,t} M_t \tag{50}$$

Where nominal exports value is defined as:

$$P_{X,t} X_t \cong e_t P_{o,t}^f Y_{o,t} \tag{51}$$

And nominal imports value is given by:

$$P_{M,t} M_t \cong e_t P_{o,t}^f Y_{o,t}^I \; . \; e_t P_t^f Y_{I,t} \tag{52}$$

In a symmetric equilibrium, all importers and non-oil producers make the same decision so that $y_{no,t}(i)$ $y_{no,t}$, $y_{I,t}(i) = y_{I,t}$, $p_{I,t}(i) = p_{I,t}$ and $p_{no,t}(i) = p_{no,t}$. Having assumed symmetry, the next step is to obtain the steady state condition for variables and rewrite them in this situation. The log-linearized equations of the model are presented in Appendix.

4. Solution

In this part, the model is estimated using Bayesian method but first the data and the method used to estimate model parameters are described.

4.1. Data

Time series quarterly adjusted data for the variables of real GDP, inflation, real consumption, real effective exchange rate, and real oil revenues of the economy of Iran during 1988:1 to 2011:1 are used to estimate the presented model[1]. Using Hodrik-Prescott filter، trend component is separated from data and the analysis is conducted for cyclical component. Another important stage in completion of DSGE models is to quantify model parameters. Indexes that can be calibrated according to data of the economy of Iran are summarized in table 1.

Table 1: Calibration of structural parameters

Parameter	Definition	Value	Source
β	Discount factor	0.985	Jalali Naini, Naderian(2011)
γ	the inverse of inter-temporal elasticity of substitution	2.17	Jalali Naini, Naderian(2011)
σ	Frish elasticity of labor supply	2.17	Taei(2006)
δ	The depreciation rate of capital	0.042	Amini, Haji Mohammad (2005)
$\frac{kno}{k}$	Steady state ratio of capital in non-oil sector to total capital	0.81	Author’s calculation
$\frac{\bar{c}}{\bar{y}}$	Steady state ratio of consumption to GDP	0.49	Author’s calculation
$\frac{\bar{\iota}}{\bar{y}}$	Steady state ratio of investment to GDP	0.28	Author’s calculation

1. All data are extracted from the time series published by the CBI except real effective exchange rate which comes from IFS.

Parameter	Definition	Value	Source
$\frac{\bar{g}}{\bar{y}}$	Steady state ratio of government expenditures to GDP	0.19	Author's calculation
$\frac{\bar{s}\bar{p}_o^f\bar{y}_o}{\bar{y}}$	Steady state ratio of oil exporting revenues to GDP	0.26	Author's calculation
$\frac{\bar{s}\bar{p}_o^f\bar{y}_o^I - \bar{s}\bar{y}_I}{\bar{y}}$	Steady state ratio of imports to GDP	0.22	Author's calculation
$\frac{\bar{S}\bar{P}_o^f\bar{Y}_o}{\bar{g}}$	Steady state ratio of oil exporting revenues to government expenditures	0.5	Author's calculation

Source: Author's calculation

4.2. Estimation of model parameters

The model is estimated by using the Bayesian method and solved through the Dynare software. Bayesian estimation of a model is made based on a likelihood function which is obtained by solving a model in log-linearized format. In this method, prior distribution of parameters provides the additional information for estimation of model parameters. Prior distribution of each parameter is selected according to its features and characteristics of the considering distribution. For example, Beta distribution can be used for those parameters that must lie in [0 1] interval. Therefore, this distribution is applied to the parameters of price stickiness and share of production factors in each sector. Moreover, inverse Gamma distribution is used for non-negative parameters. That is why it is used for standard deviation of shocks such as oil price shocks which have a non-negative range. The remaining parameters have a normal distribution. Thus, normal distribution is used for all monetary policy coefficients and for the capital adjustment costs in each sector.

Table 2: Estimation Results

Parameter	Definition	Density	Value	Source
α_o	Share of capital in the production of oil	beta	0.6	0.61
α_{no}	Share of capital in the production of non-oil goods	beta	0.41	0.38
θ_{no}	Share of oil in the production of non-oil goods	beta	0.15	0.21
$\emptyset_{no}$	Probability of price reset in non-oil goods	beta	0.65	0.53
ϕ_I	Probability of price reset in imported goods	beta	0.75	0.85
χ_{no}	Share of non-oil goods in the final good	beta	0.75	0.73
χ_I	Share of imported goods in the final good	beta	0.25	0.27
ψ_o	Coefficient of capital adjustment cost in oil sector	normal	6.5	6.56
ψ_{no}	Coefficient of capital adj. cost in non-oil sector	normal	5.5	5.9
$\sigma_{p_o^f}$	Standard deviation of oil price	Inverse gamma	0.5	0.5
μ_y	Coefficient on GDP	normal	0.5	0.7
μ_π	Coefficient on CPI inflation	normal	1.5	2.39
$\mu_{\pi_{no}}$	Coefficient on PPI inflation	normal	1.5	1.97
μ_s	Coefficient on real exchange rate	normal	0.25	0.18

Source: Author's calculation

5. Analysis of Impulse Response Functions (IRF)

Impulse response functions exhibit the dynamic behavior of model variables during time when a shock as big as one standard deviation occurs to a variable. Our analysis focuses on contemporaneous responses to shocks. Figure 1 demonstrates the effect of a real oil price shock on real exchange rate (s) and consumption (c). A positive oil price shock will cause an immediate decrease in real exchange rate and an increase in imports (due to rise of oil exporting revenues). As time passes, reduction of exchange rate is compensated and it returns to its steady state value. In addition, as a result of a rise in real oil prices, consumption increases in the short-run.

Figure 1: The effect of a real oil price shock on real exchange rate and consumption

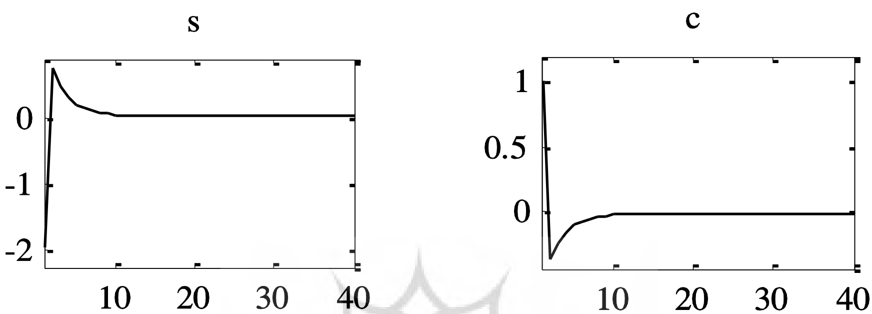


Figure 2 demonstrates the impact of a positive real oil price shock on the production of oil and non-oil sectors as well as capital, employment and GDP. As expected, after a positive real oil price shock, the country is motivated to produce more oil, which leads to an increase in demand for capital and labor in the oil sector.

As real exchange rate decreases, due to an increase in the real oil price, some parts of domestic non-oil products is substituted by imported goods, as a result, the demand for production factors in non-oil sector will be decreased. Consequently, some parts of labor force and capital leave the sector and transfer to oil sector. Therefore, the production in non-oil sector decreases. Moreover, labor market will face overall reduction in employment. In capital market, since the oil is more capital intensive than non-oil sector, demand for capital increases which in turn cause an increase in real return on capital. To sum up, we face increase of capital and its real return.

Furthermore, figure 2 exhibits the response of GDP to a real oil price shock; the current situation caused by the increase of crude oil export will lead to GDP growth in the short-run. However, GDP components are propelled towards the increase of imports as well as the shrinkage of non-oil sector.

Figure 2: The impact of a real oil price shock on oil and non-oil production, capital, employment and GDP

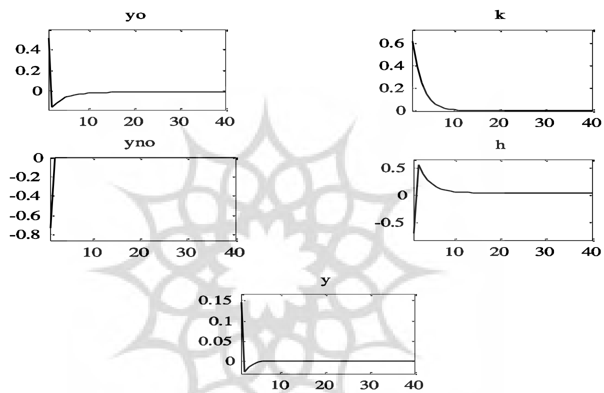
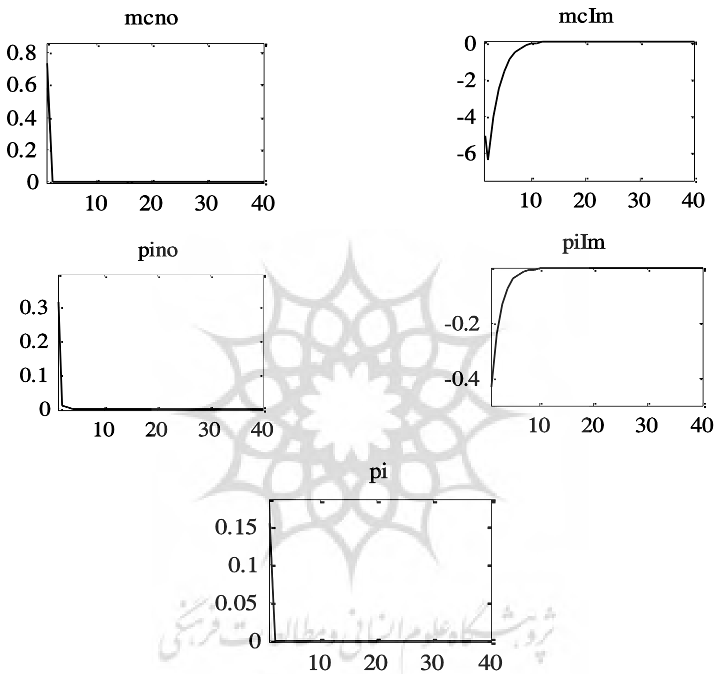


Figure 3 shows the short-run impact of a positive real oil price shock on the marginal cost in non-oil sector (mcno), import sector (mcIm) and inflation (pi). In Philips curve, non-oil inflation (pino) depends not only on future inflationary expectations but also on marginal cost in non-oil sector. Since oil is a production factor in non-oil sector in Iran, any increase in real oil price will result in increase of marginal cost and inflation in non-oil sector. Due to rise of real capital rent and real oil prices, the government pays fuel subsidies to protect domestic production. However, with the decrease of real exchange rate, marginal cost in import sector, and consequently, inflation for imported goods (piIm) go down. Since the inflation is the weighted average of imported and domestic non-oil inflations, it increases in average. But a reduction in imported inflation prevents CPI inflation to rise enormously. It implies that a large part of CPI inflation is determined exogenously.

Figure 3: The effect of a positive real oil price shock on marginal cost and inflation in non-oil and import sectors



6. Conclusion

In this paper, by using the Bayesian approach, a New Keynesian Multi sector DSGE model for Iran is designed to investigate the impact of a real oil price shock on the dynamics of economic variables. For this purpose, first a model is designed in accordance with the features of the economy of Iran. Then, we considered the role of oil from many aspects: First, as the main source of export revenues. Second, as a finance resource for government budget.

Third, as a factor of production. Moreover, the fuel subsidies are included in the model. Finally as opposed to conventional New Keynesian model which assumes that the law of one price applies to all imported goods, we assumed sticky prices both in the non-oil and import sectors of Iran.

Then, the results attained from baseline model are interpreted by focusing on posterior means and impulse response function. The contemporaneous responses after a positive real oil price shock exhibit a decrease in real exchange rate and an increase in imports due to rise of oil exporting revenues, and an increase in consumption. Moreover, as a result of a real oil price shock, oil production increases, while, the non-oil production decreases. To sum up, as a result of real oil price shock, GDP increases, however the high share of the oil sector in the GDP of Iran explains the positive response of the latter. In addition, we face an increase in capital and a reduction in employment as a whole. Furthermore, although CPI inflation increases, but a reduction in imported inflation prevents CPI inflation to rise enormously. It implies that a large part of CPI inflation is determined exogenously.

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Appendix

The log-linearized equations of the model:
Optimizing representative household in the form of log-linearized

$$\tilde{o}_t \cong 0\varphi\tilde{c}_t$$

$$\tilde{o}_t \cong \varpi\tilde{h}_t \; 0 \; \tilde{w}_t$$

$$E_t(\tilde{o}_{t.1} \, 0 \, \tilde{o}_t) . \; E_t[(1 0 \varepsilon(1 0 \gamma))\tilde{q}_{t.1} . \; \varepsilon/ \;_j(\tilde{k}_{j,t.2} \, 0 \, 2\tilde{k}_{j,t.1} . \; \tilde{k}_{j,t})] \cong 0$$

$$\tilde{i}_{j,t.1} \cong \frac{1}{\gamma}[\tilde{k}_{j,t.1} \, 0 \, (1 0 \gamma)\tilde{k}_{j,t}]$$

$$E_t(\tilde{R}_t . \; \tilde{o}_{t.1} \, 0 \, \tilde{o}_t \, 0 \, \tilde{\sigma}_{t.1}) \cong 0$$

$$E_t[(\tilde{o}_{t.\text{١}} \, 0 \, \tilde{o}_t) . \; (\tilde{s}_{t.\text{١}} \, 0 \, \tilde{s}_t) \, 0 \, \tilde{\sigma}^f_{t.\text{١}} . \; \tilde{R}^f_t . \; \tilde{v}_t] \cong \text{٠}$$

$$\tilde{R}_t \, 0 \, \tilde{R}^f_t \, 0 \, \tilde{v}_t \cong E_t\tilde{s}_{t.1} . \; E_t\tilde{\sigma}_{t.1} \, 0 \, \tilde{s}_t \, 0 \, E_t\tilde{\sigma}^f_{t.1}$$

$$\tilde{R}^f_t \cong \upsilon_{R^f}\tilde{R}^f_{t01} . \; \eta_{R^f,t}$$

$$\tilde{\sigma}^f_t \cong \upsilon_{\sigma^f} \tilde{\sigma}^f_{t01} . \ \eta_{\sigma^f,t}$$

Optimizing oil sector in the form of log-linearized

$$\tilde{y}_{o,t} \cong \tilde{A}_{o,t} . \ \delta_o \tilde{k}_{o,t} . \ \varepsilon_o \tilde{h}_{o,t}$$

$$\tilde{k}_{o,t} \cong \tilde{s}_t . \ \tilde{p}^f_{o,t} \tilde{y}_{o,t} \ 0 \ \tilde{q}_t$$

$$\tilde{h}_{o,t} \cong \tilde{s}_t . \ \tilde{p}^f_{o,t} . \ \tilde{y}_{o,t} \ 0 \ \tilde{w}_t$$

$$\tilde{p}^f_{o,t} \cong \upsilon_{p_o f} \tilde{p}^f_{o,t01} . \ \eta_{p^f_o,t}$$

$$\tilde{A}_{o,t} \cong \upsilon_{A_o} \tilde{A}_{o,t01} . \ \eta_{A_o,t}$$

Optimizing non-oil sector in the form of log-linearized

$$\tilde{y}_{no,t} \cong \tilde{A}_{no,t} . \ \delta_{no} \tilde{K}_{no,t} . \ \varepsilon_{no} \tilde{h}_{no,t} . \ \tau_{no} \tilde{y}^I_{o,t}$$

$$\tilde{k}_{no,t} \cong \tilde{y}_{no,t} \ 0 \ \tilde{q}_t . \ \tilde{m}c_{no,t}$$

$$\tilde{h}_{no,t} \cong \tilde{y}_{no,t} \ 0 \ \tilde{w}_t . \ \tilde{m}c_{no,t}$$

$$\tilde{y}^I_{o,t} \cong \tilde{y}_{no,t} \ 0 \ \tilde{p}_{o,t} . \ \tilde{m}c_{no,t}$$

$$\tilde{m}c_{no,t} \cong \delta_{no} \tilde{q}_t . \ \varepsilon_{no} \tilde{w}_t . \ \tau_{no} \tilde{p}_{o,t}$$

$$\tilde{\sigma}_{no,t} \cong \varepsilon E_t \tilde{\sigma}_{no,t.1} . \ \frac{(10\iota_{no})(10\varepsilon\iota_{no})}{\iota_{no}} \tilde{m}c_{no,t}$$

$$\tilde{A}_{no,t} \cong \upsilon_{A_{no}} \tilde{A}_{no,t01} . \ \eta_{A_{no,t}}$$

Optimizing import sector in the form of log-linearized

$$\tilde{\sigma}_{I,t} \cong \varepsilon E_t \tilde{\sigma}_{I,t.1} . \ \frac{(10\iota_I)(10\varepsilon\iota_I)}{\iota_I} \tilde{m}c_{I,t}$$

$$\widetilde{mc}_{I,t} \cong \tilde{s}_t \; 0 \; \tilde{p}_{I,t}$$

$$\tilde{\sigma}_t \cong \phi_{no}\tilde{\sigma}_{no,t} \; . \; \phi_I \tilde{\sigma}_{I,t}$$

Government sector in the form of log-linearized

$$\tilde{g}_t \cong \zeta \frac{\bar{w}\;\bar{h}}{\bar{g}}(\tilde{w}_t \; . \; \tilde{h}_t) \; . \; \frac{\bar{s}\bar{p}_o^f \bar{y}_o}{\bar{g}}(\tilde{s}_t \; . \; \tilde{p}_{o,t}^f \; . \; \tilde{y}_{o,t})$$

$$\tilde{p}_{o,t} \cong (1 0 M)\tilde{p}_{o,t01} \; . \; M\tilde{s}_t \; . \; M\tilde{p}_{o,t}^f$$

Monetary policy in the form of log-linearized

$$\tilde{i}_t \cong \}_i \tilde{i}_{t01} \; . \; (1 0 \}_i)\pi_y \tilde{y}_t \; . \; (1 0 \}_i)\pi_{\sigma no}\tilde{\sigma}_{no,t} \; . \; (1 0 \}_i)\pi_\sigma \tilde{\sigma}_t \; . \; (1 0 \}_i)\pi_s \tilde{s}_t$$

The market clearing conditions

$$\tilde{y}_t \cong \frac{\bar{c}}{\bar{y}}\tilde{c}_t \; . \; \frac{\bar{i}}{\bar{y}}\tilde{i}_t \; . \; \frac{\bar{g}}{\bar{y}}\tilde{g}_t \; . \; \frac{\bar{x}}{\bar{y}}\tilde{x}_t \; 0 \; \frac{\bar{m}}{\bar{y}}\tilde{m}_t$$

$$\tilde{h}_t \cong \frac{\bar{h}_o}{\bar{h}}\tilde{h}_{o,t} \; . \; \frac{\bar{h}_{no}}{\bar{h}}\tilde{h}_{no,t}$$

$$\tilde{k}_t \cong \frac{\bar{k}_o}{\bar{k}}\tilde{k}_{o,t} \; . \; \frac{\bar{k}_{no}}{\bar{k}}\tilde{k}_{no,t}$$

$$\frac{\bar{b}^f}{\bar{R}^f \bar{v}}(\tilde{b}_t^f \; 0 \; \tilde{R}_t^f \; 0 \; \tilde{v}_t) \; 0 \; \frac{\bar{b}^f}{\bar{\sigma}^f}(\tilde{b}_{t01}^f \; 0 \; \tilde{\sigma}_t^f) \cong \bar{p}_o^f \bar{y}_o(\tilde{p}_{o,t}^f \; . \; \tilde{y}_{o,t}) \; 0 \; \bar{y}_I \tilde{y}_{I,t} \; 0$$

$$\bar{p}_o^f \bar{y}_o^I(\tilde{p}_{o,t}^f \; . \; \tilde{y}_{o,t}^I)$$