Oil Shocks in a DSGE Model for the Korean Economy

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Abstract

We augment a DSGE model for a small open economy with oil imports and assess its performance using DSGE-VAR procedure developed by Del Negro and Schorfheide (2004). The model economy uses oil imports either as direct consumption or an input of production. The empirical analysis with Korean aggregate data reveals that the model economy produces reasonable posterior estimates and works relatively well compared to impulse responses from DSGE-VAR. The shock to the deviation from the law of one price (LOP) in oil prices has an important role in explaining variability of most of observables while it is related to government's accommodating tax policy during this period.

Keywords: Bayesian Estimation, DSGE-VAR, Oil Prices, Misspecification

JEL Classifications: C52, E52, F41, Q43

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1 Introduction

The WTI crude oil price was 29.19 US dollars per barrel at the third quarter of 2003 and it peaked at 139.96 dollars by the third quarter of 2008. This rapid and continual rise in oil prices over recent years posed many questions among the general public as well as economists. Since the Korean economy depends entirely on imports for its acquisition of crude oil, households, entrepreneurs, and policy makers are interested in knowing to what extent the rise in oil prices affects the economy.

There are various channels that changes of oil prices have effects on the economy through. In our model economy, an oil price shock is reflected through the oil consumption. It generates income and substitution effect because oil is included in the consumption bundle of a typical household, that is, oil is directly consumed. An oil price shock also affects firm's decision which results in substitution of oil input in production with capital and labor hiring. The marginal costs of production faced by firms and their pricing decisions are affected; this generates dynamic effects when prices are rigid. Also the substitution with capital in production affects decisions on the capital accumulation, and this brings along longrun effects. We do not explicitly model the speculative motive of oil consumption and trading that can change the expectation formation and we assume that international oil prices are purely exogenous.

The composition of oil use in Korea is reported in Table 1. By sector the fuel for transportation accounts for 34 percent of oil consumption in 2005 while industrial use occupies 51 percent. Home and commercial share is 10 percent. Along the rows shares are listed by types of oil from an petroleum refinery. At a first glance we can notice that use of a certain type of oil is tightly linked to a certain sector. For example, most of gasoline and diesel are used as the fuel for transportation and kerosine is mostly used as the fuel for heating in home and commercial sector. Naphtha, solvent, asphalt, and lubricant are exclusively used in industry. Especially we note that the naphtha occupies 36 percent of total oil use and that it is the main input for the petrochemical industry that produces plastic related products. Because of this clear separation of oil use by type, the imported crude oil after the refinery can be categorized into direct consumption (fuels for transportation and heating) and input of production.

We present the model economy that uses oil imports either as direct consumption or an input of production. The model is a conventional new Keynesian model for a small open economy with an augmentation of oil uses. Within Bayesian estimation framework including DSGE-VARs, the empirical analysis is performed based on the Korean aggregate data. The DSGE-VAR procedure developed by Del Negro and Schorfheide (2004) provides an assessment tool of DSGE model specifications. By Bayesian analysis, we first perform model comparison to check the importance of each channel that transmits an oil price shock to the economy. The model comparison is extended to VAR models whose coefficients are restricted by DSGE models *a priori* with various degrees of tightness. In terms of fitting the data, an optimal degree of tightness, that is, an "optimal" combination between the VAR and a DSGE model is found. We can also derive more sensible impulse responses from VARs that are in line with those from the DSGE models.

We find that the model economy produces reasonable posterior estimates of the structural parameters and works relatively well compared to impulse responses from the VAR with optimal prior weight from DSGE model. The misspecification becomes very severe when either consumption or production motive of oil imports is ignored. From the variance decomposition analysis, we conclude that the variability of the domestic interest rate can be explained mainly by the oil price shocks transmitted to domestic oil prices. The shock to the deviation from the law of one price (LOP) in oil prices has an important role in explaining variability of most of observables. The impulse response analysis shows that the oil price shock has negative impacts on the most of observables at first, but it brings in positive and hump-shaped responses in a medium run. This prolonged response is mainly due to the interplay of the substitution and income effect. The low substitution elasticities between oil and core consumption, and between oil-capital aggregate and labor input, prevent the quick adjustment. In a medium run where the rigid prices and wages are renewed, the income effect from increased demand for Home goods plays an important role. We also calculate the pass-through of oil prices into the core consumption price index using estimated DSGE and VAR models and find that the pass-through is relatively low in both cases. Finally, the deviation from the LOP in oil prices has decreased but the government accommodating tax policy played a limited role during this period. Therefore, more elaborated model on government behavior is anticipated to investigate the pass-through of oil price shocks.

The rest of the paper is organized as follows. Section 2 sets up a small open economy model with oil. Section 3 describes data and estimation methods including DSGE-VARs, the main tool for empirical analysis used in this paper. Section 4 discusses empirical findings, and Section 5 concludes.

2 The Model

Following Bouakez, Rebei, and Vencatachellum (2008) and Medina and Soto (2005) we model an economy where imported oil is either directly consumed by households or used as an input of production. Most common source of direct consumption is fuel for heating and transportation. It is also obvious that oil is used in the production. Noting that the oil use and the capital are substitutable in production, we introduce the capital unlike Medina and Soto (2005).

Households are heterogeneous in the sense that they are monopolistic labor suppliers but wage setting by each household is limited by reoptimization probability. Each household's consumption basket consists of Home and Foreign goods and oil. Firms are monopolistically competitive firms that produce differentiated goods. Just like the wage setting of households, the price setting behavior is characterized as á la Calvo that introduces nominal stickiness of output price of the economy. The government plays a passive role in this model where it runs a balanced budget without any government spending. Monetary authority plays monetary policy based on the interest rate feedback rule. As an open economy, imports consist of oil and Foreign goods either for consumption and investment while only Home goods that are produced with oil, capital, and labor are exported. Exchange rate pass through is perfect for import and export prices except oil prices. Since we treat the Korean economy as a small open economy, foreign sectors are modeled as a set of exogenous processes.

2.1 Households

The domestic economy is populated by a continuum of monopolistically competitive households indexed by $j \in [0, 1]$. Each household supplies a differentiated labor services to firms. There exists a set of perfectly competitive employment agencies that combine the different labor services from households into an aggregate labor index H_t, defined as

$$H_t = \left(\int_0^1 H_t(j)^{\frac{\nu_L - 1}{\nu_L}} \, dj \right)^{\frac{\nu_L}{\nu_L - 1}}$$

where ν_L is the elasticity of substitution across different labor services. Let $W_t(j)$ denote the nominal wage set by household j. Then demand for this household's labor is

$$H_t(j) = \left(\frac{W_t(j)}{W_t} \right)^{-\nu_L} H_t \tag{1}$$

where the aggregate wage index W_t is given by

$$W_t = \left(\int_0^1 W_t(j)^{1-\nu_L} \, dj \right)^{\frac{1}{1-\nu_L}}$$

Household j maximizes its expected lifetime utility drawn from consumption $C_t(j)$ relative to a habit stock, real money balances $M_t(j)/P_t$, and leisure:

$$\mathbf{E}_t \left[\sum_{k=0}^{\infty} \beta^k \left(\log \left(C_{t+k}(j) - \gamma h C_{t+k-1} \right) + \frac{\chi_M}{\mu} \left(\frac{M_{t+k}(j)}{\gamma^{t+k} P_{t+k}} \right)^{\mu} - \chi_H \frac{H_{t+k}(j)^{1+\tau}}{1+\tau} \right) \right]$$

where β is the discount factor, τ is the inverse of the intertemporal substitution elasticity of hours. The habit persistence in consumption is governed by h while γ denotes the growth of the aggregate output by which it is ensured that the economy evolves along a balanced growth path. Note here that the habit stock refers to the entire economy's habit consumption rather that individual habit consumption.

The consumption bundle of household j is given as a CES aggregate of oil $O_{C,t}(j)$ consumption and non-oil core consumption $Z_t(j)$:

$$C_t(j) = \left[\omega_o^{\frac{1}{\phi_c}} O_{C,t}(j)^{1-\frac{1}{\phi_c}} + (1-\omega_o)^{\frac{1}{\phi_c}} Z_t(j)^{1-\frac{1}{\phi_c}} \right]^{\frac{\phi_c}{\phi_c - 1}}$$

where ϕ_c is the intratemporal elasticity of substitution between oil and core consumption and ω_o denotes the share of oil consumption. Oil is directly consumed as fuel for heating and transportation. The core consumption is again defined as a CES aggregate of domestically produced goods (Home goods) $C_{H,t}(j)$ and imported goods (Foreign goods) $C_{F,t}(j)$:

$$Z_t(j) = \left[(1-\omega_F)^{\frac{1}{\phi_z}} C_{H,t}(j)^{1-\frac{1}{\phi_z}} + \omega_F^{\frac{1}{\phi_z}} C_{F,t}(j)^{1-\frac{1}{\phi_z}} \right]^{\frac{\phi_z}{\phi_z - 1}}$$

where ϕ_z denotes the intratemporal elasticity of substitution between Home and Foreign goods, and ω_F is the import share. For any given level of consumption bundle $C_t(j)$ as a result of household utility maximization behavior, household j tries to maximize the profit in purchasing such a consumption bundle. Let $P_{o,t}$ and $P_{Z,t}$ denote the prices of oil and core consumption goods, respectively. We further define P_t as the price of the composite consumption good. Then the consumption bundle is composed of oil and core consumption goods:

$$O_{C,t}(j) = \omega_o \left(\frac{P_{o,t}}{P_t}\right)^{-\phi_c} C_t(j), \qquad Z_t(j) = (1-\omega_o)\left(\frac{P_{Z,t}}{P_t}\right)^{-\phi_c} C_t(j)$$

The core consumption goods basket $Z_t(j)$ is purchased in a similar fashion:

$$C_{H,t}(j) = (1-\omega_F)\left(\frac{P_{H,t}}{P_{Z,t}}\right)^{-\phi_z} Z_t(j), \qquad C_{F,t}(j) = \omega_F \left(\frac{P_{F,t}}{P_{Z,t}}\right)^{-\phi_z} Z_t(j)$$

where $P_{H,t}$ and $P_{F,t}$ are the prices of Home and Foreign goods, respectively. The price of the composite consumption good P_t, namely, the consumption-based price index (CPI), can be written as

$$P_t = \left[\omega_o P_{o,t}^{1-\phi_c} + (1-\omega_o) P_{Z,t}^{1-\phi_c}\right]^{\frac{1}{1-\phi_c}}$$

where the CPI for core consumption is given by

$$P_{Z,t} = \left[(1-\omega_F) P_{H,t}^{1-\phi_z} + \omega_F P_{F,t}^{1-\phi_z}\right]^{\frac{1}{1-\phi_z}}$$

Household j enters period t with domestic portfolio of Arrow securities $D_t(j)$ that pays out one unit of domestic currency in a particular state, foreign-currency bond $B^*_{t-1}(j)$ that pays one unit for sure, nominal money balances $M_{t-1}(j)$, and a stock of capital $K_{t-1}(j)$.[1] In period t, the household pays a lump-sum tax $T_t(j)$, earns income from selling labor and renting capital to firms, receives dividends (profits) $\Pi_t(j)$ from monopolistic firms, and adjusts the balances on domestic portfolio, foreign-currency bond, and nominal money balances. In particular, acquiring the position on foreign-currency bond entails the premium, that is, households need to pay more than the international price to purchase bonds. Now we can write the budget constraints that domestic households face each period as

$$P_t\left(C_t(j) + I_t(j)\right) + \mathbf{E}_t\left[Q_{t,t+1} D_{t+1}(j)\right] + M_t(j) + \frac{e_t B_t^*(j)}{R_t^* \Theta\left(\frac{e_t B_t^*}{P_{X,t} X_t}\right)}$$

[1] As usual, 'star' refers to foreign economy.

$$\leq W_t(j)H_t(j) + R_t^K K_{t-1}(j) + D_t(j) + M_{t-1}(j) + e_t B_{t-1}^*(j) + \Pi_t(j) - T_t(j)$$

where $Q_{t,t+1}$ is the stochastic discount factor used for evaluating consumption streams, R_t^K is the nominal rental rate of capital, e_t is the nominal exchange rate, and R_t^* is the nominal international interest rate. Had it not been for the foreign bond premium, households would have paid $1/R_t^*$ as the price of the foreign bond. In reality, however, they should pay the premium $\Theta\left(\frac{e_t B_t^*}{P_{X,t}X_t}\right)$ to purchase the foreign bond. The functional form suggests that the premium is related to the ratio of the outstanding foreign debt to nominal value of exports, a measure for healthiness of the economy. That is, the premium increases as foreign debt ratio increases. For simplicity, we further assume that $\Theta(\cdot)$ show constant elasticity κ. In this case, the premium of foreign bond prices changes κ percent when the foreign debt ratio changes by 1 percent. The international interest rate, inverse of the foreign bond price, is assumed to follow a stochastic process. Households accumulate capital according to

$$K_t(j) = (1-\delta)K_{t-1}(j) + I_t(j)$$

where δ is the capital depreciation rate. Since we assume that there is no adjustment cost for investment, the consumption good and the investment good are interchangeable.Under the assumption of the complete domestic asset market, households entertains the perfect risk-sharing, which implies the same level of consumption across household regardless of the labor and rental income they receive each period; therefore, we can drop the notation j from consumption and investment. The household decision problem regarding consumption, savings, and investment can be characterized by the following Euler equations:

$$\mathbf{E}_t\left[\beta\left(\frac{C_{t+1}-\gamma h C_t}{C_t-\gamma h C_{t-1}}\right)^{-1} R_t \frac{P_t}{P_{t+1}}\right] = 1$$

$$\mathbf{E}_t\left[\beta\left(\frac{C_{t+1}-\gamma h C_t}{C_t-\gamma h C_{t-1}}\right)^{-1} \Theta\left(\frac{e_t B_t^*}{P_{X,t}X_t}\right) R_t^* \frac{e_{t+1}}{e_t}\frac{P_t}{P_{t+1}}\right] = 1$$

$$\mathbf{E}_t\left[\beta\left(\frac{C_{t+1}-\gamma h C_t}{C_t-\gamma h C_{t-1}}\right)^{-1} \left(\frac{R_{t+1}^K}{P_{t+1}} + 1 - \delta\right)\right] = 1$$

where $R_t = \mathbf{E}_t[Q_{t,t+1}]^{-1}$. The first and second equations are asset pricing equations regarding the real return on the purchase of domestic and foreign bonds, while the third equation is related to the return on the investment on the physical capital.

As in Erceg, Henderson, and Levin (2000) we assume that wage setting is subject to a nominal rigidity à la Calvo (1983) and Yun (1996). While each household can set the wage $W_t(j)$ of its own labor service by entertaining its monopoly power, only a fraction $(1-\theta_L)$ of households are entitled chances for full optimization at any given period, independent of the time elapsed since the last adjustment. Thus, in each period a measure $(1-\theta_L)$ of households reoptimizes its wage, while a fraction θ_L adjusts its wage according to a partial indexation rule:

$$W_{t+k}(j) = \Gamma_{W,t}^{k} W_t(j) \tag{2}$$

where $\Gamma_{W,t}^{k} = \left(\gamma \overline{\pi}^{(1-\xi_L)} \pi_{t+k-1}^{\xi_L}\right) \Gamma_{W,t}^{k-1}$. That is, households who cannot reoptimize wages update them by considering a weighted average of past CPI inflation π_{t-1} and the inflation target $\overline{\pi}$ set by the monetary authority.

Household j who has the chance to reoptimize its wage at period t chooses $\widetilde{W}_t(j)$ (and $\widetilde{H}_t(j)$ accordingly) to maximize the lifetime utility subject to the labor demand (1) and the updating rule for the nominal wage (2). The first order condition can be written as

$$\mathbf{E}_t \left[\sum_{k=0}^{\infty} (\beta\theta_L)^k \left(\left(1-\frac{1}{\nu_L}\right) \frac{\widetilde{W}_t(j)\Gamma_{W,t}^{k}}{P_{t+k}} \left(C_{t+k} - \gamma h C_{t+k-1}\right)^{-1} - \chi_H \widetilde{H}_{t+k}(j)^{\tau} \right) \widetilde{H}_{t+k}(j) \right] = 0$$

2.2 Domestic Firms

There is a continuum of monopolistically competitive Home goods producing firms indexed by $i \in [0,1]$. Home goods producers have identical CES production functions that use labor, capital service, and oil as inputs:

$$Y_{H,t}(i) = \zeta_{H,t} \left[(1-\alpha)^{\frac{1}{\phi_H}} \left(\gamma^t N_{H,t}(i)\right)^{1-\frac{1}{\phi_H}} + \alpha^{\frac{1}{\phi_H}} \left(K_{H,t}(i)^{1-\eta} O_{H,t}(i)^{\eta}\right)^{1-\frac{1}{\phi_H}} \right]^{\frac{\phi_H}{\phi_H - 1}}$$

where $N_{H,t}(i)$ and $K_{H,t}(i)$ is the labor and capital input hired by firm i, $O_{H,t}(i)$ is oil used in the production of the variety i, and $\zeta_{H,t}$ represents a stationary productivity shock in the Home goods sector that is common to all firms. The above production specification requires the oil input being combined with the capital and the unit elasticity of substitution between oil and capital is assumed. Parameter ϕ_H governs the elasticity of substitution between labor and capital-oil aggregate in production, α denotes the share of oil-capital aggregator, and η is the share of oil in oil-capital aggregator. While firms behave monopolistically in the goods market, they buy inputs competitively in the factor market. Given input prices W_t, R_t^K, and $P_{o,t}$, the cost minimization gives us

$$\frac{R_t^K}{P_{o,t}} = \frac{1-\eta}{\eta}\frac{O_{H,t}(i)}{K_{H,t}(i)}$$

$$\left(\frac{W_t}{\gamma^t P_{o,t}}\right)^{\phi_H} = \frac{1-\alpha}{\alpha}\eta^{-\phi_H}\frac{K_{H,t}(i)}{\gamma^t N_{H,t}(i)}\left(\frac{O_{H,t}(i)}{K_{H,t(i)}}\right)^{\eta+\phi_H-\eta\phi_H}$$

That is, the oil-capital ratio and labor-capital ratio are constant across firms. Therefore, the nominal marginal cost of production is given by

$$MC_t = \frac{1}{\zeta_{H,t}}\left[(1-\alpha)\left(\frac{W_t}{\gamma^t}\right)^{1-\phi_H} + \alpha\left\{\left(\frac{P_{o,t}}{\eta}\right)^{\eta}\left(\frac{R_t^K}{1-\eta}\right)^{1-\eta}\right\}^{1-\phi_H}\right]^{\frac{1}{1-\phi_H}}$$

which implies that the marginal cost of production is the same across all firms.

Price setting is again subject to a nominal rigidity à la Calvo (1983) and Yun (1996). In each period only a fraction $(1-\theta_H)$ of firms can fully optimize their output prices. The remaining firms of fraction θ_H can only adjust the price according to a partial indexation scheme:

$$P_{H,t+k}(i) = \Gamma_{H,t}^k P_{H,t}(i)$$

where $\Gamma_{H,t}^k = \left(\overline{\pi}^{(1-\xi_H)}\pi_{H,t+k-1}^{\xi_H}\right)\Gamma_{H,t}^{k-1}$ and $\pi_{H,t} = P_{H,t}/P_{H,t-1}$. For firms who do not have chances to reoptimize prices, the price adjustment factor is a weighted average between the past inflation of Home goods $\pi_{H,t-1}$ and the target inflation rate $\overline{\pi}$. The parameter ξ_H captures the degree of indexation in the economy. For firm i who has opportunity to reoptimize the output price, it chooses $\widetilde{P}_{H,t}(i)$ to maximize the expected profit

$$\mathbf{E}_t\left[\sum_{k=0}^{\infty}\theta_H^k\Lambda_{t,t+k}\left(\Gamma_{H,t}^k\widetilde{P}_{H,t}(i) - MC_{t+k}\right)\widetilde{Y}_{H,t+k}(i)\right]$$

subject to the demand function:

$$\widetilde{Y}_{H,t}(i) = \left(\frac{\widetilde{P}_{H,t}(i)}{P_{H,t}}\right)^{-\nu_H} Y_{H,t}$$

Hence, the first order condition is

$$\mathbf{E}_t\left[\sum_{k=0}^{\infty}\theta_H^k\Lambda_{t,t+k}\widetilde{Y}_{H,t+k}(i)\left(\Gamma_{H,t}^k\widetilde{P}_{H,t}(i) - \frac{\nu_H}{\nu_H-1}MC_{t+k}\right)\right] = 0$$

Note that $\Lambda_{t,t+k}$ is the marginal value of a unit of the consumption good to households, which is treated as exogenous by the firm:

$$\Lambda_{t,t+k} = \beta^k \frac{P_t}{P_{t+k}} \left(\frac{C_t - \gamma h C_{t-1}}{C_{t+k} - \gamma h C_{t+k-1}} \right)$$

Given the price charged by a firm i, its profit is given by

$$\Pi_t(i) = P_{H,t}(i) Y_{H,t}(i) - W_t N_{H,t}(i) - R_t^K K_{H,t}(i) - P_{o,t} O_{H,t}(i)$$

2.3 The Foreign Economy

The foreign demand for Home goods is given by

$$C_{H,t}^* = \omega_H^* \left(\frac{P_{H,t}^*}{P_{F,t}^*} \right)^{-\phi^*} C_t^*$$

where ω_H^* denotes the import share in the consumption basket of foreign agents and ϕ^* captures the intratemporal elasticity of substitution between Foreign and Home goods in the foreign economy. The foreign consumption C_t^* is exogenously given and follows a stochastic process.

We assume the law of one price (LOP) holds for Home goods. That is, the domestic firms cannot discriminate across markets in terms of prices. This also holds for imported Foreign goods except oil.

$$P_{H,t}^* = \frac{P_{H,t}}{e_t}, \qquad P_{F,t} = e_t P_{F,t}^*$$

We can define the real exchange rate as:

$$s_t = \frac{e_t P_{F,t}^*}{P_t}$$

Note that the price of consumption bundle of foreign agents is dominated by $P_{F,t}^*$ rather than P_t^* because home country is assumed to be a small open economy; therefore the import share of the foreign economy ω_H^* is negligible. The domestic real price of oil is given by

$$\frac{P_{o,t}}{P_t} = s_t \frac{P_{o,t}^*}{P_{F,t}^*} \zeta_{o,t} \tag{3}$$

where $P_{o,t}^*$ is the foreign currency price of oil abroad. The pass-through of oil prices is incomplete in the sense that $\zeta_{o,t}$ signifies the deviations from the law of one price in the oil price. This deviation $\zeta_{o,t}$ is assumed to follow a stochastic process. The real international oil price $P_{o,t}^*/P_{F,t}^*$ also follows a stochastic process.

2.4 Monetary Authority

Monetary policy is described by an interest rate feedback rule of the form

$$R_t = R_{t-1}^{\rho_R} \overline{R}_t^{1-\rho_R} \exp(\epsilon_{R,t})$$

where $\epsilon_{R,t}$ is a monetary policy shock and $\overline{R}_t$ is the nominal target interest rate. Monetary authority sets its target in responding to inflation and deviations of output growth rate from its trend:

$$\overline{R}_t = \overline{r\pi} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\psi_\pi} \left(\frac{Y_t}{\gamma Y_{t-1}}\right)^{\psi_y}$$

where $\overline{r}$ is real interest rate at the steady state.

2.5 Aggregation and Equilibrium

We abstract from the government spending. We further assume that the government passively runs a balanced budget every period:

$$\int_0^1 \Big(M_t(j) - M_{t-1}(j)\Big)\, dj + \int_0^1 T_t(j)\, dj = 0$$

The goods market, the labor market, and the capital market clear

$$Y_{H,t} = \int_0^1 \left(C_{H,t}(j) + C_{H,t}^*(j) + I_{H,t}(j)\right) dj$$

$$H_t = \int_0^1 N_{H,t}(i)\, di$$

$$\int_0^1 K_{t-1}(j)\, dj = \int_0^1 K_{H,t}(i)\, di$$

We consider the symmetric equilibrium where households and firms make the same decision when available. Combining equilibrium conditions, the budget constraint of the government and the aggregate budget constraint of households, we get the following dynamics of foreign bond holdings:

$$\frac{e_t B_t^*}{R_t^* \Theta\left(\frac{e_t B_t^*}{P_{X,t} X_t}\right)} = e_t B_{t-1}^* + P_{X,t} X_t - P_{M,t} M_t$$

As noted before, imports consist of oil and Foreign goods for consumption and investment while domestically produced goods are only export of the economy. Therefore, the aggregate nominal value of exports and imports are defined as

$$P_{X,t} X_t = P_{H,t} C_{H,t}^*$$

$$P_{M,t}M_t = s_t P_t(C_{F,t} + I_{F,t}) + e_t P^*_{o,t} O_t$$

where X_t and M_t denote exports and imports, respectively. Total oil imports are the sum of oil for direct consumption and that for production, $O_t = O_{C,t} + O_{H,t}$. We can also write the nominal GDP as

$$P_{Y,t}Y_t = P_t\left(C_t + I_t\right) + P_{X,t}X_t - P_{M,t}M_t$$

where $P_{Y,t}$ denotes the implicit output deflator.

2.6 Steady State

The model is equipped with deterministic trend. Hence, we first detrend variables to define the steady state. All price and wage variables are written as relative prices to the Home CPI P_t. Real variables with trend are to be divided by γ^t. At the steady state after detrending, all relative prices and the real wage are normalized to one for computational convenience.

3 Estimation Methods

This section consists of two parts. First, we briefly discuss how to estimate and evaluate the model with Bayesian approach. With the state space representation of the model, we can estimate the model within Bayesian estimation frameworks, so called, Metropolis-Hastings algorithm with Kalman filter. See An and Schorfheide (2007) for a review. Also, we introduce the DSGE-VAR framework developed in Del Negro and Schorfheide (2004) and Del Negro, Schorfheide, Smets, and Wouters (2007). DSGE-VARs are useful to check how DSGE models are misspecified. This framework tries to find out the optimal weight between two approaches, DSGEs and VARs, that fit data best. Next, we explain the data used in our analysis.

3.1 Estimation and Evaluation of DSGE Models

To establish an estimable representation, we first log-linearize the model around its nonstochastic steady state. Several solution algorithms of the linearized rational expectations system are available, for instance, Blanchard and Kahn (1980) , Uhlig (1999), and Sims (2002). With the help of the solution algorithm, the log-linearized system can be written as autoregressive model in a vector of variables:

$$\mathbf{s}_t = \Phi^{(s)}(\theta)\mathbf{s}_{t-1} + \Phi^{(\varepsilon)}(\theta)\varepsilon_t \tag{4}$$

where s_t denotes the vector of model variables in log-deviation from the steady state, ε_t is the vector of innovations to shock processes. The coefficients $\Phi^{(s)}(\theta)$ and $\Phi^{(\varepsilon)}(\theta)$ are conformable matrices whose values are dependent on the values of DSGE model parameters θ. Given that some of variables in $\mathbf{s}_t$ is not observable, we can treat (4) as the transition equation of a state space representation. Once we define a vector of observables $\mathbf{y}_t$ we can set up measurement equations:

$$\mathbf{y}_t = \Theta^{(0)}(\theta) + \Theta^{(s)}(\theta)\mathbf{s}_t \tag{5}$$

More specifically, we assume that the time period t in the model corresponds to one quarter and that the following observations are available for estimation: quarter-to-quarter per capita GDP growth rate, annualized nominal interest rate, annualized quarter-to-quarter core CPI inflation rate, annualized quarter-to-quarter hourly wage inflation, quarter-to-quarter nominal exchange rate depreciation, international oil prices relative to domestic price level, and quarter-to-quarter growth rate of oil imports. The system matrices, $\Phi^{(s)}$, $\Phi^{(\varepsilon)}$, $\Theta^{(0)}$, and $\Theta^{(\varepsilon)}$, in the state space representation, (4) and (5), are given as highly nonlinear functions of the DSGE model parameters θ.

While DSGE models are popular among the economists because of their microfoundations, the empirical performance is not so successful until Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003). On the contrary, VARs are widely used in empirical macroeconomics and considered as benchmarks for evaluating dynamic economies due to better fit of the data and forecasting power. Del Negro and Schorfheide (2004) and Del Negro, Schorfheide, Smets, and Wouters (2007) investigate possible connections between DSGE models and VARs. We first briefly mention the Bayesian approach to estimate the state space representation of DSGE models as in (4) and (5). Then we proceed further on DSGE-VAR procedure.

The Bayesian approach is widely used in the estimation of DSGE models. The main advantage is that it has a systematic way to incorporate information that is available but at the same time tricky or even impossible to formally construct the likelihood. The likelihood information $p(Y|\theta)$ contained in the data used for estimation is extracted via

Kalman filter in the state space representation, and the information that is informally available is summarized as the prior distribution $p(\theta)$. This informal information can include results from related literature that employs other data sets and models. The Bayes theorem provides the basic insight how to update the prior belief on parameters with the information contained in the data, i.e., the likelihood. With well specified prior distribution, the posterior distribution $p(\theta|Y)$ can be simulated through the Markov-chain Monte Carlo (MCMC) procedure.

Another convenient procedure in Bayesian analysis is the model selection. The posterior odd ratio is a key statistic in selecting a model among a series of competing models. We can just choose one with the highest posterior odds. With equal prior probabilities assigned to each model, the posterior odds are not different from the ratio of the marginal data densities (or the marginal likelihood, equivalently) $p(Y)$ across models. Therefore, it suffices to have a procedure to evaluate the marginal data density given the draws from the posterior distribution. This can be achieved by Geweke's (1999) modified harmonic mean estimator.

Given the state space representation of DSGE models, it is not difficult to imagine that there exists a tight link between DSGE models and VARs. That is, the cross equation relationships restricted by DSGE models can be imposed on VAR parameters; therefore we can expect a better performance of VARs with this *priori* restrictions. Del Negro and Schorfheide (2004) introduces the DSGE-VAR(λ) procedure from this perspective. The hyper parameter λ governs the tightness of the priori restrictions from DSGE models. When the DSGE prior weight λ approaches infinity, the VAR parameters are tightly restricted by the cross equation restrictions from DSGE models. When the DSGE prior weight λ approaches zero, on the contrary, the DSGE model imposes no restriction on the VAR parameters and the estimation procedure behaves like an unrestricted VAR model. Hence, by changing the value of the hyper parameter λ we can generate a series of VAR models whose parameter restrictions based on a DSGE model have different tightness.

Another interpretation of DSGE-VARs tackles misspecification issues of DSGE models. As noted before, DSGE models are well accepted among the economists since their modeling is based on economic theory and impulse response analysis is straightforward. However, restrictions derived from DSGE models are often too tight to match the data, and hence the empirical performance is usually far from satisfactory. Del Negro, Schorfheide, Smets, and Wouters (2007) point out that the data generating process of a VAR is decomposed into the DSGE model part and its possible misspecifications, and this misspecification can be modeled in a Bayesian framework. The same hyper parameter λ now refers to the degree of misspecification. As λ moves away from the infinity where only DSGE models are allowed as correct specification, the flexibility in describing the data increases. If we can find out the "optimal" value, namely $\hat{\lambda}$, it can be used to evaluate the specification of the DSGE model. In short, the larger $\hat{\lambda}$ is, the smaller is the misspecification of the DSGE model and a lot of weight should be placed on its implied restrictions.

As discussed above, we can consider a series of specifications in terms of the hyper parameter λ given a DSGE model. Noting that the best model can be selected using the posterior odds ratio in Bayesian analysis, the "optimal" weight on DSGE prior $\hat{\lambda}$ can be found by maximizing the marginal likelihood with respect to λ. When $\hat{\lambda}$ is chosen according to the posterior odds criterion, a comparison between DSGE-VAR($\hat{\lambda}$) and DSGE model impulse responses can reveal important insights about the misspecification of the DSGE model. While DSGE model impulse response is well defined, impulse responses of DSGE-VAR($\hat{\lambda}$) needs careful treatment. To obtain a proper impulse response, we should align DSGE-VAR($\hat{\lambda}$) along with structural shocks of the DSGE model. The details of this procedure can be found in Del Negro and Schorfheide (2004).

3.2 Data

Most of data are obtained through KOSIS (Korean statistical information service)[2] maintained by Korea National Statistical Office and ECOS (Economic statistics system)[3] maintained by the Bank of Korea. Seasonally adjusted real GDP is divided by population 15 years and older and its growth rate is calculated as 100 times the first difference in logs. The interest rate is the overnight call rate. The core inflation rate is calculated from core CPI as 400 times the first difference in logs. The nominal hourly wage is obtained by dividing total wage by total hours worked and its inflation is again calcu-

[2] http://www.kosis.kr

[3] http://ecos.bok.or.kr

lated as 400 times the first difference in logs. The nominal exchange rate depreciation is calculated as 100 times the first difference in logs of the effective exchange rate published by the Bank of International Settlement (BIS). The international oil price relative to domestic price level is obtained by dividing WTI crude oil spot price by CPI and being normalized after taking logs. Finally, the crude oil import is obtained from Korea National Oil Corporation[4] and then seasonally adjusted by X12 method available from EViews. Per capita term is obtained by dividing it by population 15 years and older, and then quarter-to-quarter growth rate is calculated as 100 times the first difference in logs. Data are available for 1993:Q2–2008:Q4.

4 Empirical Results

We begin this section by explaining the specification of prior distributions of structural parameters of the DSGE model. In the following discussion on the "optimal" DSGE prior weight, we also consider two variants of our baseline DSGE model. One lacks oil in consumption basket and the other excludes oil from inputs of production. We discuss how a fit changes as we move away from our baseline model. We also look into impulse response functions from our DSGE models and compare them with those from "optimal" DSGE-VARs. Finally, we investigate the behavior of deviations from the law of one price in domestic oil prices and the oil price pass-through as the international crude oil prices surges in mid-2000s.

In what follows, we use DYNARE for estimation of both DSGE models and DSGE-VARs. For each specification we generate 125,000 draws from posterior distributions and the first 25,000 draws are discarded for convergence of Markov-chain.

4.1 Prior Distribution

Prior distribution in Bayesian analysis plays an important role in the estimation of DSGE models. By specifying them, we express our own view on plausible parameter values. Actually this process re-weights the information contained in the data that are used in actual estimation. That is, we can incorporate extra information that is

[4]`http://www.petronet.or.kr`

possibly missing in estimation samples and is developed in the related literature.

To begin with, we calibrate several parameter values that are not identified in our representation. First, the substitution elasticity across differentiated labor ν_L that governs wage markup is set to 9 as in Medina and Soto (2005). The price markup parameter ν_H is not present in our linearized model. Noting that our model abstracts from government spending, we set the steady state consumption-output ratio as 0.66, which stems from the average ratio of the sum of consumption and government expenditure to GDP in our sample. The steady state investment-output ratio is 0.32 and the steady state export share is 0.38 according to our sample. From these ratios, we can derive other big ratios using steady state relationships.

Table 2 lists the marginal prior distributions for the structural parameters of the DSGE model. In general, the prior distributions used in this study are quite diffuse. As usual, the rule of thumb in choosing the distribution family for each parameter is the shape of the support. Parameters that have limits on both end, usually confined between 0 and 1, follow the beta distribution. For those with positive unbound support we specify the gamma distribution except standard deviations of shock processes for which inverse gamma distributions are assumed. Unbounded parameters are specified as normal distributions. The share of oil-capital aggregator in production α has mean 0.3, the usual capital share of an economy. With standard deviation 0.1, 90% coverage is [0.15,0.48]. The oil share in oil-capital aggregator η is centered at 0.5 since no primitive estimate is available. The quarterly depreciation rate δ has mean 0.015, implying 6% annual depreciation. Inverse of intertemporal substitution elasticity of labor τ has mean 1 and standard deviation 0.75 whose 90% coverage is [0.15,2.46]. Without preference shock as in our model, this parameter is often estimated quite small and even negative with aggregate data. Due to lack of information on the habit persistence parameter h, it is centered at 0.5 and standard deviation 0.2 to have [0.17,0.83] as 90% coverage. The elasticity of risk premium on foreign debt κ has mean 0.01 with standard deviation 0.005. The elasticity of substitution between Home and Foreign goods in core consumption ϕ_Z has relatively low mean 0.3 and it is roughly around the calibrated value in the Bank of Korea model (BOKDSGE) by Kang and Park (2007). Its counter-part in foreign consumption ϕ^* is set to 1. The elasticity between oil and core consumption ϕ_C is also low as 0.33 since there is almost no substitute for oil in the

Korean economy, especially when it comes to fuel for transportation. The elasticity between oil-capital aggregator and labor input of production ϕ_H is not obvious and hence it is set to 0.5. For more discussion of the estimates of the elasticity of energy or oil with other inputs, see Backus and Crucini (2000). Calvo rigidity parameters for price θ_H and wage θ_L are equally set to have mean 0.7. This value implies that prices and wages are reset every 3 quarters on average. Standard deviations for θ_H and θ_L are 0.1 and 0.15, respectively. Hence, 90% coverage imply that prices are reset between 2.1 and 6.8 quarters and wages between 1.7 and 11.9 quarters. Price (ζ_H) and wage (ζ_L) indexation to past inflation are all centered 0.5 and have common standard deviations 0.2. Monetary policy parameters ψ_π and ψ_y is set to have means from Taylor's (1993) values, 1.5 and 0.5, and 90% coverage, [1.19,1.84] and [0.17,0.97], respectively. We further specify weights on Foreign goods in core consumption ω_F and on oil in consumption ω_o. They are centered at 0.35 and 0.1, respectively. Persistence of shocks, $(\rho_A, \rho_o, \rho_{o^*}, \rho_{R^*}, \rho_{\pi^*}, \rho_{C^*})$ have the same specification, mean 0.75 and standard deviation 0.15.

4.2 Model Selection and DSGE Prior Weight

The main purpose of DSGE-VARs is to evaluate the (mis-)specification of DSGE models under consideration. To begin with, however, we investigate a direct estimation of structural parameters of our baseline model. Bayesian estimations of linearized DSGE models trace back to DeJong, Ingram, and Whiteman (2000), Landon-Lane (1998), and Schorfheide (2000), and they use Markov-chain Monte Carlo (MCMC) algorithm for posterior simulator while Kalman filter provides exact likelihood computations. As noted previously, a unified framework for model selection within Bayesian framework, the posterior odds ratio, makes this approach quite popular. Here we consider two restrictions on the baseline model described in Section 2. In our baseline economy, the entire volume of oil in domestic use is imported from foreign country and a fraction of oil imports is directly consumed among households. The first restricted model tackles this point and assumes that oil is not included in consumption basket (No Oil Consumption). On the contrary, oil is not used for production in the second restricted model (No Oil in Production).

The first row of Table 3 reports the log marginal likelihood of three models under consideration. The baseline model attains the highest marginal likelihood (-1329.05), followed by No Oil in Production (-1389.71) and then No Oil Consumption (-1499.42) models. That is, the baseline model best describes the data if these models are assigned the same prior probabilities. This result is somewhat expected given that both consumption and production motive of oil use in the Korean economy are sizable and significant as seen in Table 1. However, we should note that the marginal data density penalizes larger models like any information criterion and hence this result is not so obvious as it looks.

Now we turn our attention to DSGE prior weight, that is, DSGE-VARs. In practice DSGE models have VAR representations with the truncation at a particular lag order. Due to short sample periods we restrict the lags in VARs to 2. This approximate VAR representation distinct DSGE-VARs from DSGE models even with infinite weight on DSGE priors, DSGE-VAR(∞). This discrepancy is obviously seen from differences between the first and the second rows in Table 3. For each of three specifications, we try various values for the DSGE prior weight parameter λ and report results in Table 3. DSGE-VARs with the baseline model attains the highest log marginal likelihood when $\lambda = 0.5$ at -1132.4 whereas those with other two restricted models do when $\lambda = 0.4$ (-1146.8 for No Oil Consumption and -1136.5 for No Oil in Production). That is, the "optimal" prior weight for the baseline economy is higher than those for other two restricted models. This result again signifies that the degree of the misspecification in the baseline model is less than those in other two restricted models because the baseline model would put more weight on the DSGE prior. Both from the comparison of log marginal likelihoods of DSGE models and the optimal weight of DSGE priors, we can now draw the same conclusion.

4.3 Posterior Estimates

Before proceeding with the posterior estimates of the DSGE model parameters, we should pay attention to the "optimal" weight for the baseline economy. With $\hat{\lambda} = 0.5$, the best fit of the data is achieved by putting 1/3 of the weight on the DSGE model and 2/3 on the VAR model; hence, there are still some room for improvement in the model specification. Del Negro, Schorfheide, Smets, and Wouters (2007) show that the Smets-Wouters model has around 1/2 weight in their DSGE-VAR analysis. As previously discussed, another interpretation of a DSGE-VAR is to extract prior information from a DSGE model for VAR coefficients; therefore, the posterior distribution of VAR coefficients can be expressed as the posterior distribution of DSGE model parameters, given the tightness of the prior from a DSGE model $\hat{\lambda}$. This refers to the posterior distribution of DSGE-VAR($\hat{\lambda}$).

Table 4 reports posterior estimates from the DSGE model and DSGE-VAR($\hat{\lambda}$) of the baseline model. In DSGE estimation, most of parameters show information gain through likelihood, that is, the prior distribution is updated through the likelihood and is resulted in the posterior distribution. A couple of parameters, δ and θ_H, have roughly the same prior and posterior means. However, 90% coverage shrinks as they move to posterior distributions, which implies that likelihoods bring on some extra information. The capital share can be obtained from $\alpha(1-\eta)$ and its posterior mean is 0.201 for DSGE and 0.4142 for DSGE-VAR($\hat{\lambda}$). The elasticity between oil-capital aggregator and labor input of production ϕ_H attains very low posterior mean of 0.021. This implies that the oil-capital aggregator and labor are not substitutable in production and hints a big difference in log marginal likelihoods between the baseline and No Oil in Production models. In DSGE-VAR($\hat{\lambda}$) the posterior mean of this parameter is much bigger, 0.1750, which implies more flexible substitution among inputs of production and results in smaller change in log marginal likelihoods when we abstract the production motive of the oil use. The model displays relatively high degrees of price θ_H and wage θ_L rigidities, 0.711 and 0.855, with 3.5 and 6.9 quarters of duration, respectively. With DSGE-VAR($\hat{\lambda}$), these durations are 5.4 and 3 quarters, respectively. The estimated slope of Phillips curve, $\beta/(1+\beta\xi_H)$, is around 0.63 both for DSGE and DSGE-VAR($\hat{\lambda}$), and it is quite close to the Bank of Korea's calibration, 0.58. The weight on oil in consumption basket ω_o is estimated as 0.117. Persistence parameters are estimated high except one. The posterior mean of the persistence for foreign inflation shock ρ_{π^*} is 0.180. This estimate is even lower for DSGE-VAR($\hat{\lambda}$).

As pointed out in Del Negro and Schorfheide (2004), information about structural parameters of the DSGE model is gathered more slowly as the DSGE prior weight loosens. When λ is moving away from infinity priors on VAR parameters becomes less tight. Therefore, we can expect that the posterior of DSGE-VAR($\hat{\lambda}$) is closer to the prior than the posterior distribution of the DSGE model. For many parameters it is verifiable, especially for the substitution elasticity between oil-capital aggregator and labor input of production ϕ_H and that between Home and Foreign goods consumption in core consumption bundle ϕ_Z.

Fluctuations of the observables are originated from the structural shocks of our economy. Variance decompositions of the observables at the posterior mean are reported in Table 5. We can easily see that the monetary policy shock has significant contributions to the variability of output growth, oil import growth, and both inflations. However, the contributions of the technology shock are negligible, less than one percent especially for price variables. These findings coincide with the result from a standard new Keynesian economy. The domestic interest rate variability can be explained mostly by the oil price shock (Oil*; 17%), the shock on the deviation from the law of one price (LOP; 40%), and the international interest rate shock (Money*; 33%). We should note that the international oil price and the deviations from the law of one price together decide the domestic oil price, and therefore, we can say that these two shocks have large contributions in explaining the variability of the domestic interest rate, the output growth rate, and the oil import growth rate.

4.4 Impulse Response Functions

As seen previously, DSGE-VAR($\hat{\lambda}$) attains higher marginal likelihood than other two extremes: DSGEs and VARs. Basically, the DSGE-VAR($\hat{\lambda}$) is a Bayesian VAR (BVAR) with optimally weighted prior from the DSGE model. Hence, we can use it as the benchmark in evaluating the performance of the DSGE model. As is often the case with indirect inferences (e.g., Christiano, Eichenbaum, and Evans, 2005), the performance of a DSGE model is checked by comparing impulse response functions, one from a VAR and another from the DSGE model.

Figure 1(a) depicts impulse responses with respect to a monetary policy shock in the baseline economy. The posterior mean responses of the DSGE (solid line) and DSGE-VAR($\hat{\lambda}$) (dotted line) are given with 90% coverage band (gray area) for DSGE-VAR($\hat{\lambda}$). Responses of real international price of oil are omitted because this observable is purely exogenous and it responds only to its own shock in the model. We can see that responses from the DSGE model trace out those of DSGE-VAR($\hat{\lambda}$). Most of responses from the baseline DSGE model show hump-shaped and prolonged effects, but these effects are quantitatively small compared to those from the DSGE-VAR($\hat{\lambda}$). This quantitative discrepancies are originated from relatively low value of $\hat{\lambda}$, that is, 0.5. Some initial responses do not match, such as exchange rate depreciation.

Figure 1(b) shows responses to an oil price shock in the baseline economy. Again, response from the DSGE model mimics well those from DSGE-VAR($\hat{\lambda}$). When a household is hit by the oil price shock it tries to reduce the oil consumption and compensate its utility loss by substituting with the core consumption bundle. Given that the estimated elasticity of substitution ϕ_Z is low (0.166), however, this desired substitution is not fully accommodated and the aggregate consumption will decrease initially. From the firm's side, the oil input can be substituted by the capital with the unit elasticity of substitution, but this channel also drives out the household consumption for higher investment. Or the reduced oil input might be compensated by an increased labor demand, but again, the substitution elasticity ϕ_H is quite low (0.021). Therefore, the initial responses of oil import growth, output growth, core inflation, and wage inflation are negative.

The responses of aforementioned variables in subsequent periods are more interesting. As time goes by, more households can adjust to the monopolistic wage in Calvo-Yun setting. Given the higher demand for the labor input, the wage inflation turns into positive. The same story goes with the core inflation, where oil consumption is replaced by the core consumption over time and more firms adjust their Home goods output prices to the monopolistic level. It looks puzzling that oil imports growth that is initially negative due to the oil price shock stays positive in subsequent periods. Even though the oil consumption decreases, the increased core consumption requires the increase in Home goods production; hence, the income effect takes place and the oil input for production eventually increases. The total response is governed by the sum of the substitution effect in direct oil consumption, and the substitution and income effects in oil input in production. If we assume the foreign consumption demands behaves similarly, the income effect would be even bigger and it would keep oil import growth positive. We should note here again that these findings coincides with the impulse responses from the DSGE-VAR($\hat{\lambda}$)–a version of Bayesian VAR with not-so-tight priors ($\hat{\lambda} = 0.5$) imposed by the baseline model.

4.5 Pass-Through of Oil Price and Deviation from the Law of One Price

The baseline model for our analysis is constructed so that the exchange rate pass-through for all but oil is perfect. However, there is a discrepancy between international oil price and domestic oil price as in (3) and deviations from the LOP is modeled as a stochastic process whose log-deviation $\hat{\zeta}_{o,t}$ follows an AR(1) process. We can see that $\hat{\zeta}_{o,t}$ takes value 0 if the pass-through is perfect, and moves away from zero otherwise. From Table 4 it is obvious that $\hat{\zeta}_{o,t}$ is highly persistent across specifications, 0.9446 for DSGE and 0.9557 for DSGE-VAR($\hat{\lambda}$). Hence, we can expect the pass-through of oil prices into domestic price is relatively low. The pass-through rate is calculated by dividing the impulse responses of core CPI index by the responses of oil prices to oil price shock. Figure 2 depicts the pass-through rates of the oil price shock into the core CPI evaluated at the posterior means of the baseline model (dashed line) and DSGE-VAR($\hat{\lambda}$) (solid line). Since the initial response of the core inflation is negative, the pass-through for the period turns out to be negative. At the two year horizon, the pass-through is reaching 0.055 for the baseline model and 0.077 for DSGE-VAR($\hat{\lambda}$), which is close to Jongwanich and Park's (2008) estimate on Korea during 1996Q1 to 2008Q1 for PPI (0.07) but much higher than theirs for CPI (0.008).

Since the deviation from the LOP $\hat{\zeta}_{o,t}$ makes one of underlying state variables of the state space representation, we can obtain the smoothed series via Kalman filter once structural parameter values are fixed. Figure 3 shows these smoothed deviation from the LOP. Actual observations of log real international price of oil (dotted line) are also drawn for reference. The international oil price is stable until 2003 and takes off around 2004. We can see that the smoothed deviation from the LOP has also been moving around zero (that means the perfect pass-through of oil prices) until 2004 but decreases significantly afterwards. To explain changes in this deviation, we consider the government's reaction to an oil price shock. First we note that one of the main tax revenue of Korean government is the gasoline tax. Roughly 58% of the gasoline price paid by Korean customer are counted as the government revenue. Hence, the government could have lowered the gasoline tax to alleviate burdens of households and this fiscal policy could have affected the deviation from the LOP, even though the behavior of the government is not explicitly modeled in our baseline economy. Figure 4 depicts the gasoline price at the pump (solid line), the gasoline tax (dash-dotted line), and the tax ratio on gasoline consumption (dotted line) during this period. In Korea, the tax on gasoline consumption consists of a per-unit tax that is time-varying and the value-added tax with fixed rate at 10 percent. As the gasoline price increases due to an oil price shock, the effective tax rate on gasoline consumption decreases because of this composition effect. Actually, the Korean government has not accommodated the oil price surge by changing the per unit tax until the end of 2007. But there was a significant tax cut on gasoline during 2008. Thus, the tax cut that accommodates the oil price shock can explain only a little fraction of the deviation from the LOP.

5 Conclusion

In this paper we present the model economy that uses oil imports either as direct consumption or an input of production. Within Bayesian estimation framework including DSGE-VARs, the empirical analysis is performed based on the Korean aggregate data. We find that the baseline economy produces reasonable posterior estimates of the structural parameters and works relatively well compared to impulse responses from DSGE-VAR($\hat{\lambda}$), and that the misspecification will be very severe when either consumption or production motive of oil imports is ignored. From the variance decomposition analysis, we conclude that the variability of the domestic interest rate can be explained mainly by the oil price shocks transmitted to domestic oil prices. Finally, the pass-through of oil prices into the core consumption price index is relatively low and the deviation from the LOP has decreased but the government accommodating tax policy played a limited role during this period. Therefore, more elaborated model on government behavior is anticipated to investigate the pass-through of oil price shocks.

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Table 1: Oil Uses: Korea (2005)

Volume, Percent

	Industry	Transport	Home & Commercial	Public	Etc.	Total
Gasoline	0.27	7.48	0.01	0.07		7.83
Kerosene	0.72	0.01	4.27	0.09	0.09	5.18
Diesel	2.52	14.64	1.08	0.47	0.02	18.73
Bunker	5.56	3.05	1.08	0.04	3.49	13.21
Naphtha	35.90					35.90
Solvent	0.58					0.58
Jet Oil		2.67		0.62		3.29
LPG	2.70	5.70	3.43	0.03	0.18	12.04
Asphalt	1.38					1.38
Lubricant	0.65					0.65
Etc.	0.81		0.41			1.22
Total	51.09	33.55	10.27	1.30	3.78	100.00

Table 2: Prior Distribution

Name	Domain	Density	Mean	S.D.	Description
α	$[0,1)$	Beta	0.300	0.100	Capital-Oil share in production
η	$[0,1)$	Beta	0.500	0.200	Oil share in capital-oil
δ	$[0,1)$	Beta	0.015	0.002	Depreciation rate
τ	$\mathbf{R}^+$	Gamma	1.000	0.750	(inverse) EIS of labor
h	$[0,1)$	Beta	0.500	0.200	Habit persistence
κ	$\mathbf{R}^+$	Gamma	0.010	0.005	Elasticity: risk premium
ϕ_Z	$\mathbf{R}^+$	Gamma	0.300	0.200	Elasticity: H/F goods consumption
ϕ^*	$\mathbf{R}^+$	Gamma	1.000	0.400	Elasticity: H/F goods in foreign consumption
ϕ_C	$\mathbf{R}^+$	Gamma	0.330	0.150	Elasticity: Oil and core consumption
ϕ_H	$\mathbf{R}^+$	Gamma	0.500	0.300	Elasticity: Oil-capital and labor input of production
θ_H	$[0,1)$	Beta	0.700	0.100	Calvo on price
θ_L	$[0,1)$	Beta	0.700	0.150	Calvo on wage
ξ_H	$[0,1)$	Beta	0.500	0.200	Price indexation
ξ_L	$[0,1)$	Beta	0.500	0.200	Wage indexation
ψ_π	$\mathbf{R}^+$	Gamma	1.500	0.200	Responsiveness on inflation
ψ_y	$\mathbf{R}^+$	Gamma	0.500	0.250	Responsiveness on output
ρ_R	$[0,1)$	Beta	0.750	0.100	Persistence: interest rate
$\gamma^{(Q)}$	$\mathbf{R}$	Normal	0.750	0.300	Growth rate
$r^{(A)}$	$\mathbf{R}^+$	Gamma	0.500	0.200	Steady state real interest rate
$\pi^{(A)}$	$\mathbf{R}^+$	Gamma	3.000	2.000	Target inflation rate
ω_F	$[0,1)$	Beta	0.350	0.100	Weight on foreign good consumption
ω_o	$[0,1)$	Beta	0.100	0.050	Weight on oil consumption
ρ_A	$[0,1)$	Beta	0.700	0.150	Persistence: technology
ρ_o	$[0,1)$	Beta	0.700	0.150	Persistence: oil price pass-through
ρ_{o^*}	$[0,1)$	Beta	0.700	0.150	Persistence: foreign oil price
ρ_{R^*}	$[0,1)$	Beta	0.700	0.150	Persistence: foreign interest rate
ρ_{π^*}	$[0,1)$	Beta	0.700	0.150	Persistence: foreign inflation
ρ_{C^*}	$[0,1)$	Beta	0.700	0.150	Persistence: foreign consumption
σ_R	$\mathbf{R}^+$	InvGamma	0.010	2	StDev: monetary policy
σ_A	$\mathbf{R}^+$	InvGamma	0.150	2	StDev: technology
σ_o	$\mathbf{R}^+$	InvGamma	0.150	2	StDev: oil-price pass-through
σ_{o^*}	$\mathbf{R}^+$	InvGamma	0.150	2	StDev: foreign oil price
σ_{R^*}	$\mathbf{R}^+$	InvGamma	0.050	2	StDev: foreign interest rate
σ_{π^*}	$\mathbf{R}^+$	InvGamma	0.050	2	StDev: foreign inflation
σ_{C^*}	$\mathbf{R}^+$	InvGamma	0.050	2	StDev: foreign consumption

Notes: For the inverse-gamma distribution, values in S.D. column denote degrees of freedom.

Table 3: The Fit of the Small Open Economy DSGE Model

Specification	λ	Baseline	No Oil Consumption $\omega_o = 0$	No Oil in Production $\eta = 0$
DSGE		-1329.05	-1499.42	-1389.71
DSGE-VAR	∞	-1278.47	-1412.31	-1387.04
	2	-1220.09	-1219.77	-1293.64
	1.5	-1198.91	-1229.15	-1204.30
	1.25	-1206.11	-1181.97	-1183.42
	1	-1171.12	-1200.08	-1206.92
	0.75	-1185.81	-1199.96	-1211.15
	0.66	-1155.76	-1180.27	-1184.79
	0.5	-1132.41	-1157.48	-1155.61
	0.4	-1155.80	-1146.78	-1136.48

Table 4: Posterior Estimates: Baseline Model

	DSGE		DSGE-VAR($\hat{\lambda}$)	
	Mean	90% Interval	Mean	90% Interval
α	0.2287	[0.2150, 0.2431]	0.4969	[0.4268, 0.5590]
η	0.1229	[0.1122, 0.1353]	0.1665	[0.1239, 0.2101]
δ	0.0152	[0.0150, 0.0155]	0.0118	[0.0112, 0.0124]
τ	0.6227	[0.5195, 0.7242]	1.6634	[1.4049, 1.8997]
h	0.2639	[0.2205, 0.2985]	0.3122	[0.2502, 0.3828]
κ	0.0010	[0.0005, 0.0014]	0.0017	[0.0003, 0.0028]
ϕ_Z	0.1660	[0.1114, 0.2126]	0.3125	[0.2509, 0.3651]
ϕ^*	0.9382	[0.8958, 1.0343]	0.8390	[0.7174, 0.9683]
ϕ_C	0.2852	[0.2657, 0.2996]	0.2064	[0.1607, 0.2463]
ϕ_H	0.0205	[0.0086, 0.0331]	0.1750	[0.0961, 0.2511]
θ_H	0.7105	[0.6940, 0.7250]	0.8137	[0.7871, 0.8384]
θ_L	0.8545	[0.8392, 0.8763]	0.6626	[0.5779, 0.7433]
ξ_H	0.5881	[0.5029, 0.6503]	0.6000	[0.4947, 0.7151]
ξ_L	0.9790	[0.9625, 0.9959]	0.8811	[0.8243, 0.9346]
ψ_π	1.5720	[1.5413, 1.6193]	2.0209	[1.9161, 2.1411]
ψ_y	0.2711	[0.2323, 0.3247]	0.1828	[0.0831, 0.2845]
ρ_R	0.8569	[0.8477, 0.8704]	0.8179	[0.7889, 0.8569]
$\gamma^{(Q)}$	0.4120	[0.3774, 0.4388]	0.4085	[0.2545, 0.6263]
$r^{(A)}$	0.3368	[0.3131, 0.3646]	0.3328	[0.2717, 0.3966]
$\pi^{(A)}$	4.8804	[4.3918, 5.2561]	2.0724	[1.5934, 2.5767]
ω_F	0.2889	[0.2785, 0.3017]	0.2193	[0.1877, 0.2583]
ω_o	0.1174	[0.1022, 0.1323]	0.1070	[0.0843, 0.1348]
ρ_A	0.8862	[0.8638, 0.9167]	0.7943	[0.7406, 0.8490]
ρ_o	0.9446	[0.9073, 0.9640]	0.9557	[0.9033, 0.9887]
ρ_{o^*}	0.9563	[0.9451, 0.9681]	0.8932	[0.8282, 0.9689]
ρ_{R^*}	0.8229	[0.7971, 0.8500]	0.5262	[0.4542, 0.6228]
ρ_{π^*}	0.1795	[0.1670, 0.1927]	0.0773	[0.0237, 0.1249]
ρ_{C^*}	0.9305	[0.8788, 0.9627]	0.5962	[0.5108, 0.6791]
σ_R	0.0080	[0.0067, 0.0092]	0.0023	[0.0017, 0.0029]
σ_A	0.0189	[0.0157, 0.0217]	0.0188	[0.0148, 0.0228]
σ_o	0.2929	[0.2509, 0.3435]	0.0532	[0.0335, 0.0723]
σ_{o^*}	0.1759	[0.1470, 0.2013]	0.0632	[0.0459, 0.0798]
σ_{R^*}	0.0113	[0.0093, 0.0136]	0.0092	[0.0070, 0.0112]
σ_{π^*}	0.0630	[0.0537, 0.0725]	0.0307	[0.0224, 0.0387]
σ_{C^*}	0.0244	[0.0186, 0.0308]	0.0186	[0.0128, 0.0247]

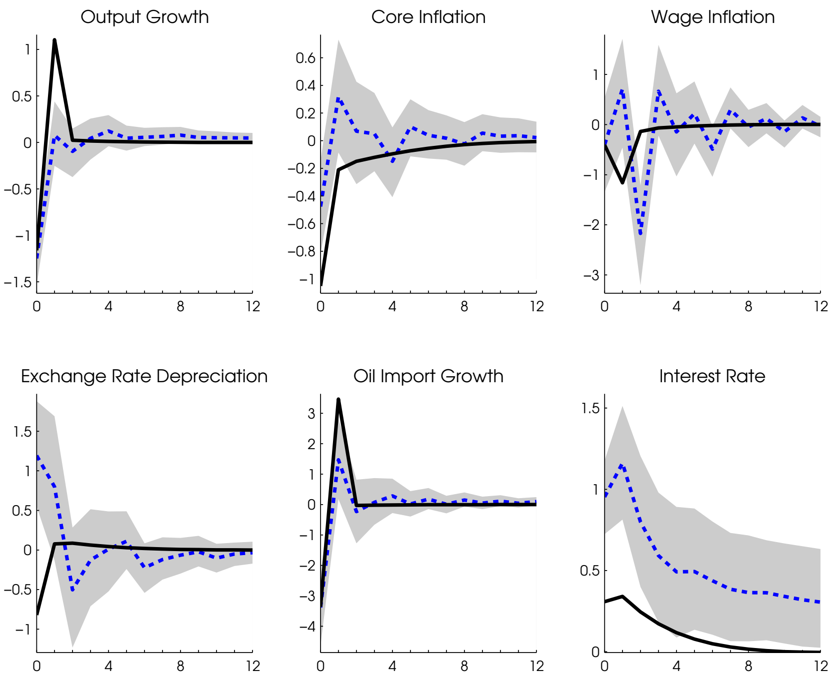
Table 5: Variance Decomposition

	Output Growth	Interest Rate	Core Inflation	Wage Inflation	Ex. Rate Dep.	Oil Import Growth
Money	0.3444	0.0159	0.1953	0.1840	0.0757	0.3268
Technology	0.0580	0.0090	0.0130	0.0040	0.0012	0.0185
Oil*	0.1103	0.1674	0.0691	0.0957	0.0311	0.1226
Dev. LOP	0.2596	0.4039	0.1681	0.2480	0.0709	0.2910
Money*	0.0437	0.3343	0.4347	0.3572	0.2642	0.0502
Inflation*	0.0108	0.0665	0.1174	0.1094	0.5561	0.0147
Consumption*	0.1731	0.0030	0.0024	0.0016	0.0007	0.1762

Notes: 'Starred' shocks on the first column denote international/foreign ones.

Figure 1: Impulse Response Functions: Baseline Model

(a) Monetary Shock



(b) Oil Price Shock

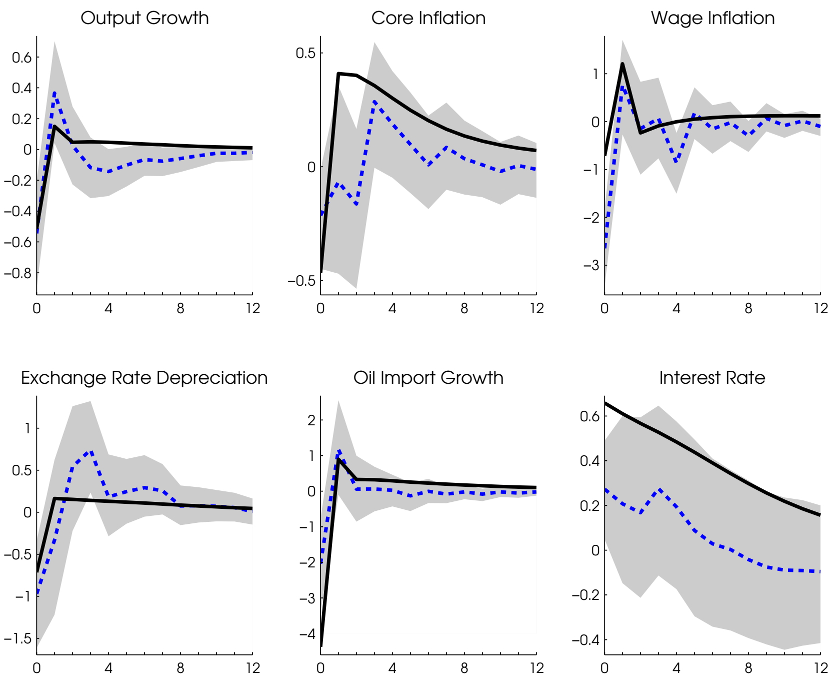


Figure 2: Pass-through of International Oil Price

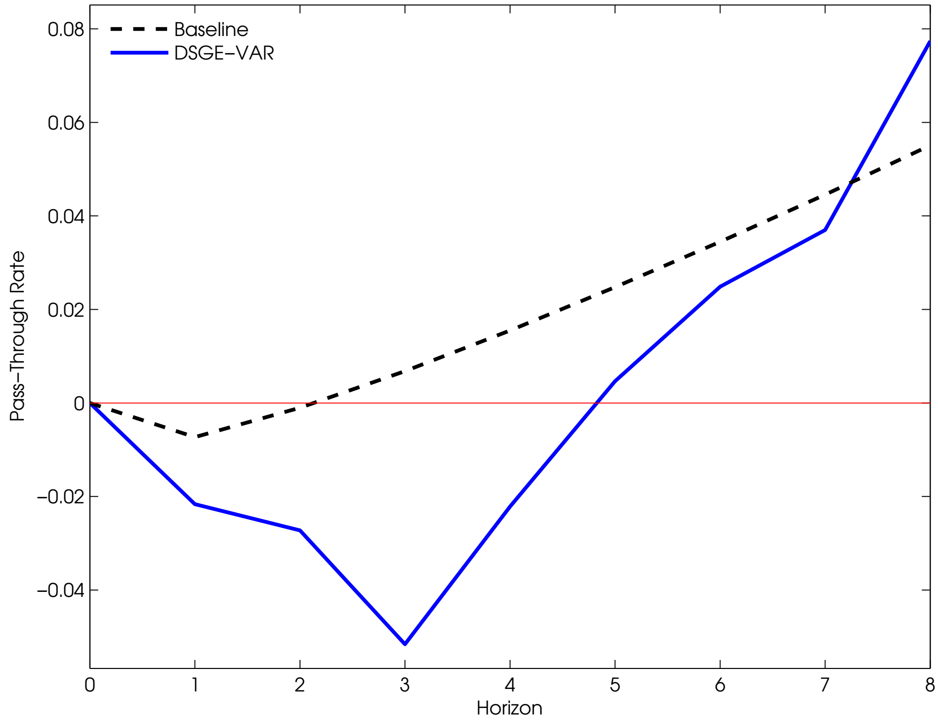


Figure 3: Deviations from the Law of One Price

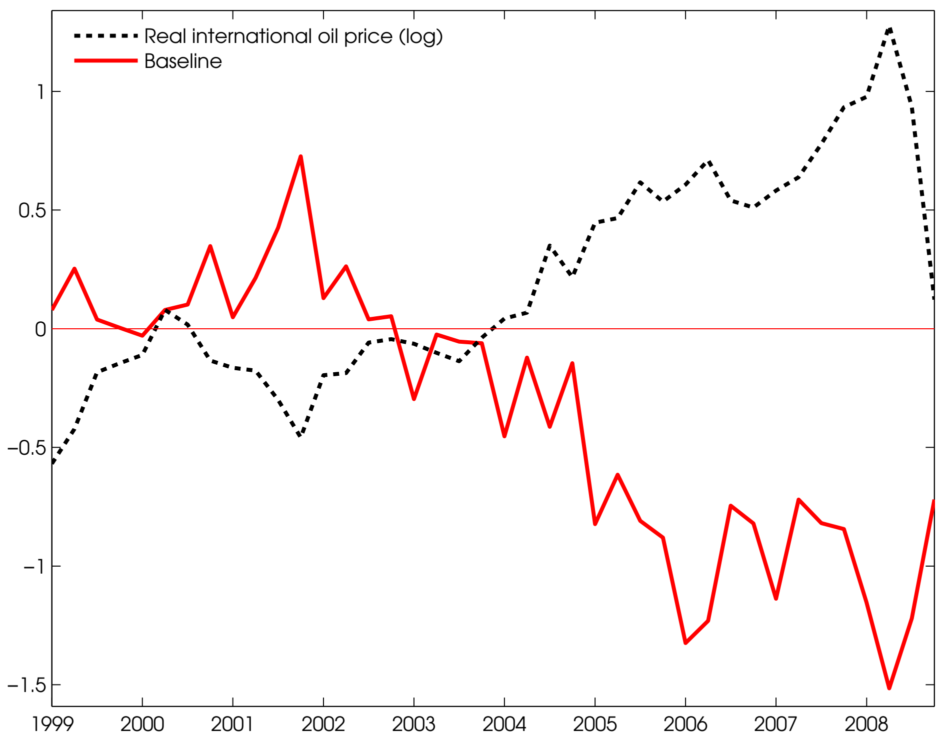


Figure 4: Gasoline Tax in Korea