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Oil Price Forecasting : A Markov Switching Approach with Unobserved Component Model

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ABSTRACT

There are many debates on the topic of the relationship between oil prices and economic growth. Through the repeated processes of conformations and contractions on the subject, two main issues are developed; one is how to define and drive oil shocks from oil prices, and the other is how to specify an econometric model to reflect the asymmetric relations between oil prices and output growth. The study, thus, introduces the unobserved component model to pick up the oil shocks and a first-order Markov switching model to reflect the asymmetric features. We finally employ unique oil shock variables from the stochastic trend components of oil prices and adapt four lags of the mean growth Markov Switching model. The results indicate that oil shocks exert more impact to recessionary state than expansionary state and the supply-side oil shocks are more persistent and significant than the demand-side shocks.

Keywords: Oil Shocks, Unobserved Component Model, Supply Shocks, Asymmetry, Markov Switching

1. Introduction

After experiencing two severe oil shocks in early and late 1970s, many studies proceed to analyze the relationship between oil prices and economic growth. Traditional macroeconomic theories provide the mechanism in which oil prices affect output

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growth. On supply-side, a hike in oil prices induces cost push effects which cause the increases in production costs. Thus, the inflationary pressures give negative effects to real output and finally slow down economic growth. On demand-side, the increases in oil prices cause income effect. High oil prices reduce real disposal incomes in terms of interest rates, and the lower income weakens the private consumption in turns. As private consumption generally takes over 50% of total GDP in a country, the decrease in consumptions inevitably reduce output growth.

Some other theories, based on more microeconomic foundations, display different viewpoints of introducing the notions of business uncertainty and operating cost. The rises in oil price postpone irreversible investments due to the future uncertainty. As these business activities tend to reduce the efficiency and to hinder optimal resource allocations, the overall increased opportunity costs scarify output growth.

The previous studies have made efforts to find any empirical evidence of the relationship between the two variables on the basis of the above theories. Hamilton (1983), the most influential leader in the field, proposed that oil price and U.S. economic growth had a very strong negative relation. Also he suggested that oil prices had a predictable power for future recessions, because he empirically proved that a hike in oil prices caused economic recession after three or four quarters later.

Mork (1989) pointed out two important factors through the confirmation and the contraction to Hamilton's works. Firstly, he argued that Hamilton did not manipulate the oil price variables properly. Oil production index used by Hamilton would be misleading to reflect oil shocks, because the oil prices in 1970s were strictly regulated by U.S. government. Secondly, he proposed that asymmetric effects existed in economic growth in the respond to oil shocks. Oil price increases could cause economic recessions, but the oil price decreases were statistically insignificant to economic expansions. His findings set new directions in considering the oil shocks from oil prices and the functional forms between oil prices and economic growth.

Most of previous studies used general equilibrium models and vector autoregressive models for the empirical research. However, Rymond and Rich (1997) approached different model specifications by introducing Markov switching model for the asymmetric features. As Markov switching model can control the economic growth into the dichotomous phases such as expansion and recession, it can avoid the problems of linearity caused by assuming symmetric relations of the two variables. In addition, Darby (1995) expanded the limited case studies to G7 countries. However, he could not derive consistent results due to the lacks of confidence of the data used in some countries. Lee *et al.* (2002) analyzed the effects of oil shocks by U.S. industry. The empirical results proposed that automobile industry was the most venerable to oil shock among oil consuming industries. Their results are very consistent with our insights.

The paper is to provide new approaches of two major concerns in the oil price and economic growth; firstly, how to drive the oil shock factors in oil prices and secondly, how to solve the asymmetric problems. We are willing to introduce unobserved component model for oil shocks variable and first order Markov switching model for asymmetric relations between oil prices and output growth. The paper is organized as follows. The following section discusses methodology and data. The third section reports and discuss the empirical results. The final section concludes our findings.

2. Methodology and data

In the analyzing the relation of oil price and economic growth, the model specification is the most important work to ensure the credibility of estimated results. However, the methodology of extracting oil shocks from oil price series is as important as the model specification, because the results would be diversified according to the definitions of oil shock variables. Gisser and Goodwin (1986) used the growth rates of nominal oil prices as oil shock variables. Figure 1, compared to Figure 2, shows that the nominal oil prices records a very strong upward trends, but the recent swing of oil prices has not reached the previous peaks of the 1970s in terms of real price. Their results would be biased whatever the implications they suggested. The choice of oil price variables, thus, is a very important issue in the field.

Hamilton, Mork and many others have explored various oil shocks from oil price data. Hamilton (1983) regards the growth rates of the producer price index (PPI) for crude oil as oil shocks. However, Mork (1989) considers that the composite index of importer and domestic producers would be more recommended than the single PPI index, because the PPI reflects only controlled domestic oil prices. Since he realizes that refiner acquisition cost (RAC) was approximately close to the marginal cost of

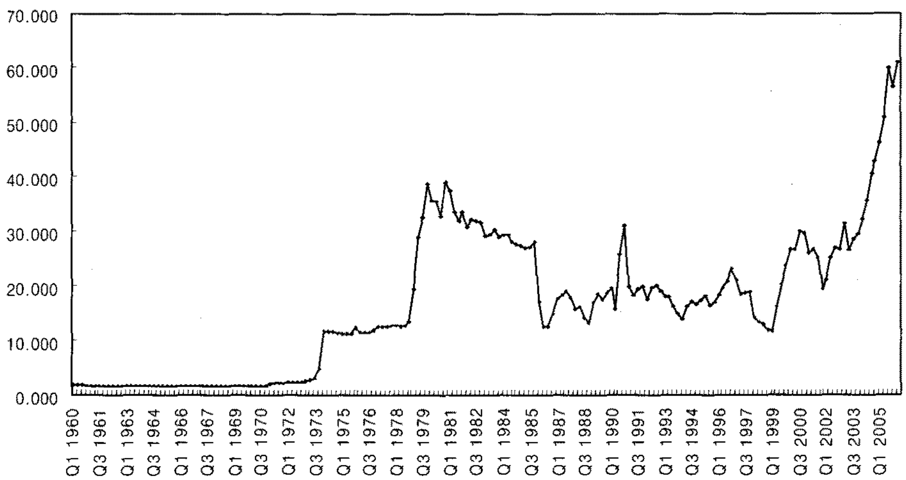

Figure 1. Nominal crude oil price 1960: I ~2006: I

both refiners, he uses the rate of change of RAC by dividing PPI as oil shocks during the government's controlled periods.

Hamilton (1996, 2003) argues that Mork's modified real oil prices are no longer appropriate for representing oil shocks. As oil price shows significantly downward trends since mid-1980s, the positive changes in real oil prices, compared the previous quarter, will mislead the significance and magnitude of oil shocks. The rebounds of the oil prices in the downward trends could be regarded as technical adjustments rather than shocks. He, thus, proposes net real oil prices which compare the current real oil prices with the previous year's maximum rather than the previous quarter if positive $O_t = O_t$ and otherwise $O_t = 0$. Lee *et al.* (1995) assume the heteroskedasticity of the variance before and after the oil crisis. They modify oil shocks variables which divided the oil prices into the variance terms of GARCH or ARCH. Despite various attempts to define oil shock variables, recently the net real oil prices proposed by Hamilton are widely accepted when estimating the relationship between oil shocks and output growth.

This study tries to drive unique oil shocks from oil price series in the basis of Hamilton's findings. Hamilton (1983) gives empirical evidences that oil prices are not determined endogenously with macro variables according to his tests of Sims' six variable model and Granger causality test. He concludes that the oil prices are affected only by historical supply-side disruptions such as the strikes of Texas Railroad

Commission in 1940s, the OPEC embargo in 1970s, Iran-Iraq War in 1980s and etc.

Thus the study introduces unobserved component model to pick up the supply-side permanent oil shocks. Generally, unobserved component model distinguishes non-stationary stochastic trend component and stationary transitory component. We employ quarterly oil price index data for the period of 1960: I~2006: I from IMF IFS database. The real oil price is constructed by deflating consumer price index (2000 = 100).[1]

$$O_t = X_t + Z_t$$
$$\begin{cases} X_t = \mu + X_{t-1} + e_{1t}, \; e_{1t} \sim \text{iid}\, N(o, \sigma_1^2) \\ Z_t = \Phi_1 Z_{t-1} + \Phi_2 Z_{t-2} + e_{2t}, \; e_{2t} \sim \text{iid}\, N(o, \sigma_2^2) \end{cases} \quad (1)$$

where O_t : real oil prices (nominal oil index (2000 = 100)/CPI index (2000 = 100)), X_t is stochastic trend component and Z_t is transitory component. e_{1t} and e_{2t} are independent white noise process. The sum of Φ_1 and Φ_2 is less than one to be stationary. We proceed unit root test to real oil price to examine the stabilities of the variable. As the statistic result comes out -0.68, we can not reject the null hypothesis of existing unit root like other price variables. In our model, the stochastic trend component, X_t, is in the form of unit root equation. Thus the unit root problems could be solved within the above stochastic equation.

We can change the above model into state-space representation. The following is a measurement equation and a transitory equation.

$$O_t = [1\ 1\ 0]\begin{pmatrix} X_t \\ Z_t \\ Z_{t-1} \end{pmatrix}$$
$$\begin{pmatrix} X_t \\ Z_t \\ Z_{t-1} \end{pmatrix} = \begin{pmatrix} \mu \\ 0_t \\ 0 \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 \\ 0 & \Phi_1 & \Phi_1 \\ 0 & 1 & 0 \end{pmatrix}\begin{pmatrix} X_{t-1} \\ Z_{t-1} \\ Z_{t-2} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \\ 0 \end{pmatrix} \quad (2)$$

1 We are willing to construct the real price of oil by deflating nominal oil price with CPI at the beginning stage. However, the CPI index was two digits in the estimated periods, whereas nominal oil price show one digit. To synchronize the level, we chose oil price variables from oil price index rather than nominal oil prices.

By using Kalman filtering methods, we can drive the stochastic trend component and transitory component.

Another issue is asymmetric relationship between oil price and economic growth. Previous studies generally adapt linear model by assuming the symmetric relations of the two variables. However, Mork (1989) tests separate repressors for real oil price increases and decreases, and rejected the null hypothesis of symmetry. Rymond and Rich (1997) introduce Markov switching model to consider the asymmetric relation between two variables. Also they find that the effects of oil shocks are to be the mean of output growth regimes rather than the time-varying transition probabilities.

We introduce a first-order Markov switching model which controls two different regime switching processes such as an expansionary state and a recessionary state.[2] In the contrary to the previous Markov switching model for oil shocks, we develop four lags in the mean growth considering the Hamilton's suggestion.[3] The quarterly real GDP data for the period of 1960: I~2006: I were downloaded from Federal Reserve Bank of ST. Louis in the form of seasonally adjusted.

The model specification of our estimating model is the first-order Markov switching with four lags of the mean growth. Suppose a discrete random variable S_t can take two possible values zero or one ($S_t = 0$ or 1) and serves as an index for the state of the economy at time t. The expected growth rate of GDP conditional on the value of S_t is given by

$$E\,(\Delta y_t / S_t) = \mu_0(1\text{-}S_t) + \mu_1 S_t \tag{3}$$

where μ_0 and μ_1 are the expected values of the growth rate during expansion and recession respectively. The final model considering oil shocks as additional variables to the mean switching growth of GDP presented by the following equation form,

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[2] We also considered a Markov switching process for the variance term. However, the empirical tests did not give any significant difference compared with Markov Switching process for mean term.

[3] Hamilton proposed that a hike in oil prices caused economic recession after three or four quarters later.

$$(\Delta y_t - \mu_t) = \Phi_1(\Delta y_{t-1} - \mu_{t-1}) + \Phi_2(\Delta y_{t-2} - \mu_{t-2}) + \Phi_3 + (\Delta y_{t-3} - \mu_{t-3}) + \Phi_4(\Delta y_{t-4} - \mu_{t-4})$$
$$+ \beta_1(\Delta O^p_{t-1} - \mu_{t-1}) + \beta_2(\Delta O^p_{t-2} - \mu_{t-2}) + \beta_3(\Delta O^p_{t-3} - \mu_{t-3}) + \beta_4(\Delta O^p_{t-4} - \mu_{t-4})$$
$$+ \delta_1(\Delta O^t_{t-1} - \mu_{t-1}) + \delta_2(\Delta O^t_{t-2} - \mu_{t-2}) + \delta_3(\Delta O^t_{t-3} - \mu_{t-3}) + \delta_4(\Delta O^t_{t-4} - \mu_{t-4}) + e_t \quad (4)$$

Transform the above functional forms briefly as the follows,

$$\Phi(L)\ (\Delta y_t - \mu_t) = \Psi(L) \sum \beta_t \Delta O^p_{t-1} + \Pi(L) \sum \delta_1 + O^t_{t-i} \quad i = 1, 2, 3, 4 \quad (5)$$

The roots of $(1 - L\,\Phi_1 - L^2\,\Phi_2 - L^3\,\Phi_3 - L^4\,\Phi_4) = 0$ lie outside the unit circle.

where $O_{t-i}{}^p$ is the growth rate of the stochastic trend component of real oil prices at time t-i, if positive $O_{t-i}{}^p = O_{t-i}{}^p$ and otherwise $O_{t-i}{}^p = 0$. $O_{t-i}{}^t$ the growth rate of the transitory component at time t-1, if positive $O_{t-1}{}^t = O_{t-1}{}^t$ and otherwise $O_{t-1}{}^t = 0$. $e_t \sim$iid N (o, σ^2). The first-order Markov switching model also requires a time series process for S_t.

$$\Pr[S_t = 1 \mid S_{t-1} = 1] = P,\ \Pr[S_t = 0 \mid S_{t-1} = 0] = q$$
$$\Pr[S_t = 0 \mid S_{t-1} = 1] = 1-P,\ \Pr[S_t = 1 \mid S_{t-1} = 0] = 1-q \quad (6)$$

3. Empirical Results

Table 1 reports the estimations results of unobserved component model for real oil prices. The coefficients $\Phi_1 + \Phi_2 < 1$ satisfied the condition of stationary.

Table 1. Parameter Estimates of the Unobserved Component Model of Real Oil Prices (quarterly data, 1960: Ⅳ~2006: Ⅰ)

$\sigma_1{}^2$	0.1195 (0.0160)
$\sigma_2{}^2$	0.0782 (0.0211)
μ	0.0077 (0.0094)
Φ_1	1.4364 (0.1749)
Φ_2	-0.5158 (0.1256)
Log likelihood	89.8981

Note: asymptotic standard errors are reported in parentheses.

Figure 2 and figure 3 plot the stochastic trend component and the transitory component of real oil price respectively for the period for 1960: I~2006: I. The oil shocks in two successive oil crises in 1973~1974 and in 1979~1980 are well detected. However, the two diagrams are quite different during 1970s when the two consecutive oil crises occurred. The stochastic trend component stayed at a certain level after the first oil crisis and jumped up higher level in the second oil crisis. We, thus, suggest that supply-side oil shocks were persistent in 1970s, whereas the transitory component responded to each crisis separately.

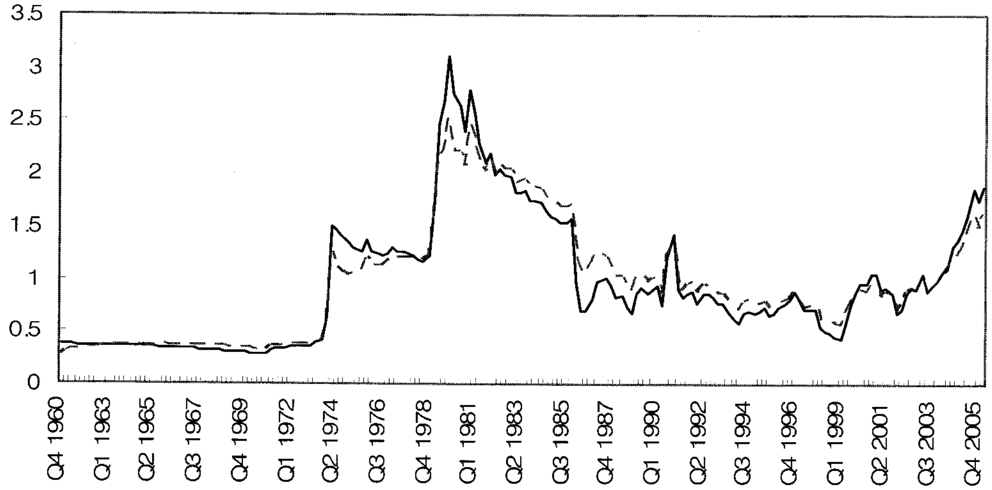

Figure 2. Real Oil Price and Its Stochastic Trend Component

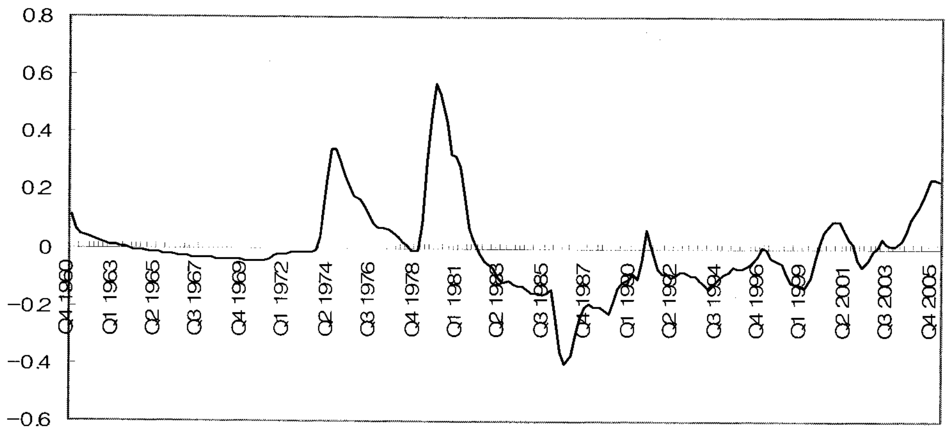

Figure 3. Cyclical Components of Real Oil Prices

With the stochastic trend component variables and the transitory component variables obtained by unobserved component model, we made inference on the regression coefficients by the first order Markov switching processes. The parameters of the model will be estimated by maximum likelihood using a nonlinear filter algorithms proposed by Hamilton.

Table 2 reports the maximum likelihood estimates of four different models. The model 1 is the univariate two-state Markov switching model for the growth rate of log GDP. The model 2 is bivariate two-state Markov switching model for the growth rate of log GDP with the stochastic trend components of real oil prices. The model 3 includes the transitory component instead of the stochastic trend components and model 4 has both of the two components.

The model 1 shows that output growth switching between two different states with mean growth estimated at 0.781% per quarter during expansion and -1.073% during recession. Two of estimates for state dependant means are statistically significant at the 1% critical level. The significantly negative signs during the recession strongly support the asymmetric features and give validity of introducing the two-state Markov switching model. However, we will not conduct the null hypothesis test for the validity of the Markov switching model against general linear model, because the transition probability matrix of p and q is not identified under the null hypothesis of linearity[4]. The transition probabilities of the two regime switches such as expansion

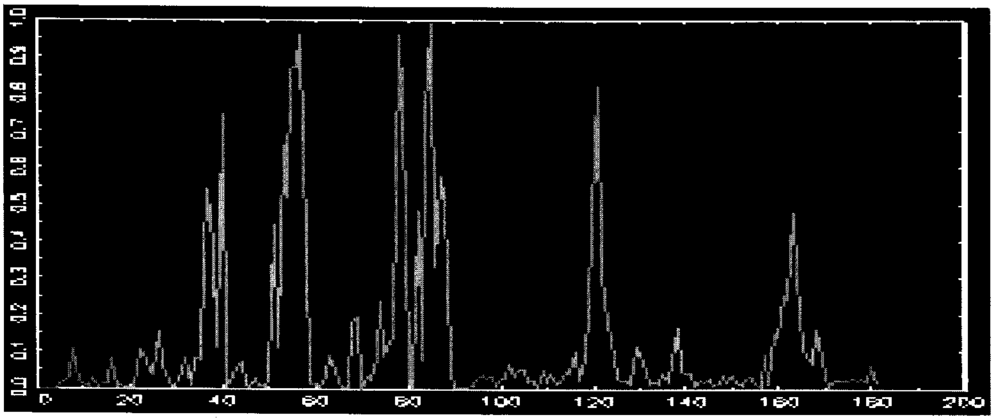

Figure 4. Filtered Probability of a Recession of Model 1 (1961: I ~2006: 1)

[4] P and q are not identified under the null hypothesis, which is a typical type of nuisance parameters. Thus we can not test the hypothesis using any distributions such as χ^2.

and recession are 0.709 and 0.955 respectively. The average durations of expansion and recession are $(1\text{-p})^{-1}$ = $(1\text{-}0.709)^{-1}$ = 3.4 quarters, $(1\text{-q})^{-1}$ = $(1\text{-}0.955)^{-1}$ = 22.2 quarters respectively.

The model 2 indicates the expansion states slightly increase from at 0.78% to 0.84% but the recession states considerably decrease from -1.07% to -1.97%. The results are consistent with the previous findings of the adverse relationship between oil prices and economic growth. To concrete our findings, we test the null hypothesis of restriction to the stochastic trend component, $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$, which is asymptotically distributed as χ^2 (4). Likelihood ratio test is 17.42 higher than both 5% and 1% significant level of 9.49 and 13.28. Thus we are very confident to reject the null hypothesis.

The transition probabilities with the additional regressor of oil shocks 0.204 and 0.978 respectively. The average durations are $(1\text{-p})^{-1}$ = $(1\text{-}0.204)^{-1}$ = 1.26 quarters, $(1\text{-q})^{-1}$ = $(1\text{-}0.978)^{-1}$ = 45.45 quarters respectively. The results assert that the permanent shocks of real oil prices shorten the periods of expansions and deepen the recession, that means that the oil shocks from the supply side prevail to all regimes. The findings are contrary to the previous study by Holmes and Wang (2003), but consistent with the results of Raymond and Rich (1997). Holmes and Wang (2003) argued that the effect of oil shocks is on the mean of expansionary state rather than recessionary state, whereas Raymond and Rich (1997) conclude that recessionary state is more venerable to oil shocks.

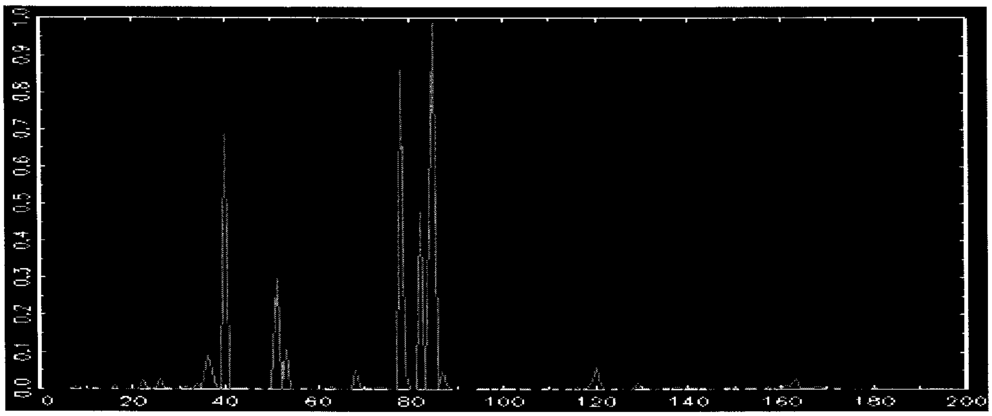

Figure 5. Filtered Probability of a Recession of Model 2 (1961: I ~2006: I)

The model 3 indicates that the coefficients of the second and third lags have the expected signs and only the second lag is significant at 5% level. Also the value of the likelihood function is quite smaller than that of the model 2, and close to the initial value of the univariate model acting as a base model. The ambiguous results imply that the transitory shocks of real oil price do not exert any influence to output growth. We, therefore, conduct the likelihood ratio test with restrictions of $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$. The statistic of 1.49 from likelihood ratio test fails to reject the exclusion of transitory shocks. Thus, the transitory shocks provide little additional information to output growth. The model 4, compared to the model 1, is improved in terms of the value of the likelihood function. However the model 4 reveals no discernible difference from the model 2. Thus, the model 4 is least preferred in the consecutive model specifications.

Table 2. Parameter Estimates of the Markov Switching Model of Real GDP (quarterly data, 1960: I~2006: I)

	Model 1	**Model 2**	**Model 3**	**Model 4**
μ_1	0.781(0.241)	0.840(0.123)	0.511(0.115)	0.838(0.124)
μ_2	-1.073(0.322)	-1.966(0.453)	-1.909(0.514)	-1.973(0.449)
Φ_1	0.107(0.102)	0.146(0.071)	0.212(0.072)	0.142(0.071)
Φ_2	0.119(0.086)	0.113(0.077)	0.155(0.078)	0.115(0.077)
Φ_3	-0.047(0.074)	-0.076(0.072)	-0.042(0.073)	-0.078(0.071)
Φ_4	0.053(0.074)	0.034(0.086)	0.068(0.085)	0.038(0.082)
β_1		-0.714(0.551)		-0.858(0.555)
β_2		-1.072(0.563)		-1.047(0.582)
β_3		-0.718(0.552)		-0.782(0.571)
β_4		-1.262(0.552)		-1.219(0.566)
δ_1			0.329(0.035)	0.033(0.033)
δ_2			-0.009(0.035)	-0.001(0.032)
δ_3	.		-0.492(0.034)	0.005(0.033)
δ_4			0.236(0.035)	-0.016(0.033)
σ^2	0.703(0.048)	0.680(0.046)	-0.688(0.047)	0.678(0.046)
q	0.955(0.034)	0.978(0.019)	0.967(0.020)	0.979(0.018)
p	0.709(0.193)	0.204(0.228)	0.164(0.234)	0.209(0.232)
Log likelihood	-206.129	-197.41814	-205.38296	-196.811

Note: Asymptotic standard errors are reported in parentheses.

4. Conclusion

Early studies in 1980s suggest that oil price have a strong impact to the economic growth. However, as the estimated periods are extended to 1990s, some empirical results indicate the relationship between oil price and output growth no longer strong as before. They, thus, argue that the effects of oil shocks are exaggerated. We understand this issue in the respect of the fluctuations of oil prices. Oil prices had increased rapidly passing through the first oil crisis until 1985, then had declined before 2000. It would be obvious that if we include the periods for low oil prices from 1986 to 1999 in the estimation, the extent of the negative relationship would be decreased. As our sample periods extended to 2006 and the oil prices have increased since 2000, the results propose that oil price have strong impacts on the output growth. That is consistent with the early studies that are leaded by Hamilton and Mork.

The results of this study suggest that the supply-side permanent oil shocks are considered as important determinants in output growth but the demand-side transitory shocks do not give any significant effects to the output growth. These results empirically support Hamilton's assumption. Hamilton proposed that oil prices are determined exogenously and the hike in oil prices, regarded as shocks, is caused by exogenous disruptions in oil supplies such as Suez Crisis, Iran-Ira War, Persian Gulf War and etc.

The modified Markov switching model assures the asymmetric business cycle which switches the expansionary state and recessionary state. The model indicates that oil price increases give more adverse effects to recessionary state rather than expansionary state. Also the oil shocks shorten the duration of expansion and extend the duration of recession. This results are consistent with Rymond and Rich (1997), but not with Holmes and Wang (2003).

The previous studies made inference on time-varying transition probabilities with lags of oil prices, but they concluded that oil shocks displayed little influence to the time-varying transition probabilities. With the reasons, this studies focus on only each regime's durations rather than its time-varying transition probabilities. However, it would be worth making inference on time-varying transition probabilities for our extended periods. In addition, the stochastic trend components have moved among three different regimes of 1960~1985 for high oil prices, 1986~1999 for low oil prices and 2000~2006 for rebound. Also the transitory components, negligible most of time sequences except the first and second oil crises, have shown the increasing tendency since 2000. Thus, the structural breaking test for the different regimes of oil price changes would be recommended for further studies.

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