Nature of Oil Price Shocks and Monetary Policy: A Case of Korea [*]

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Abstract

The goal of the paper is to assess the nature of oil price shocks in both the pre- and post-crisis of Korea. We construct a 5-variable structural VAR and find that the recent hike in oil price is induced by the increase in oil demand in contrast to the previous years when oil price run-up is mostly from supply disruptions. We also study the optimal monetary policy to oil price shocks. Based on an estimated DSGE model, we find that monetary policy should be accommodative with oil price shock in order to stabilize the economy.

JEL Classification: E32, E52, E58

Key word: Oil Price, Structural VAR, DSGE, Monetary Policy

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1   Introduction

Since the second oil crisis in 1979-1980, oil price has shown a stable trend. After the short period of price drop in 2001, oil price turned its course and increased steadily and substantially since 2002 and reached the record high in the summer of 2008. Figure 1 displays the evolution of the WTI(Western Texas Intermediate) oil price in U.S. dollars since 1970 and the Korean recession periods. This figure illustrates several episodes of oil price hikes including 1973-1974, 1979-1980, 1990, and recent price run-ups. Glancing over the figure, one can find many recession periods overlap with the oil price hikes.

Unlike the 1980s and 90s when there were many literature with ideas associating oil prices with economic recessions, the recent episode of the price run-up has been rather subdued as the oil price has not brought a sharp economic downturn unlike previous episodes until lately. Even though the price of oil has started to stabilize since the autumn of 2008 and we are no longer faced with sky-high oil prices, another round of fluctuations in oil price sparked debates from both academics and policymakers not only because it exhibited a record-breaking price level, but also macroeconomic impacts of oil shocks were different from the experiences in the 1970s as well as the origin of the recent shock.

Figure 1: Recession and Oil Price
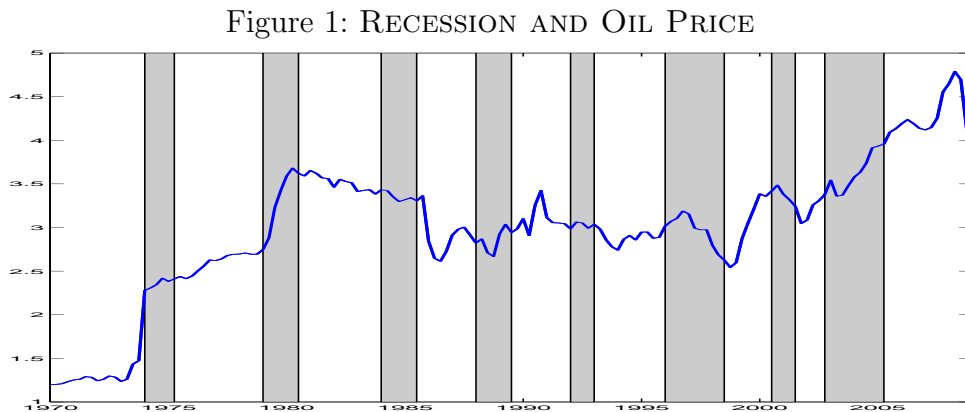
Note: Shaded areas indicate recession periods of Korea.

The increase in oil price will affect the GDP growth adversely both in consumption and production channels.[1] In consumption channel, oil price hikes will reduce disposable income as consumers pay more money to operate their vehicles and to heat their homes. The effects of the rise in oil price will be larger when the demand for oil consumption is less elastic.

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[1]Further discussion can be found in Kilian(2008).

Consumers might postpone their consumption as their disposable income is reduced, hence, the economic activities will be sluggish. Also, increase in oil prices may add uncertainty in the future economic outlook, and consumer may save more as a precautionary measure, hence it will adversely affect the economy. In addition to this, Hamilton(2005) stressed the indirect effect arising when patterns of consumption expenditure change. The shifts in expenditure patterns will disturb sectoral allocation of resources and result in cutbacks in consumption as well as increase in unemployment in the presence of friction in both labor and capital markets.

Production may decline as the GDP growth rate becomes lower when production costs are raised and secondly, large oil price changes may increase uncertainty in business investment, hence, inducing lower aggregate output. The extent to which oil price increases translated into overall rise in inflation depends on their persistence and the share of energy prices in inflation measures.(Rotemberg and Woodford 1996)

Historically, most of the previous oil price shocks arose due to supply contractions from wars and geopolitical uncertainty tied in with oil-exporting countries. Hamilton(1996) showed that most of the U.S. recessions were preceded by increases in oil prices and expounded the increase in oil prices is the main cause of recessions. Guo and Kliesen(2005) found that oil price volatility has had a significant adverse effect on fixed investment, consumption, employment and the unemployment rate using NYMEX crude oil futures data.[2] However, the latest rise in oil prices is understood to be have stemmed from strong market demands and should be treated as endogenous.[3] As economic powerhouses, China and India have become huge consumers of crude oil and the demands from other Asian countries have also increased as their economy recovered from the financial crisis of the late 1990s. Also, developed countries have decreased their interest rates in this period, which accounts for asset price bubbles and increase in commodity prices throughout this period. Some argue that the advancement of financial derivatives turned into speculative boom, contributing to the sky-high rise in energy prices. However, there appears no consensus on how much of the price increases are contributed by speculative forces and fundamental movements. Other conspicuous feature is that recent oil price hikes resulted in divergence between headline and core inflation rates which exclude volatile energy and food prices. The recent oil price

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[2]Barsky and Kilian(2004) and Kilian(2008) refused the idea of exogeneity of oil shocks to the U.S. economy. They argue that precautionary demand shocks driven by expectation shifts may have a major impact on the U.S. economy. They added this type of shocks were associated with the geopolitical events in the Middle East, hence, caused misinterpretation of the source of the shocks.

[3]Kilian(2007) provide evidence that unanticipated crude oil supply shocks are far less important than shocks from the demand for crude oil.

increases seem to slowly pass the impact to the price of non-energy goods and services and led to dissociation between the headline and core inflation. This widening gap between two measures of inflation re-ignites debates over which inflation measure the central bank should focus has been resurfaced.[4]

The goal of this paper is to analyze the nature of recent oil price hikes and their effects on the Korean macroeconomic activities. The Korean economy has experienced quite different responses of output and prices to oil price inflation compared to the two previous oil shocks. Early part of this paper will be devoted to investigate the changing patterns of the responses. Also, we will discuss whether monetary policy to oil price change has been operated optimally to stabilize the macroeconomy. For this purpose, we build a DSGE model with a Taylor type monetary policy where monetary policy responds differentially to oil and non-oil prices. This can be interpreted that monetary policy reacts to overall CPI inflation *per se*. However, the magnitude of intervention is different based on the types of price, i.e. core or non-core price.

Earlier literature on which measures of inflation the central bank should focus on to oil shocks tends to side with core inflation rather than headline inflation. The oft-quoted reasoning for this is that headline inflations are inherently noisy as they include volatile items like food and energy, and they do not reflect changes in the underlying rate of inflation. Also, monetary policy targeting headline inflation could lead to aggravate economic activity when oil shocks are transitory. Suppose that a central bank tightens its policy stance in reaction to the rise of energy prices. Monetary policy action is typically believed to have at least 6-month lag before coming into effect. However, around that time, the energy prices will eventually go back to its original path as the shock is temporary and the outcome of such monetary policy will result in decline in both unemployment and inflation which is undesirable in view of the stabilizing role of monetary policy.

Goodfriend and King(1997) suggest that the monetary policy should focus on the sticky component of prices rather than overall components, suggesting core inflation is the major price index that the central bank should be concerned with. Aoki(2001) formalize a model with two price sectors, one sticky and the other flexible, and support the view of Goodfriend and King. Blinder and Reis(2005) provide evidence that core inflation predicts future headline inflation better than headline inflation itself.[5] Erceg and Bodenstein(2008) argue that core inflation targeting in response to adverse energy supply shocks has better stabilization

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[4]Countries differ in their choice of inflation measures. For example, Bank of England as well as Bank of Korea sets headline inflation as its policy target, while the U.S. Federal Reserve put more emphasis on core inflation in its policy operation.

[5]Cogley(2002) and Rich and Steindel(2007) also found significant reversion of headline inflation to core inflation.

property for both the operational conduct of central banks compared to headline inflation targeting under sticky wage and price settings.

On the other hand, Harris et al.(2009) criticize the policy recommendations from standard new Keynesian models in that those models assumed the complete anchoring of inflation expectations. They showed the longer-term consumer expectations on inflation respond to oil shocks and allude that the Fed should have put more weight on the increase in headline inflation.[6] Describing three statistical characteristics of oil shocks from historical data: (1) permanent, (2) difficult to predict, and (3) governed by very different regimes at different points in time, Hamilton(2008) contends that the oil price shocks cannot be treated as merely transitory and the central bank should pay more attention to the development of headline inflation which includes energy and food prices.[7]

We are not going to favor one from the other in this paper. The main findings in this paper is that the recent oil shocks are triggered by demand sides in contrast to the previous oil shocks and the optimal monetary policy is to accommodate oil price inflation when the stickiness of oil prices is mild. In an estimated DSGE model, oil prices are relatively flexible compared to wages and non-oil prices and the monetary policy should be operated to accommodate oil price inflation, which is implemented by the central bank of Korea. Combining those findings, we argue that both the nature of the oil price inflation and the appropriate monetary policy are conducive to stabilizing the Korean macroeconomy.

The structure of this paper is as follows. Section 2 describes basic findings from data. A 5-variable structural VAR model is constructed and analyzed in Section 3. Section 4 presents a DSGE model with oil sector and estimation results. Section 5 investigates the shape of optimal monetary policy depending on the stickiness of oil prices. Concluding remarks are provided in Section 6.

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[6]Janet Yellen(2009) criticized Harris et al.(2009)'s view of unanchored inflation expectations that the expected inflation in 2008 was only about 10 basis points higher than what it would have been in the absence of the increase in oil price over this period.

[7]Although agreeing to the idea that the Fed should focus on core inflation, Mishkin(2007) discussed two reasons that a central bank should also watch over the headline inflation when the price of an excluded item receives a permanent shock and the headline inflation deviated from the core measure for an extended period of time. First, a longer period of high headline inflation increases the risk of inflation expectations unanchored. Second, prolonged divergence between core and headline measures of inflation could hamper communications between a central bank and the public. He described that the recent rise in oil prices seemed to be more persistent compared to past experiences and the headline inflation has deviated from the core inflation by a considerable margin during 2004-2006 periods.

Table 1: SUMMARY STATISTICS

	Pre-Crisis		Post-Crisis	
	Mean	Std. Dev.	Mean	Std. Dev.
$\triangle \log$ WTI	1.45	12.08	3.08	15.64
$\triangle \log$ CPI	2.39	1.96	0.76	0.44
$\triangle \log$ CORE	2.06	1.75	0.70	0.31
$\triangle \log$ RGDP	1.87	1.29	1.09	1.43
INTR	3.15	0.58	1.05	0.17
INTR-$\triangle \log$ CPI	1.67	0.70	0.28	0.42

Note: Measures in Quarterly growth.
Log difference from the previous quarter times 100.

2   Data

Quarterly data on the real GDP, CPI, export and oil prices(represented by the WTI) are examined in this section. In order to evaluate how the oil prices and macroeconomic activities differ before and after the crisis, we divide the data set before and after the currency crisis of 1997. The dividing year is between in 1998-1999 when the Korean economy experienced a structural break. A variety of evidence supports that the Korean economy has experienced important and long-term changes during this periods, Oh(2007), and Kim and Kang(2004) among others. Korea has introduced a free floating exchange rate system and the central bank has applied inflation targeting, departing from the previous monetary aggregate targeting in 1998. Also, a wide range of restructuring in the corporate and financial sectors have changed the landscape of those industries in these years.

For these reasons, empirical tests are based on two subperiods which are 1987:I-1997:IV (pre-crisis sample) [8] and 2000:I-2009:I (post-crisis sample), omitting 1998 and 1999. Table 2 shows selected summary statistics for log-differenced data in those two subperiods and the existence of unit roots is investigated in Table 2. Despite the increase in the standard deviation of oil prices in the post-1998 sample, those of headline inflation, core inflation, and real interest rate have substantially reduced in the same period compared to the pre-1998 sample. One interesting finding from the unit root test is that CPI rejects unit root in the post-crisis sample in all test statistics. This is consistent with low inflation of recent years in Figure 2 where the cumulative inflation processes show a pronounced difference from the earlier years.

To observe how the dynamic impact of oil shocks on the macroeconomy has changed, we

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[8]The data on interest rate is available since 1987:I
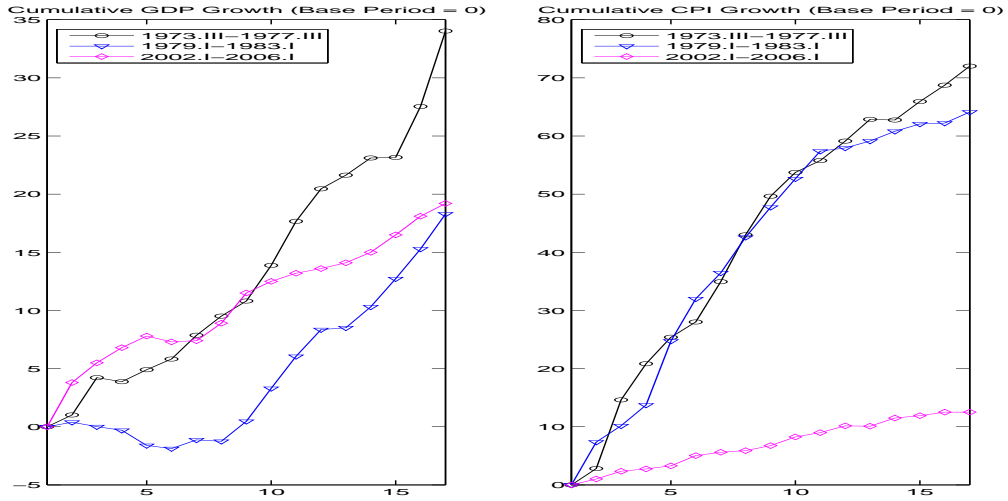
Figure 2: Cumulative Growth of GDP and CPI Inflation

Table 2: Unit Root Tests

| | Pre-Crisis | | | | | Post-Crisis | | | | |
| | PP test | | ADF test | | KPSS test | PP test | | ADF test | | KPSS test |
	ρ	t-val	ρ	t-val	LM-stat	ρ	t-val	ρ	t-val	LM-stat
WTI	-0.03	-1.63	-0.04	-1.56	0.24	-0.20	-1.85	-0.47	-3.15	0.13
CPI	-0.02	-1.92	-0.01	-1.89	0.24	-0.20	-2.31	-0.29	-2.06	0.08
CORE	-0.01	-1.78	-0.03	-2.46	0.11	-0.01	-1.53	-0.24	-3.07	0.08
RGDP	0.00	-0.15	-0.00	-0.41	0.31	-0.15	-1.73	-0.65	-2.87	0.09
INTR	-0.21	-2.09	-0.25	-2.18	0.15	-0.07	-1.74	-0.17	-2.03	0.14
$\triangle \log$ WTI	-0.86	-9.75	-0.82	-5.76	0.08	-0.54	-3.52	-0.68	-2.30	0.09
$\triangle \log$ CPI	-0.45	-6.03	-0.37	-4.14	0.11	-0.96	-5.71	-0.87	-2.84	0.06
$\triangle \log$ CORE	-0.33	-4.79	-0.18	-2.24	0.12	-0.47	-3.54	-0.47	-2.66	0.10
$\triangle \log$ RGDP	-0.83	-8.67	-0.75	-5.15	0.07	-0.93	-5.65	-1.03	-2.96	0.09
INTR- $\triangle \log$ CPI	-0.75	-5.28	-0.57	-2.59	0.11	-1.04	-6.14	-0.75	-2.49	0.11

Note: Asymptotic critical values for LM statistics are 0.216, 0.146, and 0.199 at 1%, 5%, 10% respectively

provide the cumulative growth of real GDP and CPI inflation. Each series has duration of 4 years and the oil shock datings coincide with those selected in Blanchard and Gali(2007) in Figure 2.[9]

The right hand side of the figure indicates the cumulative real GDP growths in each oil shock periods. We observe that adverse effects of oil prices on the real GDP growth are most conspicuous in the second oil shock period which is during 1979:I-1983.I. In the same period, the economic activities have been shrank almost two years before bouncing back to its growth trend. Compared to the earlier oil shocks, the recent episode brought a different picture and the real GDP growth seems to be little affected for at least one year when oil price started to climb up. Later on, the real GDP growth has declined a bit but the contraction effects

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[9]Blanchard and Gali(2007) identify 4 epidodes of oil shocks when the cumulative changes in (log) oil prices are above 50 per cent. We discard the 3rd episode(1999:I-2000.IV) as the periods are close to the 4th one(2002.I-2005.III), and those two episodes are back to back under our 4-year window convention.

are not pronounced.

The left hand side of the figure illustrates the cumulative CPI inflation of the same periods. The cumulative price increases in the first and second oil shock periods are similar. In both periods, the CPI inflation have increased around 70% in 4 years. However, the recent oil price hike haven't passed through its impact to the CPI price. The CPI inflation has reached only 12% in 4 years, i.e. 3% increase of the CPI per annum, indicating the macroeconomic effects of oil price shocks have changed in recent years.

In order to contrast the pre- and post-crisis macroeconomic responses to oil price shocks, nonparametric estimation results of real GDP and CPI inflation to oil prices are presented in Figure 3.[10] The two graphs in the left column is the response of real GDP and CPI inflation in the pre-crisis sample and the two graphs in the right column is those in the post-crisis sample. In the pre-crisis period, real GDP growth and oil price are negatively related. CPI inflation, however, is less clear on its functional form to the oil price changes. In the post-crisis period, real GDP growth are almost flat to oil price changes and one cannot find any clear functional relations between real GDP and oil prices unlike the previous sample. Turning to the overall price, increases in oil prices do not bring forth the rise in CPI inflation, indicating oil prices are not conducive to the rise in CPI inflation until recently.

Summing up, basic facts found from data point out that the nature of oil price shocks or macroeconomic responses to such shocks have been changed in a way that the economy accommodates them better compared to the previous years. The following section will discuss the possible explanations in light of Korean circumstances.

3 Dynamic Effects of Oil Price Shocks
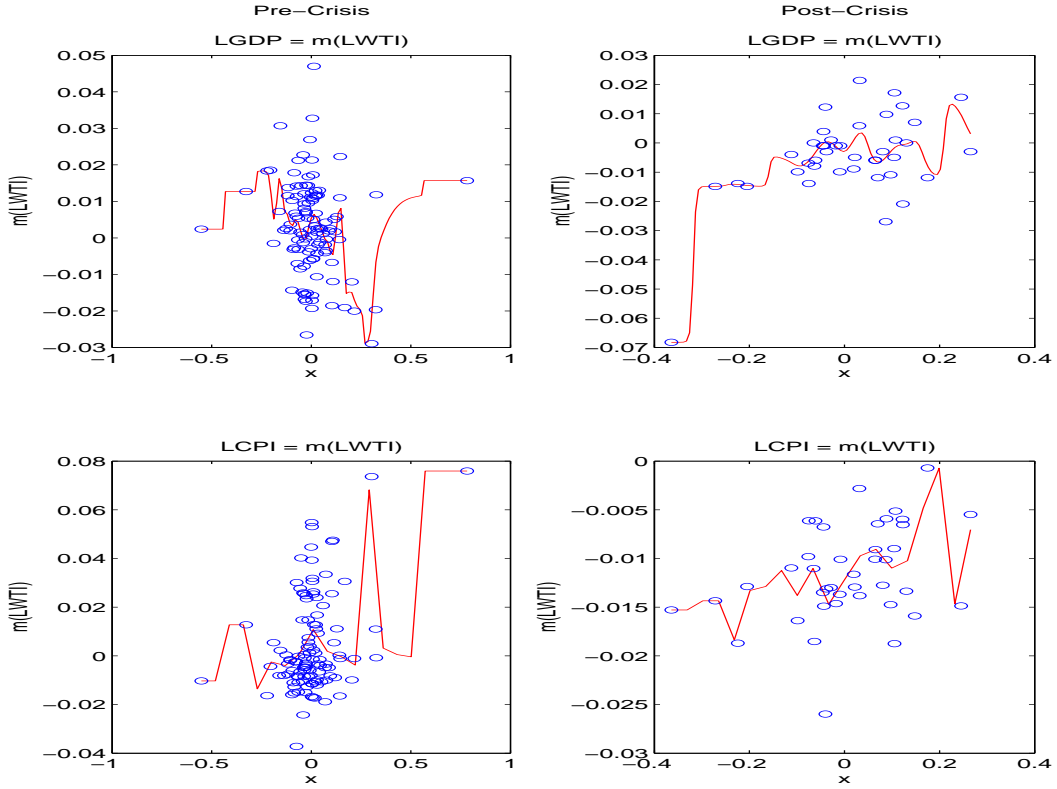
3.1 A Structural VAR Model

In this section, we will use a 5-variable VAR model as our workhorse to quantify the response of real GDP and inflation to oil price shocks. These results will be used in assessing how macroeconomic transmission mechanism of oil price have changed before and after the 1998-1999 period. Even though the 5-variable VAR methodology has many limitations to evaluate the effect of oil price shock fully, adding more macroeconomic variables require additional

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[10]In estimation, we use a Gaussian kernel regression with optimal bandwidth suggested by Bowman and Azzalini(1997).

Figure 3: NONPARAMETRIC GDP AND INFLATION RESPONSES TO OIL SHOCKS

Note: The solid line is kernel regression and circles indicate the data .

identifying assumptions that may not be realistic and likely to be less precise in estimation. In our VAR model, we assume there exist 5 types of structural shocks that affect the Korean economy: oil shock, export shock, local aggregate supply shock, local aggregate demand shock and monetary policy shock. Since, these structural shocks cannot be observed directly, we need to employ identifying restrictions to break down those shocks. Our identification assumptions are based on both long-run and short-run restrictions, which will be discussed shortly.

Let $\Delta z_t = [\Delta O_t, \Delta X_t \Delta Y_t, \Delta P_t, i - \Delta P_t]'$ denotes the log difference of oil price, export, real GDP, price index and real interest rate and we assume that Δz_t is a covariance stationary vector process suggested by the statistics in Table 2. Each element of Δz_t is demeaned, hence it has a zero mean. The structural VAR can be represented by the following formula:

$$A_0 \Delta z_t = A_1 \Delta z_{t-1} + A_2 \Delta z_{t-2} + \cdots + A_p \Delta z_{t-p} + \omega_t \tag{1}$$

where A_0 is 5×5 matrix restricting contemporaneous relations of the included variables. $\omega_t = [\omega_t^{OS}, \omega_t^{FD}, \omega_t^{LS}, \omega_t^{LD}, \omega_t^{MP}]'$ implies 5×1 column vector consisting of oil shock(OS), foreign demand shock(FD), local supply shock(LS), and local demand shock(LD) respectively and $\mathbb{E}[\omega_t] = 0$ and $\mathbb{E}[\omega_t \omega_t'] = I_{5 \times 5}$. Alternatively, the structural VAR can be expressed as follows:

$$\Delta z_t = B_1 \Delta z_{t-1} + B_2 \Delta z_{t-2} + \cdots + B_p \Delta z_{t-p} + C\omega_t = B(L)\Delta z_{t-1} + C\omega_t \tag{2}$$

where $B_j = A_0^{-1} A_j$ and $B(L) = [A_{i,j}(L)]$, $A_{i,j}(L) = a_{i,j}^0 + a_{i,j}^1 L + \cdots + a_{i,j}^p L^p$, $i, j = 1, 2, ..., 5$. $C = A_0^{-1}$. C, inverse of contemporaneous relations, is 4×4 matrix. If z_t is stationary process, the VAR system can be rewritten as a VMA(Vector Moving Average) system according to Wold representation theorem:

$$\Delta z_t = C(L)\omega_t \tag{3}$$

where $C(L) = [C_{i,j}(L)]$ for $i, j = 1, ..., 5$. Once we have $C(L)$, we can recover expressions for the levels of the different variables in terms of current and lagged values of the structural disturbances by a straightforward transformation. The reduced-form autoregressive representation of the aforementioned structural VAR is given by:

$$\Delta z_t = B(L)\Delta z_{t-1} + u_t \tag{4}$$

where $B(L) = [B_{i,j}(L)]$ for $i, j = 1, ..., 5$ and $\mathbb{E}[u_t] = 0$ and $\mathbb{E}[u_t u_t'] = \Omega$. Then, the reduced-form Wold moving average representation of Δz_t can be expressed as:

$$\Delta z_t = D(L)u_t \tag{5}$$

where $D(L) = [D_{i,j}(L)] = (I - B(L))^{-1}$ for $i, j = 1, ...5$, and $D(L)$ is invertible. Thus, u_t is the vector of innovations in the elements of Δz_t. Comparing Eq.(2) and Eq.(4), the following condition holds:

$$u_t = C\omega_t \tag{6}$$

for some 5×5 full rank matrix C. Eq.(7) implies that:

$$C(L) = D(L)C \tag{7}$$

Premultipying both sides of eq.(4) by C^{-1}, we can obtain the structural representation of Δz_t and the structural disturbance vector ω_t. The structural VAR can be identified to the extent that we introduce sufficient restrictions to determine 25 elements of matrix C. Given

C, we can recover $C(L)$ by postmultiplying $D(L)$ as in eq.(7). As the reduced-form variance-covariance matrix has 15 elements, we need 10 restrictions to just-identify the system. For that reason, we introduce 3 long-run neutrality restrictions combined with 7 short-run restrictions. Regarding to the long-run restrictions, we assume that the growth of oil price, expressed in WTI, are not affected from the local shocks, implying $C_{1,3}(1) = C_{1,4}(1) = C_{1,5}(1) = 0$. Translating these restrictions using the relation in eq.(7):

$$D_{1,1}(1)C_{1,3} + D_{1,2}(1)C_{2,3} + D_{1,3}(1)C_{3,3} + D_{1,4}(1)C_{4,3} + D_{1,5}(1)C_{5,3} = 0 \tag{8}$$
$$D_{1,1}(1)C_{1,4} + D_{1,2}(1)C_{2,4} + D_{1,3}(1)C_{3,4} + D_{1,4}(1)C_{4,4} + D_{1,5}(1)C_{5,4} = 0 \tag{9}$$
$$D_{1,1}(1)C_{1,5} + D_{1,2}(1)C_{2,5} + D_{1,3}(1)C_{3,5} + D_{1,4}(1)C_{4,5} + D_{1,5}(1)C_{5,5} = 0 \tag{10}$$

The short-run restrictions are composed of two groups: one is to limit the contemporaneous effect of shocks and the other is the contemporaneous effect of endogenous variables. Simply put, we introduce the short-run restrictions for both the matrix C and the matrix A_0. Restrictions on the matrix C, we impose absence of a contemporaneous effect of local shocks on oil price, implying the following three direction constraints on C

$$C_{1,3} = 0 \tag{11}$$
$$C_{1,4} = 0 \tag{12}$$
$$C_{1,5} = 0 \tag{13}$$

Finally, we impose linear restrictions on the relations between the contemporaneous variables on A_0: (1) contemporaneous oil price dose not affect export, (2) contemporaneous interest rate does not affect real GDP, (3) contemporaneous oil price does not affect real interest rate, and (4) contemporaneous export does not affect real interest rate. Given this specifications, we have the following restrictions, respectively:

$$A_{0,(2,1)} = 0 \tag{14}$$
$$A_{0,(3,5)} = 0 \tag{15}$$
$$A_{0,(5,1)} = 0 \tag{16}$$
$$A_{0,(5,2)} = 0 \tag{17}$$

Given $A_0^{-1} = C$, these restrictions can be map into 4 non-linear constraints on the elements of C.

3.2 Empirical Results

Figure 4 displays the cumulative impulse responses based on the estimates using the pre-crisis sample. Each column represents a one standard deviation of structural shocks and the response of three economic variables to the shocks can be read in row-wise.

To begin with the first column, we show how the economy works when there is an increases oil prices. A temporary rise in the oil price decreases both export and real GDP immediately. Export declines as the increase in oil prices contracts the economic activities of foreign countries and their import demand will also shrink consequently. The adverse oil price shock tends to permanently lower the real GDP by 0.5%. This could be caused by higher marginal costs from energy inputs or lower consumption as consumer's disposable income is reduced after paying higher energy expenses. The price measured by CPI lowers initially but climbs steadily up. One standard deviation increase of the oil prices raise the CPI by 0.2% after 20 quarters. Real interest rate goes down due to the rise in inflation.

The second column is the response of macroeconomic variables to a one standard deviation of an export shock. An increase in export shock, presumably driven by foreign demand, will raise domestic exports and real GDP will also rise. One standard deviation of an export shock shock will raise exports and real GDP by 2.1% and 0.4%, respectively, permanently. This shock has a limited impact on oil price. The price goes up until 7th quarter after the shock and slowly dies out. Real interest rate decreases due to the increase in price growth in the period of the shock but slowly crawls up and rises by 0.4% in the long run.

The third column is the response to a one-standard deviation of local AS shock. The local AS shock increases domestic output and decreases price as the textbook model predicts. The initial deflationary impact raises the real interest rate. Export decreases due to the high interest rate. The decrease in export can be ascribed to the higher financing costs for exporting sectors. With a favorable aggregate supply shocks, real interest rate rises as the marginal productivity increases. This is largely consistent with a standard model.

The fourth column shows the response of the macro variables to a one-standard deviation of local AD shock. The typical paths of real GDP and price move in the same directions, which can be found in the figure. The real interest rate can move up or down depending on the source of the AD shock. In our result, real interest rate decreases reflecting the lack of variability in the nominal rate.

Finally, the fifth column provides the response to a monetary policy shock. The monetary policy shock will lower the real GDP permanently. Inflation tends to rise in the period of

Figure 4: Impulse Responses: Based on Pre-Crisis Estimates
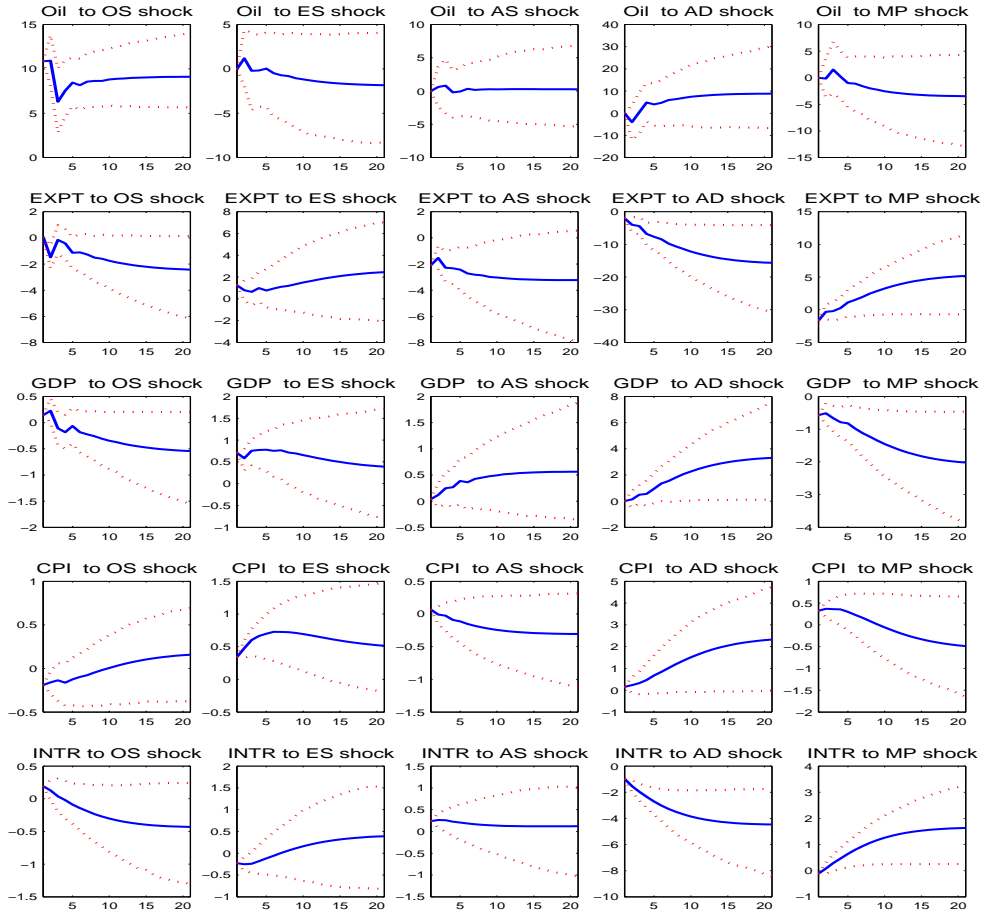
Note: The dotted lines are 90% confidence bands from bootstrapping with 10,000 iterations.

the shock reflecting, presumably, the increase in marginal costs. However, as the time lapses, inflation will slowly decline and reduced by 0.5% in the long-run. The monetary policy shock decrease export in the period of the shock but export increases over time. Increase in real interest rate can divert resources from domestic consumption to export and this could explain the export movement in respond to the monetary policy shock. However, its impacts are statistically insignificant except the early period after the shock.

Until now, we have described how the Korean economy has absorbed 4 identified shocks in the pre-crisis period. Out next task is to see whether the impact from the global supply shock delivered by rises in oil prices has any different dynamics after the Korean economy

went through a structural change. Figure 5 illustrates the impulse response based on the estimates from the post-crisis sample.

What stands out from this exercise is the impulse response of export to an oil price shock. Export increases to the oil shock, unlike the previous case. Real GDP rises immediately after the arrival of the oil price shock but it declines as the lapse of time and eventually dies out.[11] One would ascribe the different responses of real GDP and export to the different exchange rate regimes in the pre- and post- crisis period. Since 1980, Korea has introduced a multi-currency basket system and the exchange rate remained under the tight control of the government until it is replaced by the market average exchange rate in 1991. Since the adoption of the new exchange rate regime, market forces began to play an increasing role in the determination of the exchange rate. However, daily fluctuations in the exchange rate were tightly controlled and regarded close to a fixed rate system *per se*. After the outbreak of the crisis, Korea has a free floating exchange rate system and market plays the most crucial role in the valuation of the Korean Won. From this perspective, one can hypothesize that increases in oil prices raise the exchange rate and spur exports. This argument can be easily tested and the results are provided in Table 3.2. One might consider this argument sounds plausible, but it turns out that this argument cannot be supported in the data. The post-crisis coefficients of the oil price on the exchange rate is significantly negative ranging from -0.171 to -0.226, whereas those of the pre-crisis are distributed between -0.004 to 0.008, moreover statistically insignificant. The negative coefficients on the oil price observed in the post-crisis sample cannot be compatible with the exchange rate-to-export hypothesis. Hence, we need to seek somewhere else to explain the responses of export in the post-crisis period and it will be discussed in due course. The oil price shock raises the price immediately and 0.2% higher in the long run, reflecting increased flexibility in prices compared to the pre-crisis period. The real interest rate increases at the oil price shocks in contrast to the pre-crisis period where interest rate has decreased. We understand this fact is related to the more active role of the Korean monetary authority to keep the inflation under control. As noted earlier, the Korean central bank becomes more independent and is endowed with the authority to set short-term interest rate since the crisis. The response of the monetary policy to oil price hikes is the factor to observe the increase in real interest rate. These picture can be understood as the dynamic effects of the oil price shock have changed and the interactions between oil prices and domestic macroeconomic aggregates build different patterns in the post-crisis period.[12]

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[11]Similar results are found in Hooker(1996) when he used 1973:IV-1994:II U.S. sample.

[12]Blanchard and Gali(2007) found that the impulse response of the U.S GDP and CPI to oil price shocks has changed considerably between the periods before and after 1983. They suggested that the U.S. economy

Table 3: REGRESSION ESTIMATES

	Pre-Crisis				Post-Crisis			
	KRW/USD		REER		KRW/USD		REER	
WTI	-0.002	-0.004	0.007	0.008	-0.226	-0.241	-0.171	-0.197
	[-0.09]	[-0.17]	[0.20]	[0.22]	[-5.11]	[-4.84]	[-3.82]	[-3.98]
WTI(-1)		0.014		-0.008		0.035		0.062
		[0.56]		[-0.21]		[0.67]		[1.20]
Const.	4.576	4.446	2.175	2.158	3.505	3.204	2.650	2.111
	[3.87]	[3.71]	[1.25]	[1.23]	[1.30]	[1.16]	[0.97]	[0.77]
R-squared	0.0001	0.0025	0.0006	0.0012	0.4272	0.4346	0.2943	0.3230

Note: The t-values are reported in the parentheses.

The impulse responses to an one-standard deviation of local AS shock are presented in the third column in the figure. The shock raises real GDP as expected from the standard model. Although inflation decreases at the inception of the shock, its long-run impact is erratically 0.2% higher in the long run. But it is statistically insignificant and we should not give much weight on this. Real interest rate increases due to the initial deflationary pressure and increased productivity. The local AS shock in the post-crisis sample has a more pronounced effect on export compared to that in the pre-crisis sample. Contrary to the decrease to the local AS shock in the pre-crisis period, the growth of export is positive in the period of the shock. Under the ceteris paribus circumstance, the local AS shock will raise the comparative advantage of Korea which is conducive to positive export and GDP growth. However, the increase in export growth will be slowed down as the exchange rate will be adjusted to dilute the effect of comparative advantage. The fifth column shows the impulse responses to monetary policy shocks. One interesting finding is that higher interest rate will appreciate local currency resulting in decreased exports and real GDP. Increase in real interest rate diverts domestic resources to exporting sectors in the pre-crisis period in contrast to the post-crisis period when the exchange rate plays an increasingly important role in the responses of exports.

3.3 Historical Simulation

In order to figure out the differences how the oil price shock affect the Korean economy, we estimate dynamic correlations between real GDP and price in both periods. For that purpose, we estimate historical disturbances from our estimated structural VAR and eliminate all the shocks other than the oil price shocks. In the pre- and post- crisis period, oil price shocks affects both output and price. If the correlations between real GDP and price are positive,

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has faced an improved tradeoff in the post 1983 periods.

Figure 5: Impulse Responses: Based on Pre-Crisis Estimates
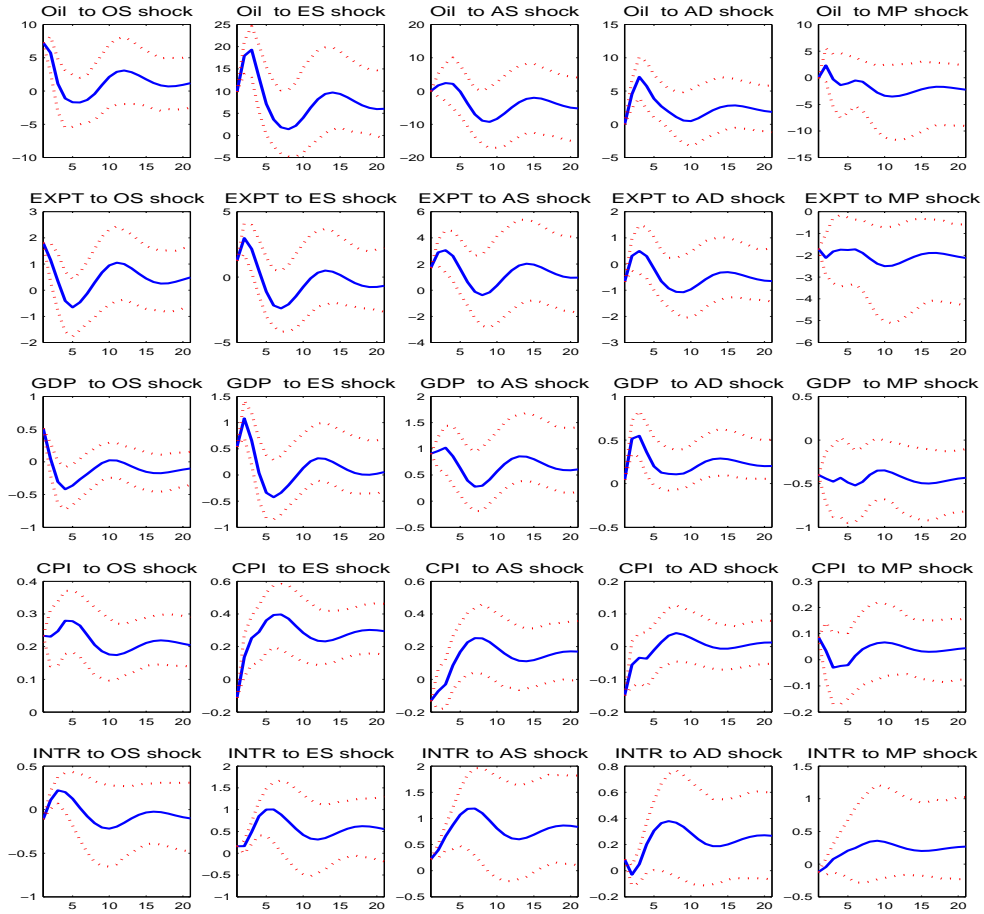
Note: The dotted lines are 90% confidence bands from bootstrapping with 10,000 iterations.

we can infer that the oil price shocks affect the aggregate demand of the economy as the shift in demand schedule will move price and real GDP in the same direction. On the contrary, negative correlations between real GDP and price imply the oil price shocks influence the aggregate supply as the shift in supply schedule will drive both price and real GDP in the opposite direction. The $j-$period ahead dynamic correlation at time t can be found as

follows:

$$Corr(\Delta\hat{Y}_{t+j}, \Delta\hat{P}_{t+j}|\Omega_t) = \frac{(\Delta\hat{Y}_{t+j} - \mathbb{E}[\Delta\hat{Y}_{t+j}|\Omega_t])(\Delta\hat{P}_{t+j} - \mathbb{E}[\Delta\hat{P}_{t+j}|\Omega_t])}{\sigma(\Delta\hat{Y}_{t+j}|\Omega_t)\sigma(\Delta\hat{P}_{t+j}|\Omega_t)}$$
$$= \frac{\eta_{\Delta\hat{Y}_{t+j}} \ \eta_{\Delta\hat{P}_{t+j}}}{\sigma(\Delta\hat{Y}_{t+j}|\Omega_t)\sigma(\Delta\hat{P}_{t+j}|\Omega_t)}$$

where $\eta_{\Delta\xi_{t,t+j}}$ is the $j-$period ahead forecasting error of $\xi(=\Delta\hat{Y}_t, \Delta\hat{P}_t)$ and Ω_t is information set up to time t. The hat on top of the variables indicates the variables are constructed to be solely affected by the oil shocks.

The dynamic correlations in the pre- and post-crisis periods are presented in Figure 6. From this exercise, we can evaluate the transmission of oil price shocks to the economy. In the short run, the oil shock affects the demand schedule and real GDP and price move in the same direction. However, comparing the magnitude of the short-run correlations, the post-crisis correlations is more than two-fold of the pre-crisis counterpart. The high correlation between output growth and inflation in the post-crisis period implies that the AS schedule is more steep in this period than the pre-crisis period. The difference in the nature of the shock is more pronounced when one looks into the long-run correlations. In the post-crisis period, long-run correlations between real GDP and price around 0.4 , indicating the oil price shock affect the aggregate demand in this period. In contrast, the long-run correlations become negative in the pre-crisis sample, implying oil price shocks influence the aggregate supply in this period. These findings combined with the earlier impulse response analysis lead to the following conclusion. The oil shocks in the pre-crisis period can be ascribed to oil supply shocks. The oil price shocks caused by disruptions in oil supply will adversely affect domestic production which renders the AS schedule move to the left resulting in the negative correlation between output growth and inflation. In contrast, the oil prices shocks observed in the post-crisis period are produced from the increase in oil demand. Oil price increase generated by the increased world demand will raise exports and domestic output which can be observed from the first column in Figure 5. Increase in world demand will shift the AD schedule to the right resulting in positive correlations between output growth and inflation.

The oil price changes, especially upward movements, have brought many economic difficulties in the past. It's still a problem but its macroeconomic impacts have been quite subdued in recent periods, as shown in our VAR evidence. We argue the nature of the shock has been changed in the recent oil price run-up. Unlike the previous year when most of the oil shocks are believed to have been driven by supply disruptions, the recent oil price rise stemmed from the increase in demand for oil. A demand-driven oil price hike keeps the Ko-

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Figure 6: Dynamic Correlation Between Real GDP and Price
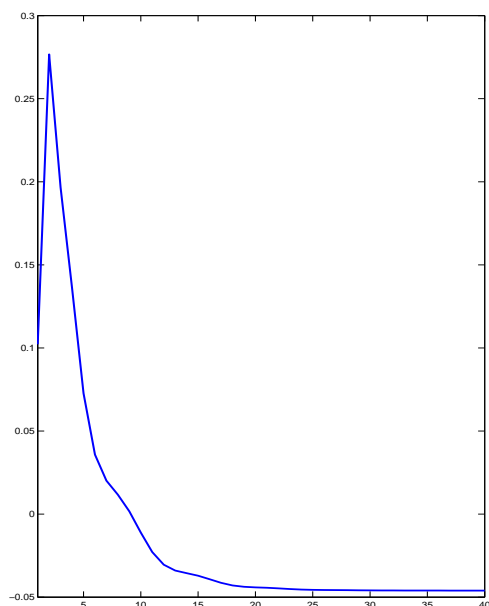
(a) Corr($\Delta Y_t, \Delta P_t$): Pre-Crisis
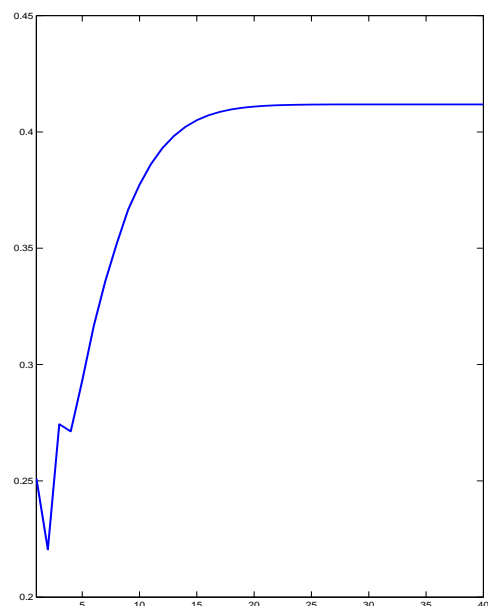
(b) Corr($\Delta Y_t, \Delta P_t$): Post-Crisis

rean economy buoyant in contrast to the macroeconomic troubles experienced in the past years.

So far, we have shown the macroeconomic impacts of the oil price change and put aside the macroeconomic policies, especially monetary policy, which is essential in understanding the propagation mechanism of external shocks. In the following section, we try to find out whether monetary policy in the post-crisis years has been conducted in a way that can stabilize macro-economy and the shape of optimal monetary policy in the face of oil price shocks based on a simplified DSGE model

4 Nominal Rigidities with the Oil Sector

4.1 A Model

In this section, we construct a small open economy nominal rigidities model with oil and non-oil sectors and extend closed economy one sector models with oil usage as in Bodenstein

et al. (2008).

We start with the production side of the non-oil sector. We denote the non-oil sector by subscript n and the oil sector by subscript o in the following equations. Firms produce final non-oil goods by aggregating intermediate goods. Namely,

$$y_{n,t} = \left[\int y_{n,t}(i)^{\frac{1}{\mu_n}} \, di \right]^{\mu_n}, \qquad \mu_n \geq 1 \tag{18}$$

where $y_{n,t}$ is the final good and $y_{n,t}(i)$ is the ith intermediate good in the non-oil sector. Final non-oil goods market is competitive and the final non-oil goods price $(P_{n,t})$ is

$$P_{n,t} = \left[\int P_{n,t}(i)^{\frac{1}{1-\mu_n}} \, di \right]^{1-\mu_n} \tag{19}$$

where $P_{n,t}(i)$ is the ith intermediate non-oil good price. Demand for the ith intermediate good is

$$y_{n,t}(i) = y_{n,t} \left[\frac{P_{n,t}(i)}{P_{n,t}} \right]^{\frac{\mu_n}{1-\mu_n}} \tag{20}$$

Production technology for the ith intermediate good is

$$y_{n,t}(i) = z_t (n_{n,t}(i))^{\alpha_n} (o_t(i))^{\alpha_o} \tag{21}$$

where $n_{n,t}(i)$ is labor input, $o_t(i)$ is oil usage and z_t is labor augmenting technology shock, which follows the law of motion given as

$$\ln z_t = z + \ln z_{z,t-1} + \zeta_{z,t} \tag{22}$$

$$\ln \zeta_{z,t} = \rho_{\zeta_z} \ln \zeta_{z,t-1} + \varepsilon_{z,t}, \qquad \varepsilon_{z,t} \sim N(0, \sigma_z) \tag{23}$$

Intermediate goods producers behave as monopolistic competitors and set prices with Calvo mechanism. Namely, they set new prices with probability $1 - \theta_n$ or adjust prices just as much as the trend inflation rate with probability θ_n in each period. Thus, the ith intermediate good producer in the non-oil sector solves

$$\max_{P_{n,t}^N} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta \theta_n)^s \, \upsilon_{t+s} \left[\pi_n^s P_{n,t}^N y_{n,t+s}(i) - MC_{n,t+s}(i) y_{n,t+s}(i) \right] \tag{24}$$

subject to the demand for the ith intermediate good (20). π_n is trend inflation rate in the non-oil sector, $P_{n,t}^N$ is newly set price, $y_{n,t}(i)$ is the ith intermediate good, and $MC_{n,t}(i)$ is

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nominal marginal cost in the non-oil sector given as

$$MC_{n,t}(i) = \frac{W_t}{\alpha_n} \frac{n_{n,t}(i)}{y_{n,t}(i)} \tag{25}$$

where W_t is nominal wage rate. The input ratio to minimize costs is

$$\frac{o_t}{n_n} = \frac{\alpha_o}{\alpha_n} \frac{W_t}{P_{o,t}} \tag{26}$$

where $P_{o,t}$ is final oil goods price. Also, v_t is the marginal value of a dollar to the household. The first-order condition with respect to $P_{n,t}^N$ is

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_n)^s \, v_{t+s} y_{n,t+s}(i) \left[\pi_n^s P_{n,t}^N - \mu_n MC_{n,t+s}(i) \right] = 0 \tag{27}$$

The oil sector works similar to the non-oil sector. Firms in the oil sector produce final oil goods by aggregating intermediate goods. Namely,

$$y_{o,t} = \left[\int y_{o,t}(i)^{\frac{1}{\mu_o}} \, di \right]^{\mu_o}, \qquad \mu_o \geq 1 \tag{28}$$

where $y_{o,t}$ is the final good and $y_{o,t}(i)$ is the ith intermediate good in the oil sector. The final oil goods price $(P_{o,t})$ is given as

$$P_{o,t} = \left[\int P_{o,t}(i)^{\frac{1}{1-\mu_o}} \, di \right]^{1-\mu_o} \tag{29}$$

where $P_{o,t}(i)$ is the ith intermediate oil good price. The demand for the ith intermediate good in the oil sector is

$$y_{o,t}(i) = y_{o,t} \left[\frac{P_{o,t}(i)}{P_{o,t}} \right]^{\frac{\mu_o}{1-\mu_o}} \tag{30}$$

Production technology for the ith intermediate good is

$$y_{o,t}(i) = z_t(cr_t(i))^{\alpha_{cr}} \tag{31}$$

where $cr_t(i)$ is crude oil input imported from abroad. We abstract labor input in the oil production for simplicity. Intermediate goods producers in the oil sector also behave as

monopolistic competitors and set prices with Calvo mechanism. The first order condition is

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_o)^s \upsilon_{t+s} y_{o,t+s}(i) \left[\pi_o^s P_{o,t}^N - \mu_o MC_{o,t+s}(i) \right] = 0 \tag{32}$$

$MC_{o,t}$ is nominal marginal cost given as

$$MC_{o,t}(i) = \frac{P_{cr,t}}{z_t \alpha_{cr} cr_t(i)^{\alpha_{cr}-1}} \tag{33}$$

where $P_{cr,t} = S_t P_{cr,t}^*$ is domestic crude oil price, which is crude oil price in dollar terms, $P_{cr,t}^*$, times nominal exchange rate, S_t.

Next, we consider the household problem. Household i maximizes expected utility

$$\mathbb{E}_t \left[\sum_{s=0o}^{\infty} \beta^s \left(U\left(c_{t+s}\right) - V\left(n_{t+s}(i)\right) \right) \right] \tag{34}$$

subject to the budget constraint

$$P_{n,t} c_{n,t} + P_{o,t} c_{o,t} + P_{m,t} c_{m,t} + B_t \leq W_t(i) n_t(i) + \Pi_t + T_t + (1 + R_{t-1}) B_{t-1} \tag{35}$$

where c_t is final consumption good, n_t is labor hours, B_t is nominal savings, Π_t is transfer from firms, T_t is transfer from government, and R_t is nominal interest rate. Final consumption good (c_t) is a composite of domestically produced non-oil consumption good ($c_{n,t}$), oil consumption good ($c_{o,t}$) and imported consumption good ($c_{m,t}$) given as

$$c_t(i) = \varkappa (c_{n,t}(i))^{1-w_o-w_m} (c_{o,t}(i))^{w_o} (c_{m,t}(i))^{w_m} \tag{36}$$

where $\varkappa = \left(\frac{1}{w_o}\right)^{w_o} \left(\frac{1}{w_m}\right)^{w_m} \left(\frac{1}{1-w_o-w_m}\right)^{1-w_o-w_m}$ is a normalizing factor. The parameter w_o and w_m are the shares of the oil and imported consumption goods in total consumption. $P_{n,t}$ is domestically produced non-oil consumption goods price, $P_{o,t}$ is oil consumption goods price and $P_{m,t} = S_t P^*$ is imported goods price in domestic currency, which is imported goods price in dollar terms, P_t^*, times nominal exchange rate, S_t. We drop subscript i except for household i's wage and labor supply assuming symmetric equilibrium.

First-order conditions except for wage setting are

$$U_{c_n,t} = \upsilon_t P_{n,t} \tag{37}$$

$$U_{c_o,t} = \upsilon_t P_{o,t} \tag{38}$$

$$U_{c_m,t} = \upsilon_t P_{m,t} \tag{39}$$

$$\frac{1}{1+R_t} = \beta E_t \frac{\upsilon_{t+1}}{\upsilon_t} \tag{40}$$

where $U_{c_n,t}$, $U_{c_o,t}$ and $U_{c_m,t}$ are the derivatives of the utility function with respect to $c_{n,t}$, $c_{o,t}$ and $c_{m,t}$ respectively. We assume utility function takes a form as

$$U(c_t) = \zeta_{c,t} \ln c_t, \qquad V(n_t(i)) = \zeta_{n,t} \varkappa_n n(i)^2 \tag{41}$$

where $\zeta_{c,t}$ and $\zeta_{n,t}$ are consumption preference shock and labor supply shock respectively and they follow the laws of motion given as

$$\ln \zeta_{c,t} = (1 - \rho_{\zeta_c}) + \rho_{\zeta_c} \ln \zeta_{c,t-1} + \varepsilon_{c,t}, \qquad \varepsilon_{c,t} \sim N(0, \sigma_c) \tag{42}$$

$$\ln \zeta_{n,t} = (1 - \rho_{\zeta_n}) + \rho_{\zeta_n} \ln \zeta_{n,t-1} + \varepsilon_{n,t}, \qquad \varepsilon_{n,t} \sim N(0, \sigma_n) \tag{43}$$

Also $\varkappa_n$ is a normalizing factor which ensures the steady state labor supply is $1/3$ of available time.

Households set wages with Calvo mechanism. Labor used for production is an aggregate of differentiated labor supply by households given as

$$n_t = \left[\int n_t(i)^{\frac{1}{\mu_w}} di \right]^{\mu_w}, \qquad \mu_w \geq 1 \tag{44}$$

The wage associated with n_t is given as

$$W_t = \left[\int W_t(i)^{\frac{1}{1-\mu_w}} di \right]^{1-\mu_w} \tag{45}$$

Demand for the ith household's labor is

$$n_t(i) = n_t \left[\frac{W_t(i)}{W_t} \right]^{\frac{\mu_w}{1-\mu_w}} \tag{46}$$

In each period, household i sets a new wage with probability $1 - \theta_w$ or adjusts its wage just as much as the trend inflation rate times the trend growth rate with probability θ_w. The

household wage setting problem is then

$$\max_{W_t^N} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta \theta_w)^s \left[-V(n_{t+s}(i)) + \upsilon_{t+s} (\pi_c \cdot z)^s W_t^N n_{t+s}(i) \right] \tag{47}$$

where π_c is final consumption goods trend inflation rate and z is economy-wide trend growth rate. The first-order condition with respect to W_t^N is given as

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta \theta_w)^s n_{t+s}(i) \upsilon_{t+s} [-\mu_w \frac{V'(n_{t+s}(i))}{\upsilon_{t+s}} + (\pi_c)^s W_t^N] = 0 \tag{48}$$

Market clearing conditions are

$$y_{n,t} = c_{n,t} + S_t x_{n,t}^* \tag{49}$$

$$y_{o,t} = o_t + c_{o,t} \tag{50}$$

$$n_t = n_{n,t} \tag{51}$$

where $x_{n,t}^*$ is the non-oil goods export in dollar terms. We abstract oil sector export for simplicity. We define the real GDP of the economy as

$$y_t = \frac{P_{n,t}}{P_{c,t}} y_{n,t} + \frac{P_{o,t}}{P_{c,t}} c_{o,t} - \frac{P_{cr,t}}{P_{c,t}} cr_t \tag{52}$$

We assume detrended log non-oil goods export in dollar terms $(\widetilde{x}_{n,t}^*)$, detrended log real exchange rate $(\widetilde{\xi}_t)$ and detrended log relative price of crude oil to foreign price level $(\widetilde{\gamma}_t)$ follow joint VAR process given as

$$F_0 \begin{bmatrix} \widetilde{x}_{n,t}^* \\ \widetilde{\xi}_t \\ \widetilde{\gamma}_t \end{bmatrix} = F(L) \begin{bmatrix} \widetilde{x}_{n,t-1}^* \\ \widetilde{\xi}_{t-1} \\ \widetilde{\gamma}_{t-1} \end{bmatrix} + \varepsilon_t^*, \qquad \varepsilon_t^* \sim N(0, \Sigma^*) \tag{53}$$

We assume $\widetilde{\gamma}_t$ does not contemporaneously affect the other variables in the VAR and we thus identify the effects of crude oil price shocks (innovations in $\widetilde{\gamma}_t$) using recursive ordering scheme so that F_0 is a lower triangle matrix.

Monetary policy follows a Taylor-type interest rate rule given as

$$R_t = \rho_R R_{t-1} + (1 - \rho_R)(\rho_{\pi_{core}} \pi_{core,t-1} + \rho_{\pi_{non}} \pi_{non,t-1} + \rho_y \widetilde{y}_{t-1}) + \varepsilon_{m,t} \tag{54}$$

where $\widetilde{y}_t$ is output gap and $\varepsilon_{m,t} \sim N(0, \sigma_m)$. We also note that the final consumption good price $(P_{c,t})$ is given as

$$P_{c,t} = P_{o,t}^{w_o} P_{m,t}^{w_m} P_{n,t}^{1-w_o-w_m} \tag{55}$$

We define core CPI inflation as CPI inflation excluding oil price inflation Then we can define $\pi_{core,t} = (w_m \pi_{m,t} + (1 - w_o - w_m)\pi_{n,t})$ and $\pi_{non,t} = w_o \pi_{o,t}$.

4.2 Estimation

In this section, we estimate the nominal rigidities model constructed above using Bayesian methods as in Smets and Wouters(2007). We estimate the model with Korean data for the sample period 2000:1Q-2009:1Q, corresponding to post Korean currency crisis period.[13]

We fix some parameters by calibration and then estimate the remaining parameters by Bayesian methods. We set the subjective discount rate β as $0.98^{1/4}$. The non-oil sector production function parameters α_n and α_o are set as 0.448 and 0.062 respectively, using the shares of labor input and intermediate oil (petroleum) use in total value-added plus intermediate oil use in the non-oil (non-petroleum) sector, obtained from the 2005 Korean input-output table. We also set α_{cr} as 0.657 using the share of intermediate crude oil use in total value-added plus intermediate crude oil use in the oil (petroleum) sector from the input-output table. We set the price and wage markup parameters, μ_n, μ_o, and μ_w as 1.1 as in the literature. We calibrate the shares of oil (petroleum) and imported goods in total consumption, w_o and w_m, as 0.021 and 0.390 respectively using the shares of oil (petroleum) and imported goods in GDP from the input-output table.

We use the log difference of real GDP, CPI inflation rate, CPI energy price inflation rate (as oil sector inflation rate), overnight call rate, linearly detrended log export in dollar (constructed as export in real GDP divided by real exchange rate and then multiplied by core CPI and divided by CPI), U.S. CPI inflation rate, linearly detrended log real effective exchange rate from BIS and linearly detrended log WTI price divided by U.S. CPI (as the relative price of crude oil to foreign price level). We obtain the data from Korea National Statistical Office, Datastream and the BIS. The eight observable variables match eight structural shocks in the model and we can identify the model.

Also we estimate the exogenous VAR block with the data and insert the estimated block in the model before the Bayesian estimations. We find a VAR with lag length one is appropriate

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[13]Estimation results of the pre-crisis period are presented and compared with the post-crisis estimates in Appendix.

based on Schwartz criterion.

We estimate parameters concerning sectoral price as well as wage stickiness, shock processes and monetary policy rule using Bayesian methods after log-linearizing the model around the stationary steady states as in Adolfson et. al.(2007) and Smets and Wouters(2008). The prior distributions for the structural parameters are described in Table 4.2.

We set the prior distribution of the non-oil sector price stickiness parameter, θ_n, as a beta distribution with the mean of 0.675 and the standard deviation of 0.2. This follows previous research as in Adolfson et. al. (2007). We set the prior distributions of the other price stickiness and wage stickiness parameters, θ_o, θ_m and θ_w, as uniform distributions on the interval [0, 1] reflecting prior uncertainty about the possible parameter values. We set the prior distribution of the parameter concerning the weight on the non-oil inflation rate, $\rho_{\pi_{core}}$, as a normal distribution with the mean of 1.5 and the standard deviation of 0.4 and the prior distribution of the parameter concerning the weight on output gap, ρ_y, as a beta distribution with the mean of 0.125 and the standard deviation of 0.1 following the literature. We set the prior distribution of the parameter concerning the weight on the oil inflation rate, $\rho_{\pi_{non}}$, as a normal distribution with the mean of 0 and the standard deviation of 2. The zero prior mean and relatively large standard deviation reflect the lack of prior information concerning the monetary policy response toward oil price inflation. We set the prior distributions of aggregate technology shock persistence and monetary policy interest rate smoothing parameters, ρ_{ς_z} and ρ_R, as beta distributions with the mean of 0.7 and the standard deviation of 0.1. We set the consumption preference shock and labor supply shock persistence parameters, ρ_{ς_c} and ρ_{ς_n}, as beta distributions with the mean of 0.5 and the standard deviation of 0.1. We set the prior distributions of all parameters concerning shock standard deviation as inverse gamma distribution with the mean of 0.2 and the standard deviation of 2. We also estimate the structural shocks covariance matrix Σ^* in the VAR block, which is identity matrix by definition, and set the prior distributions of the diagonal elements of the matrix as inverse gamma distributions with the mean of 1 and the standard deviation of 2. We will denote the ith diagonal element of the matrix by Σ_{ii}^* in the followings.

We summarize the estimated posterior distributions of the parameters in Table 4.2 as well as the prior distributions in Table 1. When we examine the estimated posterior distributions of price and wage stickiness parameters, the posterior of the non-oil sector price stickiness parameter, θ_n, is estimated to be highest with its mode being 0.945. The posterior of the oil sector price stickiness parameter, θ_o, is estimated to be lowest among the price stickiness

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Table 4: PRIORS

Parameters		Priors		
		Type	Mean	Std. Dev.
Non-oil price stickiness	θ_n	Beta	0.675	0.2
Imported goods price stickiness	θ_m	Uniform	0.5	$1/\sqrt{12}$
Oil price stickiness	θ_o	Uniform	0.5	$1/\sqrt{12}$
Wage stickiness	θ_w	Uniform	0.5	$1/\sqrt{12}$
Monetary policy non-oil inflation response	$\rho_{\pi_{core}}$	Normal	1.5	0.4
Monetary policy oil inflation response	$\rho_{\pi_{non}}$	Normal	0.0	2.0
Monetary policy output gap response	ρ_y	Beta	0.125	0.1
Interest rate smoothing	ρ_R	Beta	0.7	0.1
Aggregate tech. shock persistence	ρ_{ζ_z}	Beta	0.7	0.1
Consumption preference shock persistence	ρ_{ζ_c}	Beta	0.5	0.1
Labor supply shock persistence	ρ_{ζ_n}	Beta	0.5	0.1
Monetary policy shock std. dev.	σ_m	Inv. Gamma	0.02	2
Aggregate tech. shock std. dev.	σ_z	Inv. Gamma	0.02	2
Consumption preference shock std. dev.	σ_c	Inv. Gamma	0.02	2
Labor supply shock std. dev.	σ_n	Inv. Gamma	0.02	2
VAR cov. matrix diagonal elements	Σ_{ii}^*	Inv. Gamma	1	2

parameters with its mode being 0.685. We note the estimated degree of oil price stickiness is different from zero as we can see from the 10th percentile of the posterior. The posterior mode of imported goods price stickiness, θ_o, is 0.805 between the modes of non-oil goods price stickiness and oil goods price stickiness. The posterior of the wage stickiness parameter, θ_m, is estimated to be lower than the posteriors of the price stickiness parameters with its mode being 0.539.

Concerning the parameters of the monetary policy Taylor rule, the posterior mode of the monetary policy response to non-oil price inflation parameter, $\rho_{\pi_{core}}$, is 1.549 slightly higher than the prior mode. The posterior mode of the monetary policy output gap response parameter, ρ_y, is 0.004, lower than the prior mode. When we examine the posterior of the monetary policy response to oil price inflation, $\rho_{\pi_{non}}$, the mode is 0.121, the l0th percentile is -3.208 and the 90th percentile is 3.319. Thus the monetary policy response toward oil price inflation is rather imprecisely estimated including zero between the 10th and 90th percentile. And the estimated mode represents less anti or more accommodating policies toward oil price inflation than non-oil price inflation as mentioned in Dhawan and Jestke(2007).

We can summarize our findings from the Bayesian estimation of the model as follows. First, the degree of oil sector price stickiness is relatively lower than non-oil sector price stickiness as in the literature. The oil sector price is not, however, completely flexible differ-

Table 5: POSTERIORS FROM THE MODEL ESTIMATION

Parameters		Posteriors			
		Mode	Std. Dev.	10th Per.	90th Per.
Non-oil price stickiness	θ_n	0.945	0.009	0.928	0.958
Imported goods price stickiness	θ_m	0.805	0.044	0.745	0.893
Oil price stickiness	θ_o	0.685	0.051	0.626	0.771
Wage stickiness	θ_w	0.539	0.102	0.440	0.703
Mon. policy non-oil response	$\rho_{\pi_{core}}$	1.588	0.378	1.105	2.209
Mon. policy oil response	$\rho_{\pi_{non}}$	0.121	1.984	-3.208	3.319
Mon. policy output gap response	ρ_y	0.004	0.008	2.796e-5	0.029
Interest rate smoothing	ρ_R	0.702	0.089	0.540	0.828
Aggregate tech. shock per.	ρ_{ζ_z}	0.910	0.016	0.885	0.937
Cons. preference shock per.	ρ_{ζ_c}	0.398	0.081	0.273	0.518
Labor supply shock per.	ρ_{ζ_n}	0.443	0.091	0.297	0.577
Monetary policy shock std. dev.	σ_m	0.026	0.003	0.024	0.032
Aggregate tech. std. dev.	σ_z	0.053	0.011	0.038	0.081
Cons. preference shock std. dev.	σ_c	0.804	0.253	0.542	1.504
Labor supply shock std. dev.	σ_n	3.761	1.830	1.777	7.932
VAR cov. first diag. element	Σ_{11}^*	0.926	0.104	0.778	1.138
VAR cov. second diag. element	Σ_{22}^*	0.930	0.106	0.775	1.137
VAR cov. third diag. element	Σ_{33}^*	0.909	0.102	0.759	1.108
Marginal likelihood		393.2			

ently from the theoretical models as in Aoki(2001), in which optimal monetary policy is the complete stabilization of core inflation rate. Second, the monetary policy response toward non-core CPI inflation is rather imprecisely estimated and the estimated posterior mode represents less strict policy toward non-core CPI inflation than core CPI inflation.

5 Optimal Monetary Policy

In the following, we consider varying degrees of monetary policy responses toward non-core oil price inflation and examine the effects on CPI inflation and output gap volatilities. It would be necessary to consider different values for $\rho_{\pi_{non}}$ since its posterior distribution is imprecisely estimated. We further consider cases separately when the model economy is perturbed by each structural shocks to examine the different effects of monetary policy responses to the shocks. The other parameter values are set at their posterior modes.

We simulate the model by setting $\rho_{\pi_{non}}$ equal to -3.2081, -0.1206, 0.0, 0.1206 and 3.3194 respectively. They are respectively the 10th percentile, the negative value of the mode, zero

Table 6: MONETARY POLICY RULES, OUTPUT GAP AND CPI INFLATION VOLATILITIES

Technology Shocks			Preference Shocks		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.0332	0.2758	10th. Per.	0.0048	0.1575
-Mode	0.0328	0.2702	-Mode	0.0049	0.1584
Zero	0.0328	0.2700	Zero	0.0049	0.1584
Mode	0.0328	0.2698	Mode	0.0049	0.1585
90th. Per.	0.0324	0.2640	90th. Per.	0.0050	0.1593
Labor Supply Shocks			Oil Shocks		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.0069	0.5247	10th. Per.	0.0021	0.1861
-Mode	0.0069	0.5248	-Mode	0.0021	0.1862
Zero	0.0069	0.5248	Zero	0.0021	0.1862
Mode	0.0070	0.5248	Mode	0.0021	0.1862
90th. Per.	0.0070	0.5249	90th. Per.	0.0021	0.1864
Export Shocks (1st shocks in VAR.)			Real Exchange Rate Shocks (2nd shocks in VAR)		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.0052	0.1439	10th. Per.	0.0020	0.1697
-Mode	0.0053	0.1452	-Mode	0.0020	0.1699
Zero	0.0054	0.1453	Zero	0.0020	0.1699
Mode	0.0054	0.1453	Mode	0.0020	0.1699
90th. Per.	0.0055	0.1466	90th. Per.	0.0020	0.1702

response, the mode and the 90th percentile of the posterior distribution of $\rho_{\pi_{non}}$. We report the results in Table 5.

When the model economy is simulated with crude oil shocks only, more accommodating policies toward oil price inflation work better as we can reduce output gap volatilities without raising CPI inflation volatilities very much. This resembles the results from Dhawan and Jeske(2007). Also, in response to structural shocks except for the very persistent permanent technology shocks, more accommodative policy works better than less accommodative policy. In the case of permanent technology shocks, more anti oil inflation policy works better as can be seen in Table 5.

These results can be summarized that monetary policies with an accommodating policy toward oil price inflation works better in the estimated model except for very persistent technology shocks.

6   Conclusion

The price of crude oil has shown an increasing trend since 2002, but failed to draw much attention due to its subdued effects on economic activities before its sharp increase at the end of 2007. Since then, prices have started to inch up and real GDP contracted. Policymakers become concerned with the rising oil prices as the memory of the past specters resurfaced.

We investigate the changing nature of macroeconomic responses to oil price shocks and find that unlike the previous years, the recent run-up in oil price are induced by the increase in demand for oil. We also study the the optimal monetary policy when oil is included in both consumption and production. Based on the DSGE model, we find that optimal monetary policy should be accommodative with oil price shocks in order to stabilize CPI inflation and output gap.

There are other candidates to explain the changes in macroeconomic responses to oil price shocks in recent years. One may ascribe mild impacts of oil prices to macroeconomy to declining shares of oil in consumption and production. We look into the time series for both consumption and production shares of oil but fail to find any conspicuous changes in the shares, which is consistent with the findings in Kilian(2008).[14] We also investigate whether the wage inflation has shown any significant differences in the pre- and post-crisis periods but persuasive results cannot be found either. What we haven't tried is the role of futures market. Increased efficiency in futures market for oil could be helpful to stabilize the economy. Nonetheless, we doubt whether the futures market alone can make dramatic changes in the response of output and price for such a long period of time. However, this is the area which needs a further scrutiny and left for future research.

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[14]However, Blanchard and Gali(2008) find the decline in the share of oil in consumption and production results in a quantitatively significant implications for the recent U.S. economy.

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Appendix II: Pre-Crisis DSGE Estimation

We also estimate the model for the period 1975:1Q-2007:4Q, corresponding to the before currency crisis period. We calibrate the parameters using same methods as before and estimate the model with Bayesian methods as before. The prior distributions for the estimated parameters are set as before except for the persistence parameters for the consumption preference shocks and labor supply shocks, ρ_{ζ_c} and ρ_{ζ_n}, whose priors are set as uniform distribution on the interval [0,1] rather than beta distributions with mean 0.7 and standard deviation 0.1, utilizing more data. We also use core CPI inflation rate data in the place of overnight call rate since the call rate data is not available until early 1990s.

The estimated posteriors are reported in Table 6. They are similar to the posteriors from the post currency crisis period. Now the oil prices are somewhat less sticky than before but the posterior of the oil price stickiness parameter is still different from zero as we can see from the 10th percentile of the posterior distribution. When we examine the posterior distribution of the monetary policy response to oil price inflation, $\rho_{\pi_{non}}$, the mode is -0.006, the l0th percentile is -3.209 and the 90th percentile is 3.323, and thus the posterior is imprecisely estimated as before.

Also we simulate the model with different values of $\rho_{\pi_{non}}$ and different structural shocks and find more accommodating policy toward oil price inflation works better than less accommodating policy as before, except for the very persistent labor supply shocks as can be seen in Table 6.

Table 7: POSTERIORS FROM THE MODEL ESTIMATION: PRE-CRISIS

Parameters		Posteriors			
		Mode	Std. Dev.	10th Per.	90th Per.
Non-oil price stickiness	θ_n	0.953	0.010	0.938	0.962
Imported goods price stickiness	θ_m	0.798	0.088	0.703	0.918
Oil price stickiness	θ_o	0.464	0.055	0.395	0.548
Wage stickiness	θ_w	0.149	0.018	0.130	0.179
Mon. policy non-oil response	$\rho_{\pi_{core}}$	1.106	0.058	1.040	1.231
Mon. policy oil response	$\rho_{\pi_{non}}$	-0.006	2.367	-3.209	3.323
Mon. policy output gap response	ρ_y	0.023	0.016	0.007	0.049
Interest rate smoothing	ρ_R	0.698	0.053	0.581	0.757
Aggregate tech. shock per.	ρ_{ζ_z}	0.775	0.025	0.728	0.812
Cons. preference shock per.	ρ_{ζ_c}	0.121	0.283	3.540e-5	0.586
Labor supply shock per.	ρ_{ζ_n}	0.999	2.457e-7	0.999	0.999
Monetary policy shock std. dev.	σ_m	0.095	0.003	0.062	0.172
Aggregate tech. std. dev.	σ_z	0.111	0.013	0.090	0.134
Cons. preference shock std. dev.	σ_c	0.202	0.084	0.074	0.311
Labor supply shock std. dev.	σ_n	0.072	0.020	0.051	0.148
VAR cov. first diag. element	Σ_{11}^*	0.979	0.072	0.868	1.112
VAR cov. second diag. element	Σ_{22}^*	1.024	0.075	0.912	1.163
VAR cov. third diag. element	Σ_{33}^*	0.967	0.070	0.864	1.098
Marginal likelihood		737.5			

Table 8: Monetary Policy Rules, Output gap and CPI inflation Volatilities

Technology Shocks			Preference Shocks		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.0105	0.3481	10th. Per.	0.0011	0.0996
Mode	0.0106	0.3488	Mode	0.0011	0.0997
Zero	0.0106	0.3488	Zero	0.0011	0.0997
-Mode	0.0106	0.3488	-Mode	0.0011	0.0997
90th. Per.	0.0107	0.3495	90th. Per.	0.0011	0.0999
Labor Supply Shocks			Oil Shocks		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.9716	2.5092	10th. Per.	0.0004	0.0755
-Mode	0.2819	1.0439	-Mode	0.0004	0.0757
Zero	0.2815	1.0431	Zero	0.0004	0.0757
Mode	0.2812	1.0424	Mode	0.0004	0.0757
90th. Per.	0.1622	0.7897	90th. Per.	0.0004	0.0759
Export Shocks (1st shocks in VAR.)			Real Exchange Rate Shocks (2nd shocks in VAR)		
$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$	$\rho_{\pi_{non}}$	$S.D(\pi_c)$	$S.D(y)$
10th. Per.	0.0017	0.0551	10th. Per.	0.0024	0.0604
Mode	0.0018	0.0561	Mode	0.0025	0.0615
Zero	0.0018	0.0561	Zero	0.0025	0.0615
-Mode	0.0018	0.0561	-Mode	0.0025	0.0616
90th. Per.	0.0018	0.0572	90th. Per.	0.0025	0.0627