Macroeconomic effects of oil price shocks in a small open economy

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TITLE OF RESEARCH

**The Macroeconomic Effects of Oil Price Shocks in
a Small Open Economy**

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The Macroeconomic Effects of Oil Price Shocks in a Small Open Economy

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Abstract

The thesis studies the macroeconomic effects of oil price shocks using a dynamic stochastic general equilibrium (DSGE) model in the context of a small open economy. It examines the role of exchange rate flexibility in smoothing the adjustments of the economy to oil price shocks and provides a possible explanation to the different responses of the economy to similar oil price changes during the 1970s and after the 1980s. The thesis has three essays.

In the first essay, I set up the baseline model with labor and oil as the input factors of production. The small open economy is assumed to import oil from other countries. The study is motivated by the close relationship between terms and trade and real exchange rate fluctuations. Since the volatility of terms of trade seems largely due to the oil price shocks, the variations in oil price may actually explain the variation in real exchange rate. Also, as the economy shows very different responses to similar oil price shocks during the 1970s and after the 1980s, the effects of oil price shocks under different exchange rate regimes are analyzed. I show that one possible explanation for the apparent different responses is the policy shift to more flexible exchange rate regimes, which could have helped to absorb the exogenous shocks in the economy.

In the second essay, I extend the baseline model by including capital as an input in production. By doing this, I can examine the effects of oil price shocks in a more realistic framework. The results of the extended model are similar with the baseline model. The economy exhibits lower fluctuations in output and capital under relatively

flexible exchange rate regimes regardless of the degrees of openness. Specifically, I assume that capital accumulation is subject to the adjustment cost in which the capital rental cost after capital depreciation does not always equal to foreign nominal interest rate. I also show that the smaller impact on output can be attributed to the lower share of oil in the production.

In the third essay, oil is not only used as an input in production, it is also consumed directly by households. I compare four alternative monetary policy rules: a fixed exchange rate and three types of inflation targeting rules. Other than the exchange rate as the target of monetary policy, the presence of oil in the total consumer price index opens the question of whether monetary authorities should react to fluctuations in total CPI, non-oil CPI, or domestic production price index. The welfare analysis indicates that the central bank should choose domestic price index as its measure of inflation because it results in the lowest welfare loss. In contrast, when the central bank targets the nominal exchange rate, it results in the highest welfare loss.

Chapter 1

Introduction

1.1 Oil Price Shocks and Exchange Rate Regimes: Some Evidence

Oil price shocks are generally regarded as an important source of economic fluctuations and studies have shown a strong correlation between increase in oil prices and subsequent economic downturns.¹ The recent sharp rise in oil prices is comparable (in percentage terms measured from trough to peak) to the oil price rise in the 1970s. Instead of the stagflation as in the 1970s, however, the GDP growth and inflation have remained relatively stable in many countries. In a recent issue of World Economic Outlook (2007), the IMF research department did extensive research of the potential impact of higher oil prices on the world economy. According to their analysis, the percentage deviation in real GDP is around -0.1 for most of the developed countries, and around -0.2 for the developing countries for permanent \$5 per barrel increase in the price of oil in 2000.² On the other hand, looking back to the recessions in the 1970s, I can see most economies experienced low growth, high inflation and high unemployment at the same time. Hamilton (2008) estimates that GDP growth would have been slower by 2.9% after a 10% increase in oil price using data from 1949 to 1980 but the growth would only be 0.7% slower using data from 1949 to 2005.

¹ See Hamilton (1983, 1996), Gisser and Goodwin (1986), Rotemberg and Woodford (1996)

² \$5 per barrel is around 20% increase from the base price.

Blanchard and Gali (2007) compare the macroeconomic performance of G7 countries in the aftermath of the oil price shocks during the 1970s and the 1990s. They define a large oil shock as an episode involving a 50% cumulative change in the oil price and find that the effects of oil price shocks have been greatly reduced in the 1990s compared to the 1970s. Following their work, I compare the effect of an oil price shock for selected emerging countries.³ Table 1 shows the average inflation over eight quarters right after each episode's benchmark date (at which the cumulative rise in oil price is above 50%) minus the average inflation over eight quarters immediately preceding each run-up period (when the oil price starts to rise). The Table shows significant moderation in changes of inflation.⁴ Using a similar method, Table 2 shows moderation in changes of GDP growth. It exhibits lower higher GDP growth rate in the two recent periods of oil price increase.

A possible explanation to the milder responses to oil price shocks may be that since 1980s, many countries have switched to more flexible exchange rate regimes.⁵ As argued by Friedman (1953), flexible exchange rate regimes may insulate the economy from external shocks. He contends that when prices and wages are sticky, the effects of real shocks on output are milder under flexible exchange rate regimes because the adjustments in nominal exchange rates allow the real exchange rate to

³ We select Korea, Israel and Taiwan as the representatives of oil-importing emerging economy and they are all under flexible exchange rate regime according to de facto exchange rate arrangements after the 1990s.

⁴ Benchmark date refers to the date when the cumulative increase in oil price is above 50%.

⁵ Levy-Yeyati and Sturzenegger (2002) and Broda (2004) use various measures of de facto exchange rate regimes and document that many countries switched to more flexible exchange rate regimes. We elaborate on this point in Chapter 2.

adjust quickly thereby eliminating excess demand and mitigating the contraction in output.⁶ Under fixed exchange rate regimes, the adjustment in real exchange rate occurs through domestic prices, which adjust only slowly. This results in the persistence of excess demand and worsening of the output contraction.

Broda (2004) tests Friedman's hypothesis using a sample of 75 developing countries during the post Bretton Woods period. He assesses whether the response of real GDP, real exchange rates, and prices to terms of trade shocks differ systematically across exchange rate regimes. He finds that responses are significantly different across regimes in a way that supports Friedman's (1953) hypothesis. Countries with more flexible regimes tend to have small real GDP losses and immediate large real depreciations. Edwards and Levy-Yeyati (2005) use a sample of 100 countries to assess the impact of terms of trade shocks on output growth. Their findings are consistent with Friedman's hypothesis that the effects of terms of trade shocks are larger under more rigid exchange rate regimes.

Researchers often use exogenous shocks such as terms of trade to examine the stabilizing role of exchange rate regimes. I use oil price shocks instead of terms of trade shocks because terms of trade shock may be driven largely by oil price shocks. Figure 1 plots the annual nominal oil price and terms of trade from 1965 to 2005 and it clearly shows co-movement between the two series. Furthermore, Backus and Crucini (2000) find that the increased volatility in the terms of trade seems largely due

⁶ Real exchange rate is defined as relative price expressed in common currency or the foreign price multiplied by the nominal exchange rate divided by domestic price. Nominal exchange rate is defined as local currency divided by foreign currency.

to the increased volatility in the relative price of oil.

As I mentioned above, real exchange rates could adjust quickly or slowly to oil price shocks depending on countries' exchange rate regimes. However, real exchange rate seems to be correlated with movement in oil prices. This can be seen in Figure 2, which plots the annual nominal oil price and real exchange rate in the United States from 1975 to 2005.⁷ Hence, several authors have empirically investigated the effects of oil price shocks on real exchange rates. Zhou (1995) investigates the long-run relationship regarding the determination of the real exchange rate using a series of tests.⁸ She shows that the real exchange rates react to changes in the real oil price, the domestic and foreign fiscal variables, the differentials of productivity growth, and the monetary differentials. Chen and Chen (2007) investigate the long-run relationship between real oil prices and real exchange rates using a monthly panel of G7 countries from 1972:1 to 2005:10. They show that real oil prices may have been the dominant source of real exchange rate movements.

The goal of this thesis is to shed light on the nature of the apparent differences in the macroeconomic effects of oil price shocks. I also aim to examine the role of oil price shocks in determining the variations in real exchange rates in the context of a general equilibrium model. The general equilibrium model allows us to examine the structural relationships among output, real exchange rates and other macroeconomic variables under different exchange rate regimes in the presence of oil price shocks.

⁷ Data source: International Financial Statistics

⁸ She employs the cointegration tests, the vector error correction model, and the common stochastic trend approach with variance decomposition.

One of the limitations of dynamic stochastic general equilibrium (DSGE) models is that it cannot capture the asymmetric effects of oil price shocks. The asymmetric effects of oil price shocks are well documented in literature.⁹ Hamilton (1988) offers an explanation that asymmetry could be the result of adjustment costs to changing oil prices. He suggests that the price adjustment could retard economic activity. Therefore, rising oil prices would present two negative effects for economic activity while falling oil prices would present both positive and negative effects for economic activity. Chen, Finney and Lai (2005) analyze asymmetric gasoline price adjustment using threshold cointegration analysis. They find evidence of asymmetry not only in short-run and long-run adjustment but also across spot and future markets. In other words, a rise in oil prices results in a faster response in gasoline prices than a reduction in oil prices. They also conclude that the asymmetry occurs primarily at the down stream stage where the cost of adjustment could be even higher. This could imply that a positive oil price shock would have a larger impact on the economy than a negative oil price shock. I consider the larger economic effects of a positive oil price shock and the limitation of the DSGE model in focusing on the economic effects of positive oil price shocks.

1.2 My Approach

I evaluate the impact of oil price shocks and focus on the stabilizing role of exchange rate regimes in a small open economy using dynamic stochastic general

⁹ Mork (1994), Hamilton (1996), Huntington (1998), Hamilton and Herrera (1999)

equilibrium (DSGE) models. In the first essay, I set up my baseline model which assumes that the small open economy imports oil from other countries. Figure 3 shows a diagram of the model. The infinitely lived households do not consume oil directly and, for simplicity, domestic firms only use oil and labor as their inputs. Also, the economy is small in the sense that it cannot affect the foreign price level. Foreign output, foreign interest rate, foreign price level, and oil price denominated in foreign currency are assumed to be exogenous. To capture the frictions in the goods market, I follow Calvo (1983) in modeling pricing behavior where only a fraction of firms adjust their prices in a given period. By making specific the rule of monetary policy, I can derive the log-linearized version of the model and solve for the numerical solutions.¹⁰

I find that flexible exchange rate regimes better absorb positive oil price shocks. Under a more flexible exchange rate regime, both output and consumption have smaller fluctuations when countries are hit by positive oil price shocks. Specifically, the economy benefits from the initial currency appreciation, which induces lower input cost and inflation rate. The eventual depreciation of domestic currency can strengthen the competitiveness of home country products. On the other hand, if the nominal exchange rates are fixed, the economy can rely only on the slow adjustment in prices to get rid of excess demand in goods market. The process could be prolonged. The simulation results are consistent with Friedman's (1953) hypothesis regarding the stabilizing role of flexible exchange rate regimes. The dynamic responses of output,

¹⁰ Rotemberg and Woodford (1998), Clarida, Gali, and Gertler (1999), and Monacelli (2004) use the same monetary policy rule.

terms of trade and real exchange rate to oil price shocks are in line with the findings of Backus and Crucini (2000) and Broda (2004). Output and consumption decrease when the economy is hit by a positive oil price shock, while inflation and nominal interest rate increase. Also, terms of trade and real exchange rate are procyclical, which are in line with the findings of Mendoza (1995) and Backus and Crucini (2000).

In the second essay, I extend the baseline model and include capital as an input in production. I examine the roles of structural changes—shifts in exchange rate regime and reduced oil share of output—to explain the milder responses of the economy to similar oil price shocks after the 1990s. The extended model is more realistic since it can explain the significant effect of oil price shocks in a manner that is consistent with the observed low oil share of output. I follow Kim and Loungani (1992) in using a nested constant elasticity of substitution (CES) production function. Specifically, I assume capital accumulation is subjected to the adjustment cost. The friction in the capital market guarantees there is a difference between domestic nominal rental cost after capital depreciation and foreign nominal interest rate. Households cannot smooth their consumption immediately after the shocks using bonds. Both capital and investment drop due to positive oil price shocks, and rental cost on capital increases not only because of the higher demand on capital due to substitution effect but also because of less accumulated capital due to investment cost. My simulation results are generally consistent with those of the baseline model, which indicates that the baseline model is robust despite the exclusion of capital.

In the third essay, oil is not only used in production but also consumed directly by households. I conduct a welfare analysis on which variable would be the appropriate target for the central bank: the exchange rate or three different measures of inflation. The three different measures of inflation are overall CPI, non-oil CPI, and domestic production price index. I find that welfare loss is highest when the central bank targets the exchange rate. The welfare loss is lowest when the central bank targets domestic prices.

The thesis is organized as follows: Chapter 2 builds up the baseline model and considers the role of flexible exchange rate regimes in mitigating oil price shocks; Chapter 3 extends the baseline model by introducing capital accumulation with adjustment cost; and Chapter 4 introduces oil in the consumption basket and discusses the welfare effects when the central banks target the exchange rate and different measures of inflation. Chapter 5 concludes the thesis.

Table 1 Oil shock episodes: change in inflation (%)

	O1	O2	O3	O4	AVG(1, 2)	AVG (3,4)
Israel	3.5	12.7	-1.6	-0.35	8.1	0.975
Korea	3.27	2.65	-4.73	1.28	2.96	-1.725
Taiwan	-1.4	2.1	-0.1	0.15	0.35	0.025

Notes: 1. As in Blanchard and Gali (2007), O1, O2, O3, O4 represent four episodes during which a cumulative change in oil price is above 50%. The benchmark date for each episode: O1 (1974:1), O2 (1979:3), O3 (1999:3), O4 (2003:1). The run-up period for each episode: O1 (1973:3~1974:1), O2 (1979:1~1980:2), O3 (1999:1~2000:4), O4 (2002:1~2007:3); 2. Data source: International Financial Statistics, Data Stream. I focus on the oil-importing emerging countries, but the limited data for the given period do not allow us to include more countries.

Table 2 Oil shock episodes: change in GDP growth (%)

	O1	O2	O3	O4	AVG(1, 2)	AVG (3,4)
Israel	-6.64	4.6	0	0.7	-2.04	0.7
Korea	-0.72	-2.6	1.4	-0.1	-3.32	1.3
Taiwan	-1.7	-1.1	-1.05	0.87	-1.4	0.09

Note: 1. Period definition is the same as in the change in inflation, the average GDP Growth rate over eight quarters after each benchmark date is compared against the average GDP growth rate over eight quarters immediate preceding each run-up period; 2. Data source: International Financial Statistics, Data Stream.

Figure 1 Nominal oil price and terms of trade

Figure 2 Nominal oil price and real exchange rate

Figure 3 Model structure

Chapter 2

Oil price Shocks, Exchange rate, and Macroeconomic Fluctuations:

A Baseline Model

2.1 Introduction

Over the past thirty years, researchers have explored the relationships between oil price shocks and the macroeconomic performance and have viewed oil price shocks as an important source of economic fluctuations. The rise in oil price could have a direct effect on the economy as it could alter households' consumption decisions and firms' cost structure through which it eventually changes the domestic price level. A sharp rise in oil price often causes concerns that economic downturns will subsequently follow. Indeed, oil price increases are considered to be the main reason for the "stagflation" in the 1970s. In contrast, the dramatic rise in oil price over the last few years did not induce significant economic decline. While the price of West Texas Intermediate oil was about US\$19 per barrel by the end of 2001, it reached US\$90 per barrel by the end of 2007. When oil prices tripled after 2000, most economies did not experience recessions. In some countries affected by the oil price hikes, the recessions have been milder than in the 1970s. A question that arises is: why are macroeconomic effects of oil price shocks so different in the 2000s from the 1970s?

One possible explanation to the different economic effects of the oil price shocks in the 1970s compared to the 2000s may be that countries have switched to more

flexible exchange rate regimes in the past thirty years.¹¹ In the early 1970s, major currencies (US dollar and French Franc) began to float, but most developing countries continued to peg their exchange rate—either to a single key currency (usually US dollar or French Franc) or to a basket of currencies. The International Monetary Fund (IMF) uses the de jure classification of exchange rate regimes based on the publicly stated commitments of monetary authorities. From 1975 to 1996, an increasing number of developing countries have adopted flexible exchange rate regimes. Only 10 percent of developing countries were under flexible exchange rate regime in 1975, and over 50 percent adopted flexible exchange rate regime in 1996.¹²

Instead of de jure classification of exchange rate regimes, Broda (2004) uses Ghosh, Ostry and Wolf's (1994) de facto classification of exchange rate to group 75 developing countries according to their the exchange rate regimes. He classifies less than 10 countries under intermediate and flexible exchange regimes and more than 60 countries under fixed exchange rate regime in 1973. In contrast, he classifies more than 50 countries under flexible exchange rate regime and less than 25 countries under fixed exchange rate regime in 1998. Levy-Yeyati and Sturzenegger (2002) classify the exchange rate regimes of 183 countries based on the volatility of reserves and exchange rates. They report that in 1974, 74% of countries can be classified under the fixed exchange rate regime and 26% of countries can be

¹¹ Blanchard and Gali (2007) attribute the mild effects of the oil price shocks in recent years to the four factors: good luck, smaller share of oil in production, more flexible labor market, and improvements in monetary policy.

¹² IMF World Economy Outlook (October 1997).

classified under intermediate of flexible exchange rate regimes. By 2000, 58% are under fixed exchange rate regime and 42% are under intermediate and flexible exchange rate regimes. Rogoff et al. (2003) use Reinhart and Rogoff's (2004) "Natural" classification, which considers severe macroeconomic episodes that could cause large devaluations as "free falling" rather than flexible exchange rates and information on dual or parallel exchange rates as alternatives to official exchange rates. Rogoff et al. find that emerging economies have moved from harder pegs toward softer pegs or more flexible exchange rate regimes from the 1970s to the 2000. This trend generally holds from 1970 to 1990 with countries moving away from harder to softer pegged regimes. However, they report a reversal of this trend after 1990 for developing countries and European Union countries.

When countries change to more flexible exchange rate regimes, they could better insulate their economies from oil price shocks. This idea was first proposed by Friedman (1953). He argues that with sticky prices, an economy hit by real shocks can change relative prices quickly when nominal exchange rates are flexible so it experiences smaller variations in output. More specifically, if the exchange rates are flexible, relative prices adjust with the movement in the nominal exchange rates thereby reducing the excess demand in the goods market. In contrast, if the nominal exchange rates are fixed, relative prices between countries cannot adjust quickly due to short run price stickiness. This exacerbates the excess demand in the goods market, which in turn makes the real economy more volatile. Hence, the impact on output would be larger when the country's exchange rate is fixed.

Friedman's hypothesis may be tested by examining the relationship between exchange rate regimes and macroeconomic aggregates such as output and inflation. Ghosh et al. (1997) use least square regression models on data of 136 countries over thirty years to examine the link among exchange rate regimes, GDP growth, and inflation. They find that inflation is lower and output volatility is higher under pegged than under floating exchange rate regimes. Their findings are consistent with Friedman's hypothesis. Broda (2004) studies the relationship among real GDP, real exchange rates, and prices across different exchange regimes when countries are hit by terms of trade shocks. Using a panel vector autoregressive (VAR) model and a sample of 75 developing countries from 1973-1996, he finds real GDP to be less volatile and real exchange rates to adjust more quickly under flexible than pegged exchange rate regimes. He also finds that most of the adjustments under pegged regimes occur in domestic prices. He finds support for Friedman's hypothesis. Edwards and Levy-Yeyati (2005) also consider the impact of terms-of-trade shocks on the macro economy under alternative exchange rate regimes. They use growth regressions on a sample of 100 countries over the period 1974-2000 to show that terms of trade shocks are amplified in countries with more rigid exchange rate regimes. Their findings are consistent with Friedman's hypothesis. Instead of terms-of-trade shocks, Al-Abri (2007) investigates the impact of oil price shocks on the economies of nine OECD countries from 1973 to 2004.¹³ He classifies nine countries based on their exchange rate regimes. Using a panel VAR model, he finds

¹³ Backus and Crucini (2000) find that variability in the terms of trade can be accounted for mostly by variability in the relative oil price during the 1972 to 1987 period.

less variability in output growth under flexible exchange rate than fixed exchange rate regimes. His findings support Friedman's hypothesis.

Generally, empirical studies examine the effects of terms-of-trade or oil price shocks under different exchange rate regimes using regression models such as the VAR to decompose the direct effects of the shocks on output and other macroeconomic variables. However, these empirical studies have the following limitations. (1) The VAR model is estimated in reduced form so it cannot fully capture the structural relationships of the variables to determine the channels through which the shocks can affect output. (2) The studies are conducted in post-Bretton Woods period during which countries have changed their exchange rate regimes. This could cause the VAR coefficients to be unstable and subject the results to the Lucas critique. (3) The grouping of countries based on their exchange rate regimes is complicated not only by countries' changing their exchange rate regimes over time but also by the inconsistency between the countries' de jure and de facto classification of their exchange rate regimes.

In this chapter, I use a baseline dynamic stochastic general equilibrium (DSGE) model to examine the effects of an oil price shock on a small open economy under different exchange rate regimes. The model is characterized by nominal rigidities in the adjustment of prices. To simplify the analysis, I consider only two inputs in production: labor and oil. I assume productivity as exogenous. Oil price is also considered exogenous and it is used only in the domestic production. To compare the impact of oil price shocks under different exchange rate regimes, I use an interest

rate rule that assigns different weights to deviations of nominal exchange rate from a theoretical parity.¹⁴

The model indicates that the positive oil price shocks results in a smaller drop in output and consumption under flexible exchange rate than fixed exchange rate regimes. This is consistent with Friedman's hypothesis. Considering that countries have changed to more flexible exchange rate regimes from 1973 to the 1990, I show that the switch to more flexible exchange rate could partly explain the milder impact of the recent oil price shocks on output and consumption. I also find that fluctuations of nominal and real exchange rates are more pronounced under flexible exchange rate than under fixed exchange rate.

2.2 Related Literature

Many researchers have examined the impact of oil price shocks on major macroeconomic variables either empirically or theoretically in the context of closed or open economies. From the empirical perspective, evidence shows a statistically significant correlation between high oil price and low GDP growth. Hamilton (1983) uses a six-variable system of equations to examine the role of oil price in the movement of output. He finds that oil price increases contributed to the recessions in the United States and most OPEC countries from 1970s to 1980s. Gisser and Goodwin (1986) and Burbidge and Harrison (1984) find similar evidence for a larger group of countries. In contrast, Bernanke, Gertler and Watson (1997)—BGW

¹⁴ Monacelli (2004) uses a similar monetary policy setting.

hereafter—focus on the role of the response of monetary policy to oil price shocks in the United States. They argue that the rise in oil prices itself could not dampen the economy. Instead, they contend that recessions are mainly caused by contractionary monetary policy implemented by the Federal Reserve in response to the oil price shock. They compare scenarios under alternative policies using VAR and show that the resulting tightening of monetary policy is the key factor for economic downturns after oil price shocks. They conclude that expansionary policy can alleviate the recessionary effects of an oil price shock. Hamilton and Herrera (2004) challenge BGW's suggestion by pointing out that the Fed may not be able to reduce federal funds rate by enough points through additional money creation. They also indicate that the oil price changes in BGW's research are much smaller than they should be using a different model specification.

Empirical studies have focused on the effects of oil price shocks and the role of monetary policy response to the shocks. These studies have used VAR models to decompose the direct effects of oil price shocks on output and other macroeconomic variables and to analyze monetary policies. As mentioned above, VAR analysis is limited by the lack of structural interpretation on its reduced-form coefficients. Hence, it is difficult to determine the contributions of monetary policy and to evaluate alternative monetary policy regimes.

From the theoretical perspective, Bruno and Sachs (1982), Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000) analyze the effects of oil price increases on output. Kim and Loungani (1992) as well as Finn (2000) analyze

the impact of oil price increases under perfect competition with real business models. Kim and Loungani (1992) innovatively include energy as a productive input and model the relative price of energy as an exogenous random process. They show that the introduction of energy price shocks reduces the reliance of the real business cycle models on unobserved technology shocks. Finn (2000) shows that an increase in the price of energy works much like an adverse technology shock which induces contraction in economic activity. He also shows that the power and persistence of energy price shocks come from the relationship between energy usage and capital services.¹⁵ That is, energy is essential to the utilization of capital. Capital is never fully utilized because of energy costs and depreciation costs. Rotemberg and Woodford (1996) address the effects of positive oil price shocks in an imperfect-competition framework using a dynamic general equilibrium model. They argue that the imperfect-competition model has greater power in explaining the relationships between oil price shocks and economic aggregates. Nevertheless, since the above models do not assume price rigidities, they cannot consider nominal variables and the role of monetary policy. Hence, these models cannot address issues pertaining to the interaction between oil price shocks and monetary policy.

More recently, Clarida, Gali and Gertler (2000) estimate a forward-looking monetary policy reaction function for the post war United States economy. They demonstrate a significant difference in the way monetary policy was conducted before and after 1979. They argue that the difference could be an important source

¹⁵ Capital services are defined as the product of capital stock at the beginning of the period and the utilization rate of capital during that period.

of the shift in macroeconomic behavior. Their estimates indicate that the Federal Reserve's stabilizing policy is not implemented well during the pre-1979 period in the sense that the nominal interest rate moved less than one-for-one with expected inflation. To stabilize the economy, the Federal Reserve aggressively reduced the nominal interest rate with injected liquidity during the pre-1979 period. The injected liquidity, however, could raise current and expected inflation, which would induce an offsetting upward pressure on the nominal interest rate. Leduc and Sill (2004) use a similar monetary policy rule to investigate the effects of oil price shocks in the United States in the context of a closed economy. They find that after an oil price shock, the systematic component of monetary policy accounts for up to two thirds of the fall in output. Their model shows that interest rate rules that place a high weight on inflation lead to a smaller loss in output. In contrast, the interest rate rules that place a high weight on output gap lead to worse outcomes for output, inflation, and interest rate.

The current theoretical literature on oil price shocks often use models that assume a closed economy. However, empirical literature finds that oil price changes affect real exchange rates and relative prices, which in turn affect output. To address the effects of oil price shocks on relative prices and real exchange rates, I use an open-economy DSGE model, also known as the new open-economy macroeconomic (NOEM) model, which was developed by Obstfeld and Rogoff (1995, 2000). These models embed micro-founded behavior into DSGE framework. The advantages of these models for monetary policy analysis are two-fold. First, because of the

microfoundations, an explicit discussion of the parameters and shocks makes it possible to compare the different policy regimes. Second, the utility of households in the economy provides a consistent welfare criterion for policy analysis.

Based on a NOEM framework, Goodfriend and King (1997) and Devereux (2000) use open economy DSGE models to study the short-run dynamics and long-run relationship between macroeconomic aggregates. Goodfriend and King (1997) analyze the effect of monetary policy using two complementary approaches: aggregate demand and aggregate supply. They find that inflation expectation is still critical to successful monetary policy rule under NOEM framework, but the expectation is amendable to management by a monetary policy rule. Devereux (2000) uses a two-country sticky price DSGE model to see whether fixing the exchange rate prevents macroeconomic adjustment in relative price from occurring in face of terms of trade shocks. He concludes that a pegged exchange rate regime outperforms a floating exchange rate regime if monetary policy is passive. If monetary policy is active, exchange rate flexibility leads to lower fluctuations in output and employment. These models allow tracking exchange rate effects and at the same time examining the interactions between different economic sectors, monetary and fiscal policies, and key economic indicators.¹⁶

My baseline NOEM model differs from the previous models that examine oil price shocks in two important dimensions. First, oil price shocks are analyzed in an open economy framework. This assumption allows for the examination of the

¹⁶ See Lane (2000), Gali and Monacelli (2002), Bergin (2003), Monacelli (2004)

relationship between oil price shocks and real exchange rate fluctuations. Second, it allows for sensitivity analysis under changing exchange rate regimes, which has not been addressed before.

The rest of this chapter is organized as follows. Section 2.3 presents the model, and section 2.4 describes its calibration. Section 2.5 presents the simulation and sensitivity analysis, and section 2.6 concludes.¹⁷

2.3 The Model

To analyze the way in which oil price shocks affect macroeconomic aggregates, I use a DSGE model of a small open economy. There are two assumptions. First, households do not consume oil directly. Following Kim and Loungani (1992) and Rotemberg and Woodford (1996), oil will only be used in production. Second, the economy is small in the sense that it cannot affect the foreign price level. Foreign interest rate, foreign output level, and foreign inflation are exogenous.

2.3.1 Households

The households consume baskets of differentiated domestic and foreign goods (They are both tradable and indexed by j). Define $P_{H,t} \equiv \left(\int_0^1 P_{H,t}(j)^{1-\theta} dj \right)^{1/(1-\theta)}$ and $P_{F,t} \equiv \left(\int_0^1 P_{F,t}(j)^{1-\theta} dj \right)^{1/(1-\theta)}$ as the utility-based price indexes associated to the baskets of domestic and foreign varieties of goods, respectively. Both price indexes are

¹⁷ The derivation of the model is shown in appendix A.

expressed in units of domestic currency. Let $P_{H,t}(j)$ (or $P_{F,t}(j)$) be the price of the individual good j , where $\vartheta > 1$ is the elasticity of substitution between varieties within each category. In each period, the households optimally allocate their expenditure on differentiated goods within each category. The demand functions for a specific product are:

$$C_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\vartheta} C_{H,t}, C_{F,t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\vartheta} C_{F,t} \quad (2.1)$$

For all $j \in [0,1]$, good j is produced by a continuum of firms (owned by domestic households), where $C_{H,t} \equiv \left(\int_0^1 C_{H,t}(j)^{\vartheta-1/\vartheta} dj \right)^{\vartheta/\vartheta-1}$ and $C_{F,t} \equiv \left(\int_0^1 C_{F,t}(j)^{\vartheta-1/\vartheta} dj \right)^{\vartheta/\vartheta-1}$ are composite indexes of domestic and foreign (imported) goods, respectively. The households consume a constant elasticity of substitution (CES) composite of both home products ($C_{H,t}$) and foreign products ($C_{F,t}$):

$$C_t = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1} \quad (2.2)$$

where $\gamma \in [0,1]$. γ is the share of home-produced goods in total consumption, $(1-\gamma)$ represents the share of foreign-produced goods, and $\rho > 1$ is the elasticity of substitution between domestic and foreign goods. A consumption-based price index can be written as:

$$P_t = \left(\gamma P_{H,t}^{1-\rho} + (1-\gamma) P_{F,t}^{1-\rho} \right)^{1/1-\rho} \quad (2.3)$$

The domestic economy is populated by a continuum of infinitely-lived identical households, which is indexed by i . From here on, I will drop the indexation for simplicity. Across time, the representative domestic household maximizes the utility function given by:

$$E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] \quad (2.4)$$

where $\sigma > 0$, $\varphi > 0$. β is the discount factor and $\beta \in (0,1)$. $1/\sigma$ is the intertemporal elasticity of substitution, and φ is the elasticity of labor substitution. E_t is the expectation operator. C_t is the consumption and N_t is the labor supply of the representative household at time t . The first term in the objective utility function represents the utility of goods consumption and the second term captures the disutility of work effort. In each period, the representative household holds only bonds denominated in domestic currency as his assets. He derives income from working and makes consumption decisions. In the baseline model, I assume there is no capital accumulation. The household's budget constraint can be written as:

$$P_t C_t + E_t (B_{t+1}) = W_t N_t + (1+i_t) B_t + \tau_t \quad (2.5)$$

where B_t is the quantity of nominal bonds acquired in time t and expiring in time $t+1$, i_t is the nominal interest rate, W_t is the nominal wage, and τ_t is the lump-sum transfer payment.

The first order conditions (FOC) deduced from the maximization of equation (2.4) subject to the budget constraint, equation (2.5), with respect to C_t and B_{t+1} generate the following relationships:

$$\frac{C_t^{-\sigma}}{N_t^{\varphi}} = \frac{P_t}{W_t} \quad (2.6)$$

$$\beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = E_t \left(\frac{1}{1+i_{t+1}} \frac{P_{t+1}}{P_t} \right) \quad (2.7)$$

Equation (2.6) states the relationship between the utility from consumption and disutility for labor. Equation (2.7) is the Euler equation governing the dynamic

evolution of consumption. Given the nominal interest rate, if the current price level is low relative to the future price level, the current consumption is encouraged over the future consumption.

To keep the analysis simple, in this small open economy, domestic production does not affect foreign price level, so $P_t^* = P_F^*$. Assuming that foreign households have similar preferences as those of domestic households, the foreign demand for home produced good j is given by:¹⁸

$$C_{H,t}^*(j) = \left(\frac{P_{H,t}^*(j)}{P_{H,t}^*} \right)^{-\theta} C_{H,t}^* = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\theta} C_{H,t}^* \quad (2.8)$$

where

$$C_{H,t}^* = (1 - \gamma^*) \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\rho} C_t^* \quad (2.9)$$

2.3.2 Domestic firms

The representative firm acts as a monopoly in the production of a single good j . For simplicity, I employ a Cobb-Douglas production function. The firm uses two inputs, labor and oil, according to the following specification:

$$Y_t(j) = A_t N_t^\alpha (j) O_t^{1-\alpha} (j) \quad (2.10)$$

where $0 < \alpha < 1$. α represents labor share in the production. Variable A_t represents a total factor productivity shifter that is common to all firms. N_t and O_t represent labor and oil, respectively.

I follow Monacelli (2004) in addressing the price stickiness in which the firm can

¹⁸ Here and afterward, * represent rest of the foreign countries.

be imagined as composed of two units: a production unit and a pricing unit. The constant return to scale production technology implies that the unit cost equals to the nominal marginal cost, then the efficiency condition can be written as:

$$mc_t \frac{\partial Y_t(j)}{\partial N_t(j)} = \frac{W_t}{P_{H,t}} \quad (2.11)$$

$$mc_t \frac{\partial Y_t(j)}{\partial O_t(j)} = \frac{\varepsilon_t P_{O,t}^*}{P_{H,t}} \quad (2.12)$$

where mc_t is the real marginal cost. $P_{O,t}^*$ is the oil price denominated in foreign currency, and ε_t is the nominal exchange rate.

Following Calvo (1983), firms set prices on a staggered basis. In each period, firms that adjust their price are randomly selected, and a fraction $1-\phi_p$ of all firms adjusts while the remaining ϕ_p fraction does not adjust. The parameter ϕ_p represents the degree of nominal rigidity. A larger ϕ_p implies fewer firms adjust their price and the expected time between price changes will be longer. As the pricing unit, the domestic firm j faces domestic and foreign demand. Profits at some future date $t+k$ are affected by the choice of price at time t only if the firm has not received another opportunity to adjust its price between time t and time $t+k$. The probability of this situation is ϕ_p^k . This implies that the domestic firm j will reset price $P_{H,t}^{New}$ to maximize their profit which can be expressed as:

$$E_t \left\{ \sum_{k=0}^{\infty} \phi_p^k \beta^k \Lambda_{t,t+k} [P_{H,t}^{new}(j) - MC_{t+k}(j)] Y_{t+k}(j) \right\} \quad (2.13)$$

subject to the overall demand

$$Y_{t+k}(j) \leq \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\theta} [C_{H,t+k} + C_{H,t+k}^*] \quad (2.14)$$

where $\Lambda_{t,t+k}$ is the time-varying portion of the firm's discount factor. MC_t is the nominal marginal cost.

The first order condition of this problem is given by:

$$E_t \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} \left\{ Y_{t+k}(j) + (P_{H,t}^{new}(j) - MC_{t+k}(j)) \frac{\partial Y_{t+k}(j)}{\partial P_{H,t}^{new}(j)} \right\} \quad (2.15)$$

The optimal pricing condition is given by:

$$P_{H,t}^{new}(j) = \left(\frac{\vartheta}{\vartheta - 1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} MC_{t+k}(j) Y_{t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} Y_{t+k}(j) \right\}} \quad (2.16)$$

Equation (2.16) describes the dynamic markup for price setting. When the price signal ϕ_p equals to zero, equation (2.16) reduces to $P_{H,t}^{new}(j) = (\vartheta/\vartheta - 1) MC_t$, which means the firm sets the price as a constant markup over the nominal marginal cost. In a symmetric equilibrium where the law of large numbers holds, the domestic aggregate price index evolves according to:

$$P_{H,t} = \left[\phi_p P_{H,t-1}^{1-\vartheta} + (1 - \phi_p) (P_{H,t}^{new})^{1-\vartheta} \right]^{(1/1-\vartheta)} \quad (2.17)$$

2.3.3 Price level, terms of trade and real exchange rate

The nominal exchange rate ε_t is the price of one unit of foreign currency in terms of domestic currency. With the law of one price, $P_{H,t} \equiv \varepsilon_t P_{H,t}^*$, and $P_{F,t} \equiv \varepsilon_t P_{F,t}^*$. The terms of trade are defined as the price of the imported good relative to the price of the domestic good:

$$S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\varepsilon_t P_{F,t}^*}{P_{H,t}} \quad (2.18)$$

The real exchange rate is then defined as:

$$\varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t} \quad (2.19)$$

In a small open economy, the domestic price changes do not affect the foreign price level, so without loss of generality, I assume that $P_{F,t}^* = P_t^*$. I also assume that the foreign price level is determined by the prices of non-oil goods and oil. Hence, it can be expressed as $P_t^* = (P_{NO,t}^*)^{\gamma_{no}} (P_{O,t}^*)^{1-\gamma_{no}}$. For simplicity, I assume $P_{NO,t}^*$ to be constant and normalized to 1, so the foreign non-oil inflation is zero, which implies $\pi_{NO,t}^* = 0$. The total CPI inflation is defined as $\pi_t \equiv \log(P_t/P_{t-1})$ and the domestic inflation is defined as $\pi_{H,t} \equiv \log(P_{H,t}/P_{H,t-1})$.

The no arbitrage condition, acquired from the Euler equation and the real exchange rate definition, can be written as

$$\frac{1+i_t^*}{1+i_t} = \frac{\varepsilon_t}{\varepsilon_{t+1}} \quad (2.20)$$

2.3.4 Monetary policy and exchange rate regimes

Following Monacelli (2004), the rule of monetary policy acts in a way that deviations of inflation, output and nominal exchange rate from their long-run target have feedback effect on short-run movements of the nominal interest rate.¹⁹ The following equation describes the target for the nominal interest rate:

$$(1+i_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} Y_t^{\omega_y} \varepsilon_t^{\frac{\omega_\varepsilon}{1-\omega_\varepsilon}} \quad (2.21)$$

¹⁹ See also Taylor (1993), Rotemberg and Woodford (1998), Clarida, Gali and Gertler (1999) and Monacelli (2004). One issue here is whether the monetary authority should target total CPI inflation as opposed to domestic inflation. The different inflation targets will be compared in chapter 4.

Here, $\bar{i}_t$ is the inflation target, $\omega_\pi, \omega_y, \omega_e$ are weights assigned to the movements of inflation, output, and nominal exchange rate. The actual short-run interest rate is determined based on monetary authority's desire to smooth changes in the nominal interest rate:

$$(1+i_t) = (1+\bar{i}_t)^{1-\chi} (1+i_{t-1})^\chi \quad (2.22)$$

By taking a log-linear approximation of (21) and (22), there is²⁰

$$\hat{i}_t = \tilde{\omega}_\pi \bar{\pi}_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_e \hat{\varepsilon}_t + (1-\chi) \hat{i}_{t-1} \quad (2.23)$$

where $\tilde{\omega}_\pi = (1-\chi) \omega_\pi$, $\tilde{\omega}_y = (1-\chi) \omega_y$, $\tilde{\omega}_e = (1-\chi) (\omega_e / (1-\omega_e))$, $\hat{i}_t \approx \log(1+i_t / 1+\bar{i})$

This specification follows Monacelli (2004) and allows the approximation of the systematic behavior of monetary policy under floating and fixed exchange rate regimes. More specifically, $\omega_e = 0$ represents floating exchange rate regime, and $\omega_e = (0,1]$ represents managed to fixed exchange rate regime.

2.3.5 Steady state equilibrium

In the steady state, I assume that all variables are constant.²¹ Hence, the steady state foreign price level and the terms of trade are normalized to one. I also assume $P_{H,t}(j) = P_{H,t}$, $Y_t(j) = Y_t$, $N_t(j) = N_t$ since all firms take identical decisions in symmetric equilibrium.

Assuming bonds are in zero net supply, the equilibrium in the domestic goods market requires:

$$\bar{C}_H + \bar{C}_H^* = \bar{Y} \quad (2.24)$$

²⁰ Here after, the lower case letters with $\wedge$ denote log-deviations from respective steady state values.

²¹ A variable with a bar on top denotes the variable at its steady state.

From the Euler equation, the steady-state nominal interest rate is

$$\bar{i} = \frac{1}{\beta} - 1 \quad (2.25)$$

From equation (2.10), (2.11), and (2.12), the oil-output ratio is:

$$\frac{\bar{O}}{\bar{Y}} = (1 - \alpha) \bar{MC} \quad (2.26)$$

And the labor-output ratio is

$$\frac{\bar{N}}{\bar{Y}} = \alpha \bar{C}^{-\sigma} \bar{MC} \bar{N}^{-\varphi} \quad (2.27)$$

With the domestic price level normalized, the steady state marginal cost $\bar{MC} = \frac{\vartheta - 1}{\vartheta}$, which makes the steady state markup equals to $1 / \bar{MC}$.

From equation (2.1) and equation (2.2), there is

$$\bar{C}_F = \left(\frac{1 - \gamma}{\gamma} \right) \bar{C}_H \quad (2.28)$$

2.3.6 The log-linearized version of FOC and other conditions

The model is solved by taking log-linear approximation around the steady state. I use the variable with a hat to denote the deviation of a variable from the steady state and as a variable with a bar to denote the steady state. The model is described by a system of linear equations.

Aggregate demand

By taking the log-linearization of equation (2.3) and using the definition of inflation, the following equation can be obtained:

$$\hat{\pi}_t = \gamma \hat{\pi}_{H,t} + (1 - \gamma) (\hat{p}_{F,t} - \hat{p}_{F,t-1}) \quad (2.29)$$

From FOC of household's maximization, there is

$$\sigma E_t(\hat{c}_{t+1}) - \sigma \hat{c}_t = E_t(\hat{i}_{t+1}) - E_t(\hat{\pi}_{t+1}) \quad (2.30)$$

From equation (2.20), the no-arbitrage condition implies that

$$\hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t \quad (2.31)$$

From equation (2.9), foreign demand on domestic product can be described as

$$\hat{c}_{H,t}^* = \rho \hat{s}_t + \hat{y}_t^* \quad (2.32)$$

Here I assume that foreign consumption equals to foreign output, which are both exogenous.

From equation (2.1) and (2.2), together with equation (2.18), domestic demands on home and foreign goods are described by

$$\hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_t; \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_t \quad (2.33)$$

The market equilibrium

$$\bar{Y} \hat{y}_t = \bar{C}_H \hat{c}_{H,t} + \bar{C}_H^* \hat{c}_{H,t}^* \quad (2.34)$$

Aggregate supply

The production function suggests that

$$\hat{y}_t = \hat{a}_t + \alpha \hat{n}_t + (1-\alpha) \hat{o}_t \quad (2.35)$$

Log-linearizing equation (2.16) and equation (2.17), the forward-looking Phillips curve for domestic inflation is

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \frac{(1-\phi)(1-\beta\phi)}{\phi} \bar{m}c_t \quad (2.36)$$

The determination of real marginal cost can be obtained from combining equation (2.6) and equation (2.11):

$$\bar{m}c_t = \sigma \hat{c}_t + (\varphi+1) \hat{n}_t + (1-\gamma) \hat{s}_t - \hat{y}_t \quad (2.37)$$

Monetary policy rule

By taking a log-linear approximation of (2.21) and (2.22), there is

$$\hat{i}_t = \tilde{\omega}_\pi \pi_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_\varepsilon \hat{\varepsilon}_t + \chi \hat{i}_{t-1} \quad (2.38)$$

where $\tilde{\omega}_\pi = (1 - \chi) \omega_\pi$, $\tilde{\omega}_y = (1 - \chi) \omega_y$, $\tilde{\omega}_\varepsilon = (1 - \chi) (\omega_\varepsilon / (1 - \omega_\varepsilon))$, $\hat{i}_t \approx \log(1 + i_t / 1 + \bar{i})$

Exogenous process

The stochastic processes for the foreign interest rate, foreign output, nominal oil price, and productivity shifter can be summarized as

$$(1 + i_t^*) = (1 + i_{t-1}^*)^{\rho^r} \exp(\xi_t^r) \quad (2.39)$$

$$Y_t^* = Y_{t-1}^{\rho^y} \exp(\xi_t^y) \quad (2.40)$$

$$A_t = A_{t-1}^{\rho^a} \exp(\xi_t^a) \quad (2.41)$$

$$P_{O,t}^* = (P_{O,t-1}^*)^{\rho^{po}} \exp(\xi_t^{po}) \quad (2.42)$$

2.4 Model Parameterization

The model is solved numerically and the parameter choices for the model are summarized in Table 1.²² By following the business cycle literature, the annual discount rate β is set at 0.96 and marginal disutility of work effort φ is set to 3. The probability of price non-adjustment ϕ is set at 0.75, which is commonly accepted in the Calvo (1983) pricing model. The steady-state markup $\vartheta / (\vartheta - 1)$ equals to 1.2. The inverse of elasticity of intertemporal substitution σ is set at 1.01.

²² For the numerical solution of the model, we modify Uhlig's Matlab program and attach it in the appendix. The program is implemented using the methods of undetermined coefficients. For details, please refer to Uhlig (1995).

As to the monetary policy rule parameters, I set the benchmark values $\omega_\pi = 1.5$ and $\omega_y = 0$. The zero weight on the output gap enables the change in the monetary policy to focus on deviations in inflation and nominal exchange rate. In the simulations, I use $\omega_\epsilon = 0.1$ as flexible exchange rates and $\omega_\epsilon = 0.99$ as fixed exchange rate. The sensitivity analysis illustrates the managed-fixed exchange rate regimes with $0.1 < \omega_\epsilon < 0.99$. In all calibrations, I compare a setting in which ω_π is kept constant and ω_ϵ changes.

The standard deviations of shocks in productivity and foreign output are normalized to 1. The standard deviation of oil price is calibrated to 0.0151, which is consistent with Darrat, Gilley, and Meyer's (1996) empirical analysis. The serial correlation of the oil price shocks equals to 0.8, which is from the time series evidence on the West Texas Intermediate crude price series. Following Monacelli (2004) σ_ϵ' is 0.01379. As the essay concentrates on the effects of an oil price shock, the results from other shocks are not reported.

2.5 Simulation Result

Figures 5 and 6 illustrate the effects of a positive oil price shock on key macroeconomic variables. When a positive oil price shock hits the economy, both domestic and total CPI inflation rise due to the higher marginal cost. This results in an initial appreciation of the domestic currency. Under the flexible exchange rate regime, the rule of monetary policy puts the highest weight on inflation, which induces much larger increase in the short-run nominal interest rate in the current

period. The initial appreciation of domestic currency can partially mitigate the higher import price for oil. The increase in nominal interest rate forces depreciation of the domestic currency eventually, which strengthens the competitiveness of the domestic goods. Therefore, inflation rate is lower and output variations are smaller in this case. In contrast, under the fixed exchange rate regime, the economy does not benefit from the initial currency appreciation. Hence, marginal cost increases more and inflation rate is higher than under floating. To counter the interest rate increase, central bank has to create enough liquidity in money market to increase money supply, which can drive up the inflation even further. The adjustment in this case is much longer and variations in output could be larger compared to floating. Above all, if the nominal exchange rate floats, the necessary adjustments in relative prices are made by the nominal exchange rate instead of excess demand in goods market. The results are consistent with Freidman's (1953) hypothesis.

I trace the dynamic responses of output, terms of trade, real exchange rate to oil price shocks. The results show that both output and consumption drop with positive oil price shocks. Moving from fixed to flexible exchange rate regime, the absolute value of correlation between real exchange rate and oil price increases, which means oil price has greater impact on real exchange rate under flexible than fixed exchange rate regime. The impulse response results also indicate that real exchange rate and terms of trade are procyclical, which are in line with findings of Mendoza (1995) and Backus and Crucini (2000).

2.5.1 Sensitivity analysis: from fixed to flexible exchange rate regime

Table 3 and Figure 4 summarize the standard deviations of some important macroeconomic variables with different degrees of flexibility in the nominal exchange rate when the model is driven by a positive oil price shock. I assign a range of values for ω_ϵ from 0.99 for fixed exchange rate regime to 0.1 for flexible exchange rate regime. I define volatility as the standard deviations of these variables. Without external shocks, all variables take their steady-state value.

Several results emerge. First, both real and nominal exchange rate fluctuations are higher under more flexible exchange rate regimes when the small open economy is hit by oil price shocks. On the other hand, output and consumption are more volatile under the fixed exchange rate regime. These observations are consistent with Friedman's (1953) hypothesis regarding the different exchange rate regimes: the higher volatility in the nominal and real exchange rate mitigates the real shocks on the economy. Second, in moving from fixed to flexible exchange rate regime, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This result implies that nominal and real exchange rates are strongly correlated, and the correlation between nominal and real exchange rates is consistent with Mussa's (1986) findings. Monacelli (2004) also shows that changing exchange rate regimes causes variations in both nominal and real exchange rates regardless of different types of underlying shocks. Third, small open economies that fix their exchange rates experience lower fluctuations in price than those who allow their currency to float.

2.5.2 Sensitivity analysis: different degree of openness

I address the role of openness under two exchange rate regimes: the flexible vs. the fixed exchange rate. Table 4 summarizes the simulation results. I use $1-\gamma$, the share of imported goods in total consumption, as a proxy of openness.²³ As $1-\gamma$ increases from left to right, the share of imported goods rises in the consumption basket. The relatively higher $1-\gamma$ means higher degree of openness. A few interesting results stand out. First, output and consumption are always more volatile under fixed than floating exchange rates, which means that the virtue of flexible exchange rate regime holds regardless of the different degree of openness. Second, both nominal and real exchange rates are more volatile under flexible exchange rate regime. Third, the real exchange rate exhibits lower fluctuations with higher degree of openness under both fixed and flexible exchange rate regimes. This could be due to exogeneity of foreign price. Since I assume foreign goods price is constant, higher degree of openness means lower variations in the terms of trade, and therefore, lower variations in real exchange rate.

2.6 Conclusion

In this chapter, I examine the relationships between oil price shocks, exchange rate regimes, and some key macroeconomic variables by numerically solving a baseline DSGE model of a small open economy. My results suggest that more flexible exchange rate regimes could better absorb oil price shocks. Considering

²³ In the calibrated model, when γ equals to 0.8, the steady-state sum of exports and imports is roughly 40% of output.

that many countries have switched to relatively flexible exchange rate regimes—especially emerging countries—the milder effects of oil price shocks in the 1990s and 2000s compared to the 1970s could be partly due to the adoption of more flexible exchange rate regimes. Hence, the shift of exchange rate regimes may partially explain the different responses of the economy in the 1970s and 1990s to 2000.

Generally, my findings indicate that flexible exchange rate regimes could better absorb positive oil price shocks. First, under a more flexible exchange rate regime, both output and consumption have smaller fluctuations when countries are hit by positive oil price shocks. This result is in favor of Friedman's (1953) hypothesis that the short-run response of output to shocks is smoother in flexible than in fixed exchange rate regimes. Second, nominal and real exchange rate fluctuations are higher under the flexible exchange rate regime than under the fixed exchange rate regime. In moving from fixed to flexible exchange rate regime, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. This result implies that nominal and real exchange rates are strongly correlated.

Although I highlight the output consequences of oil price shocks under different exchange rate regimes, my conclusions are broadly similar to those in oil price shocks studies regarding the effects on key macroeconomic variables. First, the model shows that an oil price increase has negative effects on output and consumption. More specifically, the increasing marginal cost affects both the

demand and supply sides of the economy. From the demand side, both domestic and foreign demand on domestic goods decreases and output falls accordingly. It also leads to decreased consumption through its negative effect on real wealth. From the supply side, lower consumption increases the marginal utility of an additional unit of consumption and leads workers to increase their supply of labor, which tends to decrease real wages and has a negative effect on the supply of domestic goods. Second, the impulse response results also indicate that real exchange rate and terms of trade are procyclical, which are in line with findings of Mendoza (1995) and Backus and Crucini (2000).

Table 3 Calibration of model

Parameter	Definition and Description	Value
α	Labor share in production	0.7
β	Annual discount factor	0.96
γ	Share of home produced goods in total consumption	0.6
χ	Interest rate rule	0.8
ϕ	Price stickiness	0.75
φ	Inverse elasticity of labor supply	3
$\vartheta/(\vartheta-1)$	Steady-state markup	1.2
ρ^i	Serial correlation parameter for the foreign interest rate	0.8
ρ^y	Serial correlation parameter for the foreign output	0.9
ρ^{p_o}	Serial correlation parameter for oil price	0.8
ρ^a	Serial correlation parameter for technology	0.85
ρ	Elasticity of substitution between home and foreign product	1.01
γ^{NO}	Degree of the impact oil price on the foreign price level	0.01
σ	Inverse intertemporal elasticity of substitution	1.01
σ_{ξ}^i	Standard deviation of foreign nominal interest rate	1.379
$\sigma_{\xi}^{p_o}$	Standard deviation of oil price	1.51
σ_{ξ}^a	Standard deviation of foreign output and technology	1
ω_y	Responsiveness of monetary policy to output gap	0
ω_{ε}	Responsiveness of monetary policy to nominal exchange rate	0.99~0.1
ω_{π}	Responsiveness of monetary policy to total inflation	1.5

Table 4 Statistics for the calibrated model under different exchange rate regime

Variable	Standard Deviation HP-Filtered				
	$\omega_{\epsilon}=0.1$	$\omega_{\epsilon}=0.25$	$\omega_{\epsilon}=0.5$	$\omega_{\epsilon}=0.75$	$\omega_{\epsilon}=0.99$
Nominal Exchange Rate	4.4983	2.6868	1.6096	0.8602	0.0333
Real Exchange Rate	2.0631	1.6756	1.4061	1.3398	0.8001
Consumption	4.9416	4.9977	5.7111	5.8691	6.0057
Output	1.0375	1.0638	1.3424	1.7104	2.1978
Interest Rate	1.5337	1.1963	1.2265	1.6316	1.6135
Domestic Price	0.6433	0.29	0.4671	0.7063	0.7675
Price	1.4556	1.0242	0.5447	0.3795	0.4543

Note: Standard deviations are obtained from Hodrick-Prescott filtered data shows the responsiveness of monetary policy to exchange rate. The higher the value, the more responsive is the monetary policy to exchange rate implying the more rigid the exchange rate regime.

Table 5 Statistics with different degree of openness

Variable	Standard deviation HP-Filtered					
	$1-\gamma=0.25$		$1-\gamma=0.40$		$1-\gamma=0.55$	
	Fixed	Floating	Fixed	Floating	Fixed	Floating
Nominal exchange rate	0.0356	3.9935	0.0333	4.4983	0.0302	4.1135
Real exchange rate	1.2491	2.5716	0.8001	2.0631	0.5429	1.3731
Output	2.8981	1.009	2.1978	1.0375	1.8921	1.2166
Interest rate	1.7019	1.0749	1.6135	1.5337	1.7427	1.6424
Domestic Price	0.8648	0.4555	0.7675	0.6433	0.5975	0.6897
Price	0.6441	1.0442	0.4543	1.4556	0.2612	1.7014

Figure 4 Variability of some macroeconomic aggregates in moving from flexible to fixed

Figure 5 Effect of oil price shock under flexible exchange rate regime

Figure 6 Effect of oil price shock under fixed exchange rate regime

Appendix A

a. Mathematical Derivation

Assumptions:

- The economy is small in the sense that it cannot influence the foreign price level.
- Oil is imported from other countries for domestic production; households do not consume oil directly.
- The foreign price level is composed of oil price and non-oil goods price which is constant over time.

Households

The domestic economy is populated by a continuum of infinitely-lived identical households, which is index by i ; I drop the indexation for simplicity. Across time, the representative domestic household maximizes utility function which is given by:

$$(A1) \quad E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \right]$$

The consumption price index is

$$(A2) \quad C_t = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1}$$

From equation (1) and equation (2), I need to maximize C_t subject to the following constraint $M = P_{H,t} C_{H,t} + P_{F,t} C_{F,t}$, where M is fixed expenditure between home and foreign goods.

The Lagrangian equation indicates

$$L = (\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho})^{\rho/(1-\rho)} - \lambda_t (P_{H,t} C_{H,t} + P_{F,t} C_{F,t} - M)$$

then there are

$$(A1a) \quad C_t^{1/(\rho-1)} \gamma^{1/\rho} C_{H,t}^{-1/\rho} = \lambda_t P_{H,t}$$

$$(A1b) \quad C_t^{1/(\rho-1)} (1-\gamma)^{1/\rho} C_{F,t}^{-1/\rho} = \lambda_t P_{F,t}$$

$$(A1c) \quad P_{H,t} C_{H,t} + P_{F,t} C_{F,t} = M$$

From equation (A1a) and (A1b), there is $\frac{\gamma^{1/\rho} C_{H,t}^{-1/\rho}}{(1-\gamma)^{1/\rho} C_{F,t}^{-1/\rho}} = \frac{P_{H,t}}{P_{F,t}}$

Then consumption on foreign goods in terms of domestic goods can be expressed as

$$(A1d) \quad C_{F,t} = \left(\frac{1-\gamma}{\gamma} \right) C_{H,t} \left(\frac{P_{H,t}}{P_{F,t}} \right)^\rho$$

Substitute (A1d) into (A1c), there is

$$(A3) \quad P_{H,t} C_{H,t} + P_{F,t} \left[\left(\frac{1-\gamma}{\gamma} \right) C_{H,t} \left(\frac{P_{H,t}}{P_{F,t}} \right)^\rho \right] = M$$

$$\Rightarrow \{ \gamma P_{H,t}^{1-\rho} + P_{F,t}^{1-\rho} (1-\gamma) \} C_{H,t} = \frac{M \gamma}{P_{H,t}^\rho}$$

Since $\gamma P_{H,t}^{1-\rho} + P_{F,t}^{1-\rho} (1-\gamma) = P_t^{(1-\rho)}$, I have $P_t^{(1-\rho)} C_{H,t} = \frac{M \gamma}{P_{H,t}^\rho}$

With $\frac{M}{P_t} = C_t$, I can obtain the optimal allocation between domestic goods and

foreign goods which is given by

$$(A4) \quad C_{H,t} = \left(\frac{P_{H,t}}{P_t} \right)^{-\rho} C_t, C_{F,t} = (1-\gamma) \left(\frac{P_{F,t}}{P_t} \right)^{-\rho} C_t$$

The representative household's budget constraint is given by

$$(A5) \quad P_t C_t + E_t (B_{t+1}) = W_t N_t + (1+i_t) B_t + \tau_t$$

Maximize equation (A1) subject to equation (A5), the first order conditions are

$$(A6) \quad \frac{C_t^{-\sigma}}{N_t^\sigma} = \frac{P_t}{W_t}$$

$$(A7) \quad \beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = \frac{1}{1+i_{t+1}} E_t \left(\frac{P_{t+1}}{P_t} \right)$$

Domestic firms

The firms' production function is given by

$$(A8) \quad Y_t(j) = A_t N_t^\alpha(j) O_t^{1-\alpha}(j)$$

With CRTS production function, the marginal cost and unit cost will coincide, the production efficiency condition implies that

$$(A9) \quad mc_t \frac{\partial Y_t(j)}{\partial N_t(j)} = \frac{W_t}{P_{H,t}}$$

$$(A10) \quad mc_t \frac{\partial Y_t(j)}{\partial O_t(j)} = \frac{\varepsilon_t P_{O,t}^*}{P_{H,t}}$$

Domestic firms can reset their price to maximize

$$(A11) \quad E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} [P_{H,t}^{new}(j) - MC_{t+k}(j)] Y_{t+k}(j) \right\}$$

Subject to the demand function which is given by

$$(A12) \quad Y_{t+k}(j) \leq \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} [C_{H,t+k} + C_{H,t+k}^*]$$

$$\text{Since } \frac{\partial Y_{t+k}(j)}{\partial P_{H,t}^{new}(j)} = -\vartheta \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} * \frac{1}{P_{H,t}^{new}(j)} [C_{H,t+k} + C_{H,t+k}^*] = -\vartheta Y_{t+k}(j) * \frac{1}{P_{H,t}^{new}(j)}$$

Then the markup equation is

$$(A13) \quad P_{H,t}^{new}(j) = \left(\frac{\vartheta}{\vartheta-1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} MC_{t+k}(j) Y_{t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} Y_{t+k}(j) \right\}}$$

When $\phi_p = 0$, there are no price rigidities, I have

$$(A14) \quad P_{H,t}^{new}(j) = (\vartheta/\vartheta - 1) MC_t$$

Uncovered interest rate parity

$$(A15) \quad \frac{1+i_t^*}{1+i_t} = \frac{\varepsilon_t}{\varepsilon_{t+1}}$$

Terms of trade and real exchange rate

Law of one price holds for exports and imports, which indicate

$$(A16) \quad P_{H,t} = \varepsilon_t P_{H,t}^*, P_{F,t} = \varepsilon_t P_{F,t}^*$$

The terms of trade are defined as the price of the imported good relative to the price of the domestic good.

$$(A17) \quad S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\varepsilon_t P_{F,t}^*}{P_{H,t}}$$

The real exchange rate is defined as the relative price between foreign and domestic country

$$(A18) \quad \varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t}$$

Monetary policy and exchange rate regimes

The target for the nominal interest rate:

$$(A19) \quad (1+\bar{i}_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} Y_t^{\omega_y} \varepsilon_t^{\frac{\omega_\pi}{1-\omega_\pi}}$$

The determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate is:

$$(A20) \quad (1+i_t) = (1+\bar{i}_t)^{1-x} (1+i_{t-1})^x$$

Steady State

- a) A variable with bar on top means the steady state.
- b) I normalize the steady state foreign price level and steady state terms of trade
- c) Assume bonds are in zero net supply.

The equilibrium in the domestic goods market requires:

$$(A21) \quad \bar{C}_H + \bar{C}_H^* = \bar{Y}$$

From Euler equation (A7), the steady-state gross nominal interest rate

$$(A22) \quad \bar{i} = \frac{1}{\beta} - 1$$

From equation (A8), (A9), and (A10), the oil-output ratio is:

$$(A23) \quad \frac{\bar{O}}{\bar{Y}} = (1 - \alpha) * \bar{MC}$$

And the labor-output ratio is

$$(A24) \quad \frac{\bar{N}}{\bar{Y}} = \alpha * \bar{MC} * \bar{C}^{-\sigma} \bar{N}^{-\varphi}$$

From equation (A1a) to equation (A1d), together with the normalized steady state terms of trade, there is

$$(A25) \quad \bar{C}_F = \left(\frac{1 - \gamma}{\gamma} \right) \bar{C}_H$$

Log-linearized model

Aggregate demand

From equation (A3), with the definition of inflation, the following equation can be obtained:

$$(A26) \quad \bar{\pi}_t = \gamma \bar{\pi}_{H,t} + (1 - \gamma) (\bar{p}_{F,t} - \bar{p}_{F,t-1})$$

From FOC of household's maximization, there is

$$(A27) \quad \sigma E_t(c_{t+1}) - \sigma c_t = E_t(i_{t+1} - \pi_{t+1})$$

From equation (20), the international risk sharing condition implies that

$$(A28) \quad \hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t$$

From equation (9), foreign demand on domestic product can be described as

$$(A29) \quad \hat{c}_{H,t}^* = \rho \hat{s}_t + \hat{y}_t^*$$

From equation (A3) and (A2), domestic demands on home and foreign goods are described by

$$(A30) \quad \hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_t; \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_t$$

Log-linearize equation (A21) implies

$$(A31) \quad \bar{Y} \hat{y}_t = \bar{C}_H \hat{c}_{H,t} + \bar{C}_H^* \hat{c}_{H,t}^*$$

Aggregate supply

The production function suggests that

$$(A32) \quad \hat{y}_t = \hat{a}_t + \alpha \hat{n}_t + (1-\alpha) \hat{o}_t$$

Log-linearization of equation (A12) and equation (A13)

$$(A33) \quad \bar{\pi}_{H,t} = \beta \bar{\pi}_{H,t+1} + \frac{(1-\phi)(1-\beta\phi)}{\phi} \bar{m}_{C,t}$$

The determination of real marginal cost can be obtained from combining equation

(A9) and equation (A17):

$$(A34) \quad \bar{m}_{C,t} = \sigma \hat{c}_t + (\varpi + 1) \hat{n}_t + (1-\gamma) \hat{s}_t - \hat{y}_t$$

Monetary policy rule

$$(A35) \quad \hat{i}_t = \tilde{\omega}_\pi \bar{\pi}_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_\varepsilon \hat{\varepsilon}_t + \chi \hat{i}_{t-1}$$

where $\tilde{\omega}_\pi = (1-\chi)\omega_\pi$, $\tilde{\omega}_y = (1-\chi)\omega_y$, $\tilde{\omega}_\varepsilon = (1-\chi)(\omega_\varepsilon/1-\omega_\varepsilon)$, $\hat{i}_t \approx \log(1+i_t/1+\bar{i})$

Exogenous process

$$(A36) \quad (1+i_t^*) = (1+i_{t-1}^*)^{\rho^*} \exp(\xi_t^*)$$

$$(A37) \quad Y_t^* = Y_{t-1}^{\rho^{y^*}} \exp(\xi_t^{y^*})$$

$$(A38) \quad A_t = A_{t-1}^{\rho^a} \exp(\xi_t^a)$$

$$(A39) \quad P_{O,t}^* = (P_{O,t-1}^*)^{\rho^{p_o}} (\xi_t^{p_o})$$

Appendix A (Continued)

b. Attached Matlab Code

Endogenous Variables: $\hat{p}_{F,t}, \hat{i}_t, \hat{s}_t, \hat{c}_t, \hat{\pi}_t, \hat{\pi}_{H,t}, \hat{\varepsilon}_t, \hat{\varepsilon}_t^r, \hat{y}_t, \hat{o}_t, \hat{n}_t, \bar{mc}_t$

Exogenous Variables: $\hat{p}_{O,t}^*, \hat{i}_t^*, \hat{y}_t^*, \hat{a}_t$

%% SETTING PARAMETERS:

```
alpha =0.7; %
beta =0.96; %
gama =0.6; %
gama_o =0.01; %
theta=6; %
phi =0.75; %
chi =0.5; %
psi =3; %
sigma =1.01; %
omega_pi=1.5; %
omega_y =0; %
omega_e =0.1; %
om_pi =(1-chi)*omega_pi; %
om_y =(1-chi)*omega_y; %
om_e =(1-chi)*omega_e/(1-omega_e); %
mc_bar =(theta-1)/theta; %
mu =(1-phi)*(1-beta*phi)/phi; %
rho =1.01; %
rho_o =0.8; %
rho_a =0.85; %
rho_yf =0.9; %
rho_if =0.8; %
sigma_if =1.378; %
sigma_po=1.51; %
sigma_a =1; %
sigma_yf=1; %

lamda_a =alpha^alpha*(1-alpha)^(1-alpha)*mc_bar; %
lamda_b =((1-(1-alpha)*mc_bar)/alpha/mc_bar)^(sigma*alpha/(1-sigma)); %
lamda_c =(1-sigma)/alpha/(psi+sigma); %
n_bar =(lamda_a/lamda_b)^lamda_c; %
c_bar =(((1-(1-alpha)*mc_bar)*n_bar^(psi+1)/alpha/mc_bar)^(1/(1-sigma))); %
```

```

ch_bar = gama*c_bar; %
cf_bar = c_bar-ch_bar; %
y_bar = n_bar^(psi+1)*c_bar^sigma/alpha/mc_bar; %
o_bar = y_bar-c_bar; %
chf_bar = cf_bar+o_bar; %

```

%% DECLARING THE MATRICES:

```

VARNAMES = [ 'import price' , '%1 X1
              'interest rate' , '%2 X2
              'terms of trade' , '%3 X3
              'consumption' , '%4 X4
              'domestic inflation' , '%5 Y1
              'total inflation' , '%6 Y2
              'nominal exchange rate' , '%7 Y3
              'real exchange rate' , '%8 Y4
              'output' , '%9 Y5
              'oil' , '%10 Y6
              'labor' , '%11 Y7
              'marginal cost' , '%12 Y8
              'oil price' , '%13 Z1
              'technology' , '%14 Z2
              'foreign interest rate' , '%15 Z3
              'foreign output' , '%16 Z4

```

%% EQUATIONS:

%% NON-EXPECTATIONAL EQUATIONS:

```

% (4) 0 = (1-gama)*s(t)-(1-gama)*s(t-1)-pft(t)+pft(t-1)+pih(t)
% (5) 0 = pi(t)-gama*pih(t)-(1-gama)*pft(t)+(1-gama)*pft(t-1)
% (6) 0 = pft(t)-e(t)-gama_o*po(t)
% (7) 0 = q(t)-gama*s(t)
% (8) 0 = y(t)-a(t)-alpha*n(t)-(1-alpha)*o(t)
% (9) 0 = y_bar*y(t)-ch_bar*c(t)-rho*(chf_bar+(1-gama)*ch_bar)*s(t)-chf_bar*yft(t)
% (10) 0 = mc(t)-o(t)-s(t)-(1-gama_o)*po(t)+y(t)
% (11) 0 = mc(t)-sigma*c(t)-(psi+1)*n(t)-(1-gama)*s(t)+y(t)
% (12) 0 = i(t)-om_pi*pi(t)-om_y*y(t)-om_e*e(t)-chi*i(t-1)

```

%% EXPECTATIONAL EQUATIONS:

```

% (1) 0 = E_t{sigma*c(t+1)-sigma*c(t)-i(t+1)+pi(t+1)}
% (2) 0 = E_t{ i(t)-ift(t)-e(t+1)+e(t) }
% (3) 0 = E_t{ pih(t)-beta*pih(t+1)-mu*me(t) }

```

```
%%% EXOGENOUS EQUATIONS:
```

```
% (13)  yf(t+1) = rho_yf*yf(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (14)  po(t+1) = rho_o*po(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (15)  a(t+1)  = rho_a*a(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (16)  if(t+1)  = rho_if*if(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
```

```
%%% FIND MATRICES FOR FORMAT:
```

```
% 0 = AA*X(t)+BB*X(t-1)+CC*Y(t)+DD*Z(t)
```

```
% AA  9x4
% BB  9x4
% CC  9x8
% DD  9x4
```

```
% 0 = E_t{ FF*X(t+1)+GG*X(t)+HH*X(t-1)+JJ*Y(t+1)+KK*Y(t)+LL*Z(t+1)+MM*Z(t) }
```

```
% FF  3x4
% GG  3x4
% HH  3x4
% JJ  3x8
% KK  3x8
% LL  3x4
% MM  3x4
```

```
% Z(t+1) = NN*Z(t)+epsilon(t+1), with E_t{epsilon(t+1)}=0
```

```
% NN  4x4
```

```
% for pf(t),    i(t),        s(t),                c(t)
AA=[0,          0,          1-gama,                0
    -(1-gama),  0,          0,                    0
    1,          0,          0,                    0
    0,          0,          -gama,                 0
    0,          0,          0,                    0
    0,          0,          -rho*(chf_bar+(1-gama)*ch_bar), -ch_bar
    0,          0,          -1,                    0
    0,          0,          -(1-gama),              -sigma
    0,          1,          0,                    0];
```

```
display (AA);
```

```
% for pf(t-1),  i(t-1),    s(t-1),  c(t-1)
BB=[ 0,          0,          -(1-gama), 0
```



```

(1-gama),    0,    0,    0
0,           0,    0,    0
0,           0,    0,    0
0,           0,    0,    0
0,           0,    0,    0
0,           0,    0,    0
0,           0,    0,    0
0,          -chi,  0,    0];

display (BB);

%for pih(t),    pi(t),    e(t),    q(t),    y(t),    o(t),    n(t),    mc(t)

CC=[ 1,        -1,        0,        0,        0,        0,        0,        0
    -gama,     1,        0,        0,        0,        0,        0,        0
        0,        0,       -1,        0,        0,        0,        0,        0
        0,        0,        0,        1,        0,        0,        0,        0
        0,        0,        0,        0,        1,       -(1-alpha),  -alpha,    0
        0,        0,        0,        0,        y_bar, 0,        0,        0
        0,        0,        0,        0,        1,       -1,        0,        1
        0,        0,        0,        0,        1,        0,       -(psi+1),    1
        0,       -om_pi,  -om_e,    0,       -om_y,  0,        0,        0];

display (CC);
disp('rank of CC');
rank(CC)

%for po(t),    a(t),    if(t),    yf(t)
DD=[ 0,        0,        0,        0
      0,        0,        0,        0
    -gama_o,    0,        0,        0
      0,        0,        0,        0
      0,       -1,        0,        0
      0,        0,        0,    -chf_bar
    -(1-gama_o), 0,        0,        0
      0,        0,        0,        0
      0,        0,        0,        0];

display (DD);

%for pf(t+1),  i(t+1),  s(t+1),  c(t+1)
FF=[0,        -1,    0,    sigma
     0,        0,    0,    0
     0,        0,    0,    0];

```

```

display (FF);

%for pf(t), i(t), s(t), c(t)
GG=[ 0,    0,    0, -sigma
      0,    1,    0,    0
      0,    0,    0,    0];

display (GG);

%for pf(t-1),i(t-1),s(t-1),c(t-1)
HH=zeros(3,4);

display (HH);

%for pih(t+1), pi(t+1), e(t+1), q(t+1), y(t+1), o(t+1), n(t+1), mc(t+1)
JJ=[ 0,      1,      0,      0,      0,      0,      0,      0
      0,      0,     -1,      0,      0,      0,      0,      0
     -beta,    0,      0,      0,      0,      0,      0,      0];

display (JJ);

%for pih(t), pi(t), e(t), q(t), y(t), o(t), n(t), mc(t)
KK=[ 0,      0,      0,      0,      0,      0,      0,      0
      0,      0,      1,      0,      0,      0,      0,      0
      1,      0,      0,      0,      0,      0,      0,     -mu];

display (KK);

LL=[0,0,0,0
     0,0,0,0
     0,0,0,0];

display (LL);

% for po(t), a(t), if(t), yf(t)
MM=[ 0,      0,      0,      0
      0,      0,     -1,      0
      0,      0,      0,      0];

display (MM);

```

```
NN=[rho_o, 0, 0, 0
    0, rho_a, 0, 0
    0, 0, rho_if, 0
    0, 0, 0, rho_yf];
```

```
Sigma=[sigma_po^2, 0, 0, 0
        0, sigma_a^2, 0, 0
        0, 0, sigma_if^2, 0
        0, 0, 0, sigma_yf^2];
```

```
% SETTING OPTIONS:
```

```
[l_equ,m_states] = size(AA);
[l_equ,n_endog ] = size(CC);
[l_equ,k_exog   ] = size(DD);
```

```
PERIOD      = 4; % number of periods per year, i.e. 4 for quarterly
GNP_INDEX=3  ;% Index of output among the variables selected for HP filter
IMP_SELECT  = [2:9 ]; % Vector with the indices of the variables to be plotted: all X
variables
```

```
DO_SIMUL    = 1; % Calculates simulations
SIM_LENGTH=150;
```

```
%DO_MOMENTS = 1; % Calculates moments based on frequency-domain methods
```

```
%DO_ENLARGE =1;
```

```
HP_SELECT   = 1:(m_states+n_endog+k_exog); % Selecting the variables for the HP Filter
```

```
%IMP_JOINT=0;IMP_SUBPLOT=1;
```

```
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Chapter 3

Oil Price Shocks in an Extended Model with Capital and Investment

3.1 Introduction

The volatility of output has fallen dramatically since the 1980 with the timing and nature of the decline varying across countries. This phenomenon has been widespread and persistent and is known as the “Great Moderation”. The International Monetary Fund (IMF) uses a rolling 10-year standard deviation of world GDP growth to show that volatility has fallen progressively since its peak in the 1970s. Specifically, the industrial countries experienced high volatility during the 1950s but it declined in the 1960s. Volatility rose again in the 1970s because of the oil price shocks. After the 1980s, volatility in industrial countries fell significantly. The volatility of output in emerging countries has also declined in recent years even though it is still quite high compared to industrial countries. Despite the rising share of emerging economies in the global economy, the world economy has experienced a reduction in the volatility of output since the 1980s.²⁴

A growing body of research focuses on the role of monetary policy in exacerbating and then moderating the effects of oil price shocks during the 1970s and after the 1980s, respectively. Bernanke, Gertler, and Watson (1997) argue that much of the decline in output in the 1970s is due to the rise in interest rate, which resulted from the Federal Reserve Bank’s response to the high inflation due to oil

²⁴ IMF World Economic Outlook (2007)

price shocks. Romer and Romer (2002) suggest that US policymakers underestimated the natural rate of unemployment in the early 1970s. Hence, they undertook expansionary policies which resulted in high inflation. To combat inflation, the policymakers tightened monetary policy towards the end of the 1970s. This time, they overestimated the natural rate of unemployment. Believing that unemployment was lower than the natural rate, policymakers conducted a much tighter monetary policy than necessary to fight inflation. This caused a severe recession. In this context, some researchers argue that the primary reason for the recessions in the 1970s is the contractionary monetary policies implemented by the Federal Reserve in response to inflation concerns caused by rising oil prices.²⁵

After the 1980s, the improvement in monetary policy is considered as one of the reasons for the moderation of output volatility. Blanchard and Simon (2001), for example, document the large decline in output volatility in the last twenty-five years. They conduct a comparison between two periods using quarterly data for US economy: one for the period 1947:1 to 1981:4 and the other for the period 1982:1 to 2000:4. Their results show a clear decline in output volatility of United States and a similar pattern for G7 countries. Regarding the causes of the decline in output, they suggest that the improvement of monetary policy accounts for the decrease in output volatility in the mid-1980s. Similarly, Stock and Watson (2002) find that the sharp decline in the volatility of GDP growth is mirrored by declines in the variance of growth rates of consumption and production of durables goods, and in residential

²⁵ See Bernanke, Gertler and Watson (1997), Barsky and Kilian (2001), Kim and Nelson (1999)

fixed investment. Their research for the causes of the moderation suggests that the improved monetary policy contributes approximately 10% to 25% of the decline in output volatility. They also find that the reduction in identifiable shocks such as commodity price shocks or productivity shocks has reduced the variance of output growth. Blanchard and Gali (2007) study the changing effects of oil price shocks and suggest that in addition to credibility of monetary policy, the reduction of real wage rigidities and the declining share of oil in economy can all account for the moderating effects of oil price shocks.

Generally, researchers empirically investigate the role of monetary policy in exacerbating or moderating the effects of shocks using VAR models to decompose the effects of oil price shocks on output and analyze alternative monetary policies. However, as I mentioned in the previous chapter, it is difficult to evaluate alternative monetary policies using VAR analysis.

In this chapter, I extend my baseline model and include capital in production. I want to show that the structural changes—changes in exchange rate regimes and reduction in the share of oil in output—help to explain the different responses of economy. Although the baseline model is in line with current literature in including only oil and labor in production, the importance of including capital and investment in the model relies on the fact that capital is commonly used in production. In addition, the baseline model assumes the share of oil in output to be around 30%, which

contradicts another fact that the share of oil in output is quite low.²⁶ I follow Kim and Loungani (1992) in adding oil in the standard production function in which oil and capital are substitutes.²⁷ In the model, the share of oil share in production is allowed to vary. In this manner, oil share in production is much lower compared with the baseline model. This is consistent with the evidence, which indicates that the share of oil in output has decreased over the last thirty years²⁸

When capital is introduced in the model, oil price shocks alter households' investment decisions, which in turn have influence on capital accumulation. When oil price increases, households make less investment because of higher investment cost on investment goods, and less capital is accumulated for the next period. Therefore, oil price shocks affect the production behavior in two ways. First, firms use less oil due to the high oil price. Second, firms have higher demand on capital since the two inputs—oil and capital—are substitutes. The high demand on capital together with less capital stock drives up rental cost, which makes output decline.

The main contribution of this extension is to use a model based on preferences, technology, and stochastic processes governing shocks to examine the economic

²⁶ Dhawan and Jeske (2007) compute the share of energy in output as nominal spending on energy divided by nominal GDP using annual data. On average, the annual energy share of output is about 6.5 percent from the 1970 to 1985 and 4 percent from 1986 to 2005 in the United States.

²⁷ In contrast, Finn (1995, 2000) introduces a capital utilization rate and assumes oil and capital as complimentary. Whether capital and oil are substitutes or complements is unresolved in empirical literature. Generally, studies using pooled cross-section data find that energy and capital are substitutes while studies using time series data find that energy and capital are complements. See Apostolakis (1990) for a survey of the literature.

²⁸ As we mentioned above, Blanchard and Gali (2007) consider the lower share of oil in output as one of the reasons for the Great Moderation. They compare two alternative versions of the model with parameters calibrated using 1973 and 1997 data on the share of oil in production costs and consumption expenditure.

responses to oil price shocks under different exchange rate regimes in a more realistic framework. The results are generally consistent with those of the baseline model, which indicates that the baseline model is robust despite the exclusion of capital. Both capital and investment drop with positive oil price shocks, and rental cost on capital increases due to higher demand on capital. The impact on macroeconomic aggregates is reduced due to the lower oil share of output.

The simulation results suggest that the interest rate is more sensitive to changes in inflation under flexible exchange rate regime. The anti-inflation activity of the central bank may raise both real and nominal interest rate, which induces lower expectations on future inflation rate. These results are consistent with Clarida, Gali, and Gertler's (2000) empirical findings that the response of interest rate has been stronger to variations in inflation over the past two decades relative to the 1970s,

3.3 The Model

The extended model shares similar properties with the baseline model. It is still populated by identical, infinitely lived households who consume baskets of differentiated domestic and foreign goods (which are both tradable by assumption). These households not only derive income from working but also from renting physical capital to the domestic firms. There are three inputs for domestic production: labor, capital, and oil. Still, I assume households do not consume oil directly, which means oil price shocks affect the small open economy through the production channel.

3.3.1 Households

Similar to the baseline model, the representative household's behavior is described by static and dynamic stages. In the first stage, the representative household makes his consumption decisions on domestic and foreign goods. The consumption index is:

$$C_t = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1} \quad (3.1)$$

where $\gamma \in [0,1]$ is the share of home-produced goods in total consumption, then $(1-\gamma)$ represents the share of foreign-produced goods. $\rho > 1$ is the elasticity of substitution between domestic and foreign goods. For simplicity, I assume that the investment composite index $ln_t(In_{H,t}, In_{F,t})$ has an identical expression. A utility-based consumer price index is the same as the one in the baseline model, which is:

$$P_t = \left(\gamma P_{H,t}^{1-\rho} + (1-\gamma) P_{F,t}^{1-\rho} \right)^{1/1-\rho} \quad (3.2)$$

The optimal allocation of any given expenditure between domestic and foreign goods yields the isoelastic consumption demands:

$$C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_t} \right)^{-\rho} C_t; C_{F,t} = (1-\gamma) \left(\frac{P_{F,t}}{P_t} \right)^{-\rho} C_t \quad (3.3)$$

In the second stage, the domestic household maximizes:²⁹

$$E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \right] \quad (3.4)$$

where all the parameters have the same meaning as in chapter two. In the dynamic period, the household holds bonds denominated in domestic currency, rents out his

²⁹ We drop the indexation for simplicity as in chapter 2.

capital to the home-based monopolistic competitive firm, and derives income from working. Therefore, the household's budget constraint is written as:

$$P_t(C_t + In_t) + E_t(B_{t+1}) = W_t N_t + Z_t K_t + (1 + i_t) B_t + \tau_t \quad (3.5)$$

Again, B_t is the quantity of nominal bonds acquired at time t and expiring at time $t+1$, i_t is the nominal interest rate, W_t is the nominal wage and Z_t is the nominal rental cost. τ_t represents the lump-sum transfer payment. As in Monacelli (2004), the capital accumulation is subjected to adjustment cost and is written as:

$$K_{t+1} = (1 - \delta) K_t + \Phi\left(\frac{In_t}{K_t}\right) K_t \quad (3.6)$$

where δ is the physical depreciation rate of capital. The function $\Phi(\cdot)$, which is increasing and concave, assumes the adjustment cost in capital accumulation. That is, In_t units of investment translate into $\Phi(In_t/K_t) K_t$ units of addition capital. In the open economy context, the introduction of capital adjustment costs guarantees the difference between the speed of adjustment of physical and financial capital. Without capital adjustment cost, households are able to use bonds to smooth their consumption immediately after the oil price shocks. Therefore, the adjustment cost is necessary to obtain more persistent differences between the international real interest rate and the domestic rental cost of capital after depreciation in capital.

The first order conditions derived from the utility maximization of equation (3.4) subject to the budget constraint of equation (3.5) and the capital accumulation of equation (3.6) with respect to $C_t, N_t, B_{t+1}, In_t, K_{t+1}$ are:

$$\frac{C_t^{-\sigma}}{N_t^\varphi} = \frac{P_t}{W_t} \quad (3.7)$$

$$\beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = E_t \left(\frac{1}{1+i_{t+1}} \frac{P_{t+1}}{P_t} \right) \quad (3.8)$$

$$Q_t = C_t^{-\sigma} \left[\Phi_{ln} \left(\frac{In_t}{K_t} \right) \right]^{-1} \quad (3.9)$$

$$Q_t = \beta E_t \left[C_{t+1}^{-\sigma} \frac{Z_{t+1}}{P_{t+1}} + Q_{t+1} \left(1 - \delta + \Phi \left(\frac{In_{t+1}}{K_{t+1}} \right) - \frac{In_{t+1}}{K_{t+1}} \Phi_{ln} \left(\frac{In_{t+1}}{K_{t+1}} \right) \right) \right] \quad (3.10)$$

Equation (3.7) states the relationship between the utility from consumption and disutility for labor. Equation (3.8) is the Euler equation governing the dynamic evolution of consumption. Equation (3.9) specifies the intertemporal conditions for efficiency in physical capital investment. It determines the investment rate as a function of Q_t , which is the market value of one unit of capital. Equation (3.10) is the evolution of Q_t over time. I assume that there is no average or marginal costs of adjustment in the steady state. Hence, the steady state $\Phi(\cdot)$ is subject to $\bar{Q} = \Phi' \left(\frac{In}{K} \right)^{-1} = 1$, and $\Phi \left(\frac{In}{K} \right) = \delta = \frac{In}{K}$.

The specifications for the rest of the world are similar to the baseline model. Assuming that foreign households have similar preferences as those of the home country, the foreign demand for home produced good j is given by:

$$C_{H,j}^* (j) = \left(\frac{P_{H,j}^* (j)}{P_{H,j}^*} \right)^{-\theta} C_{H,j}^* = \left(\frac{P_{H,j} (j)}{P_{H,j}} \right)^{-\theta} C_{H,j}^* \quad (3.11)$$

where $C_{H,j}^* = (1 - \gamma^*) \left(\frac{P_{H,j}^*}{P_t^*} \right)^{-\rho} C_t^*$

3.3.2 Domestic firms

In the small open economy, there is a continuum of monopolistically competitive

firms, indexed by $j \in [0,1]$. Following Kim and Loungani (1992), I employ a nested constant elasticity of substitution production function with constant return to scale. Firms use three input factors, labor, capital and oil, according to the following specification:

$$Y_t(j) = A_t \left[\iota K_t^{1-\nu}(j) + (1-\iota) O_t^{1-\nu}(j) \right]^{(1-\alpha)/(1-\nu)} N_t^\alpha(j) \quad (3.12)$$

where $0 < \alpha < 1$, $\iota > 0, \nu > 0$. In addition to the usual inputs: labor and capital, production is assumed to require the use of oil. The elasticity of substitution between capital and oil equal to $1/\nu$. Labor share in production is given by α . This function form allows us to relax the assumption of unitary elasticity of substitution between capital and oil that would be imposed by a Cobb-Douglas function.

In the production unit, the constant return to scale production technology implies that the unit cost equals to the nominal marginal cost (MC). Hence, the efficiency conditions for the choice of labor, capital, and oil demands are respectively:

$$mc_t \frac{\partial Y_t(j)}{\partial N_t(j)} = \frac{W_t}{P_{H,t}} \quad (3.13)$$

$$mc_t \frac{\partial Y_t(j)}{\partial K_t(j)} = \frac{Z_t}{P_{H,t}} \quad (3.14)$$

$$mc_t \frac{\partial Y_t(j)}{\partial O_t(j)} = \frac{\varepsilon_t P_{O,t}^*}{P_{H,t}} \quad (3.15)$$

where mc_t is the real marginal cost. Firms' pricing behavior is similar to the baseline model. I follow Calvo (1983) in modeling the domestic firm's pricing behavior. The domestic firm j will reset $P_{H,t}^{New}$ to maximize their profit,

$$E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} \left[P_{H,t}^{new}(j) - MC_{t+k}(j) \right] Y_{t+k}(j) \right\} \quad (3.16)$$

subject to the overall demand $Y_{t+k}(j) \leq \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} [C_{H,t+k} + C_{H,t+k}^*]$

The optimal pricing condition is given by:

$$P_{H,t}^{new}(j) = \left(\frac{\vartheta}{\vartheta-1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} MC_{t+k}(j) Y_{t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} Y_{t+k}(j) \right\}} \quad (3.17)$$

The above equation describes the dynamic markup for price setting. When the price signal ϕ_p equals to zero, equation (3.17) reduces to $P_{H,t}^{new}(j) = (\vartheta/\vartheta-1) MC_t$. In a symmetric equilibrium where the law of large numbers holds, the domestic aggregate price index evolves according to:

$$P_{H,t} = \left[\phi_p P_{H,t-1}^{1-\vartheta} + (1-\phi_p) (P_{H,t}^{new})^{1-\vartheta} \right]^{(1/1-\vartheta)} \quad (3.18)$$

The definitions of terms of trade, real exchange rate, and the formulation of monetary policy are the same as in chapter two.

3.3.3 Steady state and market equilibrium

In the steady state, all variables are assumed to be constant. Hence, the steady state foreign price level and the terms of trade are normalized to one. In a symmetric equilibrium where all firms take identical decisions, it holds that $P_{H,t}(j) = P_{H,t}$, $Y_{H,t}(j) = Y_{H,t}$, $N_t(j) = N_t$ for all j and t . Assuming bonds are in zero supply, the equilibrium in the domestic goods market requires:

$$\bar{C}_H + \bar{C}_H^* + \bar{I}n = \bar{Y} \quad (3.19)$$

From equation (3.8), the steady-state gross nominal interest rate

$$\bar{i} = \frac{1}{\beta} - 1 \quad (3.20)$$

From equation (3.10), together with the assumption on the steady state capital adjustment, the rental cost on capital:

$$\bar{Z} = \frac{1}{\beta} - 1 + \delta \quad (3.21)$$

Since there is neither average nor marginal capital adjustment cost in the steady state, I have:

$$\bar{I}n = \delta \bar{K} \quad (3.22)$$

Equation (3.14) and (3.15) imply that the capital-oil ratio is given by:

$$\left(\frac{\bar{K}}{\bar{O}} \right)^{-\nu} = \frac{(1-t)}{t} \bar{Z} \quad (3.23)$$

From equation (3.12) and (3.13), the labor-output ratio is given by:

$$\frac{\bar{N}}{\bar{Y}} = \frac{\alpha \bar{MC}}{C^\sigma N^\sigma} \quad (3.24)$$

From equation (3.12), (3.13), and (3.14), the capital-output ratio is given by:

$$\frac{\bar{K}}{\bar{Y}} = \frac{(1-\alpha) \bar{MC}}{\bar{Z} + \Psi} \quad (3.25)$$

where $\Psi = \left[\frac{(1-t) \bar{Z}}{t} \right]^{\frac{1}{\nu}}$

In the steady state, I assume the small open economy is in balanced trade position (export equals to import), there is:

$$\bar{C}_H^* = \bar{C}_F + \bar{O} \quad (3.26)$$

From equation (3.24), (3.25), and (3.26), the steady state consumption can be expressed as:

$$\bar{C} = \left\{ 1 - \frac{(1-\alpha)\overline{MC}[\Psi + \delta]}{\bar{Z} + \Psi} \right\} \bar{Y} \quad (3.27)$$

3.3.4 The log-linearized version of FOC and other conditions

The model is solved by taking log-linear approximation around the steady state. I use a variable with a hat to denote the deviation from the steady state and a variable with a bar to denote the steady state. The model is described by a system of linear equations.

Aggregate demand

By taking log-linearization of equation (3.2), with the definition of inflation, the following equation can be obtained:

$$\pi_t = \gamma \pi_{H,t} + (1-\gamma)(p_{F,t} - p_{F,t-1}) \quad (3.28)$$

From equation (3.8), the Euler equation is given by:

$$\sigma E_t(\hat{c}_{t+1}) - \sigma \hat{c}_t = E_t(\hat{i}_{t+1}) - E_t(\hat{\pi}_{t+1}) \quad (3.29)$$

This equation shows that the household's consumption adjusts according to the evolution of nominal interest rate and the expected inflation rate. Higher expectation on future inflation rate will encourage household's current consumption over future consumption.

From equation (3.9) and equation (3.10), the efficiency conditions on the investment demand are given by:

$$\hat{q}_t = -\sigma \hat{c}_t + \frac{1}{\eta}(\hat{m}_t - \hat{k}_t) \quad (3.30)$$

$$\hat{q}_t = E_t[(1-\beta)\sigma \hat{c}_{t+1} - \beta \bar{Z}(\hat{z}_{t+1} - \hat{p}_{t+1}) + \beta \hat{q}_{t+1}] \quad (3.31)$$

where $\eta = -\frac{(In/K)\Phi'_{In}(In/K)}{\Phi'_{In}(In/K)} > 0$. Equation (3.30) relates the price of capital q directly to investment, and inversely to the stock of capital k (with elasticity $1/\eta$). The price of capital does not always equal to unity, which reflects the existence of adjustment cost. Equation (3.31) states the evolution of q over time.

The uncovered interest parity implies that:

$$\hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t \quad (3.32)$$

From equation (2.1) and (2.2), together with equation (2.18), domestic demand on home and foreign goods are described by:³⁰

$$\hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_t; \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_t \quad (3.33)$$

The market equilibrium:

$$\bar{Y}\hat{y}_t = \bar{C}_H\hat{c}_{H,t} + \bar{C}_H^*\hat{c}_{H,t}^* + \bar{In}\hat{m}_t \quad (3.34)$$

Aggregate supply

The production function suggests that

$$\hat{y}_t = \hat{a}_t + \alpha\hat{n}_t + \iota(1-\alpha)\hat{k}_t + (1-\iota)(1-\alpha)\hat{o}_t \quad (3.35)$$

Log-linearizing equation (3.17) and equation (3.18), the forward-looking Phillips curve for domestic inflation is:

$$\pi_{H,t} = \beta\pi_{H,t+1} + \frac{(1-\phi)(1-\beta\phi)}{\phi}\bar{m}c_t \quad (3.36)$$

The determination of real marginal cost can be obtained from combining equation (3.7) and equation (3.13):

$$\bar{m}c_t = \sigma\hat{c}_t + (\varphi+1)\hat{n}_t + (1-\gamma)\hat{s}_t - \hat{y}_t \quad (3.37)$$

³⁰ The log-linearized version of demand on home and foreign goods is the same as in chapter 2.

The efficiency condition between capital and oil implies that

$$v\hat{o}_t - v\hat{k}_t = \hat{z}_t - \hat{\varepsilon}_t - \hat{p}_{o,t}^* \quad (3.38)$$

Endogenous State Variables

From equation (3.6), the capital accumulation can be described by:

$$\hat{k}_{t+1} = (1 - \delta)\hat{k}_t + \delta\hat{i}_t \quad (3.39)$$

Monetary policy rule

By taking a log-linear approximation of (2.21) and (2.22), there is:

$$\hat{i}_t = \tilde{\omega}_\pi \pi_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_\varepsilon \hat{\varepsilon}_t + \chi \hat{i}_{t-1} \quad (3.40)$$

where $\tilde{\omega}_\pi = (1 - \chi)\omega_\pi$, $\tilde{\omega}_y = (1 - \chi)\omega_y$, $\tilde{\omega}_\varepsilon = (1 - \chi)(\omega_\varepsilon / (1 - \omega_\varepsilon))$, $\hat{i}_t \approx \log(1 + i_t / (1 + \bar{i}))$

Exogenous process

The stochastic processes for the foreign interest rate, foreign output, nominal oil price and domestic technology can be summarized as:

$$(1 + i_t^*) = (1 + i_{t-1}^*)^{\rho^{i^*}} \exp(\xi_t^{i^*}) \quad (3.41)$$

$$Y_t^* = Y_{t-1}^{\rho^{y^*}} \exp(\xi_t^{y^*}) \quad (3.42)$$

$$A_t = A_{t-1}^{\rho^a} \exp(\xi_t^a) \quad (3.43)$$

$$P_{o,t}^* = (P_{o,t-1}^*)^{\rho^{po}} \exp(\xi_t^{po}) \quad (3.44)$$

3.4 Model Parameterization

The model is solved numerically and the parameter values of the model are summarized in Table 5. Besides the parameters that are already discussed in the previous chapter, several new parameters must be specified. I follow Kim and Loungani's (1992) work and set v equals to 1.7, which translates into an elasticity

of substitutability of 0.59.³¹ For the benchmark calibration, I set the parameter $\iota = 0.9$, and the annual depreciation rate $\delta = 0.1225$. The elasticity of investment rate to the price of capital η equals to 3. The rest of the parameters have the same values as in the baseline model.

3.5 Simulation Result

Figures 8 and 9 illustrate the effects of a positive oil price shock on key macroeconomic variables. The results show similar patterns as the baseline model. When a positive oil price shock hits the economy, both domestic and total CPI inflation rise due to the increase in marginal cost. Output and consumption drop accordingly. Moving from fixed to flexible exchange rate regime, the absolute value of correlation between real exchange rate and oil price increases, which means oil price has greater impact on real exchange rate under flexible exchange rate than fixed. Figures 8 and 9 also show that real exchange rate and terms of trade are procyclical. These results are in line with findings of Mendoza (1995) and Backus and Crucini (2000).

Regarding the magnitude of changes in the output, the impulse response shows a smaller decrease in output and consumption compared to the baseline model. Since capital and oil are nested together in the production function, the oil share of output is greatly reduced. The impulse response of my model suggests that output will drop

³¹ To investigate the role of energy in business cycles, Backus and Crucini (2000) argue that the high elasticity of substitution produces strongly counterfactual implications for the time series of prices and quantities in the world oil market. They set ν equals to 11 which translate into an elasticity of substitutability of 0.09. Atkeson and Kehoe (1999), however, suggest that the high elasticity of substitution could be more appropriate to capture the secular change in energy use.

approximately 0.02% with a one percent increase in oil price. This is much closer to the IMF estimate of 0.0125% with a one percent increase in the oil price than in the baseline model.³² In the baseline model, the output declines around 0.15% with a one percent increase in the oil price shock.

As in chapter 2, I present the simulation results under different exchange rate regimes. First, the model is analyzed with different degrees of flexibility in the nominal exchange rate. The calibration allows choosing $\omega_\epsilon = 0.99$ for fixed and $\omega_\epsilon = 0.1$ for flexible exchange rate regime. Second, I examine the results in changes in the economy's openness. Third, I compare different shares of oil and capital in production to see whether the lower oil share induces smaller variations in output.

3.5.1 Sensitivity analysis: from fixed to flexible exchange rate regime

Table 6 and Figure 7 summarize the standard deviations of some important macroeconomic variables with different degrees of flexibility in nominal exchange rate when the model is driven by positive nominal oil price shocks. I define volatility as the standard deviations of these variables. Without external shocks, all variables take their steady-state value.

The results are similar to the baseline model. First, both real and nominal exchange rate fluctuations are higher under more flexible exchange rate regimes when the small open economy is hit by an oil price shock. On the other hand, output and consumption are more volatile under the fixed exchange rate regimes. Second, in

³² IMF reports that \$5 per barrel (20 percent) increase in oil price will reduce the level of global output by around 1/4 percent.

moving from fixed to flexible exchange rate regimes, the proportional rise in volatility of the nominal exchange rate is coupled by a rise in volatility of the real exchange rate. Third, small open economies that peg their exchange rates have higher variations in the domestic price level. On the other hand, under flexible exchange rate regime, the variations in the domestic price level are lower, which suggests that a stronger anti-inflationary focus of monetary policy can reduce the volatility in inflation and output at the same time. This results are consistent with Clarida, Gali, and Gertler (2002)'s empirical findings.

3.5.2 Sensitivity analysis: different degree of openness

Table 6 summarizes the results on the role of openness under flexible and fixed exchange rate regimes. From left to right, the degree of openness decreases. I use the $1 - \gamma$, the share of foreign goods in total consumption, as the proxy of openness. The relatively higher $1 - \gamma$ means higher degree of openness. A few results stand out. First, the real and nominal exchange rates are much more volatile under flexible than under fixed exchange rate regime regardless of the degree of openness. Second, output and capital are more volatile under fixed than floating exchange rate regime, which suggests that more flexible exchange rate regimes can mitigate the exogenous oil price shocks regardless of the degree of openness. Third, output exhibits less fluctuation with higher degree of openness under both fixed and flexible exchange rate. The intuition is that the domestic household can substitute their investment goods with foreign products, which by assumption is relatively cheaper. Since the

investment composite index $In_t(In_{H,t}, In_{F,t})$ has an identical expression as consumption, it is possible that investment has lower variations when the degree of openness is higher, which in turn makes the output less volatile. Fourth, domestic inflation will be less volatile with higher degree of openness regardless of exchange rate regimes.

3.5.3 Different oil shares as a fraction of output

I address the role of oil use as a fraction of output under different exchange rate regimes. The shift of exchange rate regime has a similar effect on the economy. Table 8 summarizes the results. The fraction of oil use in production decreases from left to right, and the economy exhibits higher variations when oil share of output is higher. Blanchard and Gali (2007) study the declining oil share in production and conclude that the reduction in the oil share in production cannot account for the full decline in volatility of output, but it clearly accounts for part of it. According to their calculations, the oil share in production is around 1.8% in 1970s, and it decreased to 1.2% after 1997. Dhawan and Jeske (2007) also present similar observations that energy use as a fraction of output has dropped significantly. They compare different shares from both households and firms and conclude that the economy's output response is determined by the significant drop in the firm's energy use. These results are consistent with the results of my model under different exchange rate regimes.

3.6 Conclusion

The model examined in this chapter shares similar properties with the baseline

model. The inclusion of capital enriches the model structure and makes the assumptions more realistic, which enables to examine the link between oil price shocks and major macroeconomic variables. In the extended model, capital is used as input and nested with oil in the production process. The households rent out their capital and make their decisions on investment goods. To capture the adjustment difference between physical and financial capital, capital accumulation is subjected to the adjustment cost.

The results regarding the role of different exchange rate regimes are similar with the baseline model. First, under the flexible exchange rate regime, there will be smaller fluctuations in total consumption, output, capital, and investment, but the nominal and real exchange rate fluctuations are higher under flexible than under fixed exchange rate regime. The results are consistent with Friedman's (1953) hypothesis that the output responses to shocks are smoother in flexible exchange rate regime. Second, it provides one possible explanation to the different responses of the economy during 1970s and 1990s to similar oil price shocks. In the latter period, the variations in the nominal exchange rate dampen the real shocks to the economy. Specifically, a small open economy benefits from initial currency appreciation, which induces lower input cost and inflation rate. The eventual depreciation of domestic currency can strengthen the competitiveness of home country products. Third, oil price shocks affect the real exchange rates as documented by Zhou (1995) and Broda (2002). This implies that the high fluctuation of real exchange rate may come from the exogenous disturbance. The impulse response indicates that real

exchange rate and terms of trade are procyclical, which is in line with findings of Mendoza (1995) and Backus and Crucini (2000).

My model also suggests the changing effects of oil price shocks. Generally, the shift to more flexible exchange rate regimes, the decline share of oil in economy, and the higher degree of openness may all account for the changing effects of oil price shocks. However, due to the exogeneity assumption on foreign production in my model, the declining effects of oil price shocks under higher degree of openness may come from the model assumption instead of economic reasoning.³³

Finally, with the introduction of capital, the impulse response indicates that the decrease in output due to a one percent increase in oil price is approximately 0.02%. This result is more in line with empirical evidence compared to 0.15% drop in output in the baseline model. The big difference in results comes from the low oil share of output in the extended model.

³³ To further our study on this issue, we probably need to assume a complete financial market. If higher degree of openness indicates higher capital inflow, the variations in output can be reduced.

Table 6 Calibration of model

Parameter	Definition and Description	Value
α	Labor share in production	0.7
β	Annual discount factor	0.96
γ	Share of home produced goods in total consumption	0.6
χ	Interest rate rule	0.5
ϕ	Price stickiness	0.75
φ	Inverse elasticity of labor supply	3
$\theta/(\theta -1)$	Steady-state markup	1.2
ρ^{i^*}	Serial correlation parameter for the foreign interest rate	0.8
ρ^{y^*}	Serial correlation parameter for the foreign output	0.9
$\rho^{p_o^*}$	Serial correlation parameter for oil price	0.88
ρ^a	Serial correlation parameter for technology	0.85
ρ	Elasticity of substitution between home and foreign product	1.01
υ	Inverse elasticity of substitution between capital and oil	1.7
δ	Annual depreciation rate	0.1225
η	Elasticity of investment rate to the price of capital	3
ι	Ratio between oil and capital stock	0.9
γ^{NO}	Degree of impact of oil price on the foreign price level	0.01
σ	Elasticity of substitution for the home country product	1/2
$\sigma_{\varepsilon}^{i^*}$	Standard deviation of foreign nominal interest rate	1.379
$\sigma_{\varepsilon}^{p_o^*}$	Standard deviation of oil price	1.51
σ_{ε}^a	Standard deviation of foreign output and technology	1
ω_y	Responsiveness of monetary policy to output gap	0
ω_e	Responsiveness of monetary policy to nominal exchange rate	0.99~0.1
ω_{π}	Responsiveness of monetary policy to total inflation	1.5

Table 7 Statistics for the calibrated model under different exchange rate regime

	Standard deviation HP-Filtered				
	$\omega_e=0.1$	$\omega_e=0.25$	$\omega_e=0.5$	$\omega_e=0.75$	$\omega_e=0.99$
Nominal exchange rate	5.1499	3.7546	2.2368	1.0921	0.0476
Real exchange rate	3.6718	3.528	3.2364	2.9305	2.6644
Interest rate	1.1809	0.9054	0.95	1.2185	1.6406
Domestic Price	0.7294	1.3231	1.971	2.3447	2.566
Consumption	7.3192	8.139	8.7399	8.9916	8.9004
output	1.2812	1.5316	2.1593	2.6738	3.0952
Capital	2.7413	2.5233	2.848	3.088	3.1816
Investment	1.3949	1.0271	1.8082	1.9444	1.9937

Note: Standard deviations are obtained from Hodrick-Prescott filtered data shows the responsiveness of monetary policy to exchange rate. The higher the value, the more responsive is the monetary policy to exchange rate implying the more rigid the exchange rate regime.

Table 8 Statistics with different degree of openness

Variable	Standard deviation HP-Filtered					
	$1-\gamma=0.4$		$1-\gamma=0.3$		$1-\gamma=0.2$	
	Fixed	Floating	Fixed	Floating	Fixed	Floating
Nominal exchange rate	0.0476	3.7546	0.0527	4.1136	0.058	4.502
Real exchange rate	2.6644	3.528	3.2314	4.4129	3.7971	5.3692
Interest rate	1.6406	0.9054	1.6376	0.6849	1.6343	0.4641
Domestic inflation	2.566	1.3231	2.698	1.3935	2.8073	1.458
Consumption	8.9004	8.139	8.0002	6.8776	7.141	5.5496
output	3.0952	1.5316	3.489	1.6939	3.8524	1.8838
Capital	3.1816	2.5233	2.7657	1.821	2.406	1.2026

Table 9 Statistics with different share of oil in production

Variable	Standard deviation HP-Filtered					
	$\iota = 0.9$		$\iota = 0.95$		$\iota = 0.99$	
	Fixed	Floating	Fixed	Floating	Fixed	Floating
Output	3.1459	1.5341	3.0952	1.5316	3.0648	1.5451
Consumption	9.104	8.3176	8.9004	8.139	8.6969	7.9285
Capital	3.0439	2.4063	3.1816	2.5233	3.3652	2.6954
Investment	2.1331	1.0273	1.9937	1.0271	1.7478	0.9971

Figure 7 Variability of some macroeconomic aggregates in moving from flexible to fixed

Figure 8 Effect of oil price shock under flexible exchange rate regime

Figure 9 Effect of oil price shock under fixed exchange rate regime

Appendix B

a. Mathematical Derivation

Assumptions:

- The economy is small in the sense that it cannot influence the foreign price level.
- Oil is imported from other countries for domestic production; households will not consume oil directly.
- The foreign price level is composed of oil price, which is exogenous in the model, and non-oil goods price, which is constant over time.
- Oil and capital are assumed to be substitute in production.
- Domestic investment has an identical expression as consumption.
- The function form of $\Phi(\cdot)$ capital adjustment cost is assumed increasing and concave.

Households

The domestic economy is populated by a continuum of infinitely-lived identical households, which is index by i ; I drop the indexation for simplicity. Across time, the representative domestic household maximizes utility function which is given by:

$$(B1) \quad E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right]$$

The consumption price index is

$$(B2) \quad C_t = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1}$$

The consumption-based price index is

$$(B3) \quad P_t = \left(\gamma P_{H,t}^{1-\rho} + (1-\gamma) P_{F,t}^{1-\rho} \right)^{1/(1-\rho)}$$

The Lagrangian equation indicates

$$L = (\gamma^{1/\rho} C_{H,t}^{(\rho-1)/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{(\rho-1)/\rho})^{\rho/(1-\rho)} - \lambda_t (P_{H,t} C_{H,t} + P_{F,t} C_{F,t} - M)$$

then there are

$$(B3a) \quad C_t^{1/(\rho-1)} \gamma^{1/\rho} C_{H,t}^{-1/\rho} = \lambda_t P_{H,t}$$

$$(B3b) \quad C_t^{1/(\rho-1)} (1-\gamma)^{1/\rho} C_{F,t}^{-1/\rho} = \lambda_t P_{F,t}$$

$$(B3c) \quad P_{H,t} C_{H,t} + P_{F,t} C_{F,t} = M$$

From equation (1a) and (1b), there is

$$\frac{\gamma^{1/\rho} C_{H,t}^{-1/\rho}}{(1-\gamma)^{1/\rho} C_{F,t}^{-1/\rho}} = \frac{P_{H,t}}{P_{F,t}}$$

Then consumption on foreign goods in terms of domestic goods can be expressed

as

$$(B3d) \quad C_{F,t} = \left(\frac{1-\gamma}{\gamma} \right) C_{H,t} \left(\frac{P_{H,t}}{P_{F,t}} \right)^\rho$$

Substitute (1d) into (1c), there is

$$P_{H,t} C_{H,t} + P_{F,t} \left[\left(\frac{1-\gamma}{\gamma} \right) C_{H,t} \left(\frac{P_{H,t}}{P_{F,t}} \right)^\rho \right] = M$$

$$\Rightarrow \{ \gamma P_{H,t}^{1-\rho} + P_{F,t}^{1-\rho} (1-\gamma) \} C_{H,t} = \frac{M \gamma}{P_{H,t}^\rho}$$

$$\text{Since } \gamma P_{H,t}^{1-\rho} + P_{F,t}^{1-\rho} (1-\gamma) = P_t^{(1-\rho)}, \text{ I have } P_t^{(1-\rho)} C_{H,t} = \frac{M \gamma}{P_{H,t}^\rho}$$

with $\frac{M}{P_t} = C_t$, I can obtain the optimal allocation between domestic goods and

foreign goods which is given by

$$(B4) \quad C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_t} \right)^{-\rho} C_t, C_{F,t} = (1-\gamma) \left(\frac{P_{F,t}}{P_t} \right)^{-\rho} C_t$$

The representative household's budget constraint is given by

$$(B5) \quad P_t (C_t + I_{n,t}) + E_t (B_{t+1}) = W_t N_t + Z_t K_t + (1+i_t) B_t + \tau_t$$

The capital accumulation is described by

$$(B6) \quad K_{t+1} = (1-\delta) K_t + \Phi \left(\frac{I_{n,t}}{K_t} \right) K_t$$

Maximize equation (1) subject to equation (5) and equation (6), The Lagrangian equation indicates

$$L_t = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] + \sum_{t=0}^{\infty} \lambda_t (P_t (C_t + I_{n,t}) + E_t (B_{t+1}) - W_t N_t - Z_t K_t - (1+i_t) B_t - \tau_t) \\ + \sum_{t=0}^{\infty} \mu_t ((1-\delta) K_t + \Phi \left(\frac{I_{n,t}}{K_t} \right) K_t - K_{t+1})$$

The first order conditions are

$$(B7) \quad \frac{C_t^{-\sigma}}{N_t^{\varphi}} = \frac{P_t}{W_t}$$

$$(B8) \quad \beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} = \frac{1}{R_t} E_t \left(\frac{P_{t+1}}{P_t} \right)$$

$$(B9) \quad Q_t = C_t^{-\sigma} \left[\Phi_{I_n} \left(\frac{I_{n,t}}{K_t} \right) \right]^{-1}$$

$$(B10) \quad Q_t = \beta E_t \left[C_{t+1}^{-\sigma} \frac{Z_{t+1}}{P_{t+1}} + Q_{t+1} \left(1 - \delta + \Phi \left(\frac{I_{n,t+1}}{K_{t+1}} \right) - \frac{I_{n,t+1}}{K_{t+1}} \Phi_{I_n} \left(\frac{I_{n,t+1}}{K_{t+1}} \right) \right) \right]$$

Equation (B7) and equation (B8) have the same meaning as in chapter two. From the

Lagrangian equation, taking first order condition with respect to $I_{n,t}$, I have

$$(B9a) \quad \lambda_t P_t + \mu_t \Phi'_{I_n} \left(\frac{I_{n,t}}{K_t} \right) = 0$$

here, $\lambda_t P_t = C_t^{-\sigma}$, μ_t has the same meaning as Tobin's q , which shows the value of an additional unit of capital. Rearrange equation (B9a), I can derive Equation (B9), which determines the investment rate as a function of Q_t (the equivalent of the Tobin's q). Taking first order condition with respect to K_{t+1} , I can get equation (B10) which describes the evolution of Q_t over time.

Domestic firms

The firms' production function is given by

$$(B11) \quad Y_t(j) = A_t \left[\iota K_t^{1-\nu}(j) + (1-\iota) O_t^{1-\nu}(j) \right]^{(1-\alpha)/(1-\nu)} N_t^\alpha(j)$$

With CRTS production function, the marginal cost and unit cost will coincide, the production efficiency condition implies that

$$(B12) \quad mc_t \frac{\partial Y_t(j)}{\partial N_t(j)} = \frac{W_t}{P_{H,t}}$$

$$(B13) \quad mc_t \frac{\partial Y_t(j)}{\partial O_t(j)} = \frac{\varepsilon_t P_{O,t}^*}{P_{H,t}}$$

$$(B14) \quad mc_t \frac{\partial Y_t(j)}{\partial K_t(j)} = \frac{Z_t}{P_{H,t}}$$

From equation (B13) and (B14), the substitution between capital and labor takes the following form

$$(B15) \quad \left(\frac{O_t}{K_t} \right)^{-\nu} = \frac{\iota \varepsilon_t P_{O,t}^*}{(1-\iota) Z_t}$$

Domestic firms can reset their price to maximize

$$(B16) \quad E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} \left[P_{H,t}^{\text{new}}(j) - MC_{t+k}(j) \right] Y_{t+k}(j) \right\}$$

Subject to the demand function which is given by

$$(B17) \quad Y_{t+k}(j) \leq \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} [C_{H,t+k} + C_{H,t+k}^*]$$

$$\text{Since } \frac{\partial Y_{t+k}(j)}{\partial P_{H,t}^{new}(j)} = -\vartheta \left(\frac{P_{H,t}^{new}(j)}{P_{H,t+k}} \right)^{-\vartheta} * \frac{1}{P_{H,t}^{new}(j)} [C_{H,t+k} + C_{H,t+k}^*] = -\vartheta Y_{t+k}(j) * \frac{1}{P_{H,t}^{new}(j)}$$

Then the markup equation is

$$(B18) \quad P_{H,t}^{new}(j) = \left(\frac{\vartheta}{\vartheta-1} \right) \frac{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} MC_{t+k}(j) Y_{t+k}(j) \right\}}{E_t \left\{ \sum_{k=0}^{\infty} \beta^k \phi_p^k \Lambda_{t,t+k} Y_{t+k}(j) \right\}}$$

When $\vartheta = 0$, there are no price rigidities, I have

$$(B19) \quad P_{H,t}^{new}(j) = (\vartheta/\vartheta-1) MC_t$$

Uncovered interest rate parity

$$(B20) \quad \frac{R_t^*}{R_t} = \frac{\varepsilon_t}{\varepsilon_{t+1}}$$

Terms of trade and real exchange rate

Law of one price holds all the time, which means

$$(B21) \quad P_{H,t} \equiv \varepsilon_t P_{H,t}^*, P_{F,t} \equiv \varepsilon_t P_{F,t}^*$$

The terms of trade are defined as the price of the imported good relative to the price of the domestic good.

$$(B22) \quad S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\varepsilon_t P_{F,t}^*}{P_{H,t}}$$

The real exchange rate is defined as the relative price between foreign and domestic country

$$(B23) \quad \varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t}$$

Monetary policy and exchange rate regimes

The target for the nominal interest rate:

$$(B24) \quad (1 + \bar{i}_t) = \left(\frac{P_t}{P_{t-1}} \right)^{\omega_\pi} Y_t^{\omega_y} \varepsilon_t^{\frac{\omega_\varepsilon}{1-\omega_\varepsilon}}$$

The determination of the actual short-run interest rate that accounts for the desire of the monetary authority to smooth changes in the interest rate is:

$$(B25) \quad (1 + i_t) = (1 + \bar{i}_t)^{1-x} (1 + i_{t-1})^x$$

Steady State

I normalize the price level in both home and foreign country in steady state and bonds are in zero supply.

The equilibrium in the domestic goods market requires:

$$(B26) \quad \bar{C}_H + \bar{C}_H^* + \bar{I}n = \bar{Y}$$

From equation (B8), the steady-state gross nominal interest rate

$$(B27) \quad \bar{i} = \frac{1}{\beta} - 1$$

From equation (B10), together with the assumption on the steady state capital adjustment, there is:

$$(B28) \quad \bar{Z} = \frac{1}{\beta} - 1 + \delta$$

Since there is no average nor marginal capital adjustment costs in steady state, then I have

$$(B29) \quad \bar{I}n = \delta \bar{K}$$

From equation (B15), I have

$$(B30) \quad \left(\frac{\bar{K}}{\bar{O}} \right)^{-\nu} = \frac{(1-t)}{t} \bar{Z}$$

From equation (B11) and (B12), the labor-output ration is given by

$$(B31) \quad \frac{\bar{N}}{\bar{Y}} = \frac{\alpha \bar{MC}}{C^\sigma \bar{N}^\sigma}$$

From equation (B13), (B14), and (B15), the capital-output ratio is given by

$$(B32) \quad \frac{\bar{K}}{\bar{Y}} = \frac{(1-\alpha) \bar{MC}}{\bar{Z} + \Psi}$$

$$\text{where } \Psi = \left[\frac{(1-l) \bar{Z}}{l} \right]^\nu$$

From equation (B12)-(B14), and equation (B26), the steady state consumption is given by

$$(B33) \quad \bar{C} = \left\{ 1 - \frac{(1-\alpha) \bar{MC} [\Psi + \delta]}{\bar{Z} + \Psi} \right\} \bar{Y}$$

Log-linearized model

Aggregate demand

From equation (B3), with the definition of inflation, the following equation can be obtained:

$$(B34) \quad \pi_t = \gamma \pi_{H,t} + (1-\gamma) (\pi_{F,t} - \pi_{F,t-1})$$

From FOC of household's maximization, there is

$$(B35) \quad \sigma E_t (\hat{c}_{t+1}) - \sigma \hat{c}_t = E_t (\hat{i}_{t+1}) - E_t (\hat{\pi}_{t+1})$$

From equation (B20), the international risk sharing condition implies that

$$(B36) \quad \hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t$$

From equation (9), foreign demand on domestic product can be described as

$$(B37) \quad \hat{c}_{H,t}^* = \rho \hat{s}_t + \hat{y}_t^*$$

From equation (B3) and (B2), domestic demands on home and foreign goods are described by

$$(B38) \quad \hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_t; \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_t$$

Log-linearize equation (B26) implies

$$(B39) \quad \bar{Y}\hat{y}_t = \bar{C}_H\hat{c}_{H,t} + \bar{C}_H^*\hat{c}_{H,t}^* + \bar{I}\hat{m}_t$$

Log-linearize the FOC of household's maximization problem, from equation (B9), the investment rate is described by

$$(B40) \quad \hat{q}_t = -\sigma\hat{c}_t + \frac{1}{\eta}(\hat{m}_t - \hat{k}_t)$$

$$\text{here } \eta \equiv -\frac{\Phi''\left(\frac{In}{K}\right)\frac{In}{K}}{\Phi'\left(\frac{In}{K}\right)} > 0$$

And the evolution of Q over time implies that

$$(B41) \quad \hat{q}_t = \beta\bar{Z}E_t\{(\hat{z}_{t+1} - \hat{p}_{t+1} - \sigma\hat{c}_{t+1}) + \beta\hat{q}_{t+1}\}$$

here in steady state, $\Phi(\cdot)$ is subject to $\bar{Q} = \Phi'\left(\frac{In}{K}\right)^{-1} = 1$, and $\Phi\left(\frac{In}{K}\right) = \delta = \frac{In}{K}$.

Log-linearize capital accumulation, there is

$$(B42) \quad E_t(\hat{k}_{t+1}) = (1-\delta)\hat{k}_t + \delta\hat{m}_t$$

Aggregate supply

The production function suggests that

$$(B43) \quad \hat{y}_t = \hat{a}_t + \alpha\hat{n}_t + \iota(1-\alpha)\hat{k}_t(1-\iota)(1-\alpha)\hat{o}_t$$

Log-linearization of equation (B18) and equation (B19)

$$(B44) \quad \bar{\pi}_{H,t} = \beta E_t(\bar{\pi}_{H,t+1}) + \frac{(1-\phi)(1-\beta\phi)}{\phi}\bar{m}_{C,t}$$

The determination of real marginal cost can be obtained from combining equation

(B7) and equation (B12):

$$(B45) \quad \bar{m}c_t = \sigma \hat{c}_t + (\varpi + 1) \hat{n}_t + (1 - \gamma) \hat{s}_t - \hat{y}_t$$

The substitution between oil and capital

$$(B46) \quad \nu \hat{o}_t - \nu \hat{k}_t = \hat{z}_t - \hat{\varepsilon}_t - \hat{p}_{o,t}^*$$

Monetary policy rule

$$(B47) \quad \hat{i}_t = \tilde{\omega}_\pi \pi_t + \tilde{\omega}_y \hat{y}_t + \tilde{\omega}_\varepsilon \hat{\varepsilon}_t + \chi \hat{i}_{t-1}$$

where $\tilde{\omega}_\pi = (1 - \chi) \omega_\pi$, $\tilde{\omega}_y = (1 - \chi) \omega_y$, $\tilde{\omega}_\varepsilon = (1 - \chi) (\omega_\varepsilon / (1 - \omega_\varepsilon))$, $\hat{i}_t \approx \log(1 + i_t / (1 + \bar{i}))$

Exogenous process

$$(B48) \quad (1 + i_t^*) = (1 + i_{t-1}^*)^{\rho^*} \exp(\xi_t^*)$$

$$(B49) \quad Y_t^* = Y_{t-1}^{\rho^*} \exp(\xi_t^*)$$

$$(B50) \quad A_t = A_{t-1}^{\rho^a} \exp(\xi_t^a)$$

$$(B51) \quad P_{o,t}^* = (P_{o,t-1}^*)^{\rho^{po}} (\xi_t^{po})$$

Appendix B (Continued)

b. Attached Matlab Code

Endogenous Variables: $\hat{p}_{F,t}, \hat{k}_t, \hat{i}_t, \hat{s}_t, \hat{c}_t, \hat{\pi}_t, \hat{\pi}_{H,t}, \hat{z}_t, \hat{\varepsilon}_t, \hat{\varepsilon}_t^r, \hat{y}_t, \hat{o}_t, \hat{n}_t, \hat{m}_t, \hat{q}_t, \hat{m}_{C,t}$

Exogenous Variables: $\hat{p}_{O,t}^*, \hat{i}_t^*, \hat{y}_t^*, \hat{a}_t$

%% SETTING PARAMETERS:

```

alpha    =0.7;    %
beta     =0.96;    %
gama     =0.6;    %
gama_o   =0.01;   %
theta    =6;       %
phi      =0.75;    %
chi      =0.5;     %
psi      =3;       %
sigma    =1/2;     %
omega_pi =1.5;     %
omega_y  =0;       %
omega_e  =0.99;    %
om_pi    =(1-chi)*omega_pi;    %
om_y     =(1-chi)*omega_y;     %
om_e     =(1-chi)*omega_e/(1-omega_e); %
mc_bar   =(theta-1)/theta;      %
mu        =(1-phi)*(1-beta*phi)/phi; %
rho      =1.01;    %
delta    =0.1225;  %
iota     =0.95;    %
upsilon  =1.7;     %
eta      =3;       %
z_bar    =1/beta-1+delta    %

rho_o    =0.88;    %
rho_a    =0.85;    %
rho_yf   =0.9;     %
rho_if   =0.8;     %
sigma_if =1.378;   %
sigma_po =1.51;    %
sigma_a  =1;       %
sigma_yf =1;       %

```

```

lamda_a=((1-iota)*z_bar/iota)^(1/upsilon); %
lamda_b=1-(1-alpha)*(lamda_a+delta)*mc_bar/(z_bar+lamda_a); %
lamda_c=alpha^alpha*(1-alpha)^(1-alpha)*mc_bar*(iota/z_bar)^((1-alpha)/(1-upsilon))*(z_b
    ar+lamda_a)^(upsilon*(1-alpha)/(1-upsilon)); %
lamda_d=(alpha*mc_bar/lamda_b)^(psi*alpha/(psi+1)); %
c_bar =(lamda_c/lamda_d)^((psi+1)/alpha/(sigma+psi)); %
n_bar =(alpha*mc_bar*c_bar^(1-sigma)/lamda_b)^(1/(psi+1)); %
y_bar =c_bar/lamda_b; %
k_bar =(1-alpha)*mc_bar*y_bar/(z_bar+lamda_a); %
o_bar =lamda_a*k_bar; %
in_bar =delta*k_bar; %
coe_1 =z_bar*k_bar/mc_bar/y_bar/(1-alpha); %
coe_2 =o_bar/mc_bar/y_bar/(1-alpha); %
ch_bar =gama*c_bar; %
cf_bar =c_bar-ch_bar; %
chf_bar =cf_bar+o_bar; %

```

%% DECLARING THE MATRICES:

```

VARNAMES = ['import price      ', %1  X1
             'interest rate    ', %2  X2
             'terms of trade   ', %3  X3
             'consumption      ', %4  X4
             'capital          ', %5  X5
             'rental cost      ', %6  X6
             'Tobin q          ', %7  X7
             'domestic inflation', %8  Y1
             'total inflation  ', %9  Y2
             'nominal exchange rate', %10 Y3
             'real exchange rate', %11 Y4
             'output          ', %12 Y5
             'investment       ', %13 Y6
             'oil              ', %14 Y7
             'labor            ', %15 Y8
             'marginal cost    ', %16 Y9
             'oil price        ', %17 Z1
             'technology       ', %18 Z2
             'foreign interest rate', %19 Z3
             'foreign output   ', %20 Z4
]

```

%% EQUATIONS:

%% NON-EXPECTATIONAL EQUATIONS:

```
% (6) 0 = tq(t)+sigma*c(t)-1/eta*in(t)+1/eta*k(t)
% (7) 0 = s(t)-s(t-1)-pft(t)+pft(t-1)+pih(t)
% (8) 0 = pi(t)-gama*pih(t)-(1-gama)*pft(t)+(1-gama)*pft(t-1)
% (9) 0 = pft(t)-e(t)-gama_o*po(t)
% (10) 0 = q(t)-gama*s(t)
% (11) 0 = y(t)-a(t)-alpha*n(t)-(1-alpha)*(1-iota)*o(t)-(1-alpha)*iota*k(t)
% (12) 0=y_bar*y(t)-ch_bar*c(t)-rho*(chf_bar+(1-gama)*ch_bar)*s(t)-chf_bar*yft(t)-in_bar*in(t)
% (13) 0 = upsilon*o(t)-upsilon*k(t)-z(t)+e(t)+po(t)
% (14) 0 = mc(t)-sigma*c(t)-(psi+1)*n(t)-(1-gama)*s(t)+y(t)
% (15) 0 = mc(t)+y(t)+pft(t)-s(t)-coe_1*(z(t)+k(t))-coe_2*(e(t)+po(t)+o(t))
% (16) 0 = i(t)-om_pi*pi(t)-om_y*y(t)-om_e*e(t)-chi*i(t-1)
```

%% EXPECTATIONAL EQUATIONS:

```
% (1) 0 = E_t{ sigma*c(t+1)-sigma*c(t)-i(t+1)+pi(t+1)}
% (2) 0 = E_t{ i(t)-ift(t)-e(t+1)+e(t) }
% (3) 0 = E_t{ pih(t)-beta*pih(t+1)-mu*mc(t) }
% (4) 0 = E_t{ k(t+1)-(1-delta)*k(t)-delta*in(t)}
% (5) 0 =
E_t{ tq(t)-beta*tq(t+1)-(1-beta)*sigma*c(t+1)+beta*z_bar*z(t+1)+beta*z_bar*gama*s(t+1)-beta*
z_bar*pft(t+1)}
```

%% EXOGENOUS EQUATIONS:

```
% (17) yft(t+1) = rho_yf*yft(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (18) po(t+1) = rho_o*po(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (19) a(t+1) = rho_a*a(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
% (20) if(t+1) = rho_if*ift(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
```

%% FIND MATRICES FOR FORMAT:

```
% 0 = AA*X(t)+BB*X(t-1)+CC*Y(t)+DD*Z(t)
```

```
% AA 11x7
% BB 11x7
% CC 11x9
% DD 11x4
```

```
% 0 = E_t{ FF*X(t+1)+GG*X(t)+HH*X(t-1)+JJ*Y(t+1)+KK*Y(t)+LL*Z(t+1)+MM*Z(t) }
```

```
% FF 5x7
% GG 5x7
```



```
% HH 5x7
% JJ 5x9
% KK 5x9
% LL 5x4
% MM 5x4
```

```
% Z(t+1) = NN*Z(t)+epsilon(t+1), with E_t{epsilon(t+1)}=0
```

```
% NN 4x4
```

```
% for pf(t),      i(t),      s(t),      c(t),      k(t),      z(t),      tq(t)
AA=[0,            0,      0,      sigma,      1/eta,      0,      1
    -1,           0,      1,      0,      0,      0,      0
    -(1-gama)     0,      0,      0,      0,      0,      0
    1,            0,      0,      0,      0,      0,      0
    0,            0,     -gama,  0,      0,      0,      0
    0,            0,      0,      0,     -(1-alpha)*iota, 0,      0
    0,            0, -rho*(chf_bar+(1-gama)*ch_bar), -ch_bar, 0, 0,      0
    0,            0,      0,      0,     -upsilon,    -1,      0
    0,            0,     -(1-gama), -sigma,      0,      0,      0
    1,            0,     -1,      0,     -coe_1,     -coe_1, 0
    0,            1,      0,      0,      0,      0,      0];
```

```
display (AA);
```

```
% for pf(t-1),   i(t-1), s(t-1), c(t-1), k(t-1), z(t-1), tq(t-1)
BB=[0,           0,      0,      0,      0,      0,      0
    1,           0,     -1,      0,      0,      0,      0
    (1-gama),     0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,            0,      0,      0,      0,      0,      0
    0,           -chi,  0,      0,      0,      0,      0];
```

```
display (BB);
```

```
%for pih(t),      pi(t),      e(t),      q(t),      y(t),      in(t),      o(t),      n(t),      mc(t)
CC=[ 0,           0,      0,      0,      0,      -1/eta,      0,      0,      0
    1,           0,      0,      0,      0,      0,      0,      0,      0
```

```
-gama,      1,      0,      0,      0,      0,      0,      0,      0
0,          0,     -1,      0,      0,      0,      0,      0,      0
0,          0,      0,      1,      0,      0,      0,      0,      0
0,          0,      0,      0,      1,      0,  -(1-iota)*(1-alpha), -alpha, 0
0,          0,      0,      0,      y_bar, in_bar,      0,      0,      0
0,          0,      1,      0,      0,      0,      epsilon,      0,      0
0,          0,      0,      0,      1,      0,      0,      -(psi+1), 1
0,          0, -coe_2,      0,      1,      0,      -coe_2,      0,      1
0,      -om_pi, -om_e,      0,      -om_y, 0,      0,      0,      0];

display (CC);
disp('rank of CC');
rank(CC)

%for po(t), a(t), if(t), yf(t)
DD=[ 0,      0,      0,      0
      0,      0,      0,      0
      0,      0,      0,      0
      -gama_o, 0,      0,      0
      0,      0,      0,      0
      0,     -1,      0,      0
      0,      0,      0,     -chf_bar
      1,      0,      0,      0
      0,      0,      0,      0
      -coe_2, 0,      0,      0
      0,      0,      0,      0];

display (DD);

%for pf(t+1), i(t+1), s(t+1), c(t+1), k(t+1), z(t+1), tq(t+1)
FF=[0,     -1,      0,      sigma,      0,      0,      0
      0,      0,      0,      0,      0,      0,      0
      0,      0,      0,      0,      0,      0,      0
      0,      0,      0,      0,      1,      0,      0
      -beta*z_bar, 0, beta*z_bar*gama, (beta-1)*sigma, 0, beta*z_bar, -beta];

display (FF);

%for pf(t), i(t), s(t), c(t), k(t), z(t), tq(t)
GG=[ 0,      0,      0,     -sigma,      0,      0,      0
      0,      1,      0,      0,      0,      0,      0
      0,      0,      0,      0,      0,      0,      0
      0,      0,      0,      0,     -(1-delta), 0,      0
      0,      0,      0,      0,      0,      0,      1];
```

```

display (GG);
%for pf(t-1),i(t-1),s(t-1),c(t-1),k(t-1), z(t-1),tq(t-1)
HH=[0,0,0,0,0,0,0,0
    0,0,0,0,0,0,0,0
    0,0,0,0,0,0,0,0
    0,0,0,0,0,0,0,0
    0,0,0,0,0,0,0,0];

display (HH);

%for pih(t+1), pi(t+1), e(t+1), q(t+1), y(t+1), in(t+1), o(t+1), n(t+1), mc(t+1)

JJ=[ 0,      1,      0,      0,      0,      0,      0,      0,      0
      0,      0,     -1,      0,      0,      0,      0,      0,      0
     -beta,    0,      0,      0,      0,      0,      0,      0,      0
      0,      0,      0,      0,      0,      0,      0,      0,      0
      0,      0,      0,      0,      0,      0,      0,      0,      0];

display (JJ);

%for pih(t), pi(t), e(t), q(t), y(t), in(t), o(t), n(t), mc(t)

KK=[ 0,      0,      0,      0,      0,      0,      0,      0,      0
      0,      0,      1,      0,      0,      0,      0,      0,      0
      1,      0,      0,      0,      0,      0,      0,      0,     -mu
      0,      0,      0,      0,      0,     -delta,    0,      0,      0
      0,      0,      0,      0,      0,      0,      0,      0,      0];

display (KK);

LL=[0,0,0,0
    0,0,0,0
    0,0,0,0
    0,0,0,0
    0,0,0,0];

display (LL);

% for po(t), a(t), if(t), yf(t)
MM=[ 0,      0,      0,      0
      0,      0,     -1,      0
      0,      0,      0,      0

```

```

0,    0,    0,    0
0,    0,    0,    0];

display (MM);

NN=[rho_o,    0,    0,    0
    0,    rho_a, 0,    0
    0,    0,    rho_if, 0
    0,    0,    0,    rho_yf];

Sigma=[sigma_po^2,    0,    0,    0
        0,    sigma_a^2,    0,    0
        0,    0,    sigma_if^2,    0
        0,    0,    0,    sigma_yf^2];

% SETTING OPTIONS:

[l_equ,m_states] = size(AA);
[l_equ,n_endog ] = size(CC);
[l_equ,k_exog   ] = size(DD);

PERIOD      = 4; % number of periods per year, i.e. 4 for quarterly
GNP_INDEX=3  :% Index of output among the variables selected for HP filter
IMP_SELECT  = [2: 5,8:13  ];
DO_SIMUL    = 1; % Calculates simulations
SIM_LENGTH=150;
DO_MOMENTS  = 1; % Calculates moments based on frequency-domain methods
%DO_ENLARGE  =1;%
HP_SELECT   = 1:(m_states+n_endog+k_exog); % Selecting the variables for the HP Filter
%IMP_JOINT=0;IMP_SUBPLOT=1;
%IMP_SINGLE=1;

do_it; % Starts calculations

```

Chapter 4

Oil Consumption, Different Measure of Inflation Rate and Welfare

4.1 Introduction

Monetary policy rules have been the subject of much work in the literature but in the context of closed economies. More recently, monetary policy rules have been investigated using the open economy framework (Svensson, 2000 and Devereux, Lane and Xu, 2006). In an open economy context, the exchange rate and shocks from the rest of the world are important for conducting monetary policy.³⁴ The real exchange rate affects relative prices between domestic and foreign goods, which in turn affect both domestic and foreign demand for domestic goods. Therefore, the movements in the real exchange rate contribute to the aggregate-demand channel for the transmission of monetary policy. There is also a direct exchange rate channel for the transmission of monetary policy to inflation since the exchange rate affects domestic currency prices of imported final goods, which enter the consumer price index (CPI). Hence, in open economies, the operating procedure of alternative monetary policies requires an endogenous reaction function, which expresses the instrument as a function of relevant domestic and foreign variables.

Among the numerous types of reaction functions or monetary policy rules in the literature, the most widely analyzed is the Taylor's (1993) monetary policy rule. The

³⁴ Svensson (2000) studies the inflation targeting in a small open economy using negative productivity shock and positive demand shock.

original Taylor rule involves two key variables: deviations in inflation and deviations in output gap. To capture the international transmission of monetary policy, researchers modify the original Taylor rule and incorporate exchange rate as transmission channel of monetary policy.³⁵ In the closed economy context, Persson and Tabellini (1996) introduce a monetary policy rule, which includes international coordination to enhance credibility using a static model. They show that a system of mandatory inflation targets could remove the incentive to deliberately engage in competitive devaluation. At the same time, it restores domestic credibility to a low inflation policy.³⁶ In the open economy context, Svensson (2000) assumes a central bank loss function, which is composed of the weighted sum of the unconditional variance corresponding to the targeting of CPI inflation and domestic inflation and stabilization of the output gap, and the smoothing of the instrument – the interest rate. He then changes the relative weight on each variable to examine the effects of inflation targeting using realistic lags in the different monetary policy transmission channels. He shows that the flexible domestic-inflation targeting successfully stabilizes both domestic inflation and the output gap.

Kollmann (2002) computes welfare-maximizing interest rate rules using a business cycle model. He assumes shocks to the domestic productivity, to the world interest rate, to the world inflation, and to the uncovered interest parity condition and calibrates to data for Japan, Germany and the United Kingdom. He concludes that the

³⁵ See Taylor (1999), Ball (1999), Rotemberg and Woodford (1998), Clarida, Gali and Gertler (1999), Svensson (2000), Monacelli (2004)

³⁶ See Blake and Westaway (1996), Nadal-De Simone et al. (1996)

optimized rule entails rather strict (but not perfect) targeting of the growth rate of the domestic producer price index, which yields a welfare level that is close to that of the economy under flexible prices.

Gali and Monacelli (2005), on the other hand, lay out a small open economy version of Calvo sticky price model and analyze the macroeconomic implications of three alternative monetary policy regimes for the small open economy using productivity as exogenous disturbance.³⁷ Under a particular parameterization of household's preference, they derive the second order approximation to the utility losses associated with suboptimal regimes when domestic inflation targeting constitutes the optimal policy.

In an open economy context, the alternative monetary policies also affect the volatility of nominal and real exchange rates. Svensson (2000) compares strict and flexible inflation targeting of CPI and domestic inflation. He finds that flexible CPI targeting limits the variations of the output gap and the real exchange rate. Kollmann (2002) finds that optimized policy rules (targeting the domestic producer price index) have a pronounced anti-inflation stance and entail significant nominal and real exchange rate volatility. Gali and Monacelli (2005) also show a policy of domestic inflation targeting implies a substantially larger volatility of both nominal and real exchange rates than CPI targeting and an exchange rate peg.

Many economists believe that "core inflation" defined as inflation excluding certain volatile prices, such as food and energy prices, is more appropriate as a

³⁷ Three alternative monetary regimes are domestic inflation targeting, CPI targeting and an exchange rate peg.

measure of the inflation rate. They argue that even though food and energy have substantial influence on the overall price level, they are quickly reversed and do not require a monetary policy response. On the other hand, their opponents argue that a rise in aggregate demand that might set off a period of higher inflation may initially show up in increases in certain sensitive prices that are set in more competitive markets. They suggest that commodity prices are good indicators of the status of the economy since they are highly responsive to changing economic conditions.³⁸

I study the relative performance of alternative monetary policies in the presence of oil price shocks using a small open economy model and compare four monetary policy rules: a fixed exchange rate regime and three inflation indicators targeted by the central bank. The three price indices are: the overall CPI, the non-oil CPI, and the domestic production price. I develop a small open economy dynamic stochastic general equilibrium model with price stickiness and address the effects of oil price shocks by introducing direct oil consumption of households as well as oil input in the production. In this essay, I do not include capital in the production since it could unnecessarily complicate the model and, as shown in Chapter 2 and 3, without adding value to the analysis. It also makes the derivation of welfare function so much more difficult.

When households consume oil directly, the oil price, together with domestic price and imported price, is included in the consumer price index (CPI). This could

³⁸ Mankiw and Reis (2003) lists the choice of the appropriate inflation indicator as one of the three open questions about price dynamics, along with the formation of inflation expectations and the existence of a trade-off between inflation and output stabilization.

have policy implications on the choice of the appropriate price index for the measure of inflation rate. That is, even though overall price level, such as CPI, is widely available and studied in literature, yet it is not necessarily the best one to serve as a target for monetary authority. I address the issue of which of the price indices serves as the best measure of inflation rate using a welfare loss function. I find that the domestic price index is the most appropriate measure of inflation because it induces less welfare loss.

The remainder of the chapter is organized as follows. Section 4.2 presents the model, and section 4.3 describes its calibration. Section 4.4 presents the simulation and sensitivity analysis. Section 4.5 conducts a welfare evaluation of the different measures of inflation rate. Section 4.6 concludes.

4.2 The Model

The model is an extension of the baseline model. I do not restate the whole model but illustrate the different parts and specify three price indices and three measures of inflation. The infinitely-lived representative household consumes a differentiated basket of domestic goods, imported goods, and oil. In each period, the household decides his consumption of goods and oil and derives wage from working. Hence, oil price changes have two-fold effects on the price level. First, oil price affects households' consumption decisions directly thereby changing the overall price level. Second, it alters firms' production, which changes the domestic price level.

4.2.1 The Consumption Bundle

Unlike chapters 2 and 3, the representative household consumes oil in addition to non-oil products. The household's consumption is composed of a basket of differentiated domestic and foreign goods (which are both tradable and indexed by j).

The consumption bundle of household j is given by:

$$C_t(j) = \left[(1-\kappa)^{\frac{1}{\psi}} \left(C_{NO,t}(j) \right)^{\frac{\psi-1}{\psi}} + \kappa^{\frac{1}{\psi}} \left(C_{O,t}(j) \right)^{\frac{\psi-1}{\psi}} \right]^{\frac{\psi}{\psi-1}} \quad (4.1)$$

where $C_{O,t}$ represents oil consumption, and $C_{NO,t}$ is a bundle of non-oil consumption which constitutes domestic and foreign goods. κ represents the oil share in the consumption basket, and parameter ψ is the elasticity of substitution between oil and non-oil consumption. The composition of the non-oil goods is the same as before, which is given by:

$$C_{NO,t} = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1} \quad (4.2)$$

Parameter ρ , as before, is the intratemporal elasticity of substitution between home and foreign products. For any given level of consumption, each household purchases a composite of home and foreign goods and oil in order to minimize the total cost of its consumption basket. That is, each household minimizes $\epsilon_t p_{O,t}^* C_{O,t}(j) + p_{NO,t} C_{NO,t}(j)$, subject to equation (4.1), where $p_{O,t}^*$ is oil price in foreign currency, and $p_{NO,t}$ is the price index in domestic currency for non-oil products. The optimal allocation of any given expenditure within each category of goods yields the demand functions for oil and non-oil goods:

$$C_{NO,t}(j) = (1 - \kappa) \left(\frac{P_{NO,t}}{P_t} \right)^{-\mu} C_t(j) \quad (4.3)$$

$$C_{O,t}(j) = \kappa \left(\frac{\varepsilon P_{O,t}^*}{P_t} \right)^{-\mu} C_t(j) \quad (4.4)$$

Analogously, the optimal composition of non-oil consumption by minimizing the cost of goods consumption basket, $P_{H,t} C_{H,t}(j) + P_{F,t} C_{F,t}(j)$, subject to equation (4.2) is given by:

$$C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_{NO,t}} \right)^{-\rho} C_{NO,t}, \quad C_{F,t} = (1 - \gamma) \left(\frac{P_{F,t}}{P_{NO,t}} \right)^{-\rho} C_{NO,t} \quad (4.5)$$

The overall consumption-based price index (CPI) and the non-oil consumption price index are given by:

$$P_t = \left[\kappa (\varepsilon P_{O,t}^*)^{1-\psi} + (1 - \kappa) P_{NO,t}^{1-\psi} \right]^{\frac{1}{1-\psi}} \quad (4.6)$$

$$P_{NO,t} = \left(\gamma P_{H,t}^{1-\rho} + (1 - \gamma) P_{F,t}^{1-\rho} \right)^{1/(1-\rho)} \quad (4.7)$$

The representative domestic household is similar as in chapters 2 and 3. The household maximizes $E_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t)$ according to the budget constraint, $P_t C_t + B_{t+1} = W_t N_t + (1 + i_t) B_t + \tau_t$. All the variables and parameters are as previously defined.

4.2.2 Different Measures of Inflation, Terms of Trade, and Real Exchange Rate

The inclusion of oil in the consumption basket enriches the model structure and the implementation of monetary policy accordingly. I assume the central bank has adopted a regime where deviations in inflation, output, and nominal exchange rate

have impact on the short-run nominal interest rate. Unlike the previous chapters, the central bank can choose one of the three price indices as the measure of inflation rate.

The question is which measure of inflation rate the central bank should target. Three

possible inflation targets are overall CPI inflation, $\pi_t = \frac{P_t}{P_{t-1}}$, non-oil CPI inflation,

$\pi_{NO,t} = \frac{P_{NO,t}}{P_{NO,t-1}}$, and domestic production inflation, $\pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$.

The terms of trade are still defined as the price of the imported good relative to the price of the domestic good.

$$S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\varepsilon_t P_{F,t}^*}{P_{H,t}} \quad (4.8)$$

The real exchange rate is then defined as:

$$\varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t} \quad (4.9)$$

Since oil is included in the consumption basket, the relationship between terms of trade and real exchange rate is³⁹

$$\varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t} \neq \frac{\varepsilon_t P_t^*}{P_{NO,t}} \quad (4.10)$$

4.2.3 Monetary Policy

The formulation of monetary policy is described in chapters 2 and 3, and the log-linear approximation version of the policy rule can be written as:

$$\hat{i}_t = \omega^\pi \pi_t^m + \omega^y \hat{y}_t + \omega^\varepsilon \hat{\varepsilon}_t + (1 - \chi) \hat{i}_{t-1} \quad (4.11)$$

³⁹ This contrast with the previous two chapters where there is no difference between non-oil price and CPI.

where $\tilde{\omega}^\pi = (1 - \chi)\omega^\pi$ with the superscript m indicating the measure of inflation, $\tilde{\omega}^y = (1 - \chi)\omega^y$, $\tilde{\omega}^\varepsilon = (1 - \chi)(\omega^\varepsilon / 1 - \omega^\varepsilon)$ and $\hat{i}_t \approx \log(1 + i_t / 1 + \bar{i})$. As defined in section 4.3.2, I consider three measures of inflation and analyze separately the monetary policy regimes in which the central bank reacts either to the changes in CPI, or in non-oil CPI (NO), or in the domestic production price index (H). Accordingly, $m \in \{CPI, NO, H\}$

4.2.4 Steady State with Direct Oil Consumption

In the steady state, I assume bonds are in zero net supply, the equilibrium in the domestic goods market requires:

$$\bar{C}_H + \bar{C}_H^* = \bar{Y} \quad (4.12)$$

Also, the small open economy has balanced trade position in the steady state, and then there is:

$$\bar{C}_H^* = \bar{C}_F + \bar{O} = \bar{C}_F + \bar{O}_p + \bar{C}_O \quad (4.13)$$

where at the steady state, $\bar{O}$ is total oil import, $\bar{O}_p$ is the oil used for production and $\bar{C}_O$ is the oil used for direct consumption. From equation (4.3) and equation (4.4), oil consumption and non-oil consumption in the steady state can be written as:

$$\bar{C}_O = \kappa \bar{C}, \quad \bar{C}_{NO} = (1 - \kappa) \bar{C} \quad (4.14)$$

Consumption on imported and domestic non-oil goods are:

$$\bar{C}_F = (1 - \gamma) \bar{C}_{NO} = (1 - \kappa)(1 - \gamma) \bar{C} \quad (4.15)$$

$$\bar{C}_H = \gamma \bar{C}_{NO} = (1 - \kappa) \gamma \bar{C} \quad (4.16)$$

The production efficiency implies that:

$$\frac{\bar{O}_p}{\bar{Y}} = (1 - \alpha) \bar{MC} \quad (4.17)$$

4.2.5 The log-linearized version of FOC and other conditions

The model is solved by taking log-linear approximation around the steady state. I use a variable with a hat to denote the deviation of a variable from the steady state and a variable with a bar to denote the steady state. Several equations need particular attention due to the three measures of inflation.

Aggregate demand

With the log-linearized version of equation (4.7) and the definition of inflation, the non-oil CPI inflation can be described by:

$$\pi_{NO,t} = \gamma \pi_{H,t} + (1 - \gamma) (\bar{p}_{F,t} - \bar{p}_{F,t-1}) \quad (4.18)$$

With the log-linearized version of equation (4.6), the overall CPI inflation can be described by:

$$\hat{\pi}_t = \kappa (\hat{\varepsilon}_t + \hat{p}_{O,t}^* - (\hat{\varepsilon}_{t-1} + \hat{p}_{O,t-1}^*)) + (1 - \kappa) \hat{\pi}_{NO,t} \quad (4.19)$$

Equation (4.18) states that the overall inflation is decided by non-oil inflation and oil price changes. The Euler equation is given by:

$$\sigma E_t (\hat{c}_{t+1}) - \sigma \hat{c}_t = E_t (\hat{i}_{t+1} - \hat{\pi}_{t+1}) \quad (4.20)$$

Here $\hat{c}_t$ refers to the deviation of total consumption, which is composed of oil consumption, domestic goods consumption, and imported goods consumption. $\hat{\pi}_{t+1}$ is the future overall inflation rate, which is affected by domestic price, imported price, and oil price.

The uncovered interest parity implies that:

$$\hat{i}_t - \hat{i}_t^* = E_t \hat{\varepsilon}_{t+1} - \hat{\varepsilon}_t \quad (4.21)$$

From equation (4.10), the log-linearized version of real exchange rate is given by:

$$\hat{q}_t = \gamma(1-\kappa)\hat{s}_t - (1-\gamma^O)\kappa\hat{p}_{O,t}^* \quad (4.22)$$

If I compare this version to the log-linearized version of real exchange rate in the previous two chapters, I can see that oil price has a direct effect on real exchange rate. More specifically, real exchange rate is positively correlated with terms of trade, and negatively correlated with oil price. γ^O and κ represent the oil share in consumption basket in the foreign and domestic economy, respectively. Equation (4.21) also indicates that real exchange rate decreases (or appreciates) more if domestic households consume more oil (higher κ). On the other hand, real exchange rate decreases less if foreign households consume more oil (higher γ^O).

From equation (4.3), (4.4), and equation (4.5), domestic demands on home and foreign goods are described by:

$$\hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_{NO,t}, \quad \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_{NO,t} \quad (4.23)$$

Domestic oil consumption and non-oil consumption are given by:

$$\hat{c}_{NO,t} = \psi\kappa\gamma\hat{s}_t + \psi\kappa(1-\gamma^O)\hat{p}_{O,t}^* + \hat{c}_t \quad (4.24)$$

$$\hat{c}_{O,t} = -\psi(1-\kappa)\left[(1-\gamma^O)\hat{p}_{O,t}^* + \gamma\hat{s}_t\right] + \hat{c}_t \quad (4.25)$$

The market equilibrium is:

$$\bar{Y}\hat{y}_t = \bar{C}_H\hat{c}_{H,t} + \bar{C}_H^*\hat{c}_{H,t}^* \quad (4.26)$$

4.3 Model Parameterization

The parameter settings are similar with the previous chapters and it is

summarized in Table 9. One parameter which needs particular attention is the oil share in the consumption basket. The average of the ratio of oil import to goods import from 1997 to 2002 in United States is approximately 11%⁴⁰. Since the share of home-good consumption γ is chosen such that the steady state sum of exports and imports is roughly 40% of output, the oil share in the consumption basket can be calculated. In the calibration of the model, I set κ equal to 0.03. This value is close to the estimate made by Medina and Soto (2005) for Chile. They estimate the steady-state share of oil in the consumption basket to be 0.04, which is consistent with the oil share utilization considered in the computation of the Chilean CPI.

4.4 Simulation Results

I simulate the sensitivity of the impact of the oil price shock on the macroeconomy under different scenarios. First, the model is analyzed under four different monetary policy rules: a fixed exchange rate rule and three types of inflation targeting rules where I use the overall CPI, the non-oil CPI, and the domestic production price index as the measure of inflation rate, respectively. The model allows choosing $\omega_e = 0.99$ for fixed exchange rate regime. I then change the price indices to analyze different inflation targeting rules. I want to see which monetary policy rule induces lower fluctuations in output. Second, I compare the three price indices that the central bank chooses as target by assigning different weights on inflation in the monetary policy rule function given a fixed weight on

⁴⁰ Data from IFS

output. By doing this, I can address the issue of which measure of inflation is appropriate for policy implementation. I can also see if assigning different weights on inflation has an impact on the domestic economy with oil price shocks. Third, I compare the effects of different share of oil in the domestic and foreign consumption basket.

4.4.1 Alternative monetary policy rules: the impulse responses

Figures 10, 11, 12 and 13 illustrate the effects of a positive oil price shock on key macroeconomic variables. I compare four monetary policy rules: a fixed exchange rate and three types of inflation targeting rules using different price index as the measure of inflation rate. When the central bank keeps the nominal exchange rate fixed, output will drop more and inflation rate is higher compared to the other monetary policy rules. When the central bank focuses on the domestic monetary policy and allows the nominal exchange rate to float, the impulse response in Figures 11 and 12 show similar patterns when the central bank choose total CPI or non-oil CPI as the measure of inflation rate. Yet output decreases less if the central bank chooses domestic inflation as the measure of inflation rate as shown in Figure 13. Also, a comparison of impulse responses in Figures 10 to 13 indicate that the inflation is the lowest if the central bank use domestic goods price index as the measure of inflation rate.

4.4.2 Sensitivity analysis: alternative monetary policy rules

Table 10 summarizes the volatilities of major economic variables with direct oil

consumption under alternative monetary policy rules. I assume $\omega_y = 0$ and $\omega_{\pi,m} = 1.5$ to be consistent with the previous chapters. The three price indices used in inflation targeting rules are the overall CPI, the non-oil CPI, and the domestic production prices. Several results emerge. First, the observations show that my conclusion about the role of exchange rate regimes still holds with direct oil consumption. Output and consumption are less volatile when the central bank allows the nominal exchange rate to float. Second, the fluctuations in output are the lowest when the central bank chooses the domestic price index as the measure of inflation rate under flexible exchange rate regime. Third, the variations in all variables exhibit lower fluctuations when households consume oil directly compared to the baseline model. The difference is mainly caused by high elasticity of substitution between oil and non-oil goods. If households can substitute their consumption easily, the overall consumption may exhibit lower fluctuations.

4.4.3 Sensitivity analysis: different assigning weight on deviations of inflation

Table 11 summarizes the results when the central bank puts increasing weight on deviations of inflation from steady state for a given weight on output gap ($\omega_y = 0.25$). The monetary policy that puts lower weight on inflation is beneficial in the sense that the volatility in output and consumption is lower, as well as the nominal interest rate.⁴¹ In my model, the increasing weight on inflation induces a higher increase in the nominal interest rate, which suggests a tighter monetary

⁴¹ In contrast, Leduc and Sill (2004) conduct similar comparison and suggest that the higher weight on the inflation deviations from steady state is beneficial. The difference comes from the injected money supply which raises current and future inflation.

policy.

The literature on monetary policy also suggests that choosing a different measure of inflation rate as a target may have impact on the volatility of real exchange rate. My simulation shows that a higher volatility of real exchange rate as the central bank puts a lower weight on the deviation of inflation using changes in overall CPI or non-oil CPI as the measure of inflation. In addition, the volatility of real exchange rate is also higher when the inflation target is the change in the domestic production price. However, when the central bank chooses changes in the domestic production price as the measure of inflation, the volatility of output is lower. The results are consistent with Kollmann (2002) and Gali and Monacelli (2005). Both conclude that the lower volatility of output is coupled with the higher volatility in real exchange rate when the central bank chooses changes in the domestic price as the measure of inflation rate. The different volatility in output also suggests that the central bank should choose the appropriate price index as the measure of inflation rate for optimal policy implementation. In section 4.5, I present the welfare loss associated with three measures of inflation rate the central bank chooses to follow.

4.4.4 Different oil shares in domestic and foreign consumption

When the domestic households consume oil directly, κ and γ^O represent oil share in the domestic and foreign consumption basket, respectively. In the calibrated model, since I assume $C_t^* = Y_t^*$, κ and γ^O describe the impact of oil price changes on change in the price level. When $\kappa > \gamma^O$ (the scenario in sections 4.4.1 and 4.4.2),

oil price shocks have larger immediate impact on the domestic economy than foreign country. The reverse is true when $\kappa < \gamma^O$, oil price shocks have smaller immediate impact on the domestic economy than the foreign economy. Under both scenarios, domestic output will drop due to higher price of oil. In the latter case, however, domestic output will decrease by less due to smaller immediate impact of the rise in the price of oil. Hence, the magnitude of increase in the price is smaller in the home country compared to the foreign country.⁴²

4.5 Optimal Monetary Policy: Welfare Analysis

I derive the welfare loss function following Gali and Monacelli (2005). To find the analytical solution, I assume both the intertemporal elasticity of substitution and the intratemporal elasticity of substitution equal to 1. As shown in Appendix D, the second order approximation of the utility-based welfare loss of the representative household is:

$$W_{e,t} = -\frac{\gamma}{2} \left\{ \frac{9}{\Theta} \sum_{t=0}^{\infty} \beta^t \hat{\pi}_{H,t}^2 + \frac{(1+\varphi)}{(1+\varphi(1-\alpha))} \sum_{t=0}^{\infty} \beta^t y_{gap,t}^2 \right\} + t.i.p. + o(\|a\|^3) \quad (4.27)$$

where $\Theta = \frac{(1-\phi)(1-\beta\phi)}{\phi}$

Therefore, the expected welfare losses can be derived in terms of variances of domestic inflation and output gap by taking unconditional expectations of (4.26) and letting $\beta \rightarrow 1$.

⁴² The representative household does not substitute his consumption on domestic goods with foreign goods because imported price increases more than domestic price

$$V_t = -\frac{\gamma}{2} \left\{ \frac{\vartheta}{\Theta} \text{var}(\hat{\pi}_{H,t}) + \frac{(1+\varphi)}{(1+\varphi(1-\alpha))} \text{var}(y_{gap,t}) \right\} + t.i.p. + o(\|a\|^3) \quad (4.28)$$

When φ is higher, which represents lower elasticity of labor supply, the relative weight on the output gap variability is higher. Hence, there is larger penalty for variations in the output gap. Also, as $(1-\alpha)$ is in the denominator of the parameter of the output gap volatility, the relative weight of the domestic inflation increases with the share of oil in the production, which also implies a larger penalty for variability of the output gap. However, if I set a lower steady state mark-up (with higher ϑ), there is larger penalty in the welfare loss function for variations in inflation.

I then use my simulation results to compare the welfare loss the monetary target the exchange rate and the inflation rate using three different measures of inflation. Based on my results, I rank the welfare losses accordingly. The rank of the welfare losses is given by:

$$V_H < V_{NO} < V_{CPI} < V_{FIXED} \quad (4.29)$$

(3.14) (3.24) (3.25) (5.08)

As I can see from the above relationship, the welfare loss is highest when the monetary target is the exchange rate. In contrast, welfare losses are lower when the exchange rates are allowed to float. This result is consistent with Friedman's (1953) hypothesis. It is also consistent to chapters 2 and 3, where the variations in the output gap and the domestic price changes are the highest when the exchange rates are fixed. Furthermore, the coefficients in the welfare loss function indicate that the

weight on the variations in domestic price is much higher than the weight on the variations in output gap.

The welfare loss is lowest when the central bank tries to target the domestic price index. Both the variations in output and domestic prices contribute to the total welfare loss, they exhibit lower fluctuations when the central bank choose domestic price index as its measure of inflation. Intuitively, since foreign prices are exogenous, only domestic price inflation corresponds to the distortions caused by the domestic price rigidity. To eliminate the price distortion, the monetary policy should react directly to the domestic price level, which could introduce stability of the economy.

4.6 Conclusion

In this chapter, I introduce oil in the consumption basket and analyze the performance of four monetary policy rules in the presence of oil price shocks. Compared with the Chapters 2 and 3, I find that the inclusion of oil in consumption basket leads to slightly lower variations in consumption, output, nominal interest rate, and overall price level. This may be explained by the assumed high elasticity of substitution between non-oil goods and oil in the consumption basket.

My results suggest broadly similar patterns especially on the role of exchange rates in mitigating or exacerbating oil price shocks. In contrast with the two previous chapters, I formally evaluate the impact of fixed and flexible exchange rate regimes using a welfare loss function. My results suggest that a fixed exchange rule not only induces higher volatility in output and inflation but also a larger welfare loss

compared to the other three monetary policy rules.

Among the three measures of inflation targeted by the central bank, I have two main results. First, it is important to distinguish between alternative price indices when modeling the dynamic effects of oil price shocks. Targeting the change in domestic production inflation may induce lower variations in output and domestic price. Hence, the welfare loss is lower. Second, my results indicate that when the central bank chooses domestic price index as the measure of inflation, the lower volatility of output is coupled by the higher variations in real exchange rate. This conclusion is consistent with the findings of Svensson (2000), Kollmann (2002) and Gali and Monacelli (2005).

Table 10 Calibration of model

Parameter	Definition and Description	Value
α	Labor share in production	0.7
β	Annual discount factor	0.96
γ	Share of home produced goods in total consumption	0.6
χ	Interest rate rule	0.5
ϕ	Price stickiness	0.75
φ	Inverse elasticity of labor supply	3
κ	Oil share in the consumption basket	0.03
ψ	Elasticity of substitution between oil and non-oil consumption	3
$\vartheta / \vartheta - 1$	Steady-state markup	1.2
ρ^{i^*}	Serial correlation parameter for the foreign interest rate	0.85
ρ^{y^*}	Serial correlation parameter for the foreign output	0.9
$\rho^{p_o^*}$	Serial correlation parameter for oil price	0.8
ρ^a	Serial correlation parameter for technology	0.8
ρ	Elasticity of substitution between home and foreign product	1.01
γ^O	Degree of oil price impact on the foreign price level	0.99
σ	Inverse elasticity of substitution for the home country product	1.01
$\sigma_{\xi}^{i^*}$	Standard deviation of foreign nominal interest rate	1.379
$\sigma_{\xi}^{p_o^*}$	Standard deviation of oil price	1.51
σ_{ξ}^a	Standard deviation of foreign output and technology	1
ω_y	Responsiveness of monetary policy to output gap	0
ω_{ε}	Responsiveness of monetary policy to nominal exchange rate	0.99–0.25
ω_{π}	Responsiveness of monetary policy to total inflation	1.5

Table 11 Statistics for the calibrated model with direct oil consumption

Variable	Standard deviation HP-Filtered			
	Flexible (H)	Flexible (NO)	Flexible (CPI)	Fixed
Nominal exchange rate	2.825	2.4651	2.4523	0.2268
Real exchange rate	1.7297	1.5351	1.528	0.7421
Consumption	3.9365	3.7537	3.7481	4.4138
Output	1.044	1.0805	1.0836	1.8423
Interest rate	0.573	0.8974	0.9125	1.0966
Domestic price	0.3867	0.3987	0.4001	0.6105
Price	1.0957	0.8203	0.8097	0.3446

Table 12 Statistics under different measure of inflation rate

	Variables	Standard Deviations HP filter		
		$\omega_m = 0.5$	$\omega_m = 1$	$\omega_m = 1.5$
Total CPI ($m : CPI$)	Output	1.0399	1.052	1.0836
	Consumption	3.864	3.7925	3.7481
	Interest Rate	0.66	0.7943	0.9125
	Total Inflation	0.998	0.9014	0.8097
	Real Exchange Rate	1.6149	1.5716	1.528
Non-oil CPI ($m : NO$)	Output	1.0398	1.0508	1.0805
	Consumption	3.8675	3.7979	3.7537
	Interest Rate	0.6541	0.7827	0.8974
	Total Inflation	1.002	0.909	0.8203
	Real Exchange Rate	1.6173	1.5765	1.5351
Production Inflation ($m : H$)	Output	1.0383	1.0362	1.044
	Consumption	3.9521	3.944	3.9365
	Interest Rate	0.5451	0.5573	0.573
	Total Inflation	1.0907	1.0908	1.0957
	Real Exchange Rate	1.6751	1.7005	1.7297

Table 13 Statistics for the calibrated model with different oil share in consumption

Variable	Standard Deviation HP-Filtered			
	$\omega_e = 0.25$		$\omega_e = 0.99$	
	$\kappa < \gamma^O$	$\kappa > \gamma^O$	$\kappa < \gamma^O$	$\kappa > \gamma^O$
Output	1.0578	1.0278	1.7615	1.4897
Consumption	4.2034	4.1687	4.5206	3.8686

Figure 10 Effect of oil price shock with fixed exchange rate

Figure 11 Effect of oil price shock with response to overall CPI

Figure 12 Effect of oil price shock with response to non-oil CPI

Figure 13 Effect of oil price shock with response to domestic inflation

Appendix C

a. Mathematical Derivation

Assumptions:

- d) The economy is small in the sense that it cannot influence the foreign non-oil price level.
- e) Oil is imported from other countries for domestic production; households also consume oil directly.
- f) The foreign price level is composed of oil price and non-oil goods price which is constant over time.

Households

Similar to the previous chapters, the households consume baskets of differentiated domestic and foreign goods (which are both tradable and indexed by j).

The consumption bundle of household j however, is given by

$$(C1) \quad C_t(j) = \left[(1-\kappa)^{\frac{1}{\eta}} \left(C_{NO,t}(j) \right)^{\frac{\eta-1}{\eta}} + \kappa^{\frac{1}{\eta}} \left(C_{O,t}(j) \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

where $C_{O,t}$ represents oil consumption, and $C_{NO,t}$ is a bundle of non-oil consumption which constitutes by domestic and foreign goods. κ represents oil share in consumption basket, and parameter η is the elasticity of substitution between oil and non-oil consumption. The composition of the non-oil consumption is the same as before, which is given by

$$(C2) \quad C_{NO,t} = \left(\gamma^{1/\rho} C_{H,t}^{\rho-1/\rho} + (1-\gamma)^{1/\rho} C_{F,t}^{\rho-1/\rho} \right)^{\rho/\rho-1}$$

From equation (C1), I need to maximize C_t subject to the following constraint $M = P_{NO,t} C_{NO,t} + \varepsilon_t P_{O,t}^* C_{O,t}$, where M is fixed expenditure between oil and non-oil goods.

The Lagrangian equation indicates

$$L = (\kappa^{1/\eta} C_{O,t}^{(\eta-1)/\eta} + (1-\kappa)^{1/\eta} C_{NO,t}^{(\eta-1)/\eta})^{\eta/(1-\eta)} - \lambda_t (P_{NO,t} C_{NO,t} + \varepsilon_t P_{O,t}^* C_{O,t} - M)$$

then there are

$$(C1a) \quad C_t^{1/(\eta-1)} \kappa^{1/\eta} C_{NO,t}^{-1/\eta} = \lambda_t P_{NO,t}$$

$$(C1b) \quad C_t^{1/(\eta-1)} (1-\kappa)^{1/\eta} C_{O,t}^{-1/\eta} = \lambda_t \varepsilon_t P_{O,t}^*$$

$$(C1c) \quad M = P_{NO,t} C_{NO,t} + \varepsilon_t P_{O,t}^* C_{O,t}$$

From equation (C1a) and (C1b), there is $\frac{\kappa^{1/\eta} C_{NO,t}^{-1/\eta}}{(1-\kappa)^{1/\eta} C_{O,t}^{-1/\eta}} = \frac{P_{NO,t}}{\varepsilon_t P_{O,t}^*}$

Then consumption on oil in terms of non-oil goods can be expressed as

$$(C1d) \quad C_{O,t} = \left(\frac{1-\kappa}{\kappa}\right) C_{NO,t} \left(\frac{P_{NO,t}}{\varepsilon_t P_{O,t}^*}\right)^\eta$$

Substitute (C1d) into (C1c), there is

$$(C3) \quad P_{NO,t} C_{NO,t} + \varepsilon_t P_{O,t}^* \left[\left(\frac{1-\kappa}{\kappa}\right) C_{NO,t} \left(\frac{P_{NO,t}}{\varepsilon_t P_{O,t}^*}\right)^\eta\right] = M$$

$$\Rightarrow \{\kappa P_{H,t}^{1-\rho} + (1-\kappa) (\varepsilon_t P_{O,t}^*)^{1-\eta}\} C_{NO,t} = \frac{Z \kappa}{P_{NO,t}^\eta}$$

Since $\kappa P_{NO,t}^{1-\eta} + (\varepsilon_t P_{O,t}^*)^{1-\eta} (1-\kappa) = P_t^{(1-\eta)}$, I have $P_t^{(1-\eta)} C_{NO,t} = \frac{M \kappa}{P_{NO,t}^\eta}$

With $\frac{M}{P_t} = C_t$, I can obtain the optimal allocation between domestic goods and

foreign goods which is given by

$$(C4) \quad C_{NO,t}(j) = (1 - \kappa) \left(\frac{P_{NO,t}}{P_t} \right)^{-\eta} C_t(j)$$

$$(C5) \quad C_{O,t}(j) = \kappa \left(\frac{\varepsilon P_{O,t}^*}{P_t} \right)^{-\eta} C_t(j)$$

Analogously, the optimal composition of non-oil consumption by minimizing the cost of goods consumption basket, $P_{H,t}C_{H,t}(j) + P_{F,t}C_{F,t}(j)$ subject to equation (88),

The optimal allocation between home and foreign goods are given by

$$(C6) \quad C_{H,t} = \gamma \left(\frac{P_{H,t}}{P_{NO,t}} \right)^{-\rho} C_{NO,t}, C_{F,t} = (1 - \gamma) \left(\frac{P_{F,t}}{P_{NO,t}} \right)^{-\rho} C_{NO,t}$$

The consumption-based price index (CPI), and the non-oil (or core consumption) consumption price index are given by

$$(C7) \quad P_t = \left[\kappa (\varepsilon P_{O,t}^*)^{1-\eta} + (1 - \kappa) P_{NO,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}$$

$$(C8) \quad P_{NO,t} = \left(\gamma P_{H,t}^{1-\rho} + (1 - \gamma) P_{F,t}^{1-\rho} \right)^{1/(1-\rho)}$$

With the above settings, the representative domestic households is similar as before, the households maximizes $E_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t)$ according to the same budget constraint, $P_t C_t + B_{t+1} = W_t N_t + (1 + i_t) B_t + \tau_t$

Different Inflation Target, Terms of Trade and Real Exchange Rate

With household's consumption bundle, three different inflation targets are overall

CPI inflation, $\pi_t = \frac{P_t}{P_{t-1}}$, non-oil CPI inflation, $\pi_{NO,t} = \frac{P_{NO,t}}{P_{NO,t-1}}$, and production

$$\text{inflation, } \pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}.$$

The terms of trade are still defined as the price of the imported good relative to the price of the domestic good.

$$(C9) S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \frac{\varepsilon_t P_{F,t}^*}{P_{H,t}}$$

The real exchange rate is then defined as

$$(C10) \varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t}$$

Since oil is included in the consumption basket, the relationship between terms of trade and real exchange rate is changed, specifically

$$(C13) \varepsilon_t^r \equiv \frac{\varepsilon_t P_t^*}{P_t} \neq \frac{\varepsilon_t P_t^*}{P_{No,t}}$$

Steady State

- d) A variable with bar on top means the steady state.
- e) I normalize the price level in both home and foreign country in steady state.
- f) Assume bonds are in zero supply.

The equilibrium in the domestic goods market requires:

$$(C12) \bar{C}_H + \bar{C}_H^* = \bar{Y}$$

From equation (C4) and equation (C5), there is

$$(C13) \bar{C}_O = \left(\frac{\kappa}{1-\kappa} \right) \bar{C}_{NO}$$

Log-linearized model

From equation (C8), with the definition of inflation, the non-oil inflation can be described by

$$(C14) \quad \pi_{NO,t} = \gamma \pi_{H,t} + (1-\gamma)(\hat{p}_{F,t} - \hat{p}_{F,t-1})$$

From equation (C3) and (C2), domestic demands on home and foreign goods are described by

$$(C15) \quad \hat{c}_{H,t} = \rho(1-\gamma)\hat{s}_t + \hat{c}_{NO,t}; \hat{c}_{F,t} = -\rho\gamma\hat{s}_t + \hat{c}_{NO,t}$$

Domestic oil consumption and non-oil consumption are given by

$$(C16) \quad \hat{c}_{NO,t} = \eta\kappa\gamma\hat{s}_t + \eta\kappa(1-\gamma^O)\hat{p}_{O,t}^* + \hat{c}_t$$

$$(C17) \quad \hat{c}_{O,t} = -\eta(1-\kappa)\left[(1-\gamma^O)\hat{p}_{O,t}^* + \gamma\hat{s}_t\right] + \hat{c}_t$$

Log-linearize equation (C12) implies

$$(C18) \quad \bar{Y}\hat{y}_t = \bar{C}_H\hat{c}_{H,t} + \bar{C}_H^*\hat{c}_{H,t}^*$$

From equation (9) and equation (10), the log-linearized version of real exchange rate is given by

$$(C19) \quad \hat{q}_t = \gamma(1-\kappa)\hat{s}_t - (1-\gamma^O)\kappa\hat{p}_{O,t}^*$$

The detailed calculation is given by

$$\begin{aligned} \hat{q}_t &= \hat{p}_{F,t} - \hat{p}_t = \hat{p}_{F,t} - (1-\kappa)\hat{p}_{NO,t} - \kappa(\hat{\varepsilon}_t + \hat{p}_{O,t}^*) = \hat{p}_{F,t} - (1-\kappa)\left[\gamma\hat{p}_{H,t} + (1-\gamma)\hat{p}_{F,t}\right] - \kappa(\hat{\varepsilon}_t + \hat{p}_{O,t}^*) \\ &= \hat{p}_{F,t} - (1-\kappa)(-\gamma\hat{s}_t + \hat{p}_{F,t}) - \kappa(\hat{\varepsilon}_t + \hat{p}_{O,t}^*) = \gamma(1-\kappa)\hat{s}_t + \kappa\hat{p}_{F,t} - \kappa(\hat{\varepsilon}_t + \hat{p}_{O,t}^*) \\ &= \gamma(1-\kappa)\hat{s}_t - (1-\gamma^O)\kappa\hat{p}_{O,t}^* \end{aligned}$$

Appendix C (Continued)

b. Attached Matlab Code

Endogenous Variables: $\hat{p}_{F,t}, \hat{i}_t, \hat{s}_t, \hat{c}_t, \hat{\pi}_t, \hat{\pi}_{H,t}, \hat{\pi}_{NO,t}, \hat{\varepsilon}_t, \hat{\varepsilon}_t^r, \hat{y}_t, \hat{o}_t, \hat{n}_t, \bar{m}c_t$

Exogenous Variables: $\hat{p}_{O,t}^*, \hat{i}_t^*, \hat{y}_t^*, \hat{a}_t$

%% SETTING PARAMETERS:

```

alpha    =0.7;      %
beta     =0.96;      %
gama     =0.6;       %
gama_o   =0.01;      %
theta    =6;         %
phi      =0.75;      %
chi      =0.5;       %
psi      =3;         %
sigma    =1.01;      %
omega_pi =1.5;       %
omega_y  =0;         %
omega_e  =0.25;      %
om_pi    =(1-chi)*omega_pi;      %
om_y     =(1-chi)*omega_y;       %
om_e     =(1-chi)*omega_e/(1-omega_e); %
mc_bar   =(theta-1)/theta;      %
mu        =(1-phi)*(1-beta*phi)/phi; %
rho      =1.01;      %
rho_o    =0.8;       %
rho_a    =0.85;      %
rho_yf   =0.9;       %
rho_if   =0.8;       %
sigma_if =1.3785;    %
sigma_po =1.51;      %
sigma_a  =1;         %
sigma_yf =1;         %
kappa    =0.03;      %

lamda_a  =alpha^alpha*(1-alpha)^(1-alpha)*mc_bar;      %
lamda_b  =((1-(1-alpha)*mc_bar)/alpha/mc_bar)^(sigma*alpha/(1-sigma)); %
lamda_c  =(1-sigma)/alpha/(psi+sigma);                  %
n_bar    =(lamda_a/lamda_b)^lamda_c;                     %

```

```

c_bar  =((1-(1-alpha)*mc_bar)*n_bar^(psi+1)/alpha/mc_bar)^(1/(1-sigma)); %
ch_bar  =gama*(1-kappa)*c_bar; %
cf_bar  =(1-gama)*(1-kappa)*c_bar; %
y_bar  =n_bar^(psi+1)*c_bar^sigma/alpha/mc_bar; %
o_bar  =y_bar-c_bar; %
chf_bar =cf_bar+o_bar+kappa*c_bar; %

```

%%% DECLARING THE MATRICES:

```

VARNAMES = [ 'import price      ', %1  X1
              'terms of trade    ', %2  X2
              'interest rate     ', %3  X3
              'total consumption ', %4  X4
              'oil price         ', %5  X5
              'nominal exchange rate ', %6  X6
              'domestic inflation ', %7  Y1
              'real exchange rate ', %8  Y2
              'nonoil inflation   ', %9  Y3
              'output            ', %10 Y4
              'labor             ', %11 Y5
              'oil in production ', %12 Y6
              'marginal cost      ', %13 Y7
              'total inflation    ', %14 Y8
              'oil price shocks   ', %15 Z1
              'technology        ', %16 Z2
              'foreign output     ', %17 Z3
              'foreign interest rate ' %18 Z4
            ]

```

%%% EQUATIONS:

%%% NON-EXPECTATIONAL EQUATIONS:

```

% (1)  0 = (1-gama)*s(t)-(1-gama)*s(t-1)-pino(t)+pih(t)
% (2)  0 = pff(t)-e(t)-gama_o*po(t)
% (3)  0 = q(t)+kappa*(1-gama_o)*po(t)-gama*(1-kappa)*s(t)
% (6)  0 = pino(t)-gama*pih(t)-(1-gama)*pff(t)+(1-gama)*pff(t-1)
% (8)  0 = pi(t)-kappa*e(t)+kappa*e(t-1)-kappa*po(t)+kappa*po(t-1)-(1-kappa)*pino(t)
% (9)  0 = mc(t)-sigma*c(t)-(psi+1)*n(t)+y(t)-(1-gama)*s(t)
% (10) 0 = i(t)-om_pi*pino(t)-om_e*e(t)-om_y*y(t)-chi*i(t-1)
% (11) 0 = y_bar*y(t)-ch_bar*c(t)-chf_bar*yf(t)-(rho*(1-gama)*(chf_bar+ch_bar))*s(t)
% (12) 0 = po(t)-rho_o*po(t-1)-pos(t)
% (13) 0 = y(t)-a(t)-alpha*n(t)-(1-alpha)*op(t)
% (14) 0 = (psi+1)*n(t)-gama*s(t)+sigma*c(t)-(1-gama_o)*po(t)-op(t)

```

%% EXPECTATIONAL EQUATIONS:

% (4) 0 = E_t{ i(t)-i(t)-e(t+1)+e(t) }
 % (5) 0 = E_t{ c(t+1)-c(t)-1/sigma*i(t+1)+1/sigma*pi(t+1) }
 % (7) 0 = E_t{ pih(t)-beta*pih(t+1)-mu*mc(t) }

%% EXOGENOUS EQUATIONS:

% (15) pos(t+1) = 0*pos(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
 % (16) if(t+1) = rho_if*if(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
 % (17) a(t+1) = rho_a*a(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0
 % (18) yf(t+1) = rho_yf*yf(t)+ iidShock(t+1) ; with E_t { iidShock(t+1) }=0

%% FIND MATRICES FOR FORMAT:

% 0 = AA*X(t)+BB*X(t-1)+CC*Y(t)+DD*Z(t)

% AA 11x6
 % BB 11x6
 % CC 11x8
 % DD 11x4

% 0 = E_t{ FF*X(t+1)+GG*X(t)+HH*X(t-1)+JJ*Y(t+1)+KK*Y(t)+LL*Z(t+1)+MM*Z(t) }

% FF 3x6
 % GG 3x6
 % HH 3x6
 % JJ 3x8
 % KK 3x8
 % LL 3x4
 % MM 3x4

% Z(t+1) = NN*Z(t)+epsilon(t+1), with E_t{epsilon(t+1)}=0

% NN 4x4

AA=zeros(11,6);
 AA(1,2)=(1-gama);
 AA(2,1)=1;
 AA(2,6)=-1;
 AA(2,5)=-gama_o;
 AA(3,5)=kappa*(1-gama_o);
 AA(3,2)=-gama*(1-kappa);
 AA(4,1)=-1-gama);

```

AA(5,6)=-kappa ;
AA(5,5)=-kappa ;
AA(6,4)=-sigma ;
AA(6,2)=-(1-gama) ;
AA(7,3)=1 ;
AA(7,6)=-om_e ;
AA(8,4)=-ch_bar ;
AA(8,2)=-(rho*(1-gama)*(chf_bar+ch_bar)) ;
AA(9,5)=1 ;
AA(11,2)=-gama ;
AA(11,4)=sigma ;
AA(11,5)=-(1-gama_o) ;

```

```
display (AA);
```

```

BB=zeros(11,6);
BB(1,2)=-(1-gama) ;
BB(4,1)=(1-gama) ;
BB(5,6)=kappa ;
BB(5,5)=kappa ;
BB(7,3)=-chi ;
BB(9,5)=-rho_o ;

```

```
display (BB);
```

```

CC=zeros(11,8);
CC(1,3)=-1 ;
CC(1,1)=1 ;
CC(3,2)=1 ;
CC(4,3)=1 ;
CC(4,1)=-gama ;
CC(5,8)=1 ;
CC(5,3)=-(1-kappa) ;
CC(6,7)=1 ;
CC(6,5)=-(psi+1) ;
CC(6,4)=1 ;
%CC(7,3)=-om_pi ; % non-oil inflation
%CC(7,1)=-om_pi ; % domestic inflation
CC(7,8)=-om_pi ; % total inflation
CC(7,4)=-om_y ;
CC(8,4)=y_bar ;
CC(10,4)=1 ;
CC(10,5)=-alpha ;
CC(10,6)=-(1-alpha) ;

```



```
CC(11,5)=(psi+1) ;  
CC(11,6)=-1 ;  
  
display (CC);  
disp('rank of CC');  
rank(CC)
```

```
DD=zeros(11,4);  
DD(8,3)=-chf_bar ;  
DD(9,1)=1 ;  
DD(10,2)=-1 ;
```

```
display (DD);
```

```
FF=zeros(3,6);  
FF(1,6)=-1 ;  
FF(2,4)=1 ;  
FF(2,3)=-1/sigma ;
```

```
display (FF);
```

```
GG=zeros(3,6);  
GG(1,3)=1 ;  
GG(1,6)=1 ;  
GG(2,4)=-1 ;
```

```
display (GG);
```

```
HH=zeros(3,6);
```

```
display (HH);
```

```
JJ=zeros(3,8);  
JJ(2,8)=1/sigma ;  
JJ(3,1)=-beta ;
```

```
display (JJ);
```

```
KK=zeros(3,8);  
KK(3,1)=1 ;  
KK(3,7)=-mu ;
```

```
display (KK);
```

```

LL=zeros(3,4);

display (LL);

MM=zeros(3,4);
MM(1,4)=-1 ;

display (MM);

NN=zeros(4,4);
NN(1,1)=0 ;
NN(4,4)=rho_if ;
NN(2,2)=rho_a ;
NN(3,3)=rho_yf ;

display (NN);

Sigma=[sigma_po^2,      0,      0,      0
        0,      sigma_a^2,      0,      0
        0,      0,      sigma_if^2,      0
        0,      0,      0,      sigma_yf^2];

% SETTING OPTIONS:

[l_equ,m_states] = size(AA);
[l_equ,n_endog ] = size(CC);
[l_equ,k_exog   ] = size(DD);

PERIOD      = 4; % number of periods per year, i.e. 4 for quarterly

GNP_INDEX= 3 ;% Index of output among the variables selected for HP filter
DO_SIMUL   = 1; % Calculates simulations
DO_HP_FILTER   = 1; %
DO_MOMENTS   = 1; % Calculates moments based on frequency-domain methods
%DO_ENLARGE=1;
HP_SELECT   = 1:(m_states+n_endog+k_exog); % Selecting the variables for the HP Filter
%IMP_JOINT=0;IMP_SUBPLOT=1;IMP_SINGLE=1;

%IMP_SELECT   = [1: 14 ]; % Vector with the indices of the variables to be plotted: all
X variables
%IMP_SELECT   = [7 : 14 ]; % Vector with the indices of the variables to be plotted: all
Y variables

do_it; % Starts calculations

```

Appendix D

I derive the second order approximation of the representative household's utility function. I assume that the monetary policy maker seeks to maximize the utility of the representative households following Galí and Monacelli (2005). I assume $\sigma = \eta = \mu = 1$ and use the following approximations repeatedly,

$$(D1) \quad \frac{X}{\bar{X}} = x + \frac{1}{2}x^2 + o(\|a\|^3) + 1$$

where $o(\|a\|^3)$ represents terms that are of order higher than the third.

The household's utility function to be approximated in a given period is

$$(D2) \quad U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} = \log C_t - \frac{N_t^{1+\varphi}}{1+\varphi}$$

Taking the second order approximation to the representative household's utility function around the steady state, I have

(D5)

$$U_t = \bar{U}(\bar{C}, \bar{N}) + U_C \bar{C} \left(\hat{c}_t + \frac{1}{2} \hat{c}_t^2 \right) + \frac{1}{2} U_{CC} \bar{C}^2 \hat{c}_t^2 - U_N \bar{N} \left(\hat{n}_t + \frac{1}{2} \hat{n}_t^2 \right) - \frac{1}{2} U_{NN} \bar{N}^2 \hat{n}_t^2$$

Equation (D5) can be written as

$$(D6) \quad U_t - \bar{U}(\bar{C}, \bar{N}) = \hat{c}_t - \bar{N}^{\varphi+1} \hat{n}_t - \frac{\bar{N}^{\varphi+1}}{2} (1+\varphi) \hat{n}_t^2 + o(\|a\|^3)$$

The flexible price equilibrium level of labor is

$$(D7) \quad \bar{N} = \left\{ \frac{\alpha \bar{MC}}{1 - (1-\alpha) \bar{MC}} \right\}^{1/(1+\varphi)}$$

Since the steady state is assumed to be efficient, the optimal allocation requires

$$(D8) \quad \bar{N}^{\varphi+1} = \gamma (1 + \varphi (1 - \alpha))$$

The derivation of equation (D8) requires I assume that $\sigma = \eta = \mu = 1$. Then I have the

following expression⁴³

$$(D8a) \quad C_t = Y_t^\gamma (Y_t^*)^{1-\gamma}$$

The optimal allocation must maximize $U(C_t, N_t)$ subject to equation (D8a) and the technology constraint.

$$(D8b) \quad Y_t = A_t N_t^\alpha O_t^{1-\alpha}$$

And the efficient input allocation implies that $O_t = \frac{(1-\alpha)}{\alpha} C_t N_t^{\varphi+1}$. Then equation

(D8b) can be written as

$$(D8c) \quad Y_t = A_t \left(\frac{1-\alpha}{\alpha} \right)^{1-\alpha} C_t^{1-\alpha} N_t^{1+\varphi(1-\alpha)}$$

The Lagrangian equation indicates

$$L = \log C_t - \frac{N_t^{1+\varphi}}{1+\varphi} + \lambda_t \left\{ C_t - \left[A_t \left(\frac{1-\alpha}{\alpha} \right) C_t^{1-\alpha} N_t^{1+\varphi(1-\alpha)} \right]^\gamma (Y_t^*)^{1-\gamma} \right\}$$

Taking FOC with respect to C_t and N_t , respectively, there are

$$(D8d) \quad \frac{1}{C_t} = -\lambda_t$$

$$(D8e) \quad -N_t^{\varphi+1} = \lambda_t \left[\gamma C_t \left[1 + (1-\alpha)\varphi \right] \right]$$

Equation (D8) can then be derived.

Substitute equation (D8) back to equation (D6), there is

$$(D9) \quad U_t - \bar{U}(\bar{C}, \bar{N}) = \hat{c}_t - \gamma \left[1 + \varphi(1-\alpha) \right] \hat{n}_t - \frac{1}{2} \gamma(1+\varphi) \left[1 + \varphi(1-\alpha) \right] \hat{n}_t^2 + o(\|\hat{a}\|^3)$$

From equation (D8c), I have

$$(D10) \quad \hat{c}_t = \gamma \hat{y}_t + (1-\gamma) \hat{y}_t^*$$

From equation (D8c), I have

⁴³ Please refer to Gali and Monacelli (2005) for a detailed discussion.

$$(D11) \quad [1 + \varphi(1 - \alpha)] \hat{n}_t = \hat{y}_{gap,t} + \hat{z}_t$$

where $\hat{y}_{gap,t} = y_t - \bar{y}_t$, and $\bar{y}_t$ is the equilibrium output level when price is flexible.

Then equation (D9) can be written as

$$(D12) \quad U_t - \bar{U}(\bar{C}, \bar{N}) = -\gamma \hat{z}_t - \frac{\gamma(1 + \varphi)}{2[1 + \varphi(1 - \alpha)]} \hat{y}_{gap,t}^2 + o(\|a\|^3)$$

I adopt Gali and Monacelli's (2005) definition of z_t , where it is defined as the price dispersion term from the production function. Making use of Lemma 1 which shows that the price dispersion term is second order, then $\hat{z}_t = \frac{\vartheta}{2} \text{var}(\hat{p}_{H,t}) + o(\|a\|^3)$.

And then I follow Woodford (2003), there is

$$(D13) \quad \sum_{t=0}^{\infty} \beta^t \text{var}\{\hat{p}_{H,t}\} = \frac{1}{\Theta} \sum_{t=0}^{\infty} \beta^t \hat{\pi}_{H,t}^2 + t.i.p. + o(\|a\|^3)$$

where $\Theta = \frac{(1 - \phi)(1 - \beta\phi)}{\phi}$ and *t.i.p.* represents the "terms independent of policy",

which include the exogenous and constant terms.

From equations (D12) and (D13), the welfare function can be written as

$$(D14) \quad W_{e,t} = -\frac{\gamma}{2} \left\{ \frac{\vartheta}{\Theta} \sum_{t=0}^{\infty} \beta^t \hat{\pi}_{H,t}^2 + \frac{(1 + \varphi)}{(1 + \varphi(1 - \alpha))} \sum_{t=0}^{\infty} \beta^t \hat{y}_{gap,t}^2 \right\} + t.i.p. + o(\|a\|^3)$$

Hence, welfare loss is

$$(D15) \quad V_t = -\frac{\gamma}{2} \left\{ \frac{\vartheta}{\Theta} \text{var}(\hat{\pi}_{H,t}) + \frac{(1 + \varphi)}{(1 + \varphi(1 - \alpha))} \text{var}(\hat{y}_{gap,t}) \right\} + t.i.p. + o(\|a\|^3)$$

Chapter 5

Conclusion

5.1 Summary of Results

This dissertation discusses the macroeconomic effects of oil price shocks in a small open economy. The contribution of the dissertation is three-fold. First, I use a dynamic stochastic general equilibrium (DSGE) model to address the impact of oil price shocks under different exchange rate regimes which are rarely discussed in the current literature. The DSGE analysis overcomes the drawbacks of traditional VAR analysis, which lie in the lack of structural interpretation on the reduced form coefficient. I conduct sensitivity analysis with different degrees of flexibility in the exchange rate regimes, which partially explain the different responses of the economy to similar oil price shocks during the 1970s and after the 1980s. Second, it fills in the gap in the lack of theoretical examination on the relationship between oil price shocks and real exchange rate variations, which is generally studied empirically. As suggested by Zhou (1995), the changes in the real oil price have impact on the variations in real exchange rate. Third, I examine the different measures of inflation rate that the central bank could choose as its inflation target. The results indicate that the proper inflation target is crucial for the success of monetary policy. Also, my simulation results are consistent with Hamilton's (1983, 2004) empirical studies. The corresponding contractionary monetary policy is not the main reason for the stagflation in the 1970s.

My findings suggest that flexible exchange rate regimes better absorb oil price shocks. First, output, consumption, capital, and investment exhibit lower fluctuations under flexible exchange rate regime. Specifically, a small open economy benefits from initial currency appreciation, which induces lower input cost and inflation rate. The eventual depreciation of domestic currency can strengthen the competitiveness of home country product. The variations of output, consumption, and capital are lower in this case. On the other hand, under fixed exchange rate regime, the necessary adjustment in real exchange rates only can be generated with excess demand in the goods market due to the price stickiness in the short run. The process is then prolonged. This result is in favor of Friedman's (1953) hypothesis that the short-run output responses to shocks are smoother in floats than in fixed. Second, nominal and real exchange rates, terms of trade and domestic price are more volatile under flexible exchange rate regime, which indicate that the shifts of exchange rate regime may induce higher exchange rate fluctuations.

Regarding the short-run dynamics of the macroeconomic aggregates, the simulations show that the model can duplicate the stylized facts documented by Broda (2004). Regarding the impact of oil price shocks, output, consumption, capital, and investment decrease when a positive oil price shock hits the economy. Domestic price, overall price, marginal cost, and nominal interest rate increase. Also, according to Mendoza (1995) and Backus (2000), real exchange rate and terms of trade are procyclical due to external oil price shocks. My model exhibits similar patterns. Since the empirical studies suggest that the oil share of output has

decreased after 1980s, my model shows that the variations in output decline with the reduced oil share in production. When I reduce the oil share of output in the extended model by introducing capital in the production, I can see the response of output is much smaller to the same magnitude of oil price shocks.

Regarding the welfare effect of alternative monetary policies, I compare four monetary policy rules: a fixed exchange rate regime and three inflation indicators targeted by the central bank. I address the issue on which monetary policy is the optimal policy rule by analytically solving a welfare loss function. I find that the domestic price index is the most appropriate measure of inflation because it induces less welfare loss.

5.2 Further Research

It is worthwhile suggesting further avenues of research, which could benefit from the framework of this thesis. First, an extensive examination of other factors which account for the stagflation period in the 1970s can help us understand the whole story of the different responses of the economy. The credibility of the relative fiscal/monetary policy and the increased commodity price could all have impact on the macroeconomy. Since most emerging economies have large government sectors, the conduct of fiscal/monetary policy might affect the pass-through of the oil price shocks. Second, an empirical investigation on the role of changing exchange rate regimes in the adjustment of the economies against oil price shocks is also an important extension. I can use panel data of emerging economies since the shift of

exchange rate regimes certainly accounts for their responses against oil price shocks.

Third, I can introduce wage rigidities into the model, which enable the study of the frictions in the labor market. The growth of nominal wages could also be an appropriate measure of inflation rate the central bank chooses to target.

Reference

- Aoki, K., 2001. Optimal monetary policy responses to relative-price changes, *Journal of Monetary Economics*, 48(1), 55-80.
- Apostolakis, B.E., 1990. Energy--capital substitutability/complementarity: the dichotomy. *Energy Economics*, 12(1), 48-58.
- Atkeson, A., Kehoe, P.J., 1999. Models of energy use: putty-putty versus putty-clay. *The American Economic Review*, 89(4), 1028-1043.
- Al-Abri, A., 2007. Oil-price shocks and macroeconomic adjustments: does the exchange rate regime matter? Manuscript, Sultan Qaboos University, Oman.
- Backus, D.K., Crucini, M.J., 2000. Oil price and the terms of trade. *Journal of International Economics*, 50(1), 185-213.
- Ball, L., 1999. Policy Rules for Open Economies. in Taylor, J.B.(ed), 1999. *Monetary Policy Rules*, Chicago, University of Chicago Press.
- Barsky, R.B., Kilian, L., 2001. Do we really know that oil caused the great stagflation? a monetary alternative. *NBER Macroeconomics Annual* 2001, 137-183.
- Bergin, P.R., 2003. Putting the new open economy macroeconomics to a test. *Journal of International Economics*, 60(1), 3-34.
- Bernanke, B.S., Gertler, M., Waston, M., 1997. Systematic monetary policy and the effects of oil price shocks. *Brookings Papers on Economic Activity*, 1997(1), 91-157.
- Blake, A., Westaway, P.F., 1996. Credibility and the effectiveness of inflation targeting regimes. *Manchester School Supplement*, 20-50.
- Blanchard, O., Gali, J., 2007. The macroeconomic effects of oil price shocks: why are the 2000s so different from the 1970s? MIT Department of Economics Working Paper, No. 07-21.
- Blanchard, O., Simon, J., 2001. The long and large decline in US output volatility. *Brookings Papers on Economic Activity*, 2001(1), 135-174.
- Broda, C., 2001. Coping with terms-of-trade shocks: pegs versus floats. *The*

- American Economic Review, 91(2), 376-380.
- Broda, C., 2004. Terms of trade and exchange rate regimes in developing countries. *Journal of International Economics*, 63(1), 31-58.
- Bruno, M., Sachs, J., 1982. Input price shocks and the slowdown in economic growth: the case of U.K. manufacturing. *The Review of Economic Studies*, 49(5), 679-705.
- Burbidge, J., Harrison, A., 1984. Testing for the effects of oil-price rises using vector autoregressions. *International Economic Review*, 25(2), 459-484.
- Calvo, G.A., 1983. Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3), 383-398.
- Chen, S., Chen, H., 2007. Oil prices and real exchange rates. *Energy Economics*, 29(3), 390-404.
- Chen, L., Finney, M., Lai, K., 2005. A threshold cointegration analysis of asymmetric price transmission from crude oil to gasoline prices. *Economic Letters*, 89, 233-239.
- Clarida, R., Gali, J., Gertler, M., 1999. The science of monetary policy: a new Keynesian perspective. *Journal of Economic Literature*, 37(4), 1661-1707.
- Clarida, R., Gali, J., Gertler, M., 2000. Monetary policy rules and macroeconomic stability: evidence and some theory. *The Quarterly Journal of Economics*, 115(1), 147-180.
- Darrat, A.F., Gilley, O.W., Meyer, D.J., 1996. US oil consumption, oil prices, and the macroeconomy. *Empirical Economics*, 21(3), 317-334.
- Devereux, M.B., 2000. A simple dynamic general equilibrium analysis of the trade-off between fixed and floating exchange rates. *Econometric Society World Congress 2000 Contributed Papers*, Econometric Society.
- Dhawan, R., Jeske, K., 2007. What determines the output drop after an energy price increase: household or firm energy share? FRB of Atlanta Working Paper, 2007-20.
- Eastwood, R.K., 1992. Macroeconomic impacts of energy shocks. *Oxford Economic Papers*, 44(3), 403-425.

- Edwards, S., Levy Yeyati, E., 2005. Flexible exchange rates as shock absorbers. *European Economic Review*, 49(8), 2079-2105.
- Eicher, T., Hull, L., 2004. Financial liberalization, openness, and convergence. *Journal of International Trade and Development*, 13(4), 443-459.
- Erceg, C.J., Henderson, D.W., Levin, A.T., 2000. Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics*, 46, 281-313.
- Finn, M.G., 1995. Variance properties of Solow's productivity residual and their cyclical implications. Federal Reserve Bank of Richmond, 94-01.
- Finn, M.G., 2000. Perfect competition and the effects of energy price increases on economic activity. *Journal of Money, Credit and Banking*, 32(3), 400-416.
- Freidman, M., 1953. The case for flexible exchange rates, *Essays in Positive Economics*. Chicago, University of Chicago Press: 157-203.
- Gali, J., Monacelli, T., 2005. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies*, 72(3), 707-734.
- Ghosh, A.R., Gulde, A.M., Ostry, J.D., Wolf, H.C., 1997. Does the nominal exchange rate regime matter? National Bureau of Economic Research Working Paper Series, No. 5874.
- Gisser, M., Goodwin, T.H., 1986. Crude oil and the macroeconomy: tests of some popular notions: note. *Journal of Money, Credit and Banking*, 18(1), 95-103.
- Goodfriend, M., King, R.G., 1997. The new neoclassical synthesis and the role of monetary policy. *NBER Macroeconomics Annual*, 12, 231-283.
- Hamilton, J.D., 1983. Oil and the Macroeconomy since World War II. *The Journal of Political Economy*, 91(2), 228-248.
- Hamilton, J.D., 1996. This is what happened to the oil price-macroeconomy relationship, *Journal of Monetary Economics*, 38(2), 215-220.
- Hamilton, J.D., 1988. A neoclassical model of unemployment and the business cycle. *Journal of Political Economy*, 96, 593-617.
- Hamilton, J.D., Herrera, A.M., 2004. Comment: oil shocks and aggregate macroeconomic behavior: the role of monetary policy. *Journal of Money, Credit*

and Banking, 36(2), 265-286.

Hamilton, J.D., 2008. Oil and the Macroeconomy. The New Palgrave Dictionary of Economics, 2nd edition. Palgrave Macmillan.

Hooker, M.A., 1996. What happened to the oil price-macroeconomy relationship? Journal of Monetary Economics, 38(2), 195-213.

Hooker, M.A., 2002. Are oil shocks inflationary? Asymmetric and nonlinear specifications versus changes in regime. Ohio State University Press, 34, 540-561.

Huntington, H., 1998. Crude oil prices and U.S. economic performance: where does the asymmetry reside? The Energy Journal, 19(4), 107-132.

Kim, C.J., Nelson, C.R., 1999. Has the U.S. economy become more stable? A Bayesian approach based on a Markov-switching Model of the business cycle. The MIT Press, 81, 608-616.

Kim, I.M., Loungani, P., 1992. The role of energy in real business cycle models. Journal of Monetary Economics, 29(2), 173-189.

Kollmann, R., 2002. Monetary policy rules in the open economy: effects on welfare and business cycles. Journal of Monetary Economics, 49(5), 989-1015.

Lane, P.R., 2002. The new open economy macroeconomics: a survey, New Developments in Exchange Rate Economics, Volume 1.

Leduc, S., Sill, K., 2004. A quantitative analysis of oil-price shocks, systematic monetary policy, and economic downturns. Journal of Monetary Economics, 51(4), 781-808.

Levy-Yeyati, E., Sturzenegger, F., 2002. Classifying exchange rate regimes: deeds vs. words. Manuscript, Universidad Torcuato Di Tella.

Mankiw, N.G., Reis, R., 2003. What measure of inflation should a central bank target? Journal of the European Economic Association, 1, 1058-1086.

Mendoza, E.G., 1995. The terms of trade, the real exchange rate, and economic fluctuations. International Economic Review, 36(1), 101-137.

Monacelli, T., 2004. Into the Mussa puzzle: monetary policy regimes and the real

- exchange rate in a small open economy. *Journal of International Economics*, 62(1), 191-217.
- Mork, K.A., 1994. Business cycles and the oil market. *Energy Journal*, 15, 15-38.
- Mussa, M., 1986. Nominal exchange rate regimes and the behavior of real exchange rates: evidence and implications. *Carnegie-Rochester Conference Series on Public Policy*, 25, 117-213.
- Nadal-De Simone, F., Dennis, R., Redward, P., 1996. A monetary conditions index for New Zealand. Discussion paper series G96/2.
- Obstfeld, M., 2006. International macroeconomics: beyond the Mundell-Fleming model. Center for International and Development Economics Research, Working Paper Series: 1000.
- Obstfeld, M., Rogoff, K., 1995. Exchange rate dynamics redux. *The Journal of Political Economy*, 103(3), 624-660.
- Obstfeld, M., Rogoff, K., 2000. New directions for stochastic open economy models. *Journal of International Economics*, 50(1), 117-153.
- Persson, T., Tabellini, G., 1996. Monetary cohabitation in Europe. NBER Working Papers, No. 5532.
- Reinhart, C., Rogoff, K., 2004. The modern history of exchange rate arrangements: a reinterpretation. *Quarterly Journal of Economics* 119: 1 – 48.
- Rogoff, K., Husain, A., Mody, A., Brooks, R., Oomes, N., 2003. Evolution and performance of exchange rate regimes. IMF Working Paper 03-243.
- Romer, C.D., Romer, D.H., 2002. The evolution of economic understanding and postwar stabilization policy. National Bureau of Economic Research Working Paper Series, 9274.
- Rotemberg, J.J., Woodford, M., 1996. Imperfect competition and the effects of energy price increases on economic activity. *Journal of Money, Credit and Banking*, 28(4), 549-577.
- Rotemberg, J.J., Woodford, M., 1998. Interest-rate rules in an estimated sticky price

- model. National Bureau of Economic Research Working Paper Series, No. 6618.
- Stock, J.H., Watson, M.W., 2002. Has the business cycle changed and why? The University of Chicago Press, 17: 159-218.
- Stock, J.H., Watson, M.W., 2005. Understanding changes in international business cycle dynamics. *Journal of European Economic Association*, 3(5), 968-1006.
- Svensson, Lars E.O., 2000. Open-economy inflation targeting. *Journal of International Economics*, 50(1), 155-183.
- Taylor, J.B., 1993. Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214.
- Taylor, J.B., 1999. *Monetary Policy Rules*. Chicago University Press, Chicago, IL
- Uhlig, H., 1995. A toolkit for analyzing nonlinear dynamic stochastic models easily. Tilburg University, Center for Economic Research, Discussion Paper: 97.
- Woodford, M., 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.
- Zhou, S., 1995. The response of real exchange rates to various economic shocks. *Southern Economic Journal*, 61(4), 936-954.