ESSAYS ON THE MACROECONOMIC EFFECTS OF OIL PRICE SHOCKS ON THE U.S. ECONOMY

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A large volume of research has acknowledged the role of oil price shocks to generate a significant stagflationary impact on U.S. and other oil importing nations. Recent research however shows a paradigm shift in this oil price-macroeconomy relationship since the mid 1980s, during which the U.S. economy has been relatively resilient to oil shocks. Both output contraction and inflationary expectations have been milder in the post mid 1980s than before. But the 2007-08 oil shock episode has re-emphasized the immense impact of the ebbs and flows of oil prices on the U.S. economys ups and downs. Global oil price peaked at $148 a barrel in June 2008. With the mortgage crisis and credit crunch, oil was another blow too many. The U.S. economy swamped into one of the greatest recessions of all times. According to Hamilton (2009), the 2007-08 oil shock had a significant contribution to the recent recession. While a lot of work have been done on the effects of oil price shocks on the U.S. economy, relatively little work has investigated what triggers oil price increase. My research illustrates why it is important to study the cause of an oil price rise. First, the effects of oil price rise on the macro variables depend heavily on what causes the shock. Secondly, whereas the oil price hikes of the 1970s and early 1980s can mostly be attributed to exogenous events in OPEC (Arab Oil Embargo, Iran-Iraq War, Iranian Revolution), a significant source of oil price spikes in the post mid 1980 era have been an increase in global oil demand confronting stagnating oil production. From a policy perspective, of course, policies aimed at dealing with higher oil prices must take careful account of what causes oil prices to

rise.

Empirical research that demonstrates the resilience of U.S. economy to oil price shocks builds on the implicit assumption that as oil price varies, everything else in the global economy is held constant. Thus all variations in oil prices are taken as alike and exogenous. This overlooks the possibility that oil price rise sparked off by diverse events can potentially lead to different repercussions. This thesis is an attempt to develop framework to study the endogenous increase in oil price. The oil price increase arises from increase in U.S. growth rate, increase in foreign growth rate and a purely exogenous oil supply shock by OPEC. The most important result is that the source of oil price rise has changed after the mid 1980s - whereas before the mid 1980s, bulk of the variation in oil price was due to supply shocks by OPEC, post mid 1980s, most of the variation in oil price is explained by increase in U.S. and foreign growth. Furthermore, if the origin of the oil price rise is the same, then the responses of most U.S. macroeconomic variables display remarkable similarity in the pre and post mid 1980s. This result gives us a new way to look at the resilience of the U.S. economic activity to oil price rise since the mid 1980s. The resilience can be explained to a significant extent by the fact that the type of shocks resulting in oil price rise has changed.

BIOGRAPHICAL SKETCH

Romita Mukherjee was born in the metropolitan city of Kolkata in India to Alpana Mukherjee and Mihir Mukherjee. She studied in Bidya Bharati School until the 10th standard and then completed her high school from South Point High School in 1998.

She did her Bachelors degree in Economics from Presidency College, Kolkata in 2001, Master of Science in Quantitative Economics from the Indian Statistical Institute in Kolkata in 2003 and Master of Philosophy from the Delhi School of Economics in Delhi in 2005, three premier institutes in Economics in India.

Romita came to Cornell University, Ithaca, NY in 2005 to pursue her Ph.D. in Economics with specialization in International Economics and Macroeconomics. Her dissertation focuses of the effect of oil price shocks on the U.S. economy. In addition to oil prices, her current research agenda includes studying the skill-composition of migrants to the U.S. economy after the post WWII.

I dedicate my thesis to Dada, Dadu, Souvik, Ma, Baba, Mum, Bapi.

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Before coming to Cornell, I spent four wonderful years at the Indian Statistical Institute, Kolkata and the Delhi School of Economics in Delhi. I am extremely thankful to all my professors and friends who were always by my side through thick and thin.

They made my days at Kolkata and Delhi a very special experience. My time in Ithaca was made enjoyable in large part due to the many friends who have become an integral part of my life. I am grateful for the quality time spent with my friends, our memorable Friday dinners and innumerable "addas" (gossips). Their friendship, support and understanding kept me afloat and smiling through storms.

I would like to convey by sincerest thanks to my parents Mr. Mihir Mukherjee and Mrs. Alpana Mukherjee who have brought me up with all honesty, courage, utmost patience and perseverance. Their contribution in shaping the person I am and the way I think today is immeasurable. In spite of being 8000 miles away from me, they were always present with their inspirations and strengths to help me when I needed them the most, providing an ever-sympathetic ear to my never ending grievances. My father's words "I think even the bad experiences have their good points whether they make me a stronger person or they teach me something new about life" is a lesson that will be in my heart forever. I also thank my in-laws Mr. Sujit Ghosh and Mrs. Jharna Ghosh for their constant support over the last five years.

I owe my loving thanks to my dear husband Souvik. Without his constant encouragement, help, understanding, tolerance and loads of patience, it would have been impossible for me to finish this work. He was always there cheering me up and standing by me through good times and bad. If I wrote down everything I ever wanted in a husband and best friend, I would not have believed I could meet someone better! Thanks for always being there for me.

Last but not the least, I thank the omnipresent God, for answering my prayers, for giving me the strength to plod on despite my constitution wanting to give up and throw in the towel, thank you so much Dear Lord.

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CHAPTER 1

INTRODUCTION

A large volume of research has acknowledged the role of oil price shocks in generating a significant stagflationary impact on the U.S. and other oil importing nations. Recent research however shows a paradigm change in this oil price-macroeconomy relationship since the mid-1980s, following which the U.S. economy has been relatively resilient to oil shocks. Both output contraction and inflationary expectations have been milder since the mid-1980s than before. But the 2007-08 oil shock episode has re-emphasized the immense impact of ebbing and flowing of oil prices on the U.S. economys ups and downs. Global oil price peaked at $148 a barrel in June 2008. With the mortgage crisis and credit crunch, oil was one blow too many. The U.S. economy plunged into one of the greatest recessions of all times. According to Hamilton (2009), the 2007-08 oil shock had a significant contribution to the recent recession. While a great deal of work has considered the effects of oil price shocks on the U.S. economy, the triggers of oil price rise remain less studied. My research illustrates the importance of studying what causes an oil price rise. First, the effects of oil price rise on the macro variables depend heavily on what causes the shock. Second, whereas the oil price hikes of the 1970s and early 1980s can be mostly attributed to exogenous events in OPEC (Arab Oil Embargo, Iran-Iraq War, Iranian Revolution), a significant source of oil price spikes in the post-mid-1980s era have been an increase in global oil demand confronting stagnating oil production. From a policy perspective, of course, policies aimed at dealing with higher oil prices must take careful account of what causes oil prices to rise. Following is a brief description of each of my papers.

1.1 Different Sources of Oil Price Rise and Their Effects on the U.S. Economy: Results From An Estimated DSGE Model

This paper develops a three-country dynamic stochastic general equilibrium model with endogenous oil price. The oil price rise can result from any of the following events: increase in U.S. growth rate, increase in U.S. consumption and investment, increase in foreign growth rate and a purely exogenous supply shock by oil-exporters. The structural parameters of the model are estimated using Bayesian techniques separately for the pre- and post-mid-1980 sample. My results show that the source of oil price rise has changed since the mid-1980s: the oil price variation due to supply disturbances by the oil-exporters is significantly higher in pre-mid-1980 sample compared to the post-mid-1980s, whereas the oil price variation due to global growth is significantly higher in the post mid-1980 sample. Furthermore, when the oil price increase is conditioned on the same source and such that oil price increases by the same magnitude, the impulse responses from my model display remarkably similar patterns across the two samples even after controlling for changes in the structural parameter estimates. This suggests that the response of U.S. aggregate real variables to oil price increase of different types has not declined over time. If the cause of oil price increase in not taken into account, i.e. if oil price is assumed to be exogenous, [Blanchard and Gali (2007)] then the U.S. economy shows a relatively muted response in the post-mid-1980 sample. Our study shows that this phenomenon can be explained largely by the fact that the composition of the causes of oil price rise has changed after the mid-1980s.

1.2 A Sectoral Analysis of Oil Price Shocks on the U.S. Economy

In this paper, I seek to explain the relatively muted response of U.S. macroeconomic variables to exogenous oil price shocks in the post-mid-1980s era. I use a factor augmented vector autoregression framework to analyze a large dataset of 103 macroeconomic indicators and sectoral data on output and prices to document some of the changes in the U.S. economic landscape which are instrumental for the muted response: (i) Composition effect the U.S. economy has evolved from a manufacturing to a service economy. The effect of the oil price shock on the aggregate PCE price and quantity indices which takes into account the true weights of the manufacturing and service sectors is significantly muted compared to the response of the PCE price and quantity indices assigning equal weight to both sectors. Further, the difference between the weighted and un-weighted price and quantity indices is significantly higher in the post-1984 sample. (ii) Faster price adjustments due to increased competition following import penetration reflected in the estimated sectoral Calvo probabilities conditional on oil shock and (iii) decoupling of the sectors with a low energy usage from highly energy-intensive sectors. Variance decomposition of sectoral output show that much of the variability of production in the highly energy intensive sectors can be explained by common factors, including oil. On the other hand, the bulk of the variability in low-energy-intensive sectors is explained by sector specific factors.

1.3 Effects of Oil Price Shocks on the U.S. Economy: Role of Oil Intensity and Wage Price Adjustments

Using a DSGE model with staggered Nash wage bargaining and with oil as a consumption good and productive input, I show that a decline in real wage rigidity (union bargaining power) plays a significant role in the dampened response of U.S. economic activity and inflation to exogenous oil price shock in the post-mid-1980s. In addition, increased energy efficiency, decline in the degree of price stickiness and improvement in monetary policy have also contributed to the observed muted response of U.S. macroeconomic aggregates to exogenous oil price shocks.

CHAPTER 2

DIFFERENT SOURCES OF OIL PRICE RISE AND THEIR EFFECTS ON THE U.S. ECONOMY: RESULTS FROM AN ESTIMATED DSGE MODEL

2.1 Introduction

"Big increases in the price of oil that were associated with events such as the 1973-74 embargo by the Organization of Arab Petroleum Exporting Countries, the Iranian Revolution in 1978, the Iran-Iraq War in 1980, and the First Persian Gulf War in 1990 were each followed by global economic recessions. The price of oil doubled between June 2007 and June 2008, a bigger price increase than in any of those four earlier episodes. In my mind, there is no question that this latest surge in oil prices was an important factor that contributed to the economic recession that began in the U.S. in 2007:Q4."
- James Hamilton in the Testimony Prepared for the Joint Economic Committee of the U.S. Congress May 20, 2009.

There exists a large literature on the macroeconomic effects of oil price fluctuations. But the broad consensus at least until a few years back was that oil price hikes induce a contraction in overall economic activity and inflationary pressures in U.S. and other oil-importing economies [Hamilton (1983), Hamilton (2006) and Mork (1994)].

However a more recent wave of empirical and theoretical studies, carried out for the U.S. economy, identified a paradigm change in the oil price-macroeconomy relationship since the mid-1980s. This research documented that the impact on U.S. economic growth and inflation is somewhat muted than two to three decades ago. A variety of explanations have been offered, including good luck [Blanchard and Simon (2001)], reduced intensity of energy usage [Bohi (1989), Bohi (1991)], a more flexible economy and better monetary policy [Blanchard and Gali (2008)]. All these explanations point to a weakening of the relationship between oil prices shocks and U.S. economic activity.

This vein of research builds on an implicit thought experiment - oil price varies, holding all other things in the world economy as fixed. However this assumption is an unrealistic one. It overlooks the wide spectrum of events that can trigger an oil price rise, treating all oil price shocks as alike and exogenous.

In this paper, we address the challenge of incorporating the various origins of oil price increases. We revisit the questions addressed in the literature on the macroeconomic effects of oil price rise, focusing on the U.S. economy. We depart from the conventional oil price literature in two ways. First, contrary to the bulk of oil price literature which regards oil price changes as exogenous, we study what mechanism leads to an oil rise in the first place. In our model, oil price increase can result from one of the following events: increase in U.S. growth rate, increase in U.S. consumption and investment, increase in foreign growth rate and a purely exogenous supply shock by oil-exporters. Second, as well as investigating the effects of oil price increases triggered by different events, we consider the role of endogenous price markup changes in U.S. the transmission of oil shocks to the U.S. macroeconomic variables. The allows us to see if the changes in the markup of U.S. firms can act as an additional transmission channel in propagating the contractionary effects of oil price increases to the real economy.

To shed light on the questions outlined above, we build a three-country dynamic stochastic general equilibrium model and estimate the structural parameters of the linearized model using Bayesian techniques with quarterly data for the U.S. economy separately for the pre- and post-mid-1980s period. We extend the traditional New Keynesian models to (1) three-country framework with two oil importing countries U.S.A. and the rest of the oil importing world and an oil exporting country, (2) oil is used as an input in the production of goods by the U.S. and the oil-importing rest of the world. Firms in the oil importing countries are assumed to adjust prices infrequently and households are assumed to set wages in a staggered fashion. The oil exporting country exports oil to the U.S. and the rest of the world. The key structural parameters of the model are jointly estimated following a Bayesian approach as in Smets and Wouters (2003), Schorfheide (2000) and Fernandez-Villaverde and Rubio-Ramirez (2004).

We show that the estimates of the structural parameters of the model change significantly after the mid-1980s. As regards to the variability of oil price, we show that the source of oil price rise has changed since the mid-1980s: the oil price variation due to supply disturbances by the oil-exporting countries is significantly higher in pre-mid-1980 sample compared to the post-mid-1980s, whereas the oil price variation due to global growth is significantly higher in the post mid-1980 sample. Further, when we condition the oil price increase on the same source such that oil price increases by the same magnitude, the impulse responses from our model display remarkably similar patterns across the two samples even after controlling for changes in the structural parameter estimates. This suggests that the response of U.S. aggregate real variables to oil price increase has not declined over time.

The importance of understanding the source of oil price rise was first emphasized by Kilian (2009). He pointed out that distinguishing between the sources of higher oil prices is crucial in assessing the effect of higher oil prices on U.S. real GDP and CPI inflation. Even from a policy perspective, policies aimed at dealing with higher oil prices must take careful account of what causes the increase. For example, Bernanke (2004) notes that, as a professor and textbook author, he “was accustomed to discussing the effects of ... rising oil prices with all other factors held equal. However, as policymakers know, everything else is never held equal. The increases in oil prices this year did not take place in isolation." Rotemberg and Woodford (1996) also observe that oil prices are not completely exogenous to the U.S. macroeconomy. Indeed the stochastic process of nominal oil prices is quite different in recent years than during earlier periods. Rotemberg and Woodford (1996) show that the period of exogenous nominal price changes effectively ends around the third quarter of 1980, when the period of endogenous nominal price changes begins. Thus it is of crucial importance to study the underlying causes of an oil price increase.

The novelty of our approach is the endogenous oil price. Our three-country framework allows us to assess how U.S. economic activity responds to oil price shocks arising from a diverse array of sources such as supply shocks from oil exporting country, demand shocks resulting from productivity gains in the U.S. or in the rest of the oil-importing world and increase in U.S. consumption and increase in Federal government spending.

This three-country framework is particularly important in the context of the most recent oil price shock episode, which everyone agrees was driven by an increase in global demand. We observed a doubling of world oil prices between June 2007 and June 2008. Whereas historical oil price shocks were primarily caused by physical disruptions of supply[1] (for example the 1973-74 embargo by the Organization of Arab Petroleum Exporting Countries, the Yom Kippur War, the Iranian Revolution in 1978 and the Iran-Iraq War in 1980), the price run-up of 2007-08 was caused by booming world demand. Particularly noteworthy was oil consumption in China, which has been growing at a 7% compound annual rate over the last two decades (see Figure 2.2 and Figure 2.3). Chinese consumption was 870,000 barrels per day higher in 2007 than it had been in 2005. The surge of China and several other developing nations into the global economic scene was

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[1] See Figure **??** for a detailed analysis of oil shocks and the associated events.

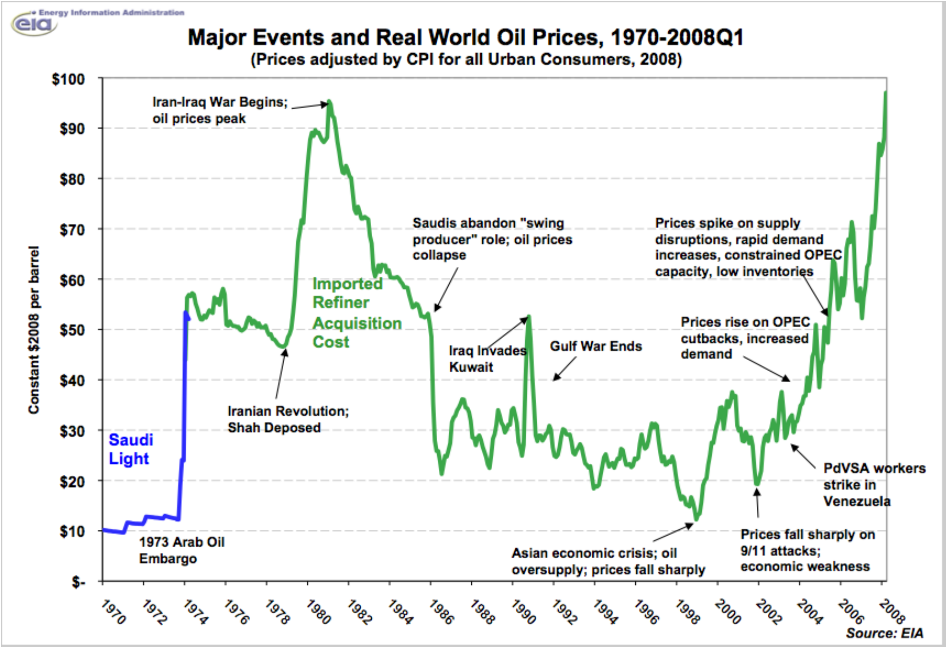

Figure 2.1: Oil Price - 1947-2009

no doubt a significant factor triggering the 2007-08 oil shock episode.[2] This important development cannot be captured in a model if we assume all oil prices to be alike and exogenous.

Our three-country set-up allows us to study the consequences of such a trigger, particularly the increase in oil demand due to economic growth in the oil-importing rest of the world. We provide a comprehensive characterization of the magnitude of the effects on the U.S. economy of oil shocks from diverse sources and we examine whether these effects have changed over time. The paper demonstrates how global oil price spikes triggered by different economic factors can lead to substantially different macroeconomic consequences for the U.S. economy. For example, impulse responses to oil shocks trig-

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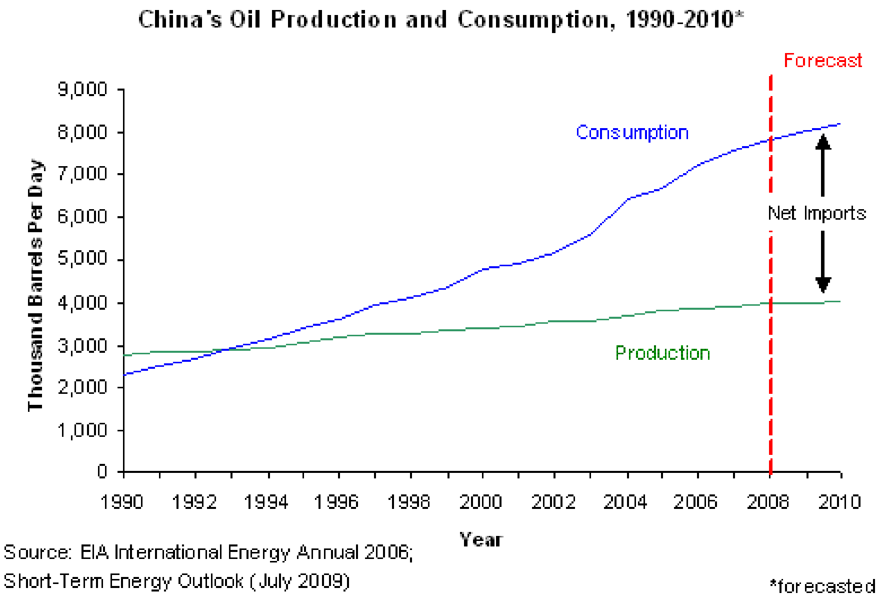
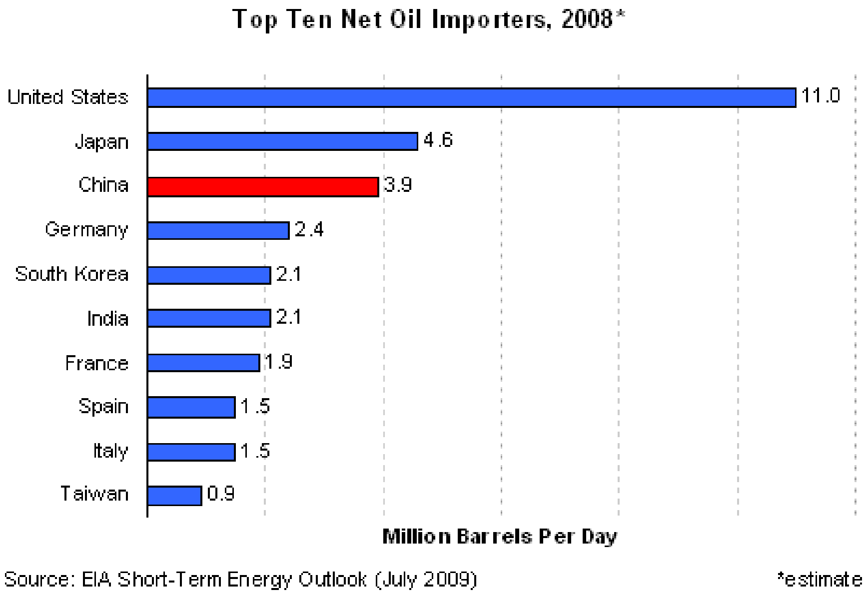
[2] China alone has averaged nearly 10% annual GDP growth for a decade, and India hasn't been far behind.


China's Oil Production and Consumption, 1990-2010*

Source: EIA International Energy Annual 2006;
Short-Term Energy Outlook (July 2009)

*forecasted

Figure 2.2: China's Oil Consumption: 1990-2010


Top Ten Net Oil Importers, 2008*

Source: EIA Short-Term Energy Outlook (July 2009)

*estimate

Figure 2.3: World's 10 Largest Oil Importers

gered by growth in the rest of the oil-importing world leads to a steeper drop in U.S. output during the post-1984 episode; an oil price supply shock leads to similar drop in U.S. GDP in both the pre- and post-1984 samples. This is in stark contrast to Blanchard and Gali (2008), who attribute a muted response of GDP to exogenous oil price shock in the post-1984 sample.

With regards to endogenous markup, we do not assume a priori that markup behavior plays an important role in the transmission of oil shock; our analysis allows us to evaluate the relevance of this channel. Rotemberg and Woodford (1996) have argued that macroeconomic consequences of higher oil prices could be amplified if markups were to rise following an oil shock. But to our knowledge, no study of oil price shock on the U.S. economy have evaluated the relevance of the markup-channel in the transmission of oil shock. We find that indeed there is an increase in the markup following an oil shock that acts as a transmission mechanism intensifying the impact of oil price increase. However the role of markup in transmission of oil shock have significantly reduced in the post-1984 period.

To model endogenous markup we follow the approach of Rotemberg and Woodford (1996). According to Rotemberg and Woodford (1991), Rotemberg and Woodford (1996), the three main approaches to explaining markup behavior can be considered as special cases of a general formulation in which markups are allowed to be a function of the ratio of expected discounted profits to current output. These three approaches are: (i) the standard case where markups are simply assumed to be exogenous;[3] (ii) the case where the markup varies inversely with the ratio of expected discounted profits to current output (associated with the so called "customer market" model of **?**),[4] and (iii) the

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[3] In our case, markup in this case will be random as in Smets and Wouters (2007).

[4] According to Phelps and Winter, a higher level of expected discounted profits relative to current output would induce each competing firm to reduce its markup in an attempt to increase its share in future sales to customers.

case where the relation between markups and the ratio of expected discounted profits to current real output is positive (as in the "implicit collusion" model of Rotemberg and Saloner (1986)[5]). Given that the ratio of expected discounted profits to current output is normally dominated by short-run developments in the latter, cases (ii) and (iii) are often referred to as situations where markups are procyclical and countercyclical, respectively. Our estimated model can assess which of the three types of markup behavior is supported by the data. Our estimates show that price markups are countercyclical, which corroborates the evidence of earlier studies on price markups, cf. Rotemberg and Woodford (1991), Banerjee and Russell (2004), Wilson and Reynolds (2005) and Jaimovich (2006).

Another advance of our analysis is its extended dataset spanning from 1960Q1-2008Q1. We truncate the dataset to 2008Q1 instead of extending it all the way up to 2010 since the monetary policy in our model cannot capture close-to-zero interest rate observed in the U.S. economy post 2008Q1. However extending the dataset till 2008 is very important, since this up-to-date dataset allows us to study the most recent run up of oil price which created a enormous stir in the world economy, ultimately leading to a global recession. According to Hamilton, this latest surge in oil prices was a significant contributing factor to the ongoing recession: "if there had there been no oil shock, we would have described the U.S. economy in 2007:Q4-2008:Q3 as growing slowly, but not in a recession."

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[5] In Rotemberg and Saloner's view, a rise in the ratio of expected discounted profits to current output allows for higher markups. In this context, implicit collusion can be sustained as an equilibrium given that a firm's deviation to a lower markup would not make it better off as such action would lead to sufficiently large losses from punishment.

2.2 Related Literature

Our work connects to four distinct strands of the literature. First, it connects to the empirical research on the relationship between oil price shocks and the U.S. economy starting with Hamilton (1983). Bernanke, Gertler and Watson, (1997) challenged Hamilton's finding, documenting that all U.S. recessions were preceded by both oil price increases as well as a simultaneous tightening of monetary policy. Using a vector autoregression methodology, they found that the systematic monetary policy response to inflation following an oil price increase accounted for the bulk of the contractionary effects of oil price shocks on the U.S. economy. Barsky and Killian (2002) and Kilian (2005) also argued that the root cause of the abysmal macroeconomic performance from 1973 to 1983 in the U.S. was poor monetary policy, not the oil shocks.

Second, our work is connects to the vein of literature that deals with theoretical models of oil price-macroeconomy relationship. Some important contributions in this area include Kim and Loungani (1991), Rotemberg and Woodford (1996), Finn (2000), Leduc and Sill (2004), and Carlstrom and Fuerst (2005). Although these studies differ in the way oil is employed in the economy (as a consumption good, as a productive input, or as a factor linked to capital utilization), and hence in the implications of oil shocks, they all make the assumption that oil price shocks are exogenous, and hence unrelated to economic fundamentals. This is not only an oversimplification from a theoretical point of view as Kilian (2009) pointed out, it is also inconsistent with what is observed in reality. Nakov and Pescatori (2007) take into account the various sources of oil price increase, but their model cannot study the effects of oil price increase triggered by an increase in growth in the rest of world. This aspect can be studied from our model, the presence of the second oil importing country in our framework adds an additional source of oil price trigger. Economists by and large seem to agree that oil shocks after the mid-1980s were driven by events outside the domain of oil exporting countries e.g. OPEC, specially demand-driven disturbances in the developing world e.g. China and India and the Eurozone. In our paper, instead of taking oil prices as exogenous, we study the underlying causes of an oil price rise, thereby endogenizing the oil price.

Third, our theoretical model draws from the real business cycle model of Backus and Crucini (2000). We extend the model to a New Keynesian framework by introducing nominal wage and price stickiness à la Calvo (1983), in a multicountry setting similar to that of Gali and Monacelli (2005). Following Christiano, Eichenbaum and Evans (2005), the model also incorporates a variable capacity utilization rate which tends to smooth the adjustment of the rental rate of capital in response to changes in output. We also follow Christiano, Eichenbaum and Evans (2005) by modeling the cost of adjusting the capital stock as a function of the change in investment. Our assumption of wage stickiness relates to the issue that with an exogenous oil sector, and absent any real rigidities (e.g. real wage rigidities as in Blanchard and Gali (2008)), there is no obvious trade-off between inflation and output gap stabilization, implying that full price stability is optimal even in the face of oil sector shocks.

In contrast to existing models, ours features an oil exporter that charges an endogenously varying oil price markup and exports oil to U.S. and the rest of the oil-importing world. The main advantage of our approach lies in explicitly modeling the oil sector from micro-founded first principles instead of assuming an exogenous process for the oil supply. Also we assume a time-varying endogenous price markup for the U.S. to study how markups react in the face of an oil shock.

Fourth, our theoretical open economy model is estimated with Bayesian methods as in Smets and Wouters (2003), Schorfheide (2000) and Fernandez-Villaverde and Rubio-Ramirez (2004). This allows us to disentangle the contribution of the Fed's monetary policy from the effects of oil shocks. We estimate most of the models parameters separately for two separate samples (1960Q1-1983Q4 and 1984Q1-2008Q1) with Bayesian techniques. This allows us to fit the volatility reduction in macroeconomic variables better compared to other works which calibrate their model.

The paper proceeds as follows. Section 2.3 contains a description of the three-country model with nominal wage and price stickiness and endogenous markup. Section 2.4 discusses our estimation of the model. Section 3.5 describes our results. Section 3.6 presents the conclusions of our analysis.

2.3 Model

In this section we set up the open-economy model that is the basis of our econometric analysis. There are three economies: oil-importing country U.S.A. which we denote by H, an oil-importing foreign sector (ROW) which we denote by F and an oil-exporting foreign country. The oil-importing country U.S.A. is a canonical sticky price economy with monopolistic competition and staggered price and wage adjustments. We impose minimum structure on the oil-importing rest of the world and OPEC.

2.3.1 Oil-Importing Country - U.S.A

There are two types of firms in the U.S.A. : a representative final-goods (finished-goods) producing firm and a continuum of intermediate-goods producing firms indexed by $i \in [0, 1]$. The final-goods sector is perfectly competitive. The final goods are used for consumption and investment by the households in the domestic economy as well as in the rest of the oil-importing world and the oil-exporting country. There is monopolistic competition in the markets for intermediate goods - each intermediate good is produced by a single monopolistically competitive firm using differentiated labor, capital and imported oil. The details of production and consumption of U.S.A. are discussed below.

Final-Goods Firms

At time t, a final good Q_t is produced by a perfectly competitive, representative firm by combining a continuum of intermediate goods, indexed by $i \in [0, 1]$ using the following technology:

$$Q_t = \Big(\int_0^1 Q_t(i)^{(\Theta_{pt}-1)/\Theta_{pt}} di \Big)^{\frac{\Theta_{pt}}{\Theta_{pt}-1}} \tag{2.1}$$

The above function is a Dixit and Stiglitz (1977) aggregator with a time-varying elasticity of substitution measured by Θ_{pt} of a firm's output to its relative price $P_{H,t}(i)/P_{H,t}$.

The aggregator is a special case of the Kimball (1995) aggregator. While the Kimball formulation works with a general aggregator $\int_0^1 \mathcal{G}(\frac{Q_t(i)}{Q_t}, \Theta_{pt})di = 1$, we work with the Dixit-Stiglitz functional form with time-varying elasticity of substitution Θ_{pt}. The choice of the specific functional form is only for computational simplicity. All our results hold true for the generalized Kimball aggregator.

Related to the time-varying elasticity of substitution Θ_{pt}, we have a time-varying price markup μ_{pt}. Shocks to μ_{pt} can be interpreted as the "cost push" shock or markup shock to the inflation equation as in Clarida, Gali and Gertler (1999). In light of costly price adjustments, the firm's actual markup hovers around its desired level over time.

The desired level of markup comprises an endogenous component, which is a function of the ratio of expected discounted profits X_t to current output, and an exogenous component which is assumed to follow an autoregressive process. We assume the process for price markup shock to be modeled as follows:

$$\begin{aligned}\mu_{pt} &= f\Big(\frac{X_t}{Q_t}\Big)\tilde{\mu}_{pt} \\ \ln\tilde{\mu}_{pt} &= \rho_{\mu_p}\ln\tilde{\mu}_{pt-1} + \epsilon_{\mu pt} \qquad (2.2)\end{aligned}$$

with the restrictions $f(\bar{X}/\bar{Q}) = \bar{\mu}_p$, where μ_p is the steady-state markup, and $f'(\bar{X}/\bar{Q}) = \mu_1$.

The parameters $\rho_{\mu_p} \in [0, 1)$ and $\epsilon_{\mu pt}$ are mean-zero, serially uncorrelated innovations which are normally distributed with standard deviation σ_{μ_p}.

Note that following the models of endogenous markup determination of Rotemberg and Woodford (1991) and Rotemberg and Woodford (1996), we can write the expected discounted profits of the firm as

$$X_t = E_t\sum_{k=1}^{\infty}\alpha^k\Lambda_{t,t+k}\Big[(P_{H,t+k} - \psi_{t+k}\Delta_{t+k})\Big]Q_{t+k} \qquad (2.3)$$

The parameter α has two different interpretations: in the "implicit collusion" model, it measures the rate at which new products are created as well as the probability that any collusive agreement will survive until the next period. In the "customer market" model of **?**, α represents the probability that a firm, for random reasons, be assigned a market share in the next period that is independent of its past pricing behavior.[6] Λ_t is the stochastic discount factor defined in the next subsection. $Q_t(i)$ denotes the time t input of the intermediate good i. The final-goods firm takes its output price $P_{H,t}$ and the intermediate input price $P_{H,t}(i)$ as given and is unable to change them.

Profit maximization of the final-goods firm implies the following demand equation for intermediate inputs:

$$Q_t(i) = \Big(\frac{P_{H,t}(i)}{P_{H,t}}\Big)^{-\Theta_{pt}}Q_t \qquad (2.4)$$

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[6] For more details refer to Rotemberg and Woodford (1991) and Rotemberg and Woodford (1996).

Integrating (2.1) and using (2.4), we obtain the following equation for the price index, which gives a relationship between the price of the final good and the price of the intermediate good:

$$P_{H,t} = \Big[\int_0^1 P_{H,t}(i)^{1-\Theta_{pt}} di\Big]^{\frac{1}{1-\Theta_{pt}}} \tag{2.5}$$

Intermediate-Goods Firms

The differentiated intermediate goods are produced by a continuum of monopolistically competitive firms $i \in [0,1]$ with labor N_t, capital K_t and imported oil O_t according to the Cobb-Douglas production technology:

$$Q_t(i) = Z_t N_t(i)^{\alpha_N} K_t(i)^{\alpha_K} O_t(i)^{\alpha_O} \tag{2.6}$$

where α_N, α_K and α_O denote respectively the share of labor, capital and imported oil in the production function, with $\alpha_N + \alpha_K + \alpha_O \leq 1$. The aggregate technology parameter Z_t is common to all firms and follows an autoregressive process

$$\ln Z_t = (1-\rho_z)\ln Z + \rho_z \ln Z_{t-1} + \epsilon_{zt} \tag{2.7}$$

with $Z > 1$ and $\rho_z \in [0,1)$, where the zero-mean, serially uncorrelated innovation ϵ_{zt} is normally distributed with standard deviation σ_z.

Oil $O_t(i)$ is imported from the oil-exporting country OPEC by firm i at the world oil price P_t^o, and $K_t(i)$ denotes the employment of capital services by firm i in a competitive rental market at the rate r_t. Labor employment $N_t(i)$ is an index of different types of labor inputs used by firm i and is defined as follows:

$$N_t(i) = \Big[\int_0^1 N_t(i,j)^{1-\frac{1}{\Theta_{wt}}} dj\Big]^{\frac{\Theta_{wt}}{\Theta_{wt}-1}} \tag{2.8}$$

where $N_t(i, j)$ denotes the quantity of labor j (supplied by the jth household) employed by firm i in period t. The parameter Θ_{wt} represents the elasticity of substitution among labor varieties. Note that here we assume a continuum of labor varieties corresponding to each household $j \in [0, 1]$.

We assume the process for the wage markup shock to follow an autoregressive process:

$$\ln \Theta_{wt} = (1 - \rho_{\theta_w}) \ln \Theta_w + \rho_{\theta_w} \ln \Theta_{wt-1} + \epsilon_{\theta wt} \tag{2.9}$$

where $\Theta_w > 0$ and $\rho_{\theta_w} \in [0, 1)$ and $\epsilon_{\theta wt}$ are mean-zero, serially uncorrelated innovations which are normally distributed with standard deviation σ_{θ_w}.

Let us denote by $W_t(j)$ the nominal wage for the labor type j in period t, for all $j \in [0, 1]$. As discussed in detail in the next section, wages are set by workers or labor unions on behalf of each type of worker, and are taken as given by the intermediate-goods producing firms. Thus at any point in time t, the firm's cost minimization yields a set of labor demand schedules for each firm i and for each labor type j, given firm's total employment $N_t(i)$

$$N_t(i, j) = \Big(\frac{W_t(j)}{W_t}\Big)^{-\Theta_{wt}} N_t(i) \tag{2.10}$$

for all $i, j \in [0, 1]$, where

$$W_t = \Big[\int_0^1 W_t(j)^{1-\Theta_{wt}} dj\Big]^{\frac{1}{1-\Theta_{wt}}} \tag{2.11}$$

denotes the aggregate wage index. Manipulating with (2.10) and (2.11), we get the convenient aggregation

$$\int_0^1 W_t(j) N_t(i, j) dj = W_t N_t(i) \tag{2.12}$$

Now we can define the profit of the firm i as $P_t(i)Q_t(i) - W_t N_t(i) - r_t K_t(i) - P^o_t O_t(i)$, where P^o_t is the relative price of oil in terms of P_t. Independently of how prices are set and assuming that the firms take the input prices of labor, capital and oil as given, the first-order conditions for the *i*th firm are given by:

$$\psi_t(i) = \frac{W_t N_t(i)}{\alpha_N Q_t(i)} = \frac{r_t K_t(i)}{\alpha_K Q_t(i)} = \frac{P^o_t O_t(i)}{\alpha_O Q_t(i)} \tag{2.13}$$

where $\psi_t(i)$ denotes the nominal marginal cost of the *i*th firm. With a Cobb Douglas production function, the marginal cost of the firm is given by the following expression:

$$\psi_t(i) = \frac{(W_t)^{\alpha_N}(r_t)^{\alpha_K}(P^o_t)^{\alpha_O}}{Z_t \alpha_N^{\alpha_N} \alpha_K^{\alpha_K} \alpha_O^{\alpha_O}} \tag{2.14}$$

Following Calvo's (1983) formalism, we assume that each intermediate-goods producing firm can reset its price only with probability $1 - \lambda_p$ in any given period, independent of the time elapsed since the last price adjustment. Also the ability of a firm to readjust its price is independent of other firms. Thus, each period a mass $1 - \lambda_p$ of intermediate-goods producers reset their prices, while the remaining fraction λ_p keep their prices unchanged. As a result, the average duration of a price is given by $(1 - \lambda_p)^{-1}$, making λ_p a natural index of price stickiness.

Let $\tilde{P}_{H,t}$ denote the price set in period t by firms reoptimizing their prices in that period. All firms will choose the same price, because they all face an identical problem. Thus a firm reoptimizing in period t will choose the price $\tilde{P}_{H,t}$ that maximizes the current market value of profits generated while that price remains effective. Therefore it solves the problem

$$\max_{\tilde{P}_{H,t}} \sum_{k=0}^{\infty} \lambda_p^k E_t\Big\{\Lambda_{t,t+k}\Big(\tilde{P}_{H,t} Q_{t+k|t} - \Psi_{t+k}(Q_{t+k|t})\Big)\Big\} \tag{2.15}$$

subject to the sequence of demand functions

$$Q_{t+k|t} = \Big(\frac{\tilde{P}_{H,t}}{P_{H,t+k}}\Big)^{-\Theta_{pt}} Q_{t+k} \tag{2.16}$$

for $k \in \{0, 1, 2, \dots\}$. Here $P_{H,t} = \Big[(1-\lambda_p)\tilde{P}_{H,t}^{1-\Theta_{pt}} + \lambda_p P_{H,t-1}^{1-\Theta_{pt}}\Big]^{1/1-\Theta_{pt}}$, $\tilde{P}_{H,t}$ is the newly set price, $\Lambda_{t,t+k} \equiv \beta^k (U_{c,t+k}/U_{c,t})/\pi_{t+k}$ is the stochastic discount factor between periods t and $t+k$, $\pi_{H,t+k} = \frac{P_{H,t+k}}{P_{H,t}}$ is the gross GDP deflator inflation rate between periods t and $t+k$, $\Psi_t(.)$ is the cost function, $Q_{t+k|t}$ denotes output in period $t+k$ for a firm that last reset its price in period t. The relative price dispersion at time t is given by

$$\Delta_t = \int_0^1 \Big(\frac{P_{H,t}(i)}{P_{H,t}}\Big)^{-\Theta_{pt}} di \tag{2.17}$$

The first-order condition associated with the problem above takes the following form:

$$\sum_{k=0}^{\infty} \lambda_p^k E_t \Big\{\Lambda_{t,t+k} Q_{t+k|t} \Big(\tilde{P}_{H,t}(\Theta_{pt+k} - 1) - \Theta_{pt+k}\psi_{t+k|t}\Big)\Big\} = 0 \tag{2.18}$$

In the absence of price rigidities or costly price adjustments ($\lambda_p = 0$), we get the firm's optimal price setting condition under flexible prices; i.e., the firm sets its markup at the frictionless level of $\Theta_{pt}/(\Theta_{pt} - 1)$:

$$\tilde{P}_{H,t}(i) = \frac{\Theta_{pt}}{\Theta_{pt} - 1}\psi_{t|t} \tag{2.19}$$

As before $\psi_{t+k|t}$ denotes the firm's nominal marginal cost. In the presence of nominal rigidities and costly price adjustments, the firm's actual markup gravitates toward its desired frictionless level over time.

Households

There is a continuum of households indexed by $j \in [0, 1]$ in the oil-importing country. A representative household j maximizes the expected present discounted value of utility streams:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U^H\Big(C_t(j), N_t(j)\Big) = \max E_0 \sum_{t=0}^{\infty} \beta^t \Big[A_t \log C_t(j) - \zeta_t \frac{N_t(j)^{1+\gamma}}{1+\gamma}\Big] \tag{2.20}$$

where $\beta \in (0, 1)$ is the household's subjective discount factor and γ is the inverse of the Frisch elasticity of labor supply. Here A_t and ζ_t are preference shocks to the marginal utility of consumption and supply of labor, respectively. The household preference shock A_t follows the autoregressive process

$$\ln A_t = (1 - \rho_a)A + \rho_a \ln A_{t-1} + \epsilon_{at} \tag{2.21}$$

where $\rho_a \in [0, 1)$ is the persistence of the preference shock and ϵ_{at} is a zero-mean, serially uncorrelated innovation which is distributed normally with standard deviation σ_a. The labor supply shock ζ_t also follows an autoregressive process

$$\ln \zeta_t = (1 - \rho_\zeta)\zeta + \rho_\zeta \ln \zeta_{t-1} + \epsilon_{\zeta t} \tag{2.22}$$

where $\rho_\zeta \in [0, 1)$ is the persistence of the preference shock and $\epsilon_{\zeta t}$ is zero-mean, serially uncorrelated innovation which is distributed normally with standard deviation σ_ζ.

The aggregate consumption bundle $C_t(j)$ consists of domestically produced goods $C_{H,t}$ and an imported foreign good $C_{F,t}$, and is given by:

$$C_t(j) = \Big[b^{\frac{1}{\eta}}(C_{H,t}(j))^{\frac{\eta-1}{\eta}} + (1 - b)^{\frac{1}{\eta}}(C_{F,t}(j))^{\frac{\eta-1}{\eta}}\Big]^{\frac{\eta}{\eta-1}} \tag{2.23}$$

where b represents a measure of home bias in consumption and the parameter $\eta \in [0, 1]$ is the elasticity of substitution between domestic and foreign goods. The optimal allocation of expenditure between domestic and foreign goods is given by

$$C_{H,t}(j) = b\Big(\frac{P_{H,t}}{P_t}\Big)^{-\eta}C_t(j) \text{ and } C_{F,t}(j) = (1 - b)\Big(\frac{P_{F,t}}{P_t}\Big)^{-\eta}C_t(j)$$

The domestic consumption good $C_{H,t}$ is a Dixit-Stiglitz aggregate of a continuum of differentiated goods $C_{H,t}(i)$, given by

$$C_{H,t} = \Big[\int_0^1 C_{H,t}(i)^{\frac{\Theta_{pt}-1}{\Theta_{pt}}} di\Big]^{\frac{\Theta_{pt}}{\Theta_{pt}-1}} \tag{2.24}$$

with the associated domestic price index

$$P_{H,t}^{1-\Theta_{pt}} = \int_0^1 P_{H,t}(i)^{1-\Theta_{pt}} di, \tag{2.25}$$

where $P_{H,t}(i)$ is the price of the ith variety or good. As before, Θ_{pt} represents the time-varying elasticity of substitution between the different domestic goods. The CPI price index P_t is given by:

$$P_t = \left[b(P_{H,t})^{1-\eta} + (1-b)(P_{F,t})^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{2.26}$$

We assume that households in the U.S.A. have access to three different types of assets: deposit $d_t(j)$, which pays gross expected real rate of return R_t, one-period non-contingent foreign bonds $B_{F,t}(j)$, one period oil exporting country bonds $B_{o,t}$ and one-period domestic contingent bonds $B_{H,t}(j)$, which pay out one unit of domestic currency in a particular state. There are no adjustments costs in the portfolio composition.

However following Turnovsky (1985), we assume each time a domestic household borrows from abroad it must pay a premium over the international price of external bonds. This premium or intermediation cost denoted by $\phi_{F,t}$ for rest of the world and $\phi_{o,t}$ for OPEC ensures that net foreign assets are stationary and to ensure a well defined steady state of the model.[7] This premium depends on the ratio of economy wide holdings of net foreign assets to nominal output and is given by $\phi_{F,t} = \varrho_t exp\Big(-\phi\Big(\frac{e_t B_{F,t}}{P_{H,t}Q_t}\Big)\Big)$ and $\phi_{o,t} = \varrho_t exp\Big(-\phi\Big(\frac{e_t B_{o,t}}{P_{H,t}Q_t}\Big)\Big)$where $B_{F,t} = \int_0^1 B_{F,t}(j)dj$ is the aggregate net foreign asset position of U.S.A.

If the U.S.A. has an overall net lender position internationally, then a household will earn a lower return on any holdings of foreign bonds. By contrast, if the economy has a net debtor position, a household will pay a higher return on any foreign debt.

Since the premium depends on the aggregate net foreign asset position of the economy, U.S. households take $\phi(.)$ as given when deciding their portfolios. In other words, households do not internalize the effect on the premium of changes in their own foreign

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[7] See Schmitt-Grohé and Uribe (2003) for further details.

asset position. The shock ϱ_t represents the exogenous component of the external intermediation premium and will be referred to as external risk premium shock. The shock process is given as

$$\ln \varrho_t = \rho_\varrho \ln \varrho_{t-1} + \epsilon_{\varrho t} \tag{2.27}$$

where $\rho_\varrho \in [0, 1)$ is the persistence of the premium shock and $\epsilon_{\varrho t}$ is a zero-mean, serially uncorrelated innovation which is distributed normally with standard deviation σ_ϱ. The intertemporal budget constraint of the household is given by:

$$\begin{aligned} C_t(j) + I_t(j) + \tau_t + \frac{d_t(j)}{R_t P_t} + \frac{e_{F,t} B_{F,t}(j)}{P_t R_t^* \phi_{F,t}} + \frac{e_{o,t} B_{o,t}(j)}{P_t R_t^o \phi_{o,t}} = \frac{W_t(j) N_t(j)}{P_t} + S_t(j) \qquad (2.28) \\ + \Big[\frac{r_t u_t(j) K_t^p(j)}{P_t} - a(u_t(j)) K_t^p(j)\Big] + \frac{d_{t-1}(j)}{P_t} + \frac{e_{F,t} B_{F,t-1}(j)}{P_t} + \frac{e_{o,t} B_{o,t-1}(j)}{P_t} + \frac{\Pi_t(j)}{P_t} \end{aligned}$$

The household income consists of four components: the nominal income from labor plus income from participation in domestic state contingent securities, $W_t(j)N_t(j) + S_t(j)$; income from capital services minus the cost associated with variations in the degree of capital utilization, $(r_t u_t(j) K_t^p(j) - a(u_t(j)) K_t(j))$; income from depositing an amount $d_t(j)$ with a financial intermediary, which earns an interest of R_t; income from one-period nominally riskless foreign bonds $B_{F,t-1}(j)$; and dividends from the final-goods firms owned by the households, $\Pi_t(j)$.

The variable e_t is the exchange rate expressed in units of home currency per unit of foreign currency. The household income is used in consumption of $C_t(j)$ units of finished goods and $I_t(j)$ units of investment goods, as well as in paying τ_t units of lump-sum tax to the government, depositing $d_t(j)$ units to the domestic financial intermediary and purchasing $B_{F,t}(j)(R_t^*)^{-1}$ units of foreign bonds purchase. We assume following Christiano, Eichenbaum and Evans (2005) the existence of a complete set of securities that insure the households against variation in the household-specific labor income. Hence the first component of aggregate labor income and the marginal utility of wealth will be identical across different types of households.

The income from renting out capital depends not only on the level of installed capital, but also on the rate of capital utilization $u_t(j)$. The stock of capital is owned by the households. The household j's stock of physical capital, K_t^p, evolves according to the equation:

$$K_{t+1}^p(j) = (1-\delta)K_t^p(j) + F(I_t(j), I_{t-1}(j)) \tag{2.29}$$

Here δ denotes the physical rate of depreciation, and $I_t(j)$ denotes investment at time t. Gross investment I_t consists of domestic and foreign final goods, and we assume that it is in the same proportion as in the consumption basket:

$$I_t(j) = \left[b^{\frac{1}{\eta}}(I_{H,t}(j))^{\frac{\eta-1}{\eta}} + (1-b)^{\frac{1}{\eta}}(I_{F,t}(j))^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{2.30}$$

The price of investment P_t is the same as given by equation (2.26). The function F in equation (2.29) denotes the technology that transforms current and past investment into installed capital for use in the following period. Capital services $K_t(j)$ are related to the physical stock of capital by $K_t(j) = u_t(j)K_t^p(j)$. Here $u_t(j)$ denotes the utilization of capital, which we assume is decided by the household. Like in Christiano, Eichenbaum and Evans (2005), we assume that the investment adjustment costs $F(I_t(j), I_{t-1}(j))$ are given by:

$$F(I_t(j), I_{t-1}(j)) = \left[1 - \mathcal{S}\left(\frac{I_t(j)}{I_{t-1}(j)}\right)\right]I_t(j) \tag{2.31}$$

The investment adjustment cost function $\mathcal{S}$ takes the following form:

$$\mathcal{S}\left(\frac{I_t}{I_{t-1}}\right) = \frac{\gamma_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{2.32}$$

Note that the function $\mathcal{S}$ satisfies the following properties: $\mathcal{S}(1) = \mathcal{S}'(1) = 0$, and $\gamma_I \equiv \mathcal{S}''(1) > 0$. As regards the provision of effective capital services, varying the intensity of utilizing the physical capital stock u_t is subject to a proportional cost $a(u_t)$, which is assumed to take the following quadratic form:

$$a(u_t) = a_1(u_t - 1) + \frac{a_2}{2}(u_t - 1)^2 \tag{2.33}$$

There are two restrictions on the capital utilization function $a(u_t)$. First, we require that $u_t = 1$ in the steady state. Second, note that $a(1) = 0$.[8] Substituting (2.31) into (2.29), we obtain the final version of the capital accumulation equation:

$$K^p_{t+1}(j) = (1-\delta)K^p_t(j) + s_{It}\Big[1 - \mathcal{S}\Big(\frac{I_t(j)}{I_{t-1}(j)}\Big)\Big]I_t(j) \tag{2.34}$$

where ϵ_{It} is the investment-specific technology shock with mean unity affecting the efficiency of the newly installed investment good. We assume ϵ_{It} follows the exogenous stochastic process

$$\log s_{It} = \rho_s \log s_{It-1} + \epsilon_{It} \tag{2.35}$$

where $\rho_s \in [0, 1)$ is the persistence of the preference shock and ϵ_{It} is a zero-mean, serially uncorrelated innovation which is distributed normally with standard deviation σ_I.

Households face two forms of uncertainty. There is aggregate uncertainty that stems from aggregate shocks, and in addition, the households encounter idiosyncratic uncertainty. Being a monopoly supplier of its own labor, a household sets its wage rate, as will be discussed in the next subsection. However, it can only adjust its wage at exogenously and randomly determined points in time. In modeling this, we follow Calvo (1983). We further restrict the analysis by making assumptions which guarantee that frictions do not cause households to become heterogeneous. Namely, we allow households to enter into insurance markets against the outcomes of these frictions. The assumption is of complete domestic financial markets in this economy - i.e., that each household can insure against any type of idiosyncratic risk through the purchase of the appropriate portfolio of securities. This preserves the representative agent framework implying that we do not need to keep track of the entire distribution of the household's wealth, which would otherwise become a state variable. Since households are identical ex ante they

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[8] The parameter a_1 will be pinned down by the model's steady state, and we will estimate the parameter a_2.

are willing to enter such insurance contracts. As a result, all households face the same budget constraint in each period which (in nominal terms) is given by (2.28).

For notational simplicity, we ignore the j for now. The representative household maximizes (2.20) subject to (2.28) and (2.34) by optimally choosing $\{C_t, K^p_{t+1}, d_t, B_{F,t}, u_t\}$.[9] Let λ_{1t} denote the Lagrangian multiplier associated with (2.28) and λ_{2t} Lagrangian multiplier associated with (2.34). The first-order necessary conditions yield the following set of equations:

$$\frac{A_t}{C_t} - \lambda_{1t} = 0 \tag{2.36}$$

$$\lambda_{1t} = \beta R_t E_t\left(\frac{\lambda_{1t+1} P_t}{P_{t+1}}\right) \tag{2.37}$$

$$\lambda_{1t} = \beta \phi_{F,t} R^*_t E_t\left(\frac{\lambda_{1t+1} P_t}{P_{t+1}} \frac{e_{F,t}}{e_{F,t+1}}\right) \tag{2.38}$$

$$\lambda_{1t} = \beta \phi_{o,t} R^o_t E_t\left(\frac{\lambda_{1t+1} P_t}{P_{t+1}} \frac{e_{o,t}}{e_{o,t+1}}\right) \tag{2.39}$$

$$\frac{r_t}{P_t} = a'(u_t) \tag{2.40}$$

$$q^k_t = \beta E_t \frac{\lambda_{1t+1}}{\lambda_{1t}}\left[r_{t+1} u_{t+1} - a(u_{t+1}) + (1-\delta) q^k_{t+1}\right] \tag{2.41}$$

$$s_{It} q^k_t\left[1 - \mathcal{S}\left(\frac{I_t}{I_{t-1}}\right)\right] = s_{It} q^k_t \mathcal{S}'\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}}\right) - \beta E_t s_{It+1} q^k_{t+1} \frac{\lambda_{1t+1}}{\lambda_{1t}} \mathcal{S}'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 + 1 \tag{2.42}$$

where $q^k_t = \frac{\lambda_{1t}}{\lambda_{2t}}$ is the price of installed capital in consumption units, also known as Tobin's q and equaling 1 in the absence of adjustment costs. The ratio $\pi_t = \frac{P_{t+1}}{P_t}$ is the one-period gross CPI inflation rate. Combining the two first-order conditions with respect to home contingent claims $B_{H,t}$ and foreign bond holdings $B_{F,t}$, we obtain an expression for (modified) uncovered interest parity (UIP) given by:

$$E_t\left(\frac{e_{F,t+1}}{e_{F,t}}\right) = \frac{\phi_{F,t} R^*_t}{R_t}$$

and

$$E_t\left(\frac{e_{o,t+1}}{e_{o,t}}\right) = \frac{\phi_{o,t} R^o_t}{R_t}$$

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[9] Note that the $N_t(j)$ is not a choice variable of the households. The households post the wage at which they are willing to supply labor. Given the wage, the firms make the employment decision. The optimal wage setting rule is discussed in the next section.

Labor Supply and Optimal Wage Setting

We assume that labor cannot move across countries. Each household specializes in the supply of a different type of labor indexed by $j \in [0, 1]$. Furthermore, each household has some monopoly power in the labor market, and posts the nominal wage at which it is willing to supply specialized labor services to firms that demand them. Alternatively, as noted in Gali (2008), we can "think of many households specializing in the same type of labor (with their joint mass remaining infinitesimal), and delegating their wage decision to trade unions that act in their interest."

In a way analogous to firms' price setting, we assume that during each period only a fraction $(1 - \lambda_w)$ of households drawn randomly from the population reoptimize their posted nominal wage. Under the assumption of full consumption risk sharing, all households reoptimizing their wage in any given period choose the same wage and will thus face an identical problem which we formalize and solve below.

First, let us see how the households choose the wage for their labor type when allowed to reset their wage. Consider a household resetting its wage in period t, and let W_t^* denote the newly reoptimized wage. The choice of W_t^* must maximize:

$$\sum_{k=0}^{\infty} (\beta\lambda_w)^k E_t\Big[A_{t+k} \ln C_{t+k|t} - \zeta_{t+k} \frac{N_{t+k|t}^{1+\gamma}}{1+\gamma}\Big] \tag{2.43}$$

where $C_{t+k|t}$ and $N_{t+k|t}$ respectively denote the consumption and labor supply in period $t + k$ of a household that last reset its wage in period t. Thus the expression (2.43) represents the expected discounted sum of utilities generated over the uncertain period during which the wage remains unchanged at the level W_t^* set in the current period. Households maximize (2.43) subject to the flow budget constraints (2.28) and a sequence of labor demand schedules given by

$$N_{t+k|t} = \Big(\frac{W_t^*}{W_{t+k}}\Big)^{-\Theta_{wt}} N_{t+k} \tag{2.44}$$

for $k = 0, 1, 2....$ and where $N_t = \int_0^1 N_t(i)di$ is the index of aggregate employment, $W_t = \left[(1-\lambda_w)W_t^{*1-\Theta_{wt}} + \lambda_w W_{t-1}^{1-\Theta_{wt}}\right]^{\frac{1}{1-\Theta_{wt}}}$ is the index of aggregate wages in period t, and Θ_{wt} (as defined before) measures the time-varying elasticity of labor to its relative wage. Instead of W_t, we will work with $\Pi_t^w = \frac{W_t}{W_{t-1}}$, the one-period gross rate of change in the nominal wage, as the endogenous variable. The first-order condition associated with the problem above is given by:

$$\sum_{k=0}^{\infty}(\beta\lambda_w)^k E_t\Big\{N_{t+k|t}U_c(C_{t+k|t}, N_{t+k|t})\Big[\frac{W_t^*}{P_t\pi_{t+k}}(\Theta_{wt+k}-1) - \Theta_{wt+k}MRS_{t+k|t}\Big]\Big\} = 0 \qquad (2.45)$$

where $\pi_{t+k} = \frac{P_{t+k}}{P_t}$ is the gross CPI inflation rate between periods t and $t+k$, and $MRS_{t+k|t} \equiv \zeta_{t+k}(N_{t+k|t})^{\gamma}\frac{C_{t+k|t}}{A_{t+k}}$ is the marginal rate of substitution between leisure and consumption.

Government and Monetary Policy

The fiscal authority is assumed to purchase an exogenous stream G_t of the final good, financed by the collection of lump-sum taxes.[10] For simplicity, we do not assume that the fiscal authority has access to domestic or international capital markets. The government budget constraint is:

$$G_t = \tau_t \qquad (2.46)$$

We define $g_t = G_t/Y_t$, where the shock process for g_t follows an AR(1) process given by:

$$\ln g_t = (1-\rho_g)g + \rho_g \ln g_{t-1} + \epsilon_{gt} \qquad (2.47)$$

with $\rho_g \in [0, 1)$ the persistence of the government spending shock and ϵ_{gt} a zero-mean, serially uncorrelated innovation which is distributed normally with standard deviation σ_g.

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[10] We assume for simplicity that government only consumes domestic goods.

The central bank in the U.S.A. is assumed to follow a forward-looking monetary policy rule given by:

$$\frac{R_t}{\bar{R}} = \Big(\frac{R_{t-1}}{\bar{R}}\Big)^{\phi_R}\Big[\Big(\frac{\pi_t}{\bar{\pi}}\Big)^{\phi_\pi}\Big(\frac{Y_t}{Y_{nt}}\Big)^{\phi_y}\Big]^{(1-\phi_R)}\tilde{R}_t \tag{2.48}$$

where Y_t is the output of GDP in the oil-importing country (defined in the next section) and $\tilde{R}_t$ is the interest rate shock which evolves according to

$$\log \tilde{R}_t = \rho_r \log \tilde{R}_{t-1} + \epsilon_{\tilde{R}t} \tag{2.49}$$

with $\rho_r \in [0, 1)$ and $\epsilon_{\tilde{R}t}$ mean-zero, serially uncorrelated disturbances which are normally distributed with standard deviation $\sigma_{\tilde{R}}$. As for the remaining quantities, $\bar{R} = \bar{\pi}/\beta$ and $\bar{\pi}$ is the target rate of inflation, ϕ_R is the interest-rate smoothing parameter and ϕ_π and ϕ_y are the policy reaction coefficients.

Aggregation

We now aggregate the input and output demands of the oil-importing country U.S.A. The aggregate labor demand in the U.S.A. is given by:

$$N_t = \int_0^1 N_t(i)di \tag{2.50}$$

while the aggregate demand for capital services and the aggregate demand for imported oil are given respectively by:

$$K_t = \int_0^1 K_t(i)di \tag{2.51}$$

and

$$O_t = \int_0^1 O_t(i)di \tag{2.52}$$

The aggregate demand for final goods is given by:

$$Q_t = \Big[\int_0^1 Q_t(i)^{\frac{\Theta_{pt}-1}{\Theta_{pt}}}\Big]^{\frac{\Theta_{pt}}{\Theta_{pt}-1}}di \tag{2.53}$$

which includes goods demanded by both the oil-importing country U.S.A. and the oil-exporting country. The oil exporting country's problem is discussed in the next section. The aggregate demand for labor, capital and oil in terms of marginal costs and price dispersion can be written as:

$$P^o_t O_t = \alpha_O \psi_t Q_t \Delta_t \tag{2.54}$$

$$W_t N_t = \alpha_N \psi_t Q_t \Delta_t \tag{2.55}$$

$$r_t K_t = \alpha_K \psi_t Q_t \Delta_t \tag{2.56}$$

where ψ_t denotes the marginal costs and Δ_t is the price dispersion as defined in (2.17). Aggregate output satisfies the following condition:

$$Q_t = \frac{Z_t}{\Delta_t} N_t^{\alpha_N} K_t^{\alpha_K} O_t^{\alpha_O} \tag{2.57}$$

2.3.2 Oil-Importing Foreign Sector

We assume that the oil-importing ROW produces output Q^*_t by using oil O^*_t and labor N^*_t. We assume labor is supplied inelastically in the oil-importing foreign sector, so that $N^*_t = 1$. Similar to in the U.S.A., there are two types of non oil-producing firms in the ROW: a representative final-goods producing firm and a continuum of intermediate-goods producing firms indexed by $i \in [0, 1]$. The final good is used for consumption in the ROW and is also imported to the U.S.A. and to the oil-exporting country discussed in the next section.

Production

At time t, the final good Q^*_t is produced by a perfectly competitive, representative firm using the continuum of intermediate goods, indexed by $i \in [0, 1]$. The technology of the final-goods firm is given as follows:

$$Q_t^* = \Big(\int_0^1 Q_t^*(i)^{(\Theta_p - 1)/\Theta_p} di \Big)^{\frac{\Theta_p}{\Theta_p - 1}} \tag{2.58}$$

We assume that there is a continuum of differentiated intermediate-goods producing firms in the oil-importing ROW. The production function of the intermediate-good firm i in the oil-importing ROW is given by a linear technology:

$$Q_t^*(i) = Z_t^*(O_t^*(i))^{\alpha_o^*} \tag{2.59}$$

The aggregate technology parameter Z_t^* follows an autoregressive process

$$\ln Z_t^* = (1 - \rho_z^*) \ln Z^* + \rho_z^* \ln Z_{t-1}^* + \epsilon_{zt}^* \tag{2.60}$$

with $Z^* > 1$ and $\rho_z^* \in [0, 1)$, where the zero-mean, serially uncorrelated innovation ϵ_{zt}^* is normally distributed with standard deviation σ_z^*.

The profit of the representative final-goods firm in the oil-importing foreign sector is given as $P_{F,t}^* Q_t^*(i) - \frac{P_t^o}{e_t} O_t^*(i)$, where P_t^o / e_t is the price of oil in units of ROW currency. Cost minimization by the firms implies that

$$\alpha_o^* \psi_t^*(i) Q_t^*(i) e_t = P_t^o O_t^*(i) \tag{2.61}$$

We assume producer currency pricing (p.c.p.), so that the prices of the imported goods are set in the same manner as the U.S. domestic prices, i.e. the prices of U.S. commodity imports adjust sluggishly as given below. As before, let λ_p denote the fraction of producers who keep prices unchanged in any given period. Let $\tilde{P}_{F,t}^*$ denote the price set in period t by firms reoptimizing their prices in that period. All firms will choose the same price, because they all face an identical problem. Thus a firm reoptimizing in period t will choose the price $\tilde{P}_{F,t}^*$ that maximizes the current market value of profits generated while that price remains effective solving the problem:

$$\max_{\tilde{P}_{F,t}^*} \sum_{k=0}^{\infty} \lambda_p^k E_t \Big\{ \Lambda_{t,t+k} \Big(\tilde{P}_{F,t}^* Q_{t+k|t}^* - \Psi_{t+k}(Q_{t+k|t}^*) \Big) \Big\} \tag{2.62}$$

subject to the sequence of demand functions

$$Q^*_{t+k|t} = \Big(\frac{\tilde{P}^*_{F,t}}{P^*_{F,t+k}}\Big)^{-\Theta_p} Q^*_{t+k} \tag{2.63}$$

for $k = 0, 1, 2...$, $P^*_{F,t} = \Big[(1-\lambda_p)(\tilde{P}^*_{F,t})^{1-\Theta_p} + \lambda_p (P^*_{F,t-1})^{1-\Theta_p}\Big]^{1/1-\Theta_{pt}}$. The newly set price is given by $\tilde{P}^*_{F,t}$, while $\Lambda^*_{t,t+k} \equiv \beta^k (U^F_{c,t+k}/U^F_{c,t})/\pi^*_{F,t+k}$ is the stochastic discount factor between periods t and $t+k$, $\pi^*_{F,t+k} = \frac{P^*_{F,t+k}}{P^*_{F,t}}$ is the gross GDP deflator inflation rate between periods t and $t+k$, $\Psi^*_t(.)$ is the cost function, $Q^*_{t+k|t}$ denotes output in period $t+k$ for a firm that last reset its price in period t.

The relative price dispersion at time t is given by

$$\Delta^*_t = \int_0^1 \Big(\frac{P^*_{F,t}(i)}{P^*_{F,t}}\Big)^{-\Theta_p} di \tag{2.64}$$

The first-order condition associated with the problem above takes the following form:

$$\sum_{k=0}^{\infty} \lambda_p^k E_t \Big\{ \Lambda^*_{t,t+k} Q^*_{t+k|t} \Big(\tilde{P}^*_{F,t}(\Theta_p - 1) - \Theta_p \psi_{t+k|t} \Big) \Big\} = 0 \tag{2.65}$$

In the absence of price rigidities or costly price adjustments ($\lambda_p = 0$), we get the firm's optimal price setting condition under flexible prices; i.e., the firm sets its markup at the frictionless level of $\Theta_p/(\Theta_p - 1)$:

$$\tilde{P}^*_{F,t}(i) = \frac{\Theta_p}{\Theta_p - 1} \psi^*_{t|t} \tag{2.66}$$

As before, $\psi^*_{t+k|t}$ denotes the firm's nominal marginal cost. In the presence of nominal rigidities and costly price adjustments, the firm's actual markup gravitates toward its desired frictionless level over time. Under the assumption of constant returns to scale, marginal costs are independent of the level of production and therefore common across firms; hence we have $\psi^*_{t+k|t} = \psi^*_{t+k}$.

Consumption

There is a continuum of households indexed by $j \in [0,1]$ in the oil-importing country ROW. A representative household j maximizes the expected present discounted value of utility streams given by:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U^F(C_t^*) = \max E_0 \sum_{t=0}^{\infty} \beta^t \log(C_t^*) \tag{2.67}$$

where $\beta \in (0,1)$ is the household's discount factor.

The consumption basket is an aggregate of U.S.-produced goods and ROW-produced goods, and is defined as:

$$C_t^* = \Big[(1-b)^{\frac{1}{\eta}}(C_{H,t}^*)^{\frac{\eta-1}{\eta}} + b^{\frac{1}{\eta}}(C_{F,t}^*)^{\frac{\eta-1}{\eta}}\Big]^{\frac{\eta}{\eta-1}} \tag{2.68}$$

where b represents the home bias and η is the elasticity of substitution between U.S. and ROW baskets.

The budget constraint of the oil-importing foreign sector is given by the following set of equations:

$$C_t^* + \frac{B_{F,t}^*}{R_t^* P_t^*} + \frac{B_{o,t}^*}{\phi_{o,t}^* R_t^o P_t^*}\frac{e_{o,t}}{e_{F,t}} = \frac{B_{F,t-1}^*}{P_t^*} + \frac{B_{o,t-1}^*}{P_t^*}\frac{e_{o,t-1}}{e_{F,t-1}} + \frac{\Pi_t^*}{P_t^*} \tag{2.69}$$

where P_t^* satisfies

$$P_t^* = \Big[(1-b)(P_{H,t}^*)^{1-\eta} + b(P_{F,t}^*)^{1-\eta}\Big]^{\frac{1}{1-\eta}} \tag{2.70}$$

and the premium $\phi_{o,t}^* = \exp\Big(-\phi\Big(\frac{e_{o,t}B_{o,t}^*}{e_{F,t}P_{F,t}^*Q_t^*}\Big)\Big)$ again depends on the ratio of holdings of net foreign assets to nominal output.

The representative household in the oil-importing foreign sector maximizes (2.67) subject to (2.69) by optimally choosing $\{C_t^*, B_{H,t}^*, B_{F,t}^*\}$. The first-order conditions for the household gives an optimal allocation of expenditures between the U.S. and ROW goods implies:

$$C^*_{H,t} = (1-b)\Big(\frac{P^*_{H,t}}{P^*_t}\Big)^{-\eta} C^*_t \text{ and } C^*_{F,t} = b\Big(\frac{P^*_{F,t}}{P^*_t}\Big)^{-\eta} C^*_t,$$

$$E_t\Big[\beta R^*_t \frac{P^*_t}{P^*_{t+1}} \frac{C^*_t}{C^*_{t+1}}\Big] = 1$$

and

$$E_t\Big[\beta R^o_t \frac{P^*_t}{P^*_{t+1}} \frac{C^*_t}{C^*_{t+1}} \frac{e_{o,t}/e_{F,t}}{e_{o,t+1}/e_{F,t+1}}\Big] = 1$$

Here we assume that changes in the exchange rate are passed through immediately to the import and export prices, so that we have[11]

$$P_{H,t} = \varkappa_t e_t P^*_{H,t} \quad \text{and} \quad P_{F,t} = \varkappa_t e_t P^*_{F,t}$$

where $\varkappa_t$ is the shock to the terms of trade in the economy and is given as

$$\ln \varkappa_t = \rho_{\varkappa} \ln \varkappa_{t-1} + \epsilon_{\varkappa t} \tag{2.71}$$

The real exchange rate is defined as the relative price of the foreign consumption basket, $RER_t = \frac{e_t P^*_t}{P_t}$.

Aggregation

The aggregate production function is given by:

$$Q^*_t = \frac{Z^*_t}{\Delta^*_t}(O^*_t)^{\alpha^*_o} \tag{2.72}$$

The aggregate demand for imported oil by ROW is given by:

$$O^*_t = \int_0^1 O^*_t(i)di \tag{2.73}$$

where Δ^*_t is as defined in equation (2.64). The aggregate demand for oil input by the ROW is given by:

$$P^o_t O^*_t = \alpha^*_o \psi^*_t Q^*_t \Delta^*_t e_t \tag{2.74}$$

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[11] If law of one price holds, then $P_{H,t} = e_t P^*_{H,t}$ and $P_{F,t} = e_t P^*_{F,t}$

2.3.3 Oil-Exporting Foreign Sector

The oil-exporting country produces oil which is used as an input in the production of intermediate goods in the oil-importing countries outlined above. Unlike most works, which treat oil production as exogenous, we treat oil production and capital additions in the oil-producing country as endogenous. Our framework of endogenous oil production allows us to distinguish between the economic effects of oil supply shocks vis-a-vis the oil demand shocks.

Production

The oil production function in the oil-exporting country (OPEC) is given by

$$Q_{o,t} = Z_{o,t} K_{o,t} \tag{2.75}$$

where $Q_{o,t}$ is the oil production at time t and $K_{o,t}$ is the stock of capital at time t.

The capital stock of the oil exporting evolves according to the following equation:

$$K_{o,t+1} = (1 - \delta) K_{o,t} + I_{o,t} \tag{2.76}$$

where δ is the rate of depreciation for the OPEC capital stock. The investment good $I_{o,t}$ imported from the U.S.A. and ROW, is an aggregate of a continuum of differentiated goods from the two oil-importing countries, and is given by the following expression:

$$I_t^o = \left[(1/2)^{\frac{1}{\eta}} (I_{H,t}^o)^{\frac{\eta-1}{\eta}} + (1/2)^{\frac{1}{\eta}} (I_{F,t}^o)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{2.77}$$

with the price given by:

$$P_t^{opec} = \left[(1/2)(P_{H,t})^{1-\eta} + (1/2)(P_{F,t})^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{2.78}$$

The optimal allocation of expenditures between U.S. imports and ROW imports of investment goods implies

$$I_{H,t}^{o} = \frac{1}{2}\Big(\frac{P_{H,t}}{P_{t}^{opec}}\Big)^{-\eta} I_{o,t} \;\text{ and }\; I_{F,t}^{o} = \frac{1}{2}\Big(\frac{P_{F,t}}{P_{t}^{opec}}\Big)^{-\eta} I_{o,t}$$

The productivity of OPEC evolves exogenously according to

$$\ln Z_{o,t} = \ln \bar{Z}_{o} + \rho_{z_o} \ln Z_{o,t-1} + \epsilon_{z_o t}, \epsilon_{z_o t} \sim iidN(0, \sigma_{z_o}^{2}) \tag{2.79}$$

Note that OPEC's market power in oil production implies that OPEC enjoys a time-varying markup over its marginal cost which is given by:

$$\mu_{t}^{o} = \frac{\alpha_{O} \mathcal{K}_{t}^{\frac{1}{1-\alpha_{O}}} Z_{o,t}}{O_{t} \delta P_{t}^{opec}} = \frac{\alpha_{O}^{*} (\mathcal{K}_{t}^{*})^{\frac{1}{1-\alpha_{O}^{*}}} Z_{o,t}}{O_{t}^{*} \delta P_{t}^{opec}} \tag{2.80}$$

where the values of $\mathcal{K}_t$ and $\mathcal{K}_t^*$ are given as $\mathcal{K}_t = \frac{W_t^{\alpha_N} r_t^{\alpha_K} N_t^{\alpha_N} K_t^{\alpha_K}}{\alpha_N^{\alpha_N} \alpha_K^{\alpha_K}}$ and $\mathcal{K}_t^* = 1$, and total oil supply $Q_{o,t} = O_t + O_t^*$. Thus the higher the share of oil in production, i.e., the higher are α_O and α_O^* in the two oil-importing countries, the higher is oil markup. Conversely, the higher the oil production, the lower the oil price and therefore the lower the markup. The novelty of this analysis is modeling the oil-producing country with a time-varying markup over marginal cost. This is different from the conventional oil-price literature which treats all changes in oil price as exogenous.

Households

The oil-exporting country is populated by a representative household that maximizes an expected present discounted value of consumption utility streams given by:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^o) = \max E_0 \sum_{t=0}^{\infty} \beta^t \log(C_t^o) \tag{2.81}$$

The consumption good C_t^o is also imported from the oil-importing countries. Like the investment good $I_{o,t}$, it is an aggregate of the differentiated goods from the oil-importing countries, given in the following form:

$$C_t^o = \left[(1/2)^{\frac{1}{\eta}}(C_{H,t}^o)^{\frac{\eta-1}{\eta}} + (1/2)^{\frac{1}{\eta}}(C_{F,t}^o)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{2.82}$$

with the same price index (2.78) as before. The budget equation for oil exporter is given by:

$$P_t^{opec}C_t^o + P_t^{opec}I_{o,t} + \frac{B_t^o}{R_{o,t}} = \frac{P_t^o}{e_{o,t}}Q_{o,t} + B_{t-1}^o \tag{2.83}$$

The optimal allocation of expenditure between U.S. and ROW imports is given by

$$C_{H,t}^o = \frac{1}{2}\Big(\frac{P_{H,t}}{P_t^{opec}}\Big)^{-\eta}C_t^o \ \text{ and } \ C_{F,t}^o = \frac{1}{2}\Big(\frac{P_{F,t}}{P_t^{opec}}\Big)^{-\eta}C_t^o$$

Also maximization of (2.81) subject to (2.83) implies

$$C_t^o = \beta E_t\Big[\frac{C_{t+1}^o}{\frac{P_{t+1}^o}{P_{t+1}^{opec}}Z_{o,t+1} + (1-\delta)}\Big] \tag{2.84}$$

and

$$E_t\Big[\beta R_{o,t}\frac{P_t^{opec}}{P_{t+1}^{opec}}\frac{C_{o,t}}{C_{o,t+1}}\Big] = 1.$$

2.3.4 Market Clearing Conditions

In equilibrium, total oil production must equal total oil consumption. Thus the oil market equilibrium is given as:

$$Q_{o,t} = O_t + O_t^* \tag{2.85}$$

The equilibrium in the home (U.S.) goods implies

$$Q_t = C_{H,t} + I_{H,t} + b\Big(\frac{P_{H,t}}{P_t}\Big)^{-\eta}a(u_t)K_t^p + G_{H,t} + C_{H,t}^* + C_{H,t}^o + I_{H,t}^o \tag{2.86}$$

Equilibrium in the goods market of the oil-importing foreign country implies

$$Q_t^* = C_{F,t} + I_{F,t} + (1-b)\Big(\frac{P_{F,t}}{P_t}\Big)^{-\eta}a(u_t)K_t^p + C_{F,t}^* + C_{F,t}^o + I_{F,t}^o \tag{2.87}$$

U.S. GDP, which we denote by Y_t, is given by total sum of domestic consumption, domestic investment and government spending plus exports minus imports:

$$\begin{aligned} Y_t &= \Big(C_{H,t} + I_{H,t} + G_{H,t}\Big) + \Big(C^*_{H,t} + C^o_{H,t} + I^o_{H,t}\Big) \\ &\quad - \frac{P^o_t}{P_{H,t}} O_t - \frac{P_{F,t}}{P_{H,t}}\Big(C_{F,t} + I_{F,t} + (1-b)\Big(\frac{P_{F,t}}{P_{H,t}}\Big)^{-\eta} a(u_t) K^p_t\Big). \end{aligned} \tag{2.88}$$

Balanced trade implies the following relations must hold:

$$e_t B_{F,t-1} + P_{H,t} C^*_{H,t} = P_{F,t}\Big(C_{F,t} + I_{F,t} + (1-b)\Big(\frac{P_{F,t}}{P_t}\Big)^{-\eta} a(u_t) K^p_t\Big) + \frac{e_t B_{F,t}}{\phi_{F,t} R^*_t} \tag{2.89}$$

$$e_{o,t} B_{o,t-1} + P^o_t O_t = P_{H,t}(C^o_{H,t} + I^o_{H,t}) + \frac{e_{o,t} B_{o,t}}{\phi_{o,t} R_{o,t}} \tag{2.90}$$

$$e_{o,t} B^*_{o,t-1} + P^o_t O^*_t = P_{F,t}(C^o_{F,t} + I^o_{F,t}) + \frac{e_{o,t} B^*_{o,t}}{\phi^*_{o,t} R_{o,t}} \tag{2.91}$$

Here $\frac{P_{H,t}}{P_{F,t}}$ denotes the terms of trade (TOT). Bonds market equilibrium conditions imply the following:

$$B_{F,t} + B^*_{F,t} = 0 \tag{2.92}$$

and

$$B_{o,t} + B^*_{o,t} + B^o_t = 0. \tag{2.93}$$

2.4 Model Estimation

2.4.1 Empirical Methodology

The equations listed in the previous section represent agents' behavior and identities that altogether form a non-linear system. This includes the first-order conditions of households and firms in the three countries, agents' budget constraints, the monetary policy rule and equations describing the exogenous processes which drive the economy.

In order to estimate the model, we start by focusing on the symmetric equilibrium for prices and quantities. We derive all the log-linearized equations of the model by taking log-linear approximations around the deterministic steady state. The derivations of the steady-state equations and the complete log linearized model are given in the appendix.

We adopt the empirical approach outlined in An and Schorfheide (2007), Smets and Wouters (2003) and estimate the model outlined above by employing Bayesian inference methods. Increasingly popular in the field of macroeconomics, Bayesian estimation involves obtaining the joint posterior distribution of the model's structural parameters based on its log-linear state-space representation. There are a multitude of advantages of using Bayesian methods to estimate a model. First, unlike GMM estimation of monetary policy rules and first-order conditions, the Bayesian analysis is system-based and fits the solved DSGE model to a vector of aggregate time series. Second, the estimation is based on the likelihood function generated by the DSGE model rather than, for instance, the discrepancy between DSGE model impulse response functions and identified VAR impulse responses as in Rotemberg and Woodford (1996) and Christiano, Eichenbaum and Evans (2005). Third, prior distributions can be used to incorporate additional information into the parameter estimation.

In the following, we briefly sketch our adopted approach and describe the data and the prior distributions used in its implementation. In this context, we also provide information on the structural shocks considered in the estimation, and describe the calibration of those parameters that we keep fixed. We then present our estimation results.

Employing Bayesian inference methods allows formalizing the use of prior empirical or theoretical information from earlier studies at both the micro and macro level in estimating the parameters of a possibly complex DSGE model. Additionally, Bayesian inference provides a natural framework for parameterizing and evaluating simple macroeconomic models that are likely to be fundamentally misspecified. As pointed out by Fernandez-Villaverde and Rubio-Ramirez (2004) and Schorfheide (2000), the inference problem is not to determine whether the model is "true" or to find the "true" value of a particular parameter, but rather to determine which set of parameter values maximize the model's ability to summarize the regular features of the data. From a practical perspective, Bayesian inference may also help to alleviate the inherent numerical difficulties associated with solving highly non-linear estimation problems.

Given the data, Bayesian estimation requires the construction of the posterior density of the parameters of interest. If we write θ for the set of parameters to be estimated through observations on a set of variables Y, the posterior density can be defined as $p(\theta|Y)$ the probability distribution of θ conditional on having observed the data Y. The posterior density forms the basis for inference in the Bayesian framework. Following Bayes's rule, the posterior density is proportional to the product of the prior density $p(\theta)$ with the distribution of the data given the parameter set, $f(Y|\theta)$:

$$p(\theta|Y) = \frac{p(\theta)f(Y|\theta)}{f(Y)}$$

where $f(Y)$ is the marginal distribution of the data. The conditional distribution function of the data given the parameter set, $f(Y|\theta)$, is equivalent to the likelihood function of the set of parameters given the data, $\mathcal{L}(\theta|Y)$. The likelihood function can be calculated from the state-space representation of the model using the Kalman Filter (see Ljungqvist and Sargent (2004) for details). Bayesian inference therefore requires (i) the choice of prior densities for the parameters of interest, and (ii) construction of the posterior from the prior densities and the likelihood function. The remainder of this section discusses briefly how to construct the posterior distribution. The choice of prior distribution is discussed later, together with the estimation results.

Given the likelihood function and a set of prior distributions, an approximation to the posterior mode of the parameters of interest can be calculated using a Laplace approximation. The posterior mode obtained in this way is used as the starting value for the Metropolis-Hastings algorithm. This algorithm allows us to generate draws from the posterior density $p(\theta|Y)$. At each iteration, a proposal density (a normal distribution with mean equal to the previously accepted draw) is used to generate a new draw, which is accepted as a draw from the posterior density $p(\theta|Y)$ with probability p.

As discussed in Geweke (1999), Bayesian inference also provides a framework for comparing alternative, not necessarily nested, and potentially misspecified models on the basis of their marginal likelihood. For a given model m, the marginal likelihood is computed by integrating out the parameter vector θ from the likelihood function:

$$\mathcal{L}(Y|m) = \int_{\theta\in\Theta} \mathcal{L}(Y|\theta, m)p(\theta|m)d\theta.$$

Thus, the marginal likelihood gives an indication of the overall likelihood of the observed data conditional on a model.

2.4.2 Data and Shocks

In estimating the model, we use quarterly time series for 12 macroeconomic variables for the U.S. economy and also data on nominal oil prices (West Texas Intermediate Crude) for two different samples: 1960Q1-1983Q4 and 1984Q1-2008Q1. The chosen break date corresponds roughly to the beginning of the Great Moderation in the United States, as identified by several authors, e.g. McConnell and Pérez-Quirós (2000).

We choose the following 12 observable variables: real GDP, real consumption, investment, government spending, total hours worked, real wages, CPI inflation, GDP deflator inflation, Federal funds rate, nominal price of West Texas Intermediate Crude, nominal exchange rate, U.S. crude oil imports. Real GDP, real consumption, investment, government spending, total oil imports and total hours worked are converted to per-capita quantities by dividing by the U.S. population over 16 years. The monthly data for CPI inflation rate, Federal Funds rate and the crude oil imports are converted to their quarterly values.

All series are seasonally adjusted. The details of the data and the corresponding sources are given in Table A.1 in the Data Appendix. In order to work with stationary series, we detrend all variables except hours worked and Federal Funds rate using log differences. We also demean all variables.

2.4.3 Calibrated Parameters

We partition the set of parameters in our log-linearized DSGE model into two subsets, namely those parameters or ratios that are calibrated and those that are estimated. The calibrated parameters are those for which solid evidence indicates their selection through calibration exercise.

We set our model period equal to one quarter, and fix the calibrated parameters as follows: We assume that the household discount factor $\beta = (1.03)^{-0.25}$, implying a steady state annualized real interest rate of 3 percent. We set $\alpha_N = 0.64$, which corresponds to a steady-state share of labor income roughly equal to 64 percent. We estimate the capital share α_K and oil share α_o separately for the two different samples described before.

As in Rotemberg and Woodford (1996), we set the value of the parameter α, which is the expected rate of growth of market share, to 0.89.

The depreciation rate of capital we take to be $\delta = 0.025$, consistent with an annual depreciation rate of 10 percent. Also we set the value of $\bar{\mu}_p$, the steady state markup, to 1.15.

We set the steady-state government share of output to 20 percent as in the data and the value of elasticity of substitution between domestic and foreign goods $\eta = 1.5$, a standard value used in macro literature [Chari et. al. (2002)].

The value of the home-bias b is chosen to be equal to 0.8 to match the steady-state U.S. export-to-GDP ratio of 18 percent and import-to-GDP ratio of 21 percent.

Following Smets and Wouters (2007), we choose Θ_w, which is the steady-state value of elasticity of substitution between different labor varieties, to be equal to 10.

Next we need to define a value for γ, inverse of the labor supply elasticity, which is not universally fixed in the literature. Gali and Monacelli (2005) give a value of 3. Yun (1996) gives a value of 4, whereas micro-evidence shows a value of 0.6. [Greenwood et.al. (1998)]. We choose $\gamma = 1$, the value reported by Christiano, Eichenbaum and Evans (2005) and Barsky et.al (2003). Table 2.1 gives a detailed overview of the calibrated parameters of the model.

Table 2.1: Calibrated parameters

Parameter	Mechanism	Value
β	Discount Factor	$(1.03)^{-0.25}$
α	Rate of growth of market share	0.89
γ	Frisch Elasticity	1
α_N	Labor share in production	0.64
$\bar{\mu}_p$	Steady State Markup	1.15
δ	Depreciation rate	0.025
b	Home Bias	0.8
Θ_w	Steady state elasticity of subs between labor	8
η	Elasticity of subs between home and foreign goods	1.5

2.4.4 Prior Distribution of Estimated Parameters

Bayesian inference starts from a prior distribution of the model's non-calibrated parameters, describing the available information prior to observing the data used in the estimation. The observed data is then used to update the priors, via Bayes's theorem, to the posterior distribution of the model's parameters. This distribution may be summarized in terms of the usual measures of location (e.g. mode and mean) and spread (e.g. standard deviation and probability intervals).

Thus in order to implement the Bayesian strategy, we must first specify the prior distribution of the parameters we want to estimate, as well as the values for parameters describing the stochastic processes of the exogenous driving forces.

The location of the prior distribution of the 35 parameters we estimate corresponds to a large extent to those in Smets and Wouters (2007) and other studies on open economy models for the U.S. (as in Backus and Crucini (2000)). For all parameters bounded between 0 and 1, we use the beta distribution. This consequently applies to the nominal wage and price stickiness parameters and also the persistence parameters of the shock processes.

For parameters assumed to be positive, such as the standard deviations of the shocks, substitution elasticities between goods and labor, and markup, we use inverse gamma distribution.

Table 2.4 give an overview of our assumptions regarding the prior distributions of the estimated parameters. All the variances of the shocks are assumed to be distributed as an inverse Gamma distribution with a degree of freedom equal to 2.

The distribution of the autoregressive parameters is assumed to follow a Beta distribution with mean 0.90 and standard error 0.05.

For the oil share parameter, α_o, the prior follows beta and corresponds to the values obtained from the estimates based on U.S. data. Estimates suggest a value of roughly 0.04 for the period 1960-1983 and then a reduced oil share of about 0.02 during 1984-2008. These estimates are in line with other studies of oil price shocks on the U.S. economy. (Blanchard and Gali (2008), Backus and Crucini (2000))

As in Smets and Wouters (2007), the parameters describing the monetary policy rule are based in a standard Taylor rule: the policy reaction coefficients of inflation and output are described by a Normal distribution with mean 1.5 and 0.125 (0.5 divided by 4) and standard errors 0.125 and 0.05 respectively. The persistence of the policy rule is determined by the coefficient on the lagged interest rate, which is assumed to be

Normally distributed around a mean of 0.75 with a standard error of 0.1.

The value of the risk premium on net foreign assets is assumed to be gamma with mean 0.001 and standard deviation 0.001, based on values reported in Backus and Crucini (2000).

The prior on the adjustment cost parameter for investment is set around 4 with a standard error of 1.5 (based on Christiano, Eichenbaum and Evans (2005)), and the capacity utilization elasticity is set at 0.5 with standard error of 0.15.

Finally we need to specify the parameters describing the wage and price setting. The Calvo probabilities are assumed to be around 0.75 with standard errors equal to 0.10 for both prices and wages, suggesting an average length of price and wage contracts of three quarters. This is comparable with the findings in Nakamura and Steinsson (2008) for prices.

2.5 Results

2.5.1 Posterior Distributions

We estimate the model using the Bayesian estimation module in DYNARE [Julliard (2001)]. Once priors have been specified, DYNARE estimates the model by first computing the posterior mode, then constructing the posterior distribution with the Metropolis-Hastings algorithm. Tables 2.4, 2.5, 2.6,2.7, 2.8 and 2.9 present the coefficient estimates of the model's structural parameters, as well as the persistence and standard deviations of the shock processes.

In this section, we first describe the coefficient estimates of the model's structural parameters for the post-1984 sample, and then compare with the pre-1984 sample estimates. Overall our model yields plausible estimates of the parameters, which are broadly in line with results from previous studies.

The estimate of the parameter governing the share of oil (oil intensity) in production, α_O, equals 0.039 in the pre-1984 sample. For the post-1984 sample, the estimate of this parameter decreases to 0.018. These values are very close to the ones reported in Blanchard and Gali (2008).

Turning to the behavioral parameters, the estimate of the Calvo parameter governing the wage rigidity equals 0.849 in the pre-1984 sample. The Calvo wage parameter for the post-1984 sample equals 0.819, suggesting an increase in the frequency of wage adjustment in the U.S. economy. This result is in line with Blanchard and Gali (2007) and Blanchard and Gali (2008), who claim that labor markets have become more flexible in the U.S. economy. It is well known that the 1960s and 1970s were times of strong unions, and high wage indexation. Currently, unions are much weaker, and wage indexation has practically disappeared, particularly in the private sector.

As regards the mode of the Calvo parameter governing the frequency of price adjustment, we also see that the post-1984 value of 0.881 is smaller than the pre-1984 value of 0.814, suggesting an increased price flexibility. This could be the result of increased import penetration that has made competition more intense and prices more flexible in recent decades. It is true that our degree of price rigidity is somewhat higher than for wage rigidity. Our estimate of the degree of price rigidity, although slightly on the higher side, is close to the Smets and Wouters (2007) estimates. However our measure of inflation is based on the GDP deflator, which consists of producer prices, which are stickier than consumer prices. In this regard, our estimate of the degree of price rigidity, and suggests a median duration of price changes of roughly four quarters, which is not too far above Nakamura and Steinsson (2008) estimates of three quarters for consumer prices.

With respect to the monetary policy, we make three important observations: first, the mode of the inflation policy coefficient is larger in the post-1984 sample (2.033 in post-1984 sample, as opposed to 1.259 in the pre-1984 sample). This reflects the strong anti-inflationary monetary policy stance of the Federal Reserve in the post-1984 period (Volcker-Greenspan period), and agrees with studies by both Clarida, Gali and Gertler (1999) and Orphanides (2001). Second, the coefficient of the output gap is also higher (0.214 in post-1984 as compared to 0.140 in the pre-1984 period). This result is consistent with Clarida, Gali and Gertler (1999), and does not support the Orphanides (2001) hypothesis of activist monetary policy in the pre-Volcker regime. Third, the interest rate smoothing parameter is higher in the second sample (0.859 in the post-1984 period) than in the first sample (0.844 in the pre-1984 period).

The estimate of the response of the markup to the ratio of expected discounted profits to current output also declines in the post-1984 sample. Our estimates suggest that the coefficient of the response of markup to the ratio of discounted profit is 0.054 in the pre-1984 sample and 0.029 in the post-1984 sample. This reduction in the coefficient coincides with the conjecture in Rotemberg and Woodford (1996). The positive value of the markup response coefficient suggests a countercyclical markup, in line with studies based on the U.S. economy.

Regarding the estimated stochastic process of the other structural shocks, the autocorrelation of the foreign technology shock is very high in both samples. The autocorrelation of the domestic technology shock and the household preference shocks are also high (of the order of 0.90). The volatility of the domestic technology shock is significantly reduced in the post-1984 period (0.121 during the pre-1984 period and 0.089 in the post-1984 period).

The standard deviation of the labor supply shock is the highest in both samples (1.601 in the pre-1984 sample and 2.109 in the post-1984 sample). The volatility wage markup shock is 0.095 in pre-1984 sample and 1.131 in the post-1984 sample. The standard deviation of the technology shock is estimated to be rather small 0.121 in the pre-1984 sample and 0.089 in the post-1984 sample. This low value can be rationalized by the introduction of variable capacity utilization, which is expected to lower the value of this coefficient as argued in King and Rebelo (2000). Finally, the standard deviation of the interest rate shock is lower in the second sample (0.018 in pre-1984 sample and 0.011 in the post-1984 sample), suggesting a more erratic monetary policy in the pre-1984 period.

Table 2.3 shows that the estimated model does a fairly good job in matching the second moments and the post-1984 volatility reduction of the variables of interest. The model slightly overestimates the volatility of GDP growth in both periods, but effectively matched the post-1984 reduction in volatility. The volatility and its reduction is very well matched for both CPI inflation and also GDP deflator inflation in both the pre- and post-1984 samples. In addition, the model clearly shows an increase in the volatility of real wages. This supports our estimate of a more flexible wage given by a reduction in the wage stickiness parameter (wage Calvo parameter) in the post-1984 sample.

Table 2.2: Tests for equality of parameters in the two samples.

Test	p-value	degrees of freedom
Wald test for all parameters	7.84×10^{-4}	34
Wald test for structural parameters	3.02×10^{-4}	10
LR test for all parameters	7.15×10^{-4}	34

Table 2.3: Second moments of observed variables in data and model.

	1960Q1:1983Q4		1984Q1:2008Q1		Percentage Change	
Variable	Data	Model	Data	Model	Data	Model
$\Delta \ln Y_t$	1.092	1.112	0.631	0.662	-42.22	-40.47
$\pi_{H,t}$	0.711	0.694	0.267	0.242	-66.10	-65.13
π_t	0.913	0.860	0.503	0.498	-44.91	-42.09
$\Delta \ln C_t$	0.841	0.876	0.548	0.574	-34.84	-34.48
$\Delta \ln I_t$	5.473	6.002	3.742	4.238	-31.63	-29.39
$\Delta \ln(W_t/P_t)$	0.587	0.614	0.832	0.846	41.74	37.79
L_t	2.913	2.811	4.162	3.911	42.88	39.13
R_t	14.592	13.757	6.844	6.531	-53.10	-52.53
$\Delta \ln P_t^o$	14.743	14.115	14.309	13.822	-2.94	-2.08
$\Delta \ln O_t$	13.031	12.886	14.419	14.094	10.65	9.37

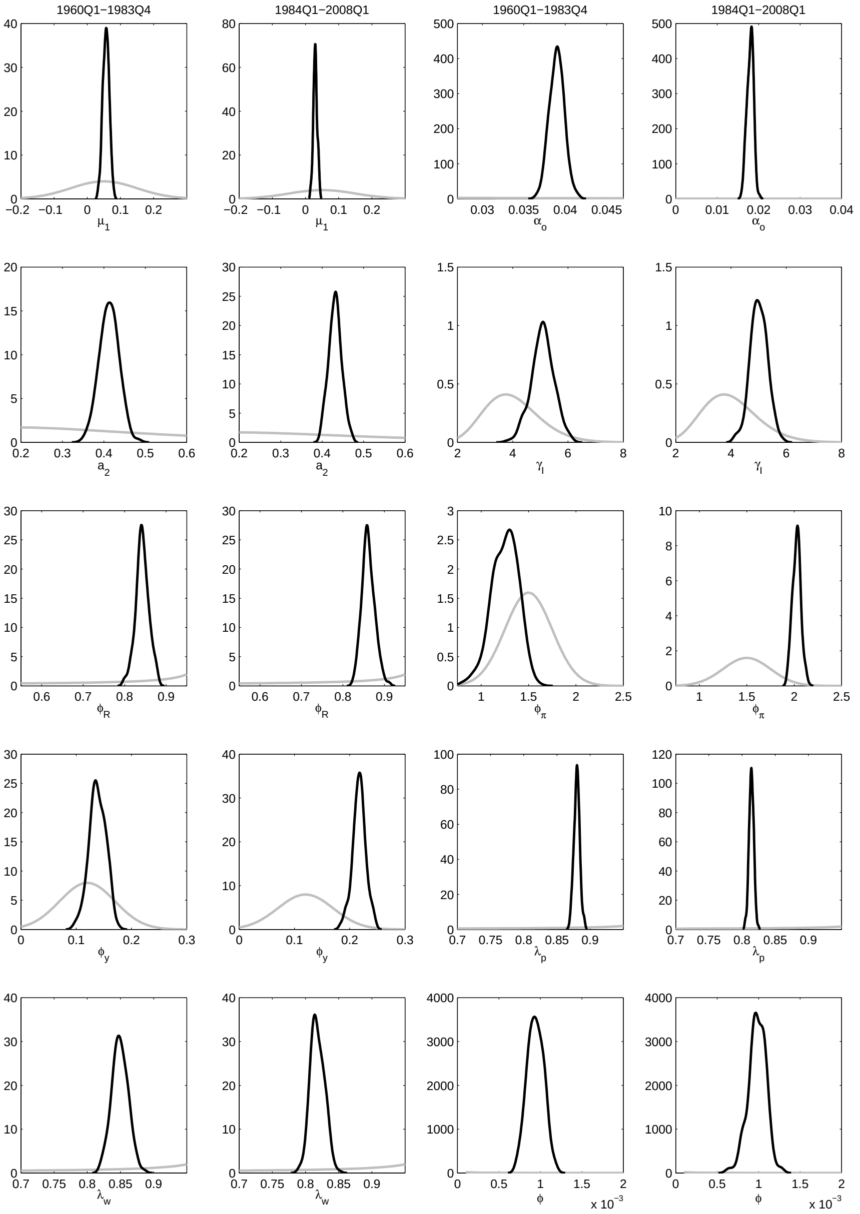

Figure 2.4: Prior(gray) and posterior(black) distributions of the estimated structural parameters

Table 2.4: Prior and posterior distributions of structural parameters:1960Q1-1983Q4

	Prior Distribution			Posterior Distribution				
Param.	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
μ_1	Normal	0.05	0.10	0.054	0.057	0.010	0.041	0.073
α_O	Beta	0.037	0.01	0.039	0.039	9.4×10^{-4}	0.038	0.041
a_2	Gamma	0.428	0.10	0.414	0.413	0.022	0.377	0.449
γ_I	Gamma	4	1	4.992	5.036	0.399	4.380	5.692
ϕ_R	Beta	0.75	0.10	0.844	0.842	0.015	0.817	0.867
ϕ_π	Normal	1.50	0.25	1.259	1.254	0.128	1.043	1.465
ϕ_y	Normal	0.12	0.05	0.140	0.139	0.016	0.113	0.165
λ_p	Beta	0.75	0.10	0.881	0.880	4.7×10^{-3}	0.872	0.888
λ_w	Beta	0.75	0.10	0.849	0.850	0.012	0.830	0.870
ϕ	Gamma	10^{-3}	5×10^{-4}	9.1×10^{-4}	9.4×10^{-4}	1×10^{-4}	8×10^{-4}	1.1×10^{-3}

Table 2.5: Prior and posterior distributions of structural parameters:1984Q1-2008Q1

	Prior Distribution			Posterior Distribution				
Param.	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
μ_1	Normal	0.05	0.10	0.029	0.030	6.1×10^{-3}	0.020	0.040
α_O	Beta	0.020	0.01	0.018	0.018	8.3×10^{-4}	0.017	0.019
a_2	Gamma	0.428	0.10	0.430	0.431	0.015	0.406	0.456
γ_I	Gamma	4	1	5.010	5.006	0.301	4.511	5.501
ϕ_R	Beta	0.75	0.10	0.859	0.860	0.015	0.835	0.885
ϕ_π	Normal	1.50	0.25	2.033	2.029	0.046	1.953	2.105
ϕ_y	Normal	0.12	0.05	0.214	0.216	0.011	0.198	0.234
λ_p	Beta	0.75	0.10	0.814	0.814	3.4×10^{-3}	0.808	0.820
λ_w	Beta	0.75	0.10	0.819	0.818	0.010	0.802	0.834
ϕ	Gamma	10^{-3}	5×10^{-4}	9.6×10^{-4}	9.8×10^{-4}	1×10^{-4}	7.9×10^{-4}	11.3×10^{-4}

Table 2.6: Prior and posterior distributions of shock processes:1960Q1-1983Q4

	Prior Distribution			Posterior Distribution				
Parameters	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
			Standard Deviations					
Labor Supply	InvGamma	0.10	∞	1.601	1.586	0.345	1.019	2.154
Terms of Trade	InvGamma	0.10	∞	0.032	0.035	2.8×10^{-3}	0.030	0.040
Investment	InvGamma	0.10	∞	0.211	0.201	0.035	0.143	0.259
Price Markup	InvGamma	0.10	∞	0.181	0.190	0.019	0.159	0.221
Government	InvGamma	0.10	∞	0.024	0.025	2.1×10^{-3}	0.022	0.029
Oil Technology	InvGamma	0.10	∞	0.167	0.170	0.011	0.152	0.188
Foreign Technology	InvGamma	0.10	∞	0.057	0.057	4.6×10^{-3}	0.054	0.060
Interest Rate	InvGamma	0.10	∞	0.018	0.018	1.7×10^{-3}	0.015	0.021
Wage Markup	InvGamma	0.10	∞	0.095	0.095	2.3×10^{-3}	0.091	0.099
Risk Premium	InvGamma	0.10	∞	0.018	0.018	1.1×10^{-3}	0.016	0.020
Preference	InvGamma	0.10	∞	0.045	0.044	7.3×10^{-3}	0.032	0.056
Domestic Technology	InvGamma	0.10	∞	0.121	0.126	9.3×10^{-3}	0.111	0.141

Table 2.7: Prior and posterior distributions of shock processes:1960Q1-1983Q4

	Prior Distribution			Posterior Distribution				
Parameters	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
		Autoregressive Coefficients						
Labor Supply	Beta	0.85	0.1	0.834	0.835	0.020	0.802	0.868
Terms of Trade	Beta	0.85	0.1	0.939	0.938	8.7×10^{-3}	0.924	0.954
Investment	Beta	0.85	0.1	0.760	0.761	0.031	0.710	0.812
Price Markup	Beta	0.85	0.1	0.871	0.869	0.013	0.848	0.890
Government	Beta	0.85	0.1	0.951	0.950	0.011	0.932	0.969
Oil Technology	Beta	0.85	0.1	0.934	0.934	0.029	0.886	0.982
Foreign Technology	Beta	0.85	0.1	0.960	0.964	4.6×10^{-3}	0.956	0.971
Interest Rate	Beta	0.85	0.1	0.390	0.387	0.039	0.323	0.451
Wage Markup	Beta	0.85	0.1	0.920	0.910	0.047	0.833	0.987
Risk Premium	Beta	0.85	0.1	0.921	0.920	0.011	0.902	0.938
Preference	Beta	0.85	0.1	0.940	0.935	3.3×10^{-3}	0.930	0.940
Domestic Technology	Beta	0.85	0.1	0.910	0.914	8.6×10^{-3}	0.900	0.928

Table 2.8: Prior and posterior distributions of shock processes:1984Q1-2008Q1

	Prior Distribution			Posterior Distribution				
Parameters	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
				Standard Deviations				
Labor Supply	InvGamma	0.10	∞	2.109	2.067	0.588	1.100	3.034
Terms of Trade	InvGamma	0.10	∞	0.041	0.040	3.1×10^{-3}	0.035	0.045
Investment	InvGamma	0.10	∞	0.100	0.106	0.019	0.075	0.137
Price Markup	InvGamma	0.10	∞	0.181	0.184	0.016	0.158	0.210
Government	InvGamma	0.10	∞	0.014	0.013	1.5×10^{-3}	0.011	0.016
Oil Technology	InvGamma	0.10	∞	0.158	0.161	0.011	0.143	0.179
Foreign Technology	InvGamma	0.10	∞	0.054	0.051	4.2×10^{-3}	0.044	0.060
Interest Rate	InvGamma	0.10	∞	0.011	0.010	2.3×10^{-3}	6.2×10^{-3}	0.014
Wage Markup	InvGamma	0.10	∞	0.131	0.138	0.011	0.120	0.157
Risk Premium	InvGamma	0.10	∞	0.009	0.010	1.9×10^{-3}	0.007	0.013
Preference	InvGamma	0.10	∞	0.026	0.023	4.6×10^{-3}	0.015	0.031
Domestic Technology	InvGamma	0.10	∞	0.089	0.086	7.3×10^{-3}	0.074	0.098

Table 2.9: Prior and posterior distributions of shock processes:1984Q1-2008Q1

	Prior Distribution			Posterior Distribution				
Parameters	Distribution	Mean	Std Dev	Mode	Mean	Std Dev	5%	95%
		Autoregressive Coefficients						
Labor Supply	Beta	0.85	0.1	0.794	0.799	0.022	0.763	0.835
Terms of Trade	Beta	0.85	0.1	0.869	0.871	0.017	0.843	0.899
Investment	Beta	0.85	0.1	0.704	0.710	0.031	0.659	0.761
Price Markup	Beta	0.85	0.1	0.806	0.801	0.022	0.765	0.837
Government	Beta	0.85	0.1	0.981	0.982	4×10^{-3}	0.980	0.984
Oil Technology	Beta	0.85	0.1	0.930	0.931	0.027	0.887	0.975
Foreign Technology	Beta	0.85	0.1	0.949	0.951	0.011	0.933	0.969
Interest Rate	Beta	0.85	0.1	0.339	0.343	0.029	0.295	0.391
Wage Markup	Beta	0.85	0.1	0.919	0.903	0.040	0.837	0.969
Risk Premium	Beta	0.85	0.1	0.937	0.934	0.013	0.913	0.955
Preference	Beta	0.85	0.1	0.959	0.961	0.014	0.938	0.984
Domestic Technology	Beta	0.85	0.1	0.904	0.900	0.010	0.884	0.916

2.5.2 Impulse Responses

In this section we will present the results of the set of impulse responses corresponding to the six shocks of our model: oil supply shock, U.S. growth shock, foreign growth shock, U.S. government spending shock, U.S. investment shock and U.S. preference shock. The black solid lines in the figures are the point estimates for the impulse responses, shown separately for the pre-1984 and post-1984 samples. The shaded areas represent the corresponding 90% credible intervals or Bayesian confidence intervals. The impulse responses shown in the figures depict the reaction of real GDP, interest rate, CPI, real consumption, price markup, labor hours, nominal wage, real investment, foreign bond holdings, oil price and oil import to each of the shocks described above. In depicting the impulse responses, we distinguish between the two periods, 1960Q1-1983Q4 and 1984Q1-2008Q1. All shocks are adjusted such that they lead to a 10% rise in the nominal oil price on impact.

The qualitative features of the responses presented in the figures are very interesting to note. We will first analyze the oil price shocks that originates from events outside the United States. Let us consider a negative oil supply shock triggered by political tensions, or supply manipulations by oil exporting countries, such that oil prices rise 10% on impact. If we condition the impulse responses in such a way that the surge in oil price is triggered by the same source in both samples and that the price changes by the same amount, we are interested in how the responses vary across samples. As expected, the oil price shock generates inflationary and recessionary pressures. However the drop in GDP is not significantly different between the samples. The drop in consumption and the rise in labor hours is also similar in the two samples, as is the increase in nominal wage. The impulse response functions for the GDP deflator and CPI are slightly lower in the second sample, but are contained within the confidence band for the first sample.

On impact, the drop in GDP in the pre-1984 sample is 1.5% while in the drop in GDP in the post-1984 sample is about 1.3%. The values for drop in consumption in the two samples are very similar at around 0.07%, and the values for GDP deflator and CPI inflation also yield similar results. The difference in the samples is even less when we consider real oil price shock. Our results stand in contrast with those of Blanchard and Gali (2008), who observed empirically that the effects of a given change in the price of oil have changed substantially over time. Their estimates point to much larger effects of oil price shocks on inflation and economic activity in the pre-1984 sample. Our findings show that the responses of some of the major macro variables are not markedly different when an oil price spike is triggered by the same event in the two samples.

Another interesting thing to note here is that our specification of the endogenous elasticity of substitution shows that the rise in markup following an oil price increase is larger in the first sample as compared to the second (about 0.8% in the first sample and 0.2% in the second sample). This result confirms the conjecture in Rotemberg and Woodford (1996) of countercyclical markup following an oil shock, but is in contrast to the perspective of Blanchard and Gali (2008), according to them the endogenous change in the markup following an oil price increase had no effect in the transmission of oil shocks.

Next we consider an oil price shock induced by growth in the rest of the oil-importing world. The respective drops in GDP in the two samples are very similar at about 0.04% on impact. The GDP deflator increases by 0.06% in the first sample and by about 0.05% on impact in the second sample. The rise in CPI in the first sample is 0.05% and in the second sample is 0.04%. The muted response of CPI in the second sample can be attributed largely to the Greenspan-Bernanke inflation targeting policy regime. Also notable is the rise in the price markup following a rise in oil price - in the first sample markup rises by 1.5% whereas the rise in markup in the second sample is only about 0.9%. The results are very similar at around 10% when we consider real oil price shock and one standard deviation oil supply shock.

Our next focus is the case when a 10% oil price increase occurs due to growth in the U.S. economy caused by a technology shock. Because of the technology shock, output increases in both samples; interestingly the increase in output in both is similar at 1.2%. The drop in the GDP deflator and the CPI inflation are also the same in both samples, and both these quantities fall by 0.75% in the two samples. As U.S. production increases, demand for oil increases, which leads to an increase in the price of oil. Induced by the technology shock, oil import increases, but the increase during the pre-1984 sample is twice as much as during the post-1984 sample. In the pre-1984 sample oil import increases by 0.02% and in the post-1984 sample oil import increases by 0.01%. This reduction in oil import can be attributed to the increased oil efficiency in the U.S. economy in the post-mid-1980s. Note that in the second sample, the reduced oil demand is sufficient to generate a 10% increase in oil price since the oil supply has become more inelastic over time. Several explanations can be advanced in this regard, "peak oil" being one of the major explanations.

The increase in oil import leads to an increase in oil price, and we have a canonical oil supply shock. As oil price increases, GDP falls, and inflation rises. However the strength of this oil shock is not enough to bring down U.S. GDP growth to below zero. Also while real wage falls in the canonical oil supply shock, in an oil shock triggered by U.S. growth, real wage actually increases. In canonical supply shock, as GDP falls, price rises, therefore real wage falls.The notable difference between the samples is in the drop in the price markup, which is significantly larger in the first sample than in the second, again confirming the conjecture of the presence of countercyclical markup as in the U.S. economy. But the countercyclicality seems to have weakened substantially between the samples. One possible reason for this is the increased price flexibility.

Finally, we consider the case of U.S. households' preference shock, such that oil price increases by 10% on impact. Due to the preference shock, GDP increases in the two samples because of increased consumption demand, but the increase is very similar, about 4.5% in both samples. Increase in demand similarly causes the CPI to increase in both samples by about 2%. Oil import rises with production, but this rise is higher in the pre-1984 sample (about 0.025% in the pre-1984 sample and 0.015% in the post-1984 sample). Again this decrease in oil import between the two samples can be attributed to the increase in oil efficiency of the U.S. economy. As oil import increases, oil price increases. Once oil price increases, GDP falls, but the strength of the oil shock induced by preference shock is not sufficient to cause a negative growth of output.

2.5.3 Variance Decomposition and Historical Decomposition

Table 2.10 decomposes the forecast error variances in real GDP, CPI inflation, real wage, price markup and oil price into each of the 12 shocks described before. In doing so, we distinguish between the two periods considered, 1960Q1-1983Q4 and 1984Q1-2008Q1. The purpose is to make a formal assessment of the contribution of each structural shock

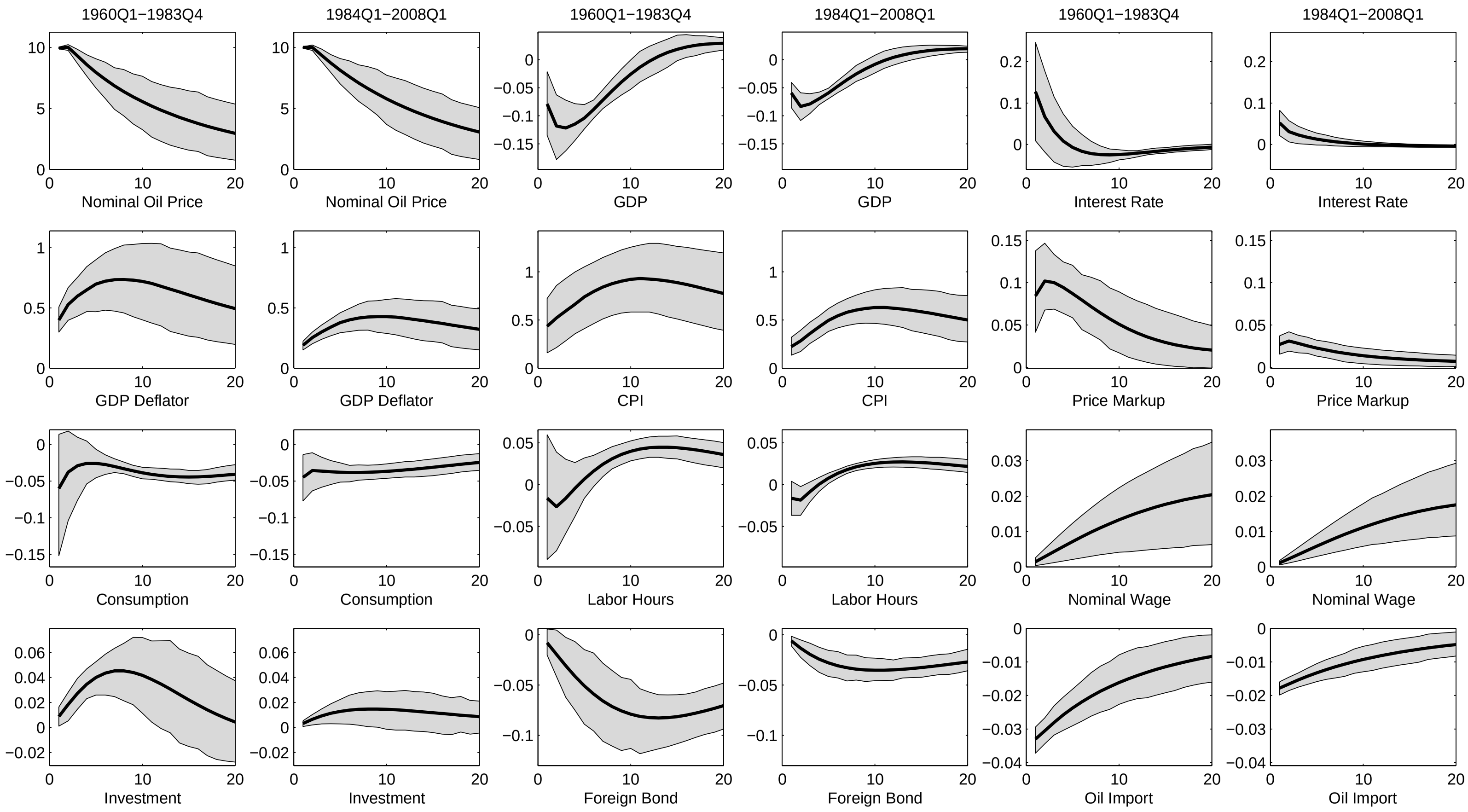

Figure 2.5: Impulse responses to oil technology shock resulting in 10% increase in nominal oil price.

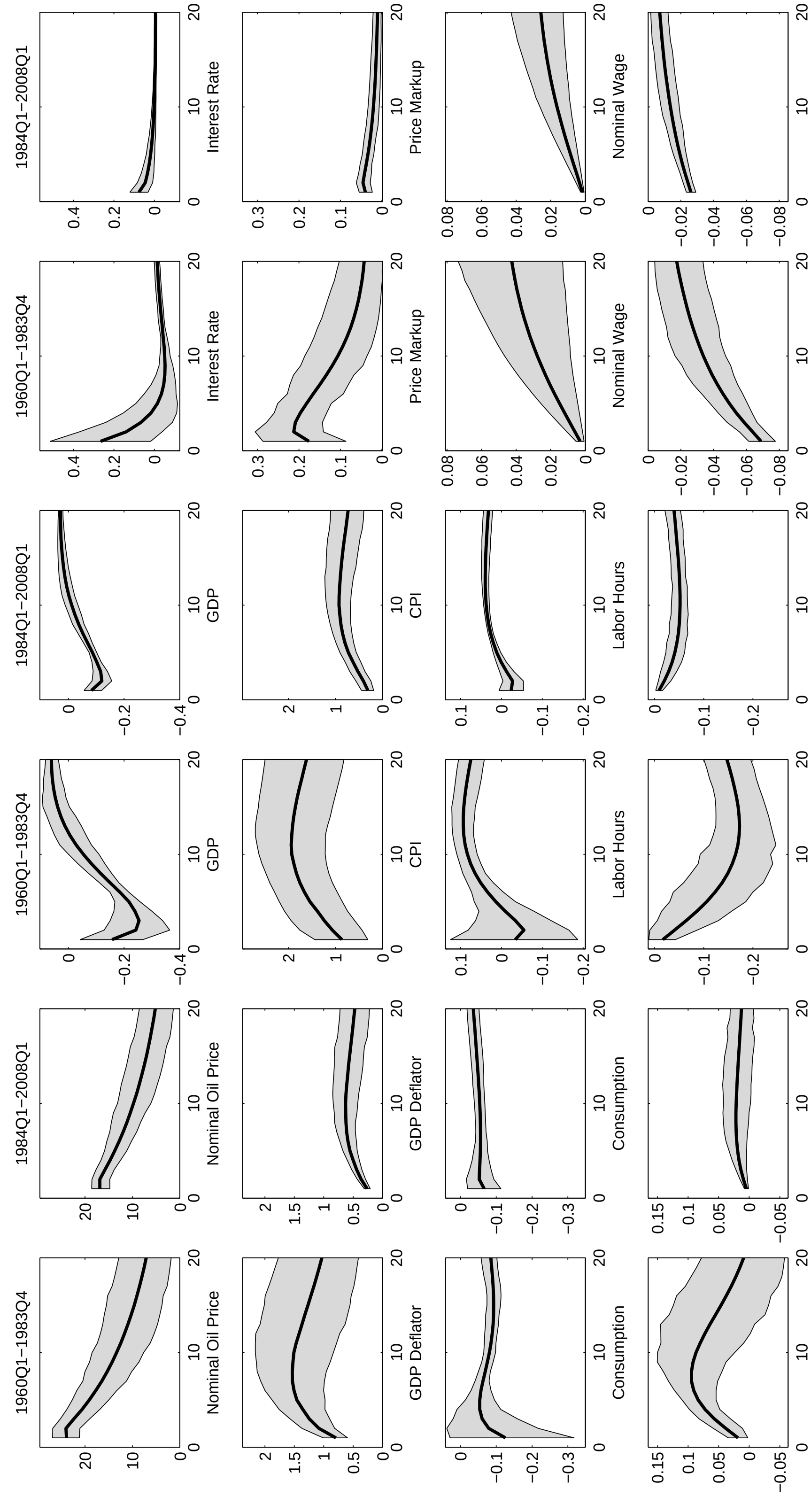

Figure 2.6: Impulse responses to one standard deviation negative oil technology shock.

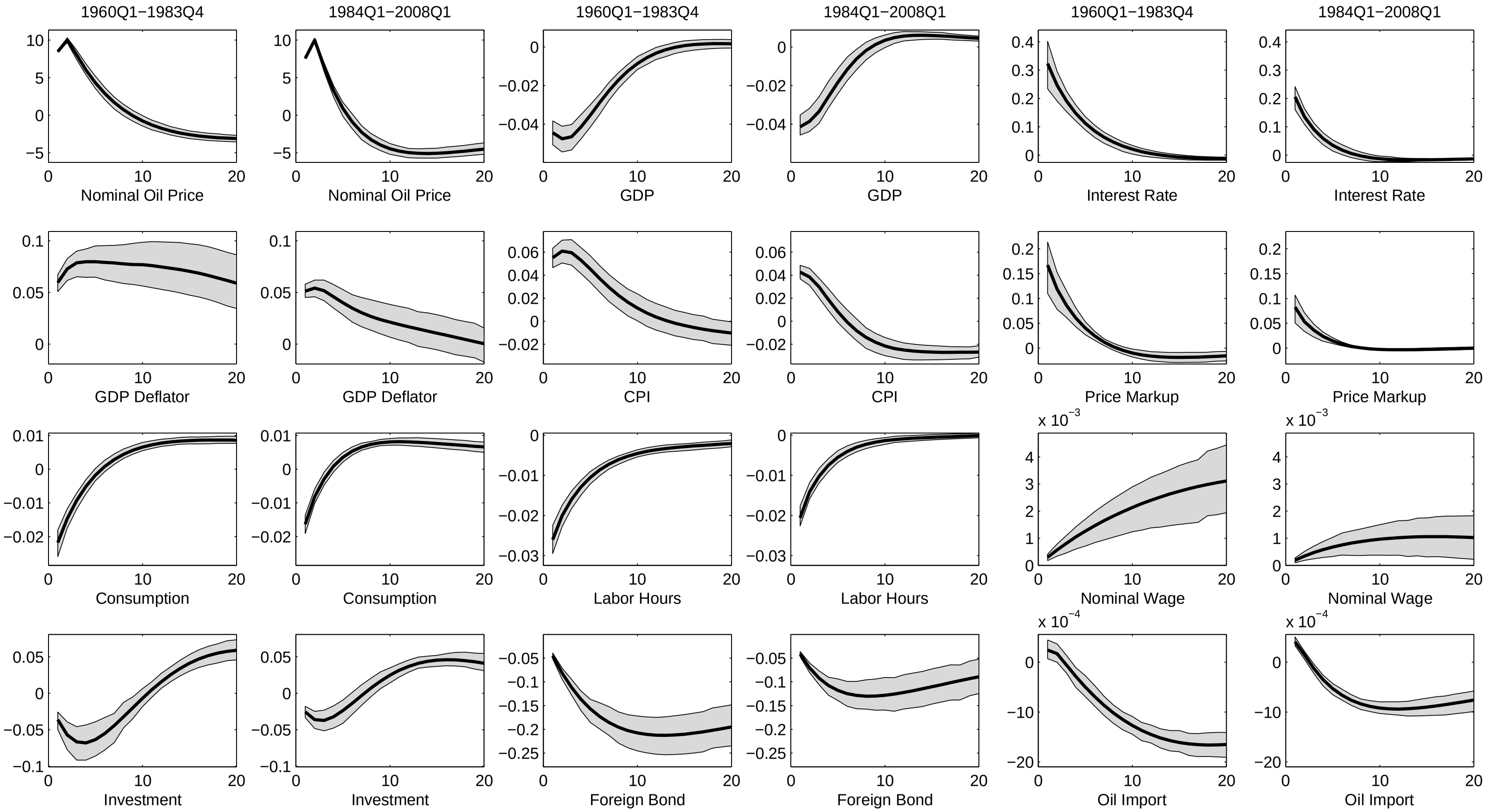

Figure 2.7: Impulse responses to foreign technology shock resulting in 10% increase in oil price.

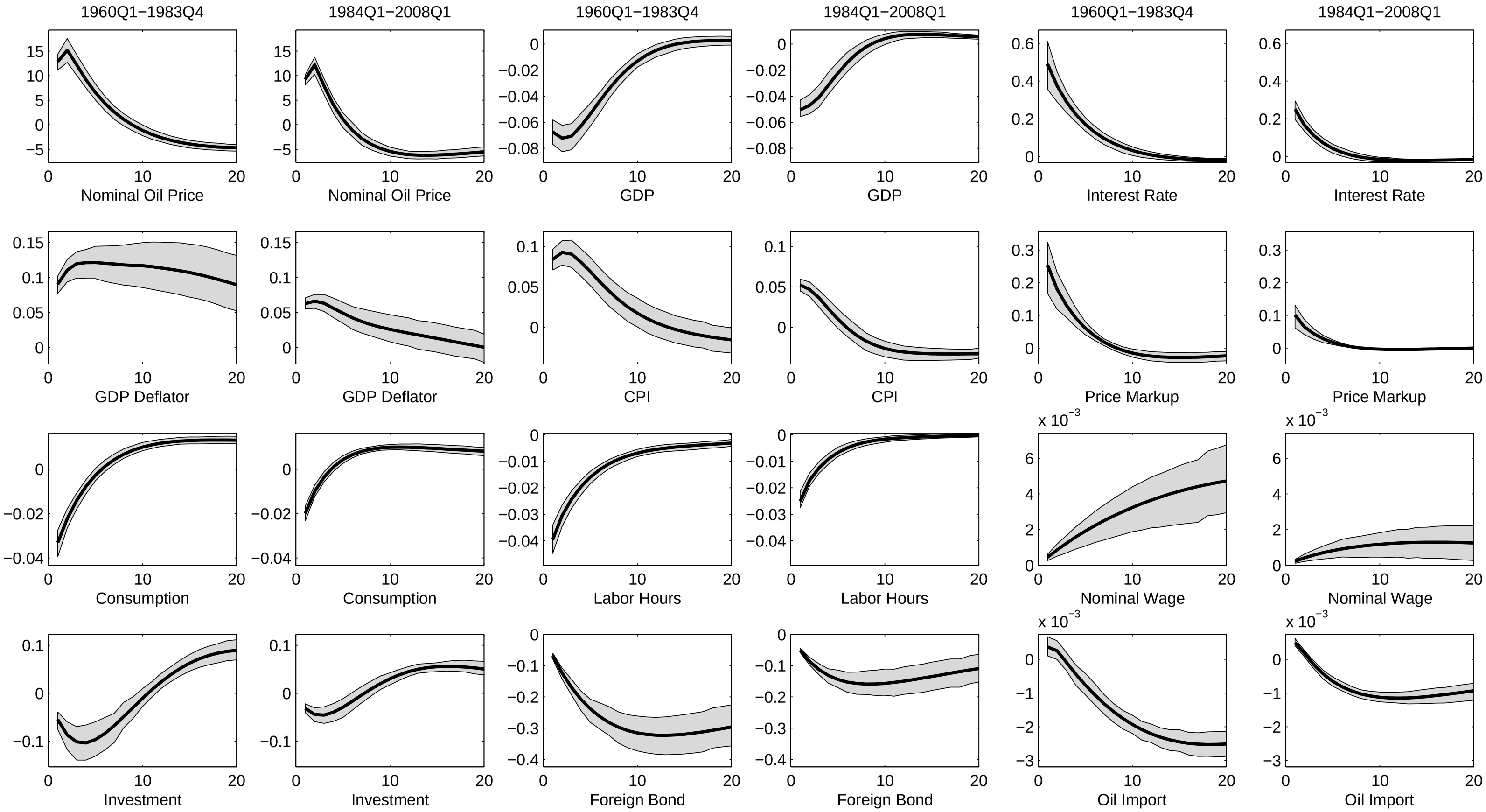

Figure 2.8: Impulse responses to one standard deviation foreign technology shock.

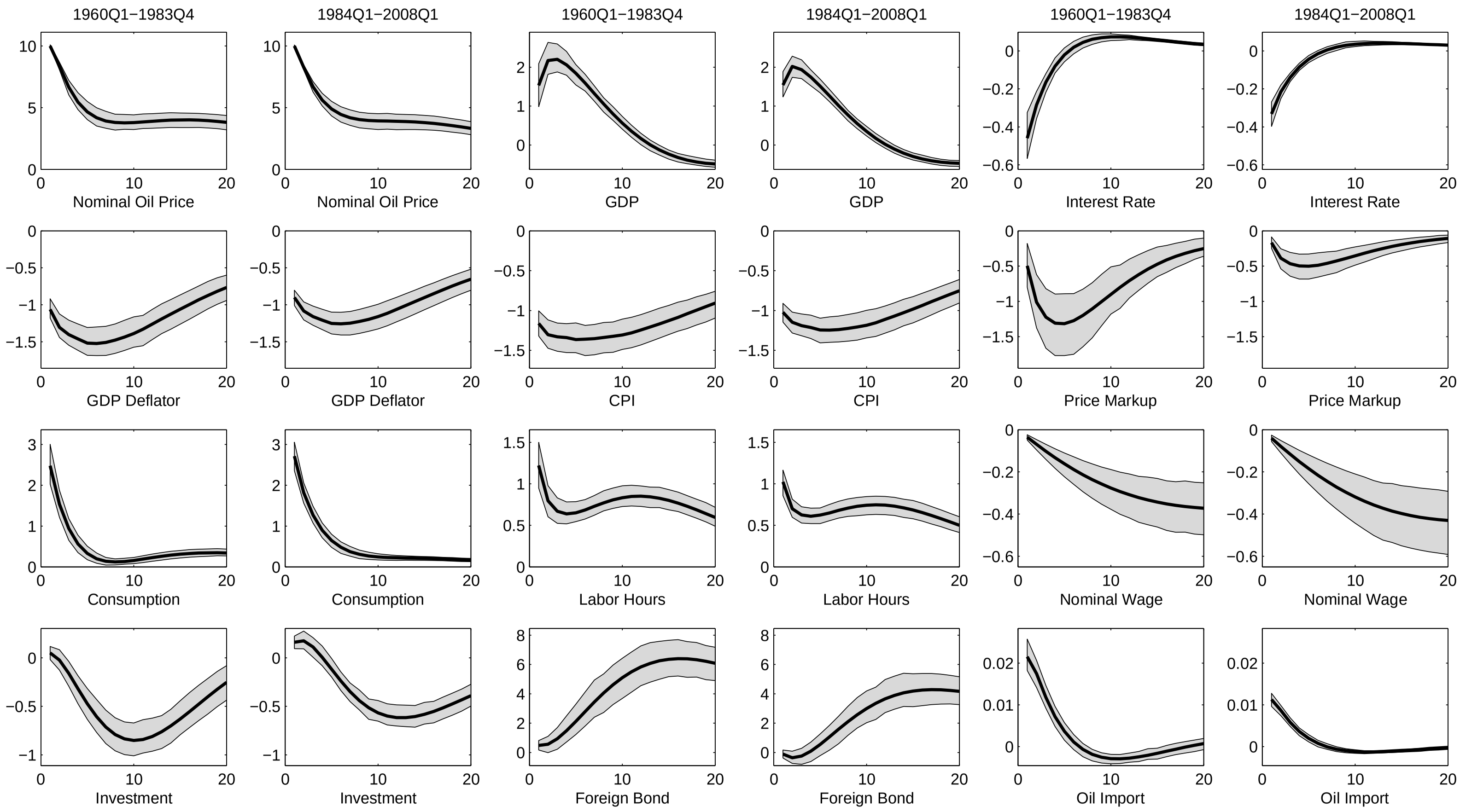

Figure 2.9: Impulse responses to domestic technology shock & 10% increase in oil price.

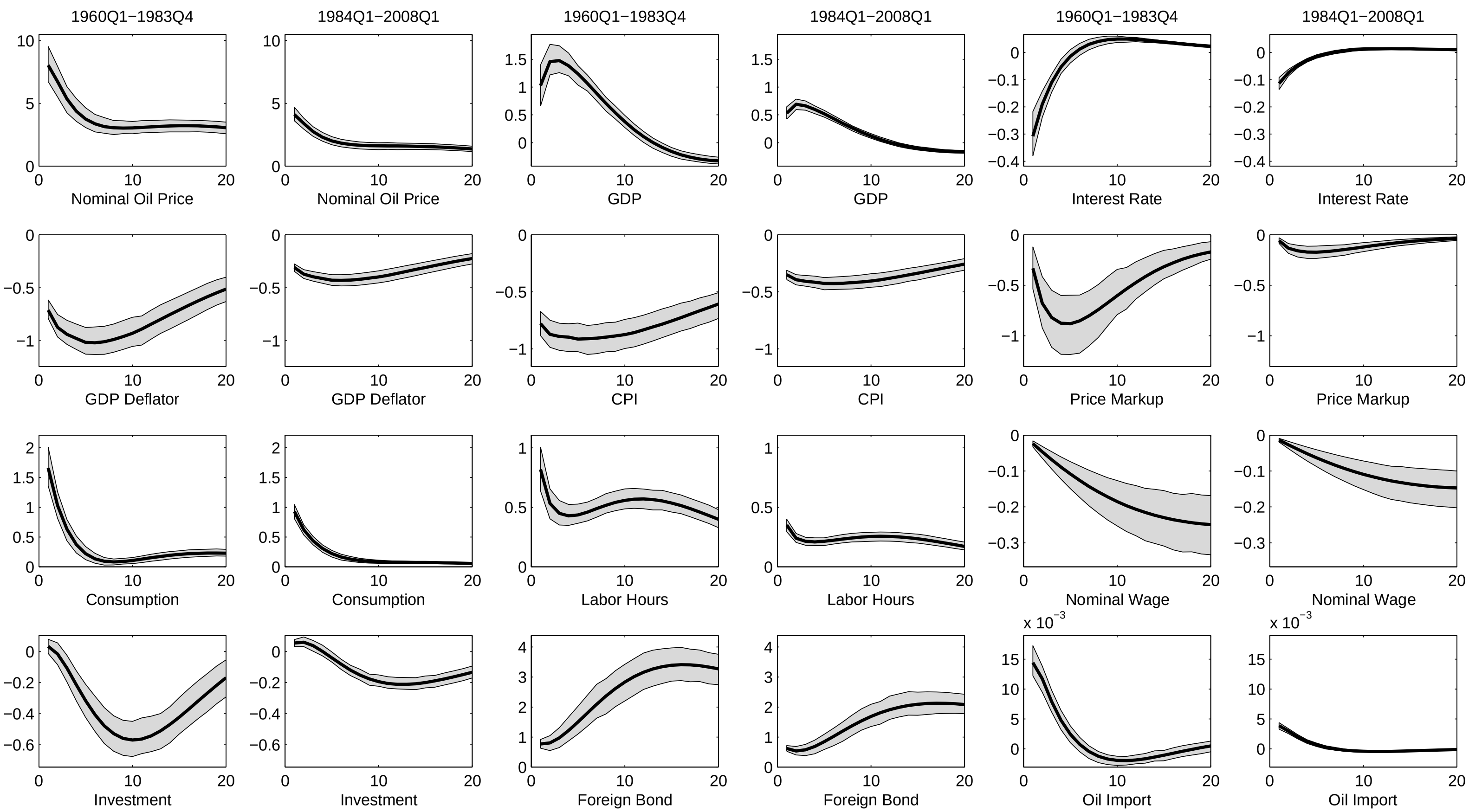

Figure 2.10: Impulse responses to one standard deviation domestic technology shock.

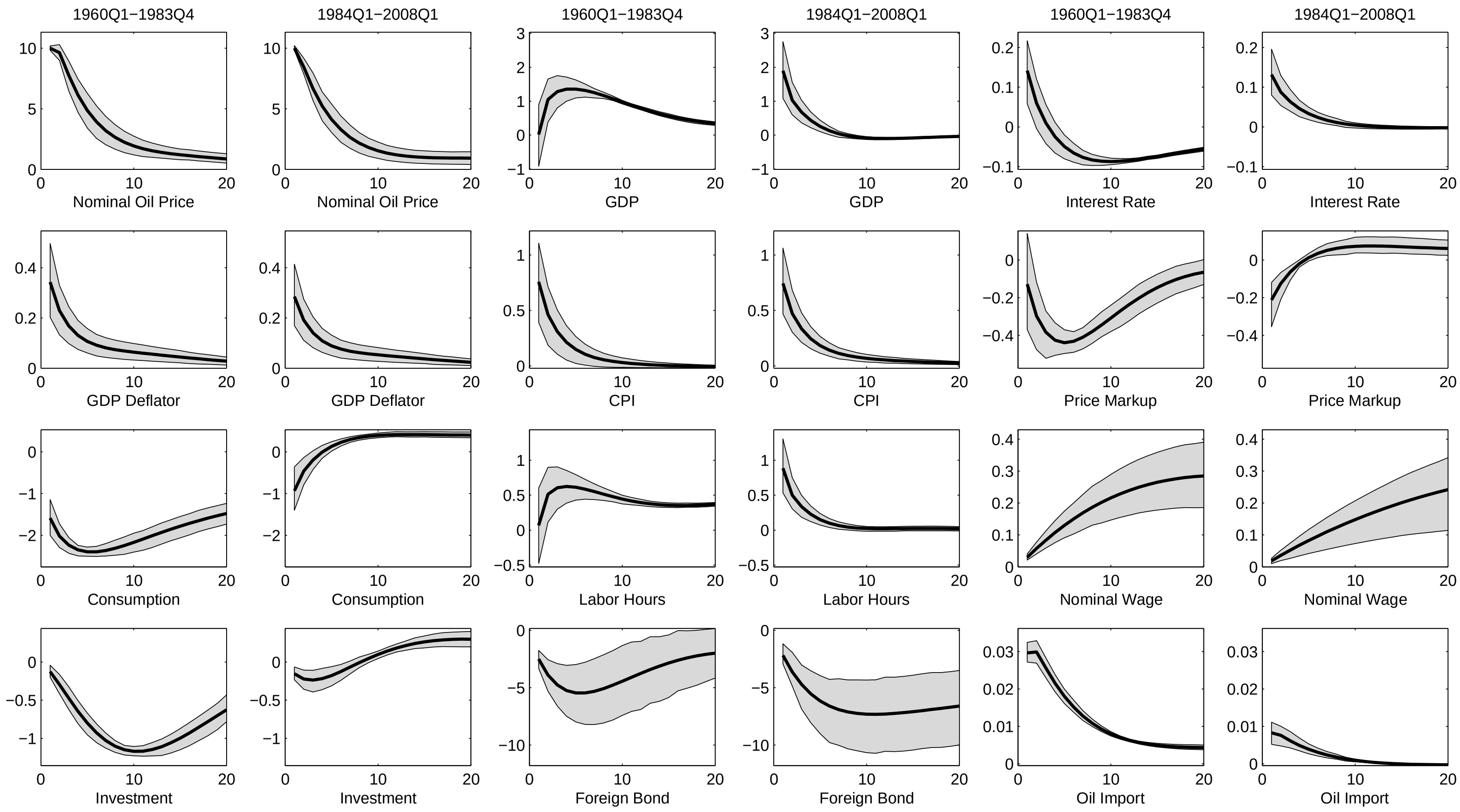

Figure 2.11: Impulse responses to government spending shock resulting in 10% increase in nominal oil price.

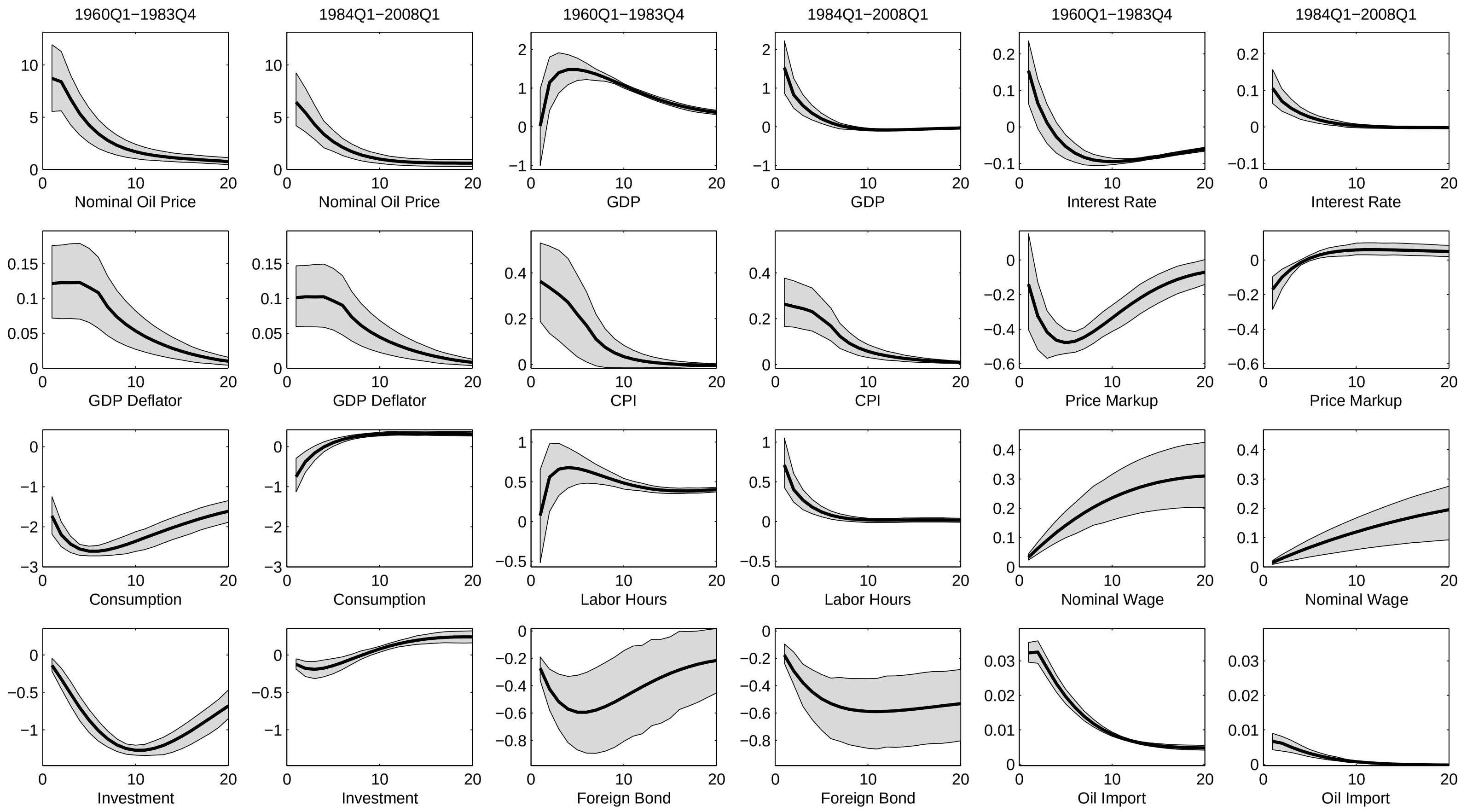

Figure 2.12: Impulse responses to one standard deviation government spending shock.

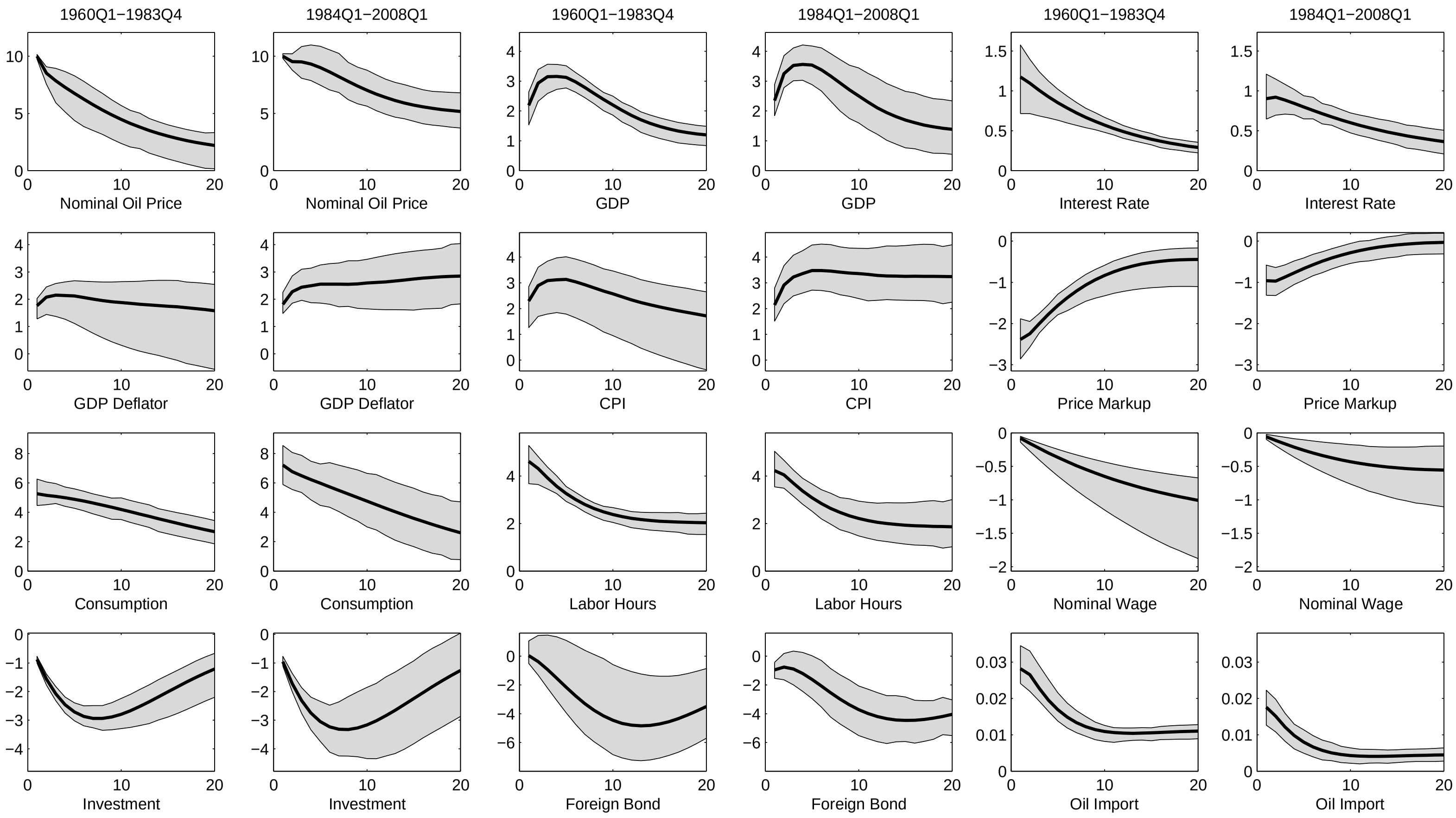

Figure 2.13: Impulse responses to domestic preference shock resulting in 10% increase in nominal oil price.

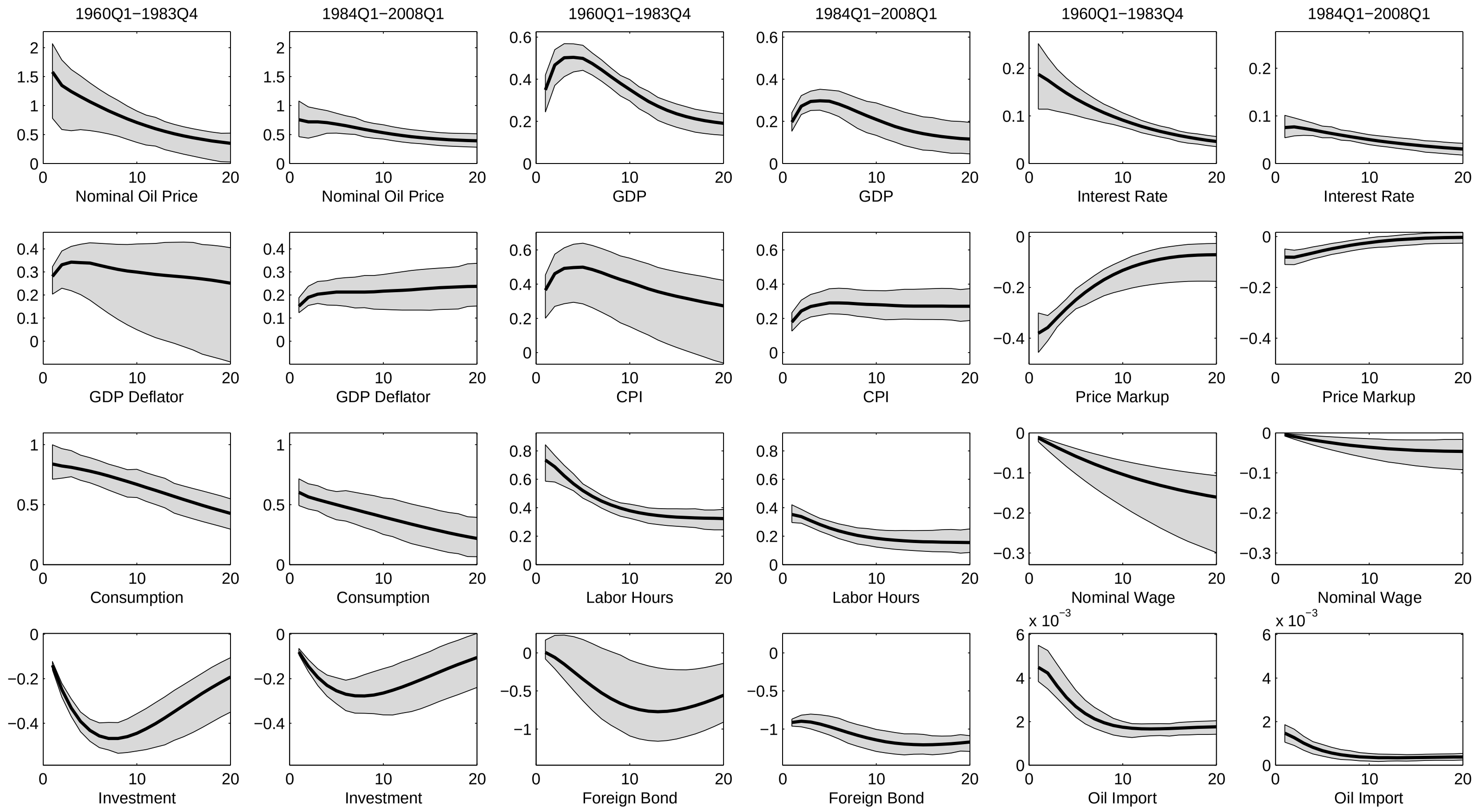

Figure 2.14: Impulse responses to one standard deviation domestic preference shock.

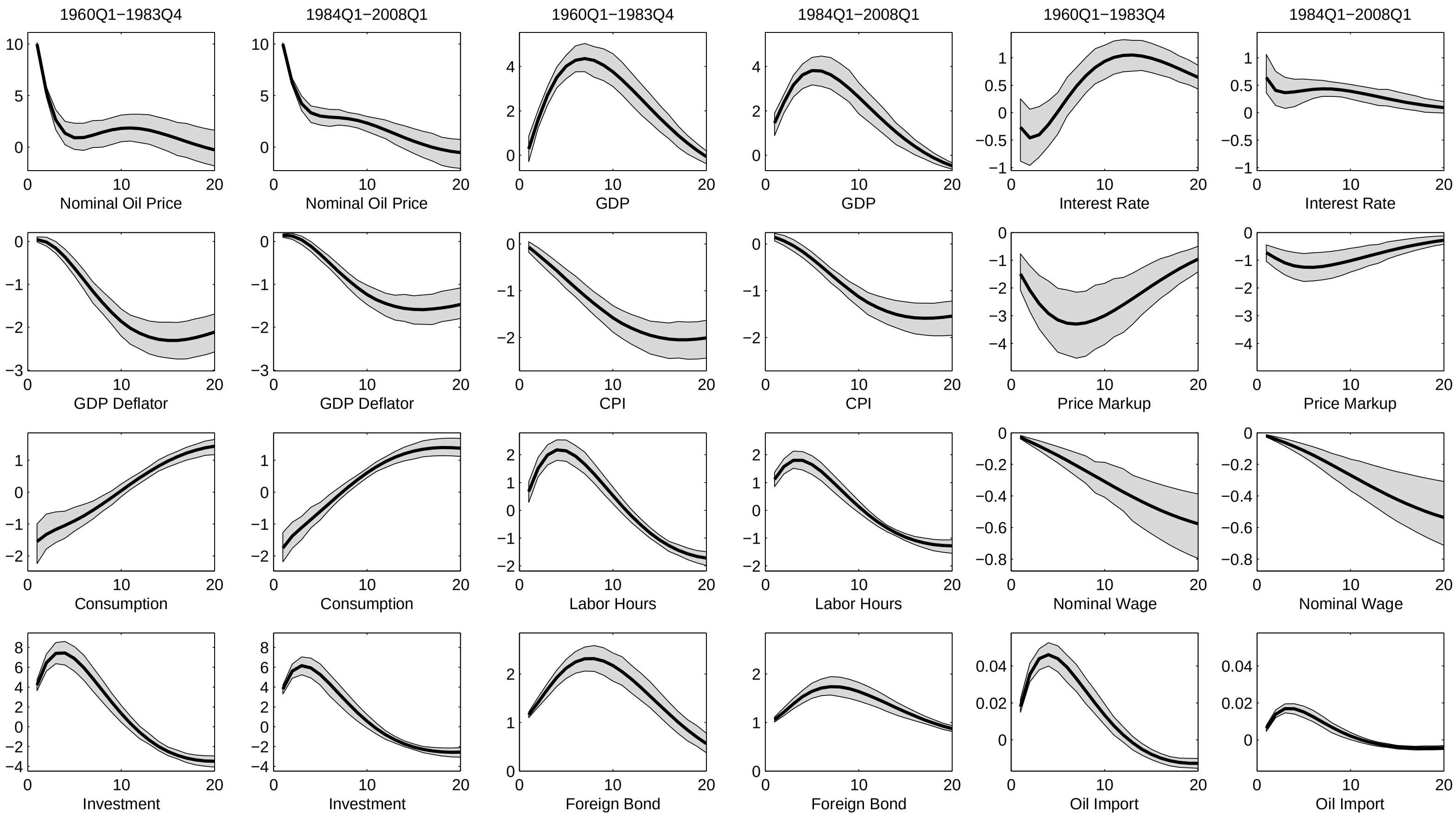

Figure 2.15: Impulse responses to an investment shock resulting in 10% increase in nominal oil price.

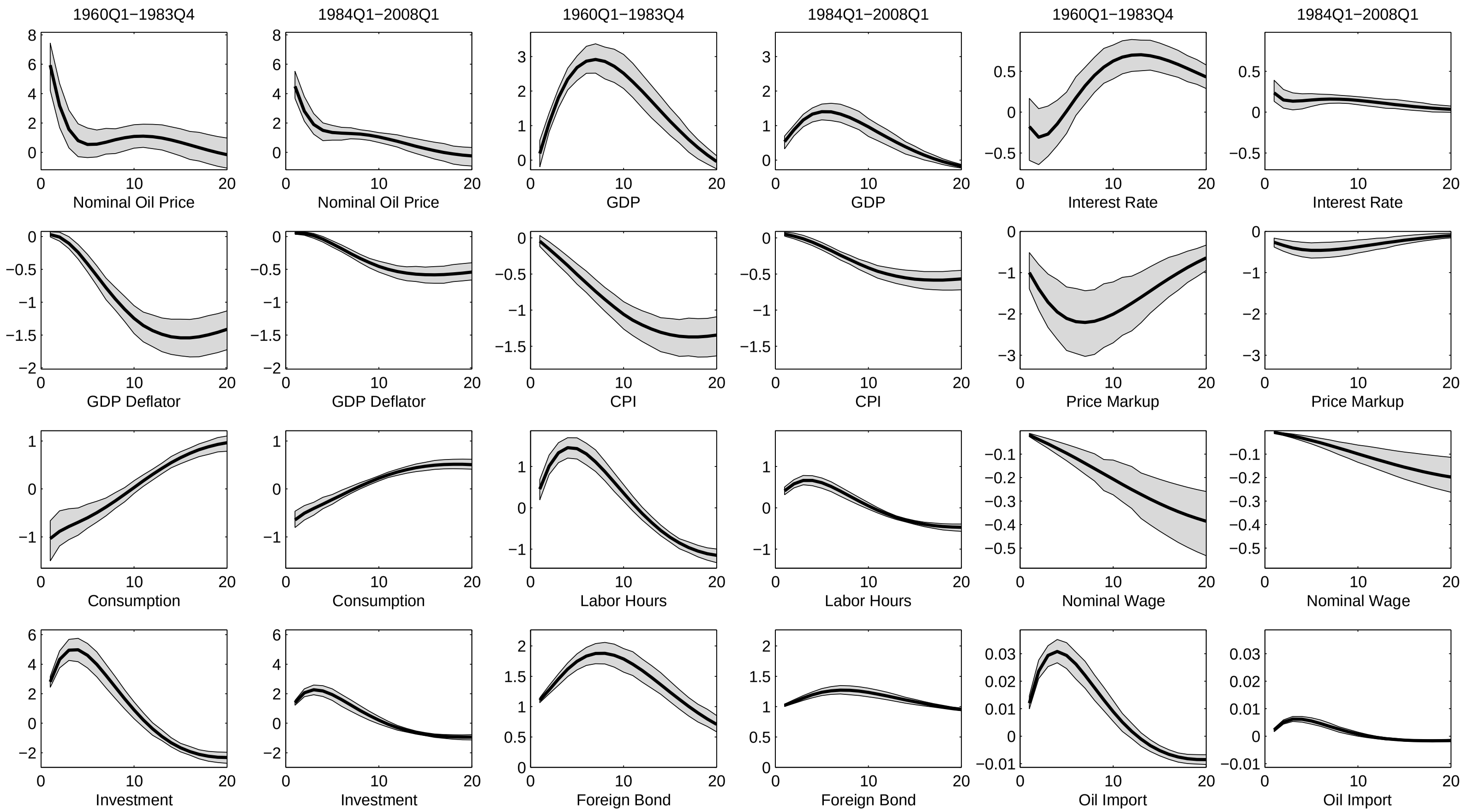

Figure 2.16: Impulse responses to one standard deviation an investment shock.

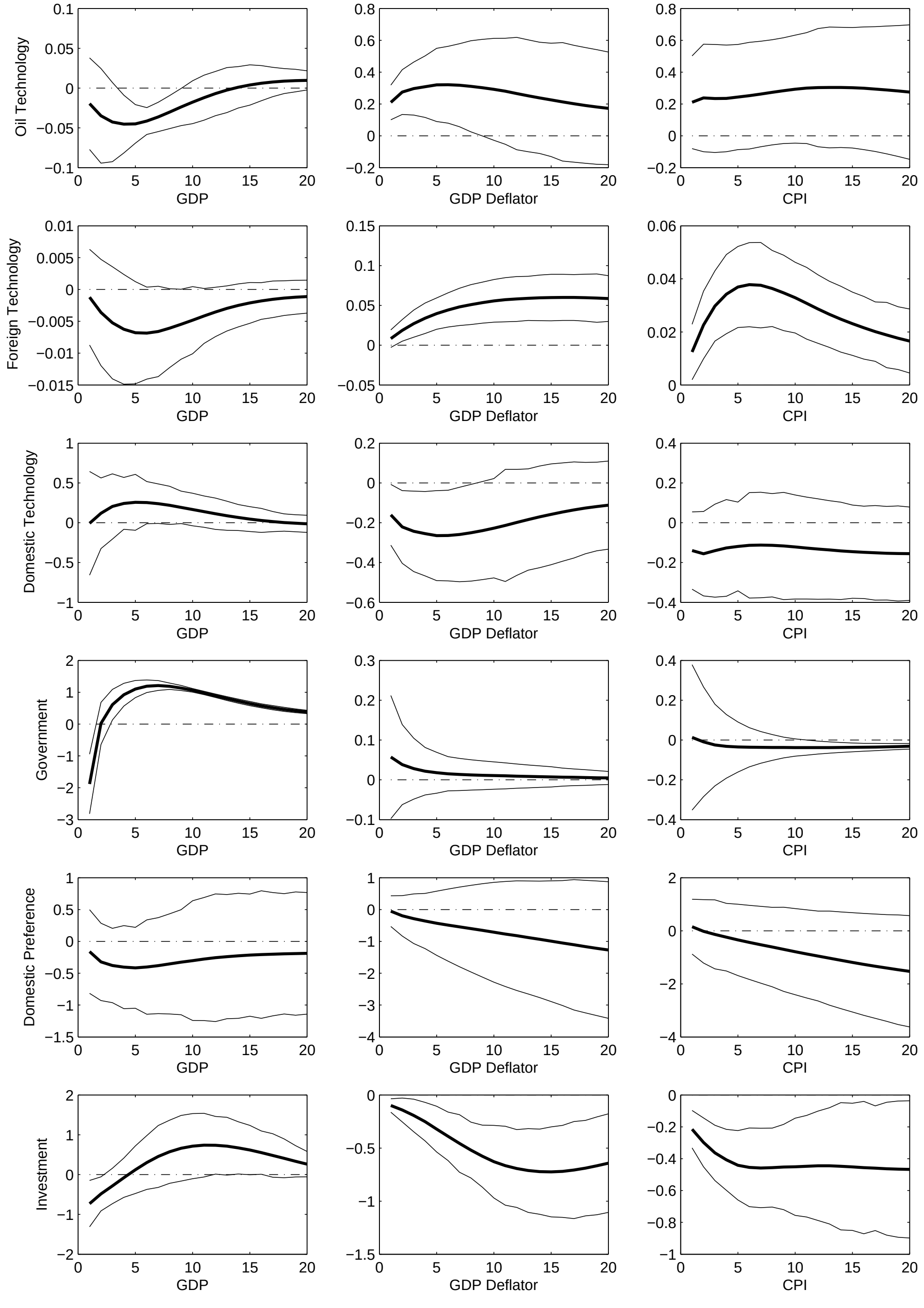

Figure 2.17: Difference between impulse responses in 1960Q1-1983Q4 and in 1984Q1-2008Q1

to fluctuations in the endogenous variables.

The variance decomposition shows that the domestic technology shock has driven real GDP fluctuations both in the first and second samples and both in the short and long run. In the short run, technology shocks explain about 13.2% of real GDP fluctuations, whereas in the second sample they explain about 9%. In the long run, domestic technology shock accounts for almost one third of GDP variability in the first sample. This result matches with Smets and Wouters (2007).

In the second sample, contribution of preference shock in explaining GDP variability increased (9.2% in the first sample and 19.2% in the second sample after the first quarter) while the contribution of price markup shock has declined (17.7% in first sample and 11.4% in the second sample after first quarter). The declining role of markup shocks corroborates our result for the impulse responses.

As far as exogenous oil supply disturbances are concerned, their contribution declines from around 10.1% to 7.7% in the short run and from 7.5% to 4.2% in the long run. In fact after four quarters, the role of oil shocks roughly halves in both samples. Finally, we note that the role of monetary policy disturbances in explaining real GDP fluctuations diminishes significantly from 11.9% to about 6.2%.

Turning to inflation, the role of exogenous oil price disturbance seems to decline in the post-1984 sample (12.8% as opposed to 17.2% in the pre-1984 period). The domestic price markup shock explains bulk of the inflation variability in the long run in the first sample (42% after 20 quarters). However the role of price markup shock declines in the post-1984 sample both in the short and the long run. At the same time, the role of wage markup shock in explaining the CPI variability increases in the second sample (from 6.9% to 9.4%). Finally the role of preference shock appears to rise over time mildly (18% in the first sample and 21% in the second sample) while the role of monetary policy disturbances in explaining inflation variability diminish significantly between the two samples (from 7.9% in the first sample to 4.8% in the second sample).

With regard to the real wage, the wage and price markup shocks together explain about half of the variation in both the pre- and post-1984 samples. The role of wage markup shock nearly doubles from 16.3% in the first sample to 30.3% in the second sample, whereas the role of price markup shock decreases from 38.1% to 20.2% in the second sample. Again as for real GDP and CPI inflation, the role of monetary policy disturbances is nearly cut in half (from 9.4% in the first sample to 5.1% in the second sample after the first quarter).

By far the most interesting result is the variance decomposition of oil price. While in the first sample, as much as 74.8% of the short run variability is explained by the OPEC supply disturbances, only 46.7% of disturbances in the second sample are explained by supply disturbances from oil exporting countries. Moreover the role of U.S. and rest of the world growth shocks explain as much as 14% and 15.2% of the oil price variability in the second sample as compared to 6.2% and 5.2% respectively in the first sample. This result echoes the outstanding growth in the U.S. and Eurozone over the last ten years and the ongoing process of industrialization in two of the world's fastest growing economies - China and India - as well as the fact that geo-political tensions in the Middle East seem to be more under control.

As for the price markup, the bulk of its variation is explained by the markup shock itself. The role of exogenous oil disturbances declines from 10.6% to 8.1% whereas the role of domestic technology and household preference shock increase in the second sample.

Table 2.10: Variance decomposition.

Shocks:	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
						Real GDP: 1960Q1-1983Q4						
1	13.2	9.2	10.6	8.2	11.9	9.1	10.1	5.0	17.7	0.2	0.7	4.1
2	13.7	9.2	11.4	8.0	11.6	8.9	10.0	5.0	17.1	0.3	0.7	4.1
4	19.8	7.9	13.3	6.1	10.2	8.0	8.1	4.8	16.5	0.9	0.4	4.0
8	27.4	7.2	9.6	4.7	9.3	6.8	7.6	4.5	16.1	2.7	0.3	4.0
12	29.0	6.4	9.5	4.3	9.2	6.5	7.5	4.1	16.0	3.3	0.3	3.9
20	29.5	6.3	9.4	4.2	9.1	6.4	7.5	4.0	15.9	3.5	0.3	3.9
40	29.6	6.2	9.4	4.2	9.1	6.4	7.5	3.9	15.8	3.6	0.3	3.9

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Real GDP: 1984Q1-2008Q1							
1	9.0	19.2	8.2	11.0	6.2	11.1	7.7	5.9	11.4	0.1	0.2	10.0
2	10.2	18.8	8.0	10.7	5.9	11.3	7.6	6.1	11.3	0.2	0.2	9.7
4	15.9	16.1	8.3	10.1	5.0	10.9	7.0	5.8	10.8	0.7	0.2	9.2
8	20.1	14.4	10.6	9.8	4.4	9.9	4.9	5.6	9.1	2.2	0.1	8.9
12	21.1	13.0	11.8	9.6	4.2	9.7	4.5	5.4	8.6	3.1	0.1	8.9
20	21.4	12.8	12.3	9.5	4.1	9.5	4.4	5.4	8.5	3.2	0.1	8.8
40	21.5	12.8	12.5	9.5	4.1	9.5	4.2	5.4	8.5	3.2	0.1	8.8

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Inflation: 1960Q1-1983Q4							
1	27.2	18.1	3.8	6.9	7.9	2.3	17.2	1.5	8.4	0.2	4.9	1.6
2	26.8	20.0	4.1	5.7	6.9	3.6	15.3	1.5	9.2	0.2	4.6	2.1
4	22.2	22.5	5.0	5.5	6.7	3.9	14.7	1.4	13.8	0.2	2.1	1.9
8	21.1	12.4	2.9	4.3	4.5	4.2	12.6	1.3	35.0	0.3	0.5	1.1
12	21.0	10.1	1.8	3.5	4.2	4.3	12.4	1.3	40.0	0.3	0.2	0.9
20	20.8	9.2	1.7	3.3	4.1	4.4	12.3	1.3	41.8	0.3	0.1	0.7
40	20.8	9.0	1.7	3.1	4.1	4.4	12.3	1.3	42.3	0.3	0.0	0.7

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
						Inflation: 1984Q1-2008Q1						
1	15.6	21.4	3.0	9.4	4.8	16.1	12.8	1.1	4.9	0.1	4.7	6.1
2	15.8	22.6	2.9	8.7	4.7	15.8	12.6	1.0	5.0	0.2	4.7	6.0
4	21.8	24.8	2.3	7.6	4.4	13.6	10.2	0.7	6.6	0.3	2.5	5.2
8	24.6	22.0	1.6	7.5	4.2	11.9	8.5	0.5	12.2	0.5	1.5	5.0
12	28.2	21.3	1.4	7.4	4.1	10.7	7.7	0.2	13.0	0.5	0.6	4.9
20	29.3	21.1	1.3	7.4	4.1	10.5	7.3	0.1	13.1	0.5	0.5	4.8
40	29.6	21.1	1.2	7.4	4.1	10.4	7.0	0.1	13.4	0.5	0.4	4.8

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Real wage: 1960Q1-1983Q4							
1	2.1	6.2	1.5	16.3	9.4	0.0	12.9	1.9	38.1	0.0	0.0	11.6
2	3.6	6.0	1.5	15.1	8.2	0.1	12.1	1.5	40.0	0.0	0.0	11.9
4	8.0	4.9	2.3	14.4	3.6	0.8	6.2	0.7	44.7	0.0	0.0	14.4
8	13.3	3.4	2.7	14.2	1.3	0.8	3.3	0.3	45.0	0.0	0.0	15.7
12	17.3	3.2	2.8	14.1	0.1	1.0	0.8	0.2	44.7	0.0	0.0	15.8
20	18.2	3.1	2.8	14.1	0.0	1.1	0.1	0.1	44.6	0.0	0.0	15.9
40	18.3	3.1	2.8	14.1	0.0	1.2	0.0	0.1	44.4	0.0	0.0	15.9

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Real wage: 1984Q1-2008Q1							
1	3.0	11.5	2.0	30.3	5.1	0.0	8.0	2.6	20.2	0.0	0.0	17.3
2	6.7	11.0	1.9	27.9	4.8	0.2	7.9	2.0	19.0	0.0	0.0	18.5
4	14.6	8.3	1.8	25.5	3.1	1.8	5.1	0.4	15.6	0.0	0.0	23.7
8	20.8	7.5	1.9	22.1	0.6	4.2	2.8	0.3	11.9	0.0	0.0	27.8
12	23.4	7.1	2.0	21.3	0.1	5.9	0.3	0.1	11.3	0.0	0.0	28.4
20	23.7	7.0	2.0	21.0	0.0	6.4	0.1	0.0	11.2	0.0	0.0	28.5
40	24.0	7.0	2.0	20.8	0.0	6.4	0.1	0.0	11.1	0.0	0.0	28.5

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Price markup: 1960Q1-1983Q4							
1	9.3	20.1	1.1	4.5	0.6	0.5	10.6	0.0	52.7	0.3	0.1	0.2
2	9.8	19.3	1.2	4.4	0.6	0.5	10.5	0.0	53.1	0.3	0.1	0.2
4	10.8	16.8	1.3	4.0	0.5	0.4	9.9	0.0	55.7	0.3	0.0	0.3
8	12.4	15.5	1.1	3.1	0.4	0.3	6.0	0.1	60.4	0.3	0.0	0.4
12	13.2	15.4	0.7	2.6	0.2	0.2	4.6	0.0	62.3	0.3	0.0	0.5
20	13.7	15.2	0.5	2.1	0.2	0.2	4.2	0.0	63.0	0.4	0.0	0.5
40	13.8	15.1	0.5	2.1	0.2	0.2	4.1	0.0	63.1	0.4	0.0	0.5

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
				Price markup: 1984Q1-2008Q1								
1	13.0	30.2	1.8	7.1	0.9	3.5	8.1	0.1	33.8	0.5	0.4	0.6
2	13.5	29.8	1.8	6.9	0.9	3.6	8.0	0.1	33.8	0.5	0.5	0.6
4	14.7	27.2	1.6	5.8	0.7	3.8	6.8	0.2	37.4	0.8	0.3	0.7
8	16.5	25.1	1.4	4.2	0.5	3.9	5.2	0.2	41.1	1.0	0.2	0.7
12	17.0	24.7	1.4	3.6	0.5	4.1	3.8	0.2	42.7	1.1	0.1	0.8
20	17.1	24.5	1.3	3.2	0.5	4.1	3.4	0.2	43.7	1.1	0.1	0.8
40	17.2	24.3	1.3	3.0	0.5	4.2	3.3	0.2	44.0	1.1	0.1	0.8

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Oil price: 1960Q1-1983Q4							
1	6.2	4.7	0.8	0.4	1.7	5.2	74.8	0.1	4.4	1.5	0.0	0.1
2	6.4	4.9	0.8	0.3	1.7	5.1	74.6	0.0	4.6	1.5	0.0	0.1
4	7.1	3.8	1.2	0.3	1.8	5.0	73.8	0.0	5.7	1.3	0.0	0.2
8	7.6	3.3	1.3	0.3	1.9	5.5	71.6	0.0	7.2	1.0	0.0	0.3
12	8.3	2.4	1.5	0.3	2.0	5.9	70.0	0.0	8.7	0.6	0.0	0.3
20	8.6	2.3	1.6	0.3	2.1	6.0	69.7	0.0	8.9	0.2	0.0	0.3
40	8.7	2.3	1.6	0.3	2.1	6.1	69.4	0.0	9.0	0.2	0.0	0.3

Table 2.10: Variance decomposition continued.

Shocks	Dom Tech	Hh Pref	Risk Premium	Wage Markup	Interest Rate	Foreign Tech	Oil Tech	Govt	Price Markup	Inv	ToT	Labor Supply
Periods												
					Oil price: 1984Q1-2008Q1							
1	13.9	12.7	1.4	0.2	2.0	15.2	46.7	0.2	4.4	2.1	0.9	0.3
2	14.4	12.6	1.5	0.2	2.1	15.8	45.5	0.5	4.5	1.8	0.8	0.3
4	16.8	12.3	1.9	0.1	2.4	17.6	40.8	0.6	5.0	1.4	0.6	0.5
8	17.7	10.9	2.0	0.1	2.8	18.4	41.2	0.7	4.7	0.7	0.2	0.6
12	17.9	10.6	2.1	0.1	2.8	19.3	41.3	0.8	4.1	0.3	0.0	0.7
20	18.0	10.6	2.1	0.1	2.9	19.5	41.4	0.8	3.7	0.2	0.0	0.7
40	18.0	10.5	2.1	0.1	2.9	19.6	41.4	0.8	3.7	0.1	0.0	0.7

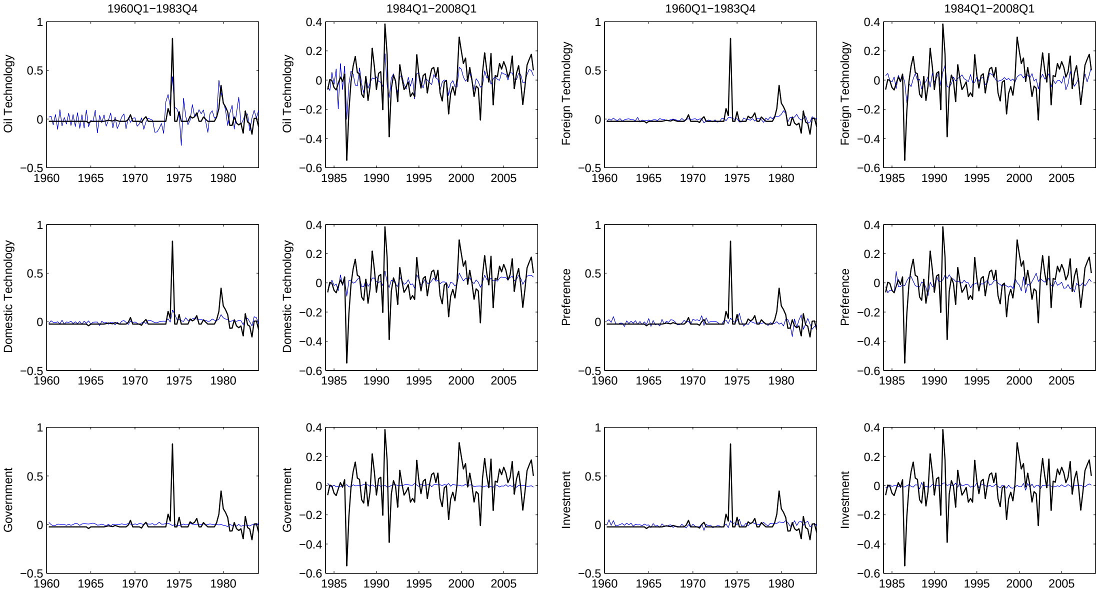

Figure 2.18: Historical Decomposition of Oil Price

The historical decompositions in figures 2.18, 2.19 and 2.20 show the contribution of each shock to the evolution of oil prices and U.S. GDP and inflation respectively. These figures represent the history of the variables for the pre- and post-1984 sample. For the evolution of oil prices, shocks to oil supply are important in the pre-1984 sample, whereas shocks to U.S. and rest of the world GDP growth and U.S. consumption shock gained importance in the post-1984 sample.

For the U.S. GDP, growth shock and investment shock both are very important. The role of oil supply shock has declined in the post-1984 sample as compared to the previous sample, whereas the role of foreign growth shock has become more important with the world economy has a whole getting more integrated and globalized. The U.S. inflation fluctuations on the other hand seem to be dominated by the domestic technology

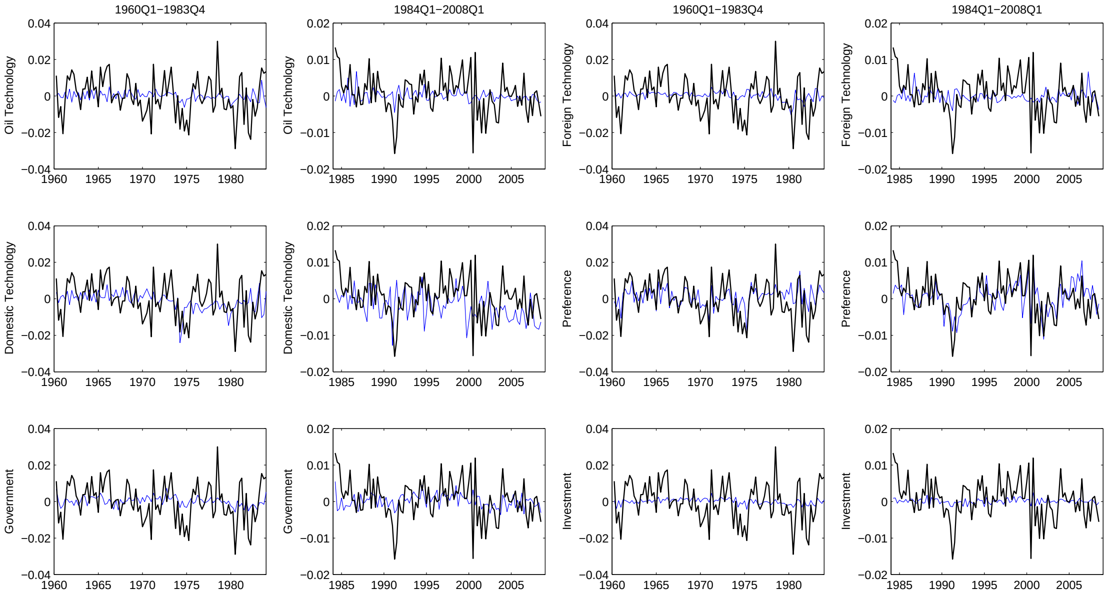

Figure 2.19: Historical Decomposition of U.S. GDP

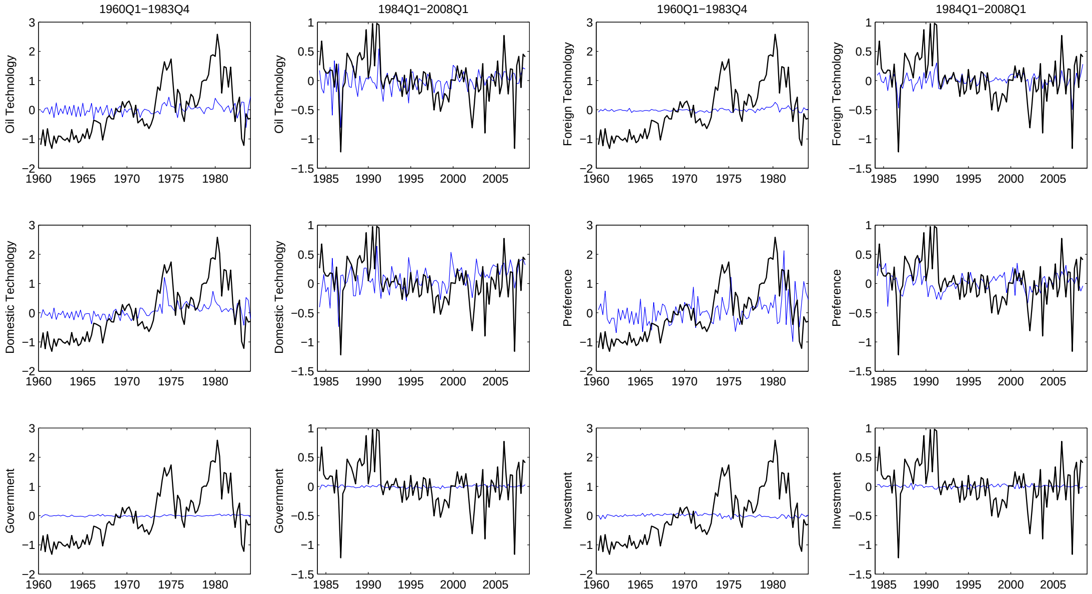

Figure 2.20: Historical Decomposition of CPI

and consumption shock.

2.5.4 Counterfactual Experiments

Table 2.11 reports counterfactual exercises that show that changes in certain parameter values have a dampening effect of oil price increase on the various U.S. macroeconomic variables. But it is interesting to note that the dampening effect is not uniform across different sources of oil price increases.

The first counterfactual experiment assumes that the U.S. economy enjoys a 20% efficiency gain in oil use i.e. α_o decreases by 20%. This is found to reduce the effect of a sudden oil price hike on both inflation and real output. For an oil supply shock, a 20% oil efficiency gain reduces the contractionary impact by 4.5%, while inflationary impact is reduced by 18.5%. For an oil price increase induced by growth shock from the rest of the world, the contractionary impact is reduced by only 1.5%, and the inflationary impact by 1.9%. Similarly, for oil price increase induced by domestic growth, the contractionary impact is reduced by about 3%. Thus the dampening impact depends on the source of oil price increase.

The second counterfactual exercise reported in Table 2.11 consists of a fall in λ_w, which amounts to reducing the wage contract duration by one quarter. This exercise indicates that more flexible wages on balance induce a milder contractionary impact following the disturbance. For an oil supply shock, higher wage flexibility reduces output contraction by about 5% after one year. However, the lower degree of labor market rigidity is also found to induce somewhat larger inflationary pressures (by about 4.5% after one year). For a foreign growth shock, however, the increase is labor market flexibility reduces the contractionary impact of oil price shocks by about 10% after one year, whereas there is no substantial effect of inflation after one year. For a domestic technology shock, there is no noticeable milder effect on GDP or inflation for an increase in wage flexibility.

The third counterfactual experiment reported in Table 2.11 consists of a fall in λ_p, such that price rigidity decreases by one quarter. This exercise shows that an increase in price flexibility reduces the contractionary impact of an oil supply shock by 10.6%. Similarly for an oil price increase induced by a foreign technology shock, a higher price flexibility reduces the contractionary impact by about 90% after the first year. At the end of two years, a higher price flexibility reduces the inflationary impact mildly by about 1.5%.

In the final counterfactual exercise, the price markup is assumed not to respond to the oil shock over the initial three years following the disturbance i.e. $\mu_1 = 0$. We find that this generates a noticeable relief to inflation and output. This result agrees with the variance decomposition results reported earlier showing that the markup does appear to be highly affected by oil price shocks. For an oil price increase induced by an oil supply shock, an unresponsive markup reduces the contractionary impact by about 18% and the inflationary impact by 23% after one year. This exercise suggests that markup behavior does play an significant role in amplifying the macroeconomic consequences of oil price disturbances, as argued by Rotemberg and Woodford (1996) for the U.S. economy. For a foreign technology shock the unresponsive markup also reduces the contractionary impact, but the magnitude is much lower, only 1.5%, with no noticeable impact on inflation.

Table 2.11: Counterfactual experiments.

	Real GDP			CPI		
Shocks	4Q	8Q	12Q	4Q	8Q	12Q
			Baseline model: 1984Q1-2008Q1			
Oil technology	-0.125	-0.044	-0.017	0.514	0.720	0.742
	(-0.142,-0.106)	(-0.061,-0.025)	(-0.038,0.004)	(0.382,0.648)	(0.552,0.902)	(0.528,0.989)
Foreign technology	-0.015	-0.003	0.001	0.022	-0.016	-0.030
	(-0.018, -0.011)	(-0.005, -0.001)	(0.000,0.002)	(0.012,0.033)	(-0.026,-0.007)	(-0.036,-0.021)
Domestic technology	2.216	0.978	0.025	-1.411	-1.425	-1.293
	(1.978,2.412)	(0.788, 1.070)	(-0.082, 0.152)	(-1.556,-1.247)	(-1.594,-1.241)	(-1.516,-1.115)
Preference	1.453	0.897	0.603	0.963	0.981	0.957
	(1.257,1.692)	(0.627,1.124)	(0.363,0.872)	(0.763,1.198)	(0.748,1.241)	(0.700, 1.244)
Government spending	0.368	0.017	-0.028	0.220	0.158	0.145
	(0.591,0.173)	(-0.019,0.057)	(-0.061,0.005)	(0.134,0.323)	(0.089,0.242)	(0.069,0.224)
Investment	1.606	1.491	0.791	-0.072	-0.371	-0.603
	(1.353,1.807)	(1.223,1.815)	(0.541,1.040)	(-0.126,-0.018)	(-0.442,-0.309)	(-0.710,-0.501)

Table 2.11: Counterfactual experiments continued.

	Real GDP			CPI		
Shocks	4Q	8Q	12Q	4Q	8Q	12Q
		20% oil efficiency gain				
Oil technology	-0.111	-0.031	0.003	0.432	0.582	0.599
Foreign technology	-0.013	-0.001	0.001	0.020	-0.014	-0.026
Domestic technology	1.969	0.891	0.034	-1.492	-1.500	-1.388
Preference	1.587	1.192	0.682	1.124	1.139	1.114
Government spending	0.451	0.027	-0.031	0.188	0.131	0.120
Investment	1.809	1.811	0.997	-0.059	-0.308	-0.490

Table 2.11: Counterfactual experiments continued.

	Real GDP			CPI		
Shocks	4Q	8Q	12Q	4Q	8Q	12Q
			$\underline{\lambda_w = 0.75}$			
Oil technology	-0.109	-0.027	0.003	0.561	0.740	0.763
Foreign technology	-0.012	-0.001	0.001	0.024	-0.013	-0.027
Domestic technology	1.869	0.809	0.003	-1.421	-1.433	-1.252
Preference	1.517	0.990	0.680	0.981	0.997	0.965
Government spending	0.352	0.016	-0.003	0.239	0.175	0.158
Investment	1.531	1.430	0.719	-0.051	-0.320	-0.524

Table 2.11: Counterfactual experiments continued.

	Real GDP			CPI		
Shocks	4Q	8Q	12Q	4Q	8Q	12Q
			$\lambda_p = 0.75$			
Oil technology	-0.108	-0.029	0.001	0.541	0.757	0. 741
Foreign technology	-0.012	-0.001	0.001	0.018	-0.019	-0.015
Domestic technology	2.316	1.141	0.029	-1.198	-1.197	-1.089
Preference	1.137	0.739	0.490	1.091	0.977	0.877
Government spending	0.461	0.011	-0.003	0.189	0.096	0.058
Investment	1.828	1.770	0.909	-0.080	-0.399	-0.647

Table 2.11: Counterfactual experiments continued.

	Real GDP			CPI		
Shocks	4Q	8Q	12Q	4Q	8Q	12Q
			$\underline{\mu_1 = 0}$			
Oil technology	-0.099	-0.023	0.004	0.410	0.575	0.570
Foreign technology	-0.012	-0.001	0.002	0.025	-0.010	-0.019
Domestic technology	1.978	0.944	0.031	-1.067	-1.097	-1.019
Preference	1.341	0.870	0.577	1.197	1.238	1.066
Government spending	0.376	0.019	-0.023	0.224	0.158	0.147
Investment	1.574	1.403	0.742	0.022	-0.289	-0.508

2.6 Conclusion

In this paper, we examine the various sources of oil price shocks. Oil price shocks are not exogenous to the U.S. economy, rather oil price shocks can be triggered by a broad spectrum of events, U.S. productivity growth, U.S. demand increase, foreign country productivity growth and also oil supply shocks induced by the oil exporting countries.

We assess the extent to which increased macroeconomic stability in the U.S. after 1984 can be accounted for by changes in the constitution of the oil price shock. We build a three country dynamic stochastic general equilibrium model to assess the impact of various types of oil price shocks. We take the model to the data with Bayesian techniques and performing counterfactual simulations. Our model involves two oil-importing economies and an oil-exporting economy. Oil price shocks in the model are not exogenous, rather endogenously determined from the demand and supply. The model incorporates staggered nominal contracts in both product and labour markets, as well as an intertemporal mechanism operating via consumption and investment demand. Moreover, the model is extended to incorporate oil usage in production and endogenous price markups.

The estimation results reported in this paper appear reasonable, in light of the U.S. economy's structural characteristics as well as the existing empirical and theoretical literature. The DSGE model estimated here has been found to exhibit fairly good forecasting properties. With regard to structural parameters, we estimate a somewhat high degree of price and wage rigidity, with the average length of wage contracts slightly exceeding 5 quarters, which is seen to decrease post-1984. The price markup is found to react positively to the ratio of expected discounted profits to current output, in line with a number of existing studies for the U.S. Additionally, the postulated Taylor rule displays higher predictability in the post-1984 period. The present study uncover evidence of significant structural change, manifested by parameter instability between the pre- and post-1984 sample periods concerning behavioral parameters and exogenous processes driving structural disturbances.

The finding that the price markup reacts positively to the ratio of expected discounted profits to current output deserves further discussion. As stressed by Rotemberg and Woodford (1996), this finding can be rationalized in terms of the "implicit collusion" model of Rotemberg and Saloner (1986), which predicts that implicit collusion can be sustained in a context of higher markups under the condition that any given firm's deviation to a lower markup would induce punishment from its competitors. Given that the ratio of expected discounted profits to current output is normally dominated by short-run developments in the current output, our finding would normally be labelled as a situation of "countercyclical" markups.

With respect to the propagation mechanisms captured by the empirical DSGE model, the qualitative features of the responses reported here are broadly in line with those obtained in the literature. In the case of oil price shocks, they are found to generate inflationary and recessionary pressures as well as a reduction in real wages and an increase in the price markup. Overall, there is evidence that impulse responses to shocks became milder in the post-1984 sample period compared with the pre-1984 period. Variance decomposition analysis allows us to detect the smaller importance of shocks affecting monetary policy and oil prices in the post-1984 period, consistent with the higher predictability of policy and fall in the persistence as well as (to a lesser extent) variability of oil disturbances. Among other shocks, technology disturbances play an important role in explaining movements in real output and inflation, as well as real wages in the medium to long term. Preference shocks increase their share in overall macroeconomic variability in the post-1984 period, becoming of special relevance in the cases of real output, inflation and real wages. Markup disturbances lose some of their importance in explaining inflation and real wages seen in the pre-1984 period, though still remain the key force behind price markup developments themselves.

Counterfactual exercises show that oil efficiency gains would alleviate the inflationary and contractionary consequences of an oil shock, while higher wage flexibility would help constrain the contractionary effects of the disturbance at the expense of wider fluctuations in inflation. Finally, the rise in price markups induced by an oil disturbance is found to considerably amplify the inflationary and contractionary effects of the shock, a finding that corroborates the prediction of the Rotemberg and Woodford (1996) model calibrated for the U.S. economy.

CHAPTER 3

A SECTORAL ANALYSIS TO OIL PRICE SHOCKS ON THE U.S. ECONOMY

3.1 Introduction

"What is black, sticky, comes in large tubs and causes depressions? No, not Marmite. Here is a string of numbers as a clue: 1974, 1979, 1991, 2000. The answer is oil - and, more precisely, large rises in the price of oil." - Andrew Oswald, "Oil Price Puts Skids Under Growth," - The Sunday Times, U.K., Sept. 2001.

Since World War II, rising oil prices have gone hand-in-hand with U.S. recessions. In fact, nine of the ten post-WWII recessions have been preceded by episodes of sharply rising oil prices (see Figure 3.1). The 1990 recession is the one exception. Economic research has long documented a relationship between oil price shocks and slowing U.S. economic activity, with the consequences being declining output growth and possible recession, higher unemployment rates, and a higher price level. Some of the earlier studies to document the oil price macroeconomy relationship include Pierce and Enzler (1974), Hamilton (1983), Rasche and Tatom (1977), Mork and Hall (1980) and Gisser and Goodwin (1986).

However the effect of oil price shocks on U.S. economic activity seems to have undergone a paradigm shift since the mid-1980s. The U.S economy was relatively resilient to these oil price shocks - the output growth has been stable, inflation expectations have been well anchored. A variety of explanations have been offered for this resilience, including better luck Blanchard and Simon (2001), reduced intensity of energy usage in the U.S. economy Bohi (1989), Bohi (1991), a more flexible economy and better monetary policy Blanchard and Gali (2007). All these explanations point to a weakening of

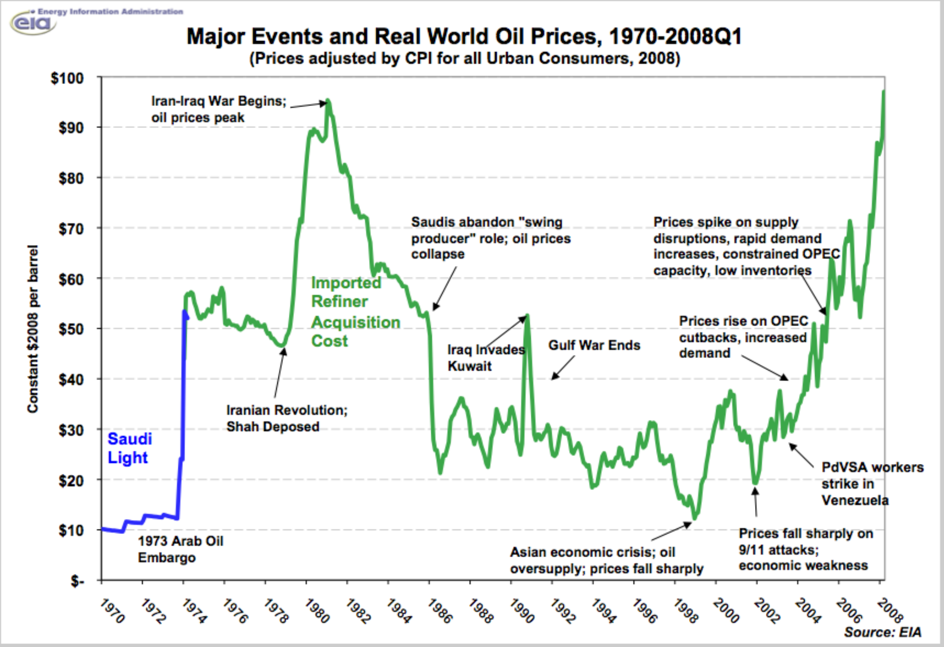

Figure 3.1: Oil Price - 1947-2009

the relationship between oil prices shocks and economic activity.

The recent oil price hikes have rekindled memories of the sharp oil price rises in the 1970s when the real oil price tripled in 1973 and then again more than doubled in 1979 (see Figure 3.1).

This paper is an attempt to ascertain empirically what led to the large responses of the economy to oil price shocks in the past, and what changes in the U.S. economy that have aided in countering the adverse effects of oil shock in the recent years. Thus the goal of this paper is to assess empirically why the U.S. economy has been able to combat the adverse effects of oil price shocks post-mid-1980s, and under what circumstances such detrimental consequences could manifest themselves again in the future.

We show three major changes in the U.S. economy that we observe very clearly from data. These changes serve as possible explanations for the muted response of U.S.

output and inflation to the oil price shocks that occurred post mid-1980s.

(i) Composition Effect - Most research seeking to identify reasons for the declining effects of oil price shocks on the U.S. economy has focused on the aggregate U.S. data, thereby ignoring the role of the "composition effect." The U.S. economy has largely evolved from a manufacturing economy to a service-driven economy. Has this transformation played a role in the muted response to oil shocks? There exists a substantial degree of heterogeneity in the levels of energy usage across sectors. While the cost share of energy may be small in aggregate U.S. output post-mid-1980s, energy inputs are of considerable importance to individual sectors of the economy. These sectors could be responsible for leading the economy into recession. Thus it is of interest to see if output during oil price shocks systematically declined more in sectors of the economy where energy is used more intensively in production, and how have their responses changed during the post-mid-1980 era. A sectoral analysis allows us to identify how the low-energy-intensity industries performed relative to the highly energy-intensive industries following an oil shock. Our results show that since the U.S. economy has become more service-oriented over the years, energy intensity of the aggregate economy has decreased. Consequently, the transformation of the U.S. economy to a service-driven one have led the economy to withstand oil shocks more efficiently.

(ii) Decoupling of the low-energy-intensive industries - We analyze the evolution of the degree of interdependence among the the three digit sectors over the period 1972-2008. Using dynamic factor model, we decompose the fluctuations in the sectoral growth rates into an economy-wide component and a sector-specific idiosyncratic component. Our results show that post mid-1980s, there is a clear classification of sectoral linkages - sectoral linkages among the low energy sectors and sectoral linkages among the high energy sectors. Sectoral linkages between the low and high-energy-intensity sectors have become substantially weaker during the post mid-1980s. Consequently, most of the effects of oil shocks are absorbed by the few energy-intensity sectors. This is turn allows for more resilience of the U.S. economy to oil price shocks during the post-mid-1980 period.

(iii) Change in the frequency of price adjustment - Finally, we analyze the impact of a change in the degree of price stickiness after the mid-1980s. Recent research (Boivin, Gionnani & Mihov (2009)) and policy discussions have noted that the potentially increased competition among firms as well as increased openness of the U.S economy since the 1990s may affect inflation and economic activity. In the light of these considerations, it is interesting to see if the frequency of price adjustment has increased after the mid-1980s. Data shows that the sectoral price indices adjust at a faster rate compared to the pre-mid-1980 period.

In this paper, we first estimate a factor augmented structural vector autoregression (FAVAR) to study the effects of oil price shock on aggregate and disaggregated U.S. prices and output. To do so, we use a large dataset of 103 macroeconomic indicators and sectoral data on prices and output. We establish that changes in the sectoral composition of the U.S. economy have played a pivotal role in the muted response of U.S. output and inflation to an oil shock. Next, we disentangle the fluctuations in U.S. sectoral production from those accounted for by aggregate or common economy-wide factors and idiosyncratic sectoral factors. This framework allows us to assess the relative importance of aggregate and sectoral factors in explaining the disaggregated output fluctuations and their evolution over time. Finally, we estimate the effects of oil price shock on both the aggregate and the disaggregated prices. We study the magnitude of the price responses to oil price shocks and investigate whether sectoral and aggregate prices adjust faster to an oil shock in the post-mid-1980 sample versus the earlier sample.

The rest of the paper is organized as follows: Section 3.2 motivates the factor augmented vector autoregressive framework, Section 3.3 discusses the econometric methodology, Section 3.4 discusses the various datasets used in our estimation, Section 3.5 presents the results of our estimation, Section 3.6 concludes.

3.2 Overview: Factor Augmented Vector Autoregression

Factor models have a long tradition in applied economics, finance and other quantitative sciences. Firstly, factor models enable a reduction in the number of explanatory variables (factors) when the variation of a cross-section of variables can be decomposed into a low-dimensional common component reflecting the shared sources of variation and a variable-specific idiosyncratic component. Macroeconomic variables tend to comove over the business cycle, and therefore their common variation over time may be explained by a few dynamic factors. Secondly, large cross-sections of time series are nowadays available to researchers and policy-makers, including central bankers who "follow literally hundreds of data series", as expressed by Bernanke, Boivin, Eliasz (2005). The potential gains of using large information sets are increased precision in forecasts and a better understanding of the economy's dynamics. In the context of the FAVAR, a much richer information set is utilized in the econometric model than in the standard vector autoregressive (VAR) model. This addresses the omitted variable problem. Moreover, because macroeconomic data are prone to measurement errors, dynamic factor analysis of large panels may help to filter out the observable variables like real GDP or inflation which may not be well represented by a single observed time series.

Econometric theory of the determination of the (optimal) number of factors has recently been developed, notably by Hallin and Liska (2008), Stock and Watson (2005) and Bai and Ng (2006), Forni etal (2002) and Bai and Ng (2002) for the class of dynamic factor models in the static representation. Including more factors in the factor model increases the statistical fit of the panel but at the cost of parsimony, whereas choosing too few factors means that the factor space is not sufficiently spanned by the estimated factors. The papers cited above propose various information criteria to guide selection of the number of factors, but these proposals do not provide information about the number of lags in the VAR. Consequently, the lag selection problem in this paper is solved using the information criteria, and for a given number of factors, also the standard Akaike and Schwartz information criteria.

As pointed out by Stock and Watson (2006), the curse of dimensionality in the VAR is turned into a "blessing" of dimensionality in factor models, making them particularly useful for representing the data-rich environment in which central banks and professional forecasters actually operate. Hence in our study of the effects of oil price shocks, we will use the factor augmented vector autoregression (FAVAR) as opposed to a standard VAR analysis.

3.3 Econometric Framework

Two ingredients must be combined to set up the Factor Augmented Vector Autoregression (FAVAR). The first ingredient is the dynamic factor model, and the second is the standard VAR with observed variables. In this section, we lay out a formal framework for FAVAR. The FAVAR methodology we use in this paper is based on the the work of Bernanke, Boivin, Eliasz (2005) and Boivin, Gionnani & Mihov (2009). As explained before, the key feature of the FAVAR framework is to provide consistent estimates of the macroeconomic factors by extracting important and relevant information from a large set of economic indicators. We estimate the empirical model by using information from a very large set of economic indicators as well as from disaggregated industry-level data for the U.S. economy. A notable advantage of this framework is that it allows the decomposition of the fluctuations in each series to a common component and a sector-specific component. It also allows us to analyze the response of all the data series to a macroeconomic disturbance, such as an oil price shock.

The FAVAR framework is in principle more flexible than the VAR framework for at least two reasons. Firstly, the VAR framework only uses a meager information set; most VARs are restricted to a set of six to eight variables. Hence the VAR analysis requires taking a stance on specific observable measures, for example, the Gross Domestic Product as a reflection of "economic activity." However "economic activity" may not be perfectly represented by the GDP or index of industrial production or for that matter by any single observable measure. Moreover any observable measure is likely to be tainted from measurement errors. A second limitation of the standard VAR analysis is the fact that, impulse responses in a standard VAR can be estimated only for a small set of included variables. FAVAR, on the other hand, allows one to obtain impulse response functions for literally any variable included in the dataset. For the context of our analysis, it allows us to document the effect of oil price shocks on disaggregated prices. It is also important to note here that the FAVAR is superior to the standard panel VAR approach. We have a large dataset of economy-wide variables as well as industry (sector) variables. Like the panel VAR approach, we do not want to a priori impose the restrictions about which variables are most important for our analysis. The FAVAR endogenously determines the most important variables by extracting the principal components from the large dataset.

We now provide a description of the implementation of the FAVAR in the context of oil price shocks on the U.S economy. Let us assume that the economy is affected by a vector $\mathbf{E}_t$ of common economy-wide components, these components being common to all variables in our dataset. To analyze the effects of oil price shocks, we include the nominal price of West Texas Intermediate Crude, denoted by OP_t in the vector of common components. The common dynamics are captured by a $K \times 1$ vector of unobserved factors $\mathbf{F}_t$, where K is small. The unobserved factors reflect general economic conditions such as the economic activity, prices, productivity, employment, etc which are difficult to capture by means of a few time series, but rather by a range of economic variables. The joint dynamics of $\mathbf{F}_t$ and OP_t are given by

$$\mathbf{E}_t = \Phi(L)\mathbf{E}_{t-1} + v_t \tag{3.1}$$

where

$$\mathbf{E}_t = \begin{bmatrix} OP_t \\ \mathbf{F_t} \end{bmatrix}$$

and $\Phi(L)$ is the lag polynomial of finite order. The error term v_t is i.i.d with mean zero. The system of equations above is a VAR in $\mathbf{E}_t$, the only difference being the fact that the factors $\mathbf{F}_t$ are unobservable. The factors $\mathbf{F}_t$, more or less exhaustively summarize of the information contained the large dataset considered in the analysis. Let $\mathbf{Y}_t$ denote the $N \times 1$ vector of information variables, where N is large, i.e., $N >> K + 1$. Also we assume that the set of informational variables $\mathbf{Y}_t$ is related to the common components $\mathbf{E}_t$ by the following relation

$$\mathbf{Y}_t = \Lambda \mathbf{E}_t + e_t \tag{3.2}$$

where Λ is a $N \times (K + 1)$ matrix of factor loadings, and the $N \times 1$ vector e_t contains the sector-specific components that are uncorrelated with the economy-wide common components $\mathbf{E}_t$. These sector-specific components are assumed to be serially correlated and also weakly correlated across sectors.

As in Bernanke, Boivin, Eliasz (2005) and Boivin, Gionnani & Mihov (2009), we estimate our empirical model using a variant of the two-step principal component approach. In the first step, we extract the principal components from the large dataset $\mathbf{Y}_t$, to obtain consistent estimates of the common factors. Let us call denote the set of principal components by $\mathcal{P}C_t$, so that our structural model in the second stage is given by

$$\mathbf{A}(L)E'_t = \epsilon_t \tag{3.3}$$

where

$$\mathbf{E}'_t = \begin{bmatrix} OP_t \\ \mathcal{P}\mathbf{C_t} \end{bmatrix}$$

and $A(L)$ is the lag polynomial of finite order, $A(L)$ is a matrix polynomial in the lag operator L, and ϵ_t is an $(K \times 1)$ vector of structural innovations or disturbances. ϵ_t is serially uncorrelated and $var(\epsilon_t) = \Sigma_\epsilon$, where Σ_ϵ is a diagonal matrix where the diagonal elements are the variances of structural disturbances. Hence the structural disturbances are assumed to be mutually uncorrelated. Note that we only consider the stochastic part of the data-generating process because it is the part of interest from the point of view of structural modeling and impulse response analysis.

We estimate a reduced form FAVAR equation given by

$$E'_t = a + bt + \sum_{i=1}^{p} B_i E'_{t-i} + u_t, \tag{3.4}$$

where B represents matrix of polynomial of lag operators and $var(u_t) = \Sigma_u$. According to Stock and Watson (2002), the principal components consistently recover the space spanned by the factors when the number of informational variables N is large and the number of principal components used is at least as large as the true number of factors.

Next we estimate the structural VAR given by (3.3). This part of the procedure is exactly similar to the structural VAR analysis, the details of which are discussed later. Our implementation of the FAVAR follows Boivin, Gionnani & Mihov (2009), since we impose the constraint that the oil price is one of the factors in the first step of estimation.

3.4 Data

Our dataset $\mathbf{Y}_t$ consists of a panel of 103 monthly macroeconomic time series. The series are transformed to induce stationarity. The details of the series in the dataset and their corresponding transformations are provided in the data appendix. The data spans from 1972:1-2008:12. The dataset contains 103 updated macroeconomic indicators, including measures of industrial production, price indices, interest rates, employment and other macroeconomic and financial variables. As found in Bernanke, Boivin, Eliasz (2005), these indicators collectively contain useful information about the state of the economy. We extend the dataset of Bernanke, Boivin, Eliasz (2005) in three major ways: first, we extend the time span to 2008:12. Second, since we are interested in the effects of oil price shocks, we append a set of macroeconomic indicators pertaining to energy. The data for the energy indicators are obtained from the Energy Information Administration (EIA). Third, we also append disaggregated industry-level data published by the Federal Reserve Board and the Bureau of Labor Statistics. In particular, we extend the dataset by adding data on index of industrial production for the 28 three-digit (NAICS classification, corresponding to the two-digit SIC classification) U.S sectors. In addition, we also annex the data on producer and consumer price indices for 31 sectors. The price data are obtained from the BLS[1]. However it is important to note that there is no one-to-one mapping from the production indices to the price indices; hence the

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[1] Refer to the data appendix for the details of the data and sources

mapping used is only approximate. Thus the entire dataset contains a total of 162 series, 103 variables on economic indicators, 28 series on sectoral industrial production indices and 31 series on the sectoral price indices.

3.4.1 Lag Length Selection

The standard results about the properties of the VAR coefficients and VAR estimation (Hamilton (1994), Chapter 11) depend on the lag length of the VAR. The same results extend to the FAVAR analysis. There are two main approaches used for selecting or testing lag length in VAR models. The first consists of rules of thumb based on the periodicity of the data and past experience regarding cyclicality of economic data. The second is based on formal hypothesis tests. We rely on formal hypothesis tests for lag length selection.

Two classical test statistics can be used to evaluate the lag length of a VAR model. The first is based on a likelihood ratio test. The likelihood ratio test compares the maximum value of the likelihood achieved for a model with p lags to a model with $p-1$ lags. The likelihood ratio function for a VAR model can be written as

$$L(\hat{\Sigma}, B, p) = -\frac{TK}{2} log(2\pi) + \frac{T}{2} log|\hat{\Sigma}^{-1}| - \frac{TK}{2}, \tag{3.5}$$

where $\hat{\Sigma}^{-1}$ is the matrix inverse of the estimated error covariance matrix and $log|\hat{\Sigma}^{-1}|$ is the logarithm of the determinant of $\hat{\Sigma}^{-1}$.

Also used to determine lag length in VAR models is the information criteria such as Akaike's information criterion (AIC), the Bayesian (or Schwarz) information criterion (BIC or SC), and the Hannan-Quinn criterion. Information criteria measures are an effort to determine the trade-off between model fit and parsimony. They are based on the likelihood function for a model, penalized by the number of parameters. For two models that fit the data equally well (i.e., the same likelihood value), the more parsimonious model pays a smaller penalty and is thus considered superior based on an information criteria measure. According to Ivanov and Killian (2001), for monthly VAR models the AIC tends to produce the most accurate structural and semi-structural impulse response estimates for realistic sample sizes. Thus with our monthly FAVAR, we use the AIC to determine lag length, suggesting an optimal lag length of 7. We are aware of the potential sensitivity of the point estimates to assumptions about lag length as in Hamilton and Herrera (2001). While including too many lags and hence an excessive number of parameters introduces sampling uncertainty in estimating the parameters, at the same time we cannot afford to overlook the fact that fewer lags also introduce omitted variable bias. So we have tried with different other lag lengths of 6, 7, 8, 9, 12, and found that this does not alter the results significantly.

3.4.2 Identification

There are several ways of recovering the parameters in the structural form equation (3.3) from the estimated parameters in the reduced form equation (3.4). Some methods give restrictions only on contemporaneous structural parameters. Others impose restrictions on the lag structure as well. A popular and convenient method is to orthogonalize reduced form disturbances by Cholesky decomposition of the white noise covariance matrix, $\Sigma_u = PP'$ (as in Sims (1980) among others), where P is a lower triangular matrix with positive elements on the main diagonal. We will use the recursive identification scheme and justify why this is a satisfactory identification approach in our case. The identifying assumption that oil prices are predetermined with respect to the

U.S. macroeconomy at monthly frequency has a long tradition in both empirical and theoretical work (see, e.g., Rotemberg and Woodford (1996); Leduc and Sill (2004); Blanchard and Gali (2007)). Recent empirical work by Killian and Vega (2008) lends support to this identifying assumption. The assumption of predeterminedness permits consistent estimation of the expected response of U.S. macroeconomic aggregates to an innovation in energy prices. In conjunction with the assumption that there are no other exogenous events that correlated with the exogenous oil price innovation, these impulse responses can be interpreted as the causal effect of the energy price innovation. More generally, we can interpret these responses as the expected change in the variables of interest associated with energy price shocks.

Following the papers cited above, we identify oil shocks by assuming that unexpected variations in the nominal spot price of oil are completely exogenous relative to the contemporaneous values of the remaining macroeconomic variables included in the VAR. The theoretical justification of this recursive structure is as follows: oil price shock can instantaneously affect the block of U.S. macroeconomic variables, but the U.S. macroeconomic block cannot affect the world oil price instantaneously or in the same month.[2] Thus in this specification, oil price is Wold-causally prior to the remaining macroeconomic variables in the system i.e., we place nominal oil price as the first variable in our ordering. Since we are interested only in oil price shock, the ordering of the remaining variables is immaterial. Note that the ordering of the federal funds rate after the oil price captures the idea that U.S Fed will tighten monetary policy in response to inflationary oil price shocks. We do not impose any restrictions on the lag structure of the variables.

Our identification assumption outlined above allows us to recover the structural innovations ϵ_t directly from the forecast errors or the reduced form residuals, u_t. We can

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[2] See discussion in Blanchard and Gali (2007)

write the reduced form equation (3.4) in such a way that the residuals of (3.4) are uncorrelated. Writing the forecast errors as linear functions of the structural innovations, we have $u_t = P\epsilon_t$. Hence $\Sigma_u = P\Sigma_\epsilon P'$. Normalizing the variances of the structural innovations to 1, i.e., assuming $\epsilon_t \sim (0, I_K)$, gives $\Sigma_u = PP'$. Hence choosing P by a Choleski decomposition solves our identification problem. This is the FAVAR extension of the standard recursive identification of oil price shocks in standard VARs.

3.5 Effect of Oil Price Shocks

The purpose of this section is to discuss the macroeconomic effects of oil price shocks on disaggregated prices and quantities, and to explore the reasons underlying changes in the effects of oil price shocks on the US economy. We use the Factor Augmented Vector Autoregression (FAVAR) approach discussed above to analyze how the effects of oil price shocks on the aggregate U.S economy have evolved over time. As mentioned before, a common problem with the small-sized VARs is that to maintain sufficient degrees of freedom, estimated VARs are typically low dimensional, involving no more than 6-8 variables. Consequently, they do not allow us to understand the effects of oil price shocks on a large number of variables of interest. The FAVAR described above allows us to circumvent this shortcoming of traditional VARs. In this section we focus on the effects of oil price shocks on our large panel of disaggregated prices and quantities.

3.5.1 Responses to Oil Price Shocks

We define an oil price shock, i.e., an unexpected 10% increase in the nominal price of West Texas Intermediate Crude (in dollars per barrel). Figure 2 shows the estimated impulse response functions for aggregate Personal Consumption Expenditure (PCE) price and quantity indices to an oil price shock, where the oil price shock is identified as a 10% innovation to the oil price equation. Estimates are reported for two different sample periods: 1972:2-1984:12 and 1984:1-2008:12. The left-hand side panel shows impulse responses for the sample 1972:2-1984:12 and the right-hand side shows impulse responses for the sample 1984:1-2005:12. The break date chosen corresponds roughly to the beginning of the Great Moderation in the United States, as identified by several authors [e.g.McConnell and Pérez-Quirós (2000)]. Note that each subperiod contains two of the four large oil shock episodes identified in the previous section. The solid (black) line shows the responses generated by our FAVAR and the dashed lines on both sides of the impulse responses show the 90% residual-based bootstrap confidence intervals.

Three important features of oil price shock dynamics emerge from the FAVAR analysis:

(i) *The mean impulse response from the FAVAR for the aggregate PCE quantity index is statistically significantly higher than the mean impulse response in the second sample:* The mean impulse response of the PCE quantity index for the pre-mid-1980 sample is -0.2826, whereas the mean impulse response for the post mid-1980 sample is -0.1521. The null hypothesis that the means are equal is rejected by a pairwise *t*-test in favor of the alternative hypothesis that the absolute value of the mean is higher in the first sample with p-value less than 10^{-4}. The PCE quantity index in the first sample reaches its trough after four quarters when it falls by -0.6%, whereas the decline in the PCE quantity index in the second sample after four quarters, is only 0.2%, about one-third of the decline in the first sample.

Table 3.1: Paired t-test for Aggregate PCE Quantity Indices

Variable	Mean	Std-Err.	Std.Dev.	95% Conf.	Interval
PRE	-0.2826	0.0131	0.0918	-0.3090	-0.2562
POST	-0.1521	0.0059	0.0415	-0.1640	-0.1402
Diff	-0.1304	0.0143	0.1006	-0.1594	-0.1015

H_0: Mean(diff)=0, H_a: Mean(Diff)< 0, t: -9.0755, DF=49, P-value=0.0000.

(ii) *The mean rise in the PCE price index is lower in the post 1984 sample:* The initial rise in the prices following the shock is higher in the second sample for the first four quarters. However the mean price response in the first sample is significantly greater than that of the second sample. The null hypothesis that the means are equal is rejected by a pairwise t test in favor of the alternate that the mean in the first sample is higher with p-value less than 10^{-4}. The peak of the impulse is reached much earlier in the second sample. However the peak is much lower in the second sample as compared to the first sample (0.22 in the second sample and 0.39 in the first sample). Furthermore, price rises faster and reaches its peak at 6 months in the second sample, while in the first sample where the peak is reached at 23 months. Thus the speed of price adjustment is much faster in the second sample than in the first sample. This suggests that aggregate prices have become more flexible and adjust faster in the second sample when compared to the first sample. More details on disaggregated price adjustments are provided in the next section.

Table 3.2: Paired t-test for Aggregate PCE Price Indices

Variable	Mean	Std-Err.	Std.Dev.	95% Conf.	Interval
PRE	0.2957	0.0107	0.0754	0.2741	0.3174
POST	0.1533	0.0053	0.0372	0.1426	0.1640
Diff	0.1424	0.0105	0.0740	0.1211	0.1637

H_0: Mean(diff)=0, H_a: Mean(Diff)< 0, t: 13.4702, DF=49, P-value=0.0000.

(iii) *Persistence of inflation is higher in the first sample*: The next two tables give the autocorrelation conditional on shock of inflation for the aggregate PCE series as well as the unweighted average PCE series. It is clear from the series that the persistence of inflation for PCE aggregate, PCE unweighted and disaggregated PCE series for manufacturing, services and energy goods and services display a very high level of persistence in the pre-mid-1980 sample. This persistence seems to have declined significantly in the second sample, implying that price adjustment after the oil shock is much faster.

3.5.2 Composition Effect

It is well known that the U.S economy has evolved into a service-driven economy over time. Often referred to as the process of "deindustrialization", the share of employment in manufacturing has fallen over the years. This appears to mirror the decline in the share of manufacturing value added in the U.S. GDP. Measured in real terms, the share of expenditure in manufacturing has also been declining in the U.S. According to the CIA World Factbook, in 2007 services made up 78.5% of the U.S. GDP, manufactur-

Table 3.3: Response of PCE Price Index at 10% Oil Price Shock: 1972:2-1984:12

	Autocorrelation of Inflation conditional on shock				Price Responses (%)	
Series	1st Order	3rd Order	6th Order	10th Order	6 Months	12 Months
PCE Total	0.885*	0.617*	0.611*	0.343*	0.2308*	0.4589*
Durables	0.870*	0.610*	0.619*	0.405*	0.2137*	0.0231*
Non Durables	0.833*	0.415*	0.506*	0.197*	0.0348*	0.0231*
Manufacturing	0.743*	0.611*	0.519*	0.328*	0.0305*	0.0082*
Services	0.845*	0.460*	0.534*	0.254*	0.0128*	0.0231*
Energy GS	0.832*	0.420*	0.447*	0.236	0.0949*	0.0606*
PCE Avg	0.897*	0.700*	0.447*	0.158	0.2396*	0.4724*

Table 3.4: Response of PCE Price Index at 10% Oil Price Shock: 1985:1-2008:12

	Autocorrelation of Inflation conditional on shock				Price Responses (%)	
Series	1st Order	3rd Order	6th Order	10th Order	6 Months	12 Months
PCE Total	0.616*	0.036*	0.042*	0.032*	0.1567*	0.1659*
Durables	0.427*	0.004*	0.069*	−0.060*	0.0065*	−0.0052*
Non Durables	0.628*	0.096*	−0.003*	0.022*	0.0715*	−0.0127*
Manufacturing	0.075	0.151	−0.145	−0.035	−0.044*	−0.0100
Services	0.629*	0.091	0.006	0.0170	0.0130*	0.0030*
Energy GS	0.644*	0.105	−0.008	0.043	−0.3069*	−0.0243*
PCE Avg	0.806*	0.608*	0.472*	0.242*	0.2136*	0.2087*

ing made up 20.5% and agriculture less than 1%. To see if this change in the sectoral composition has played a role in the dampened response of oil price shocks post 1984, let us first analyze the impulse responses of the PCE quantity and price indices in manufacturing and service sectors. Although there exists a substantial heterogeneity in the magnitude of price and quantity responses of manufacturing and services, the qualitative responses of the differences across the two samples are same - impulse responses for both sectors appear to be more muted in the second sample. The PCE quantity for manufacturing drops by 0.75% after 4 quarters in the first sample before reaching the trough, after which it shows signs of recovery. The service PCE quantity index for the first sample, on the other hand drops about 0.28% before exhibiting signs of recovery. As expected, the service sector as expected contracts by only a third of the manufacturing sector after the oil price shock. This result is intuitive: the service sector is inherently less energy-intensive and therefore less affected by energy price fluctuations. However there is a short-run adverse spillover effect from the manufacturing to the service sector that is reflected in the PCE services. As a result of the oil shock, commodity prices in manufacturing sector rise faster, hence with a fixed amount of income, consumer expenditure on services falls. This spillover effect accounts for at least a part of the contraction in the service sector. On the whole, responses of PCE quantity for manufacturing and services both display a more muted response; although in both manufacturing and services the PCE quantity index shows a persistent decline following the oil shock in both pre- and post- mid-1980 samples, the decline is only about half that experienced in the first sample. The PCE price indices for manufacturing and services in the second sample, however, show a lower volatility and a faster adjustment (less persistence).

To further corroborate the role of change in sectoral composition, we now run a counterfactual experiment. We plot the unweighted average of the impulse responses of manufacturing and services and compare those to the aggregate PCE price and quantity indices. The aggregate PCE price and quantity indices take into account the true weights of the manufacturing and service sectors, whereas the average PCE assigns equal weight to both sectors. It is interesting to note that the average price and quantity responses are different - both the rise in price and the drop in quantity for the unweighted PCE are more than the weighted (aggregate) PCE price and quantity indices shown in Figure 5.

Another interesting observation is to see how the difference between the impulse responses of the weighted and unweighted PCE indices has evolved over time. To see this, we first compute the difference between the impulse responses of the weighted and unweighted PCE price indices separately for the pre- and post- mid-1980 samples. Next we do a mean comparison test to determine if the difference between the pre and post 1985 difference is statistically significant or not. Our t-test shows (Tables 5 and 6) that the difference between the weighted and unweighted price and quantity indices are significantly higher in the post 1985 sample with a p-value of less than 10^{-4}. This implies that sectoral weights play an important role in explaining the reduced impact of oil price shocks on the U.S. output and inflation, and that the role of sectoral weights have changed significantly between the samples due to the U.S. economy moving towards a service-oriented economy.

Table 3.5: Paired t-test for Aggregate and Unweighted PCE Quantity Indices

Variable	Mean	Std-Err.	Std.Dev.	95% Conf.	Interval
PRE(Agg-Avg)	0.0086	0.0005	0.0035	0.0076	0.0097
POST(Agg-Avg)	0.0043	0.0007	0.0053	0.0028	0.0059
Diff	0.0043	0.0010	0.0073	0.0021	0.0064

H_0: Mean(diff)=0, H_a: Mean(Diff)> 0, t: 4.0901, DF=49, P-value=0.0000.

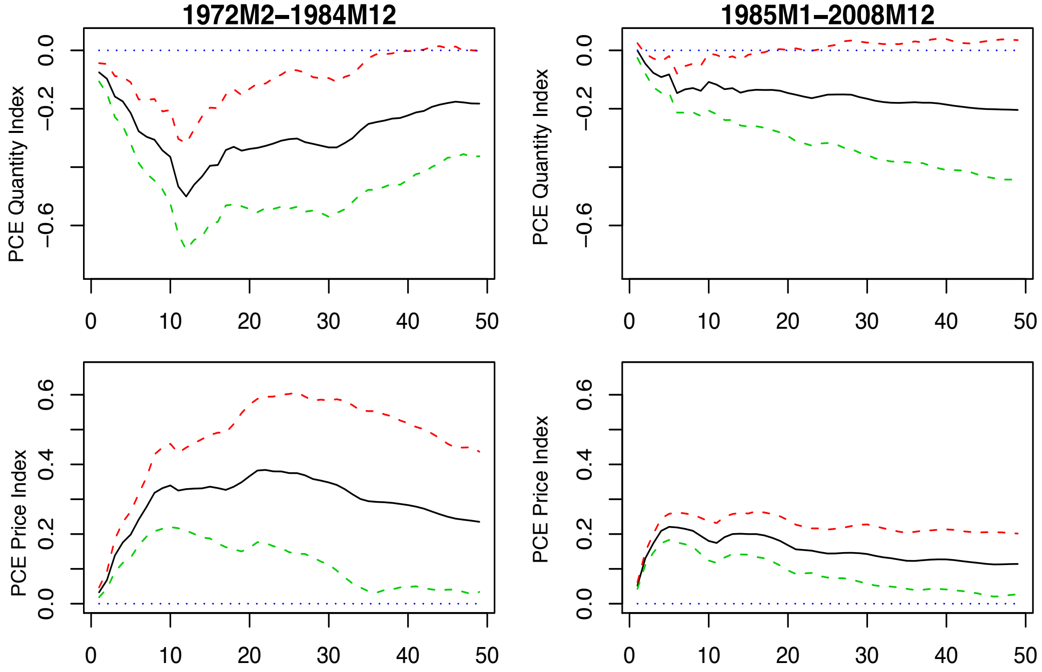

Figure 3.2: Impulse Responses of Aggregate PCE Price and Quantity Indices

Table 3.6: Paired t-test for Aggregate and Unweighted PCE Price Indices

Variable	Mean	Std-Err.	Std.Dev.	95% Conf.	Interval
PRE(Agg-Avg)	-0.0073	0.0002	0.0020	-0.0079	-0.0067
POST(Agg-Avg)	0.0382	0.0025	0.0181	-0.0434	-0.0330
Diff	0.0308	0.0025	0.0176	0.0258	0.0359

H_0: Mean(diff)=0, H_a: Mean(Diff)> 0, t: 12.2499, DF=49, P-value=0.0000.

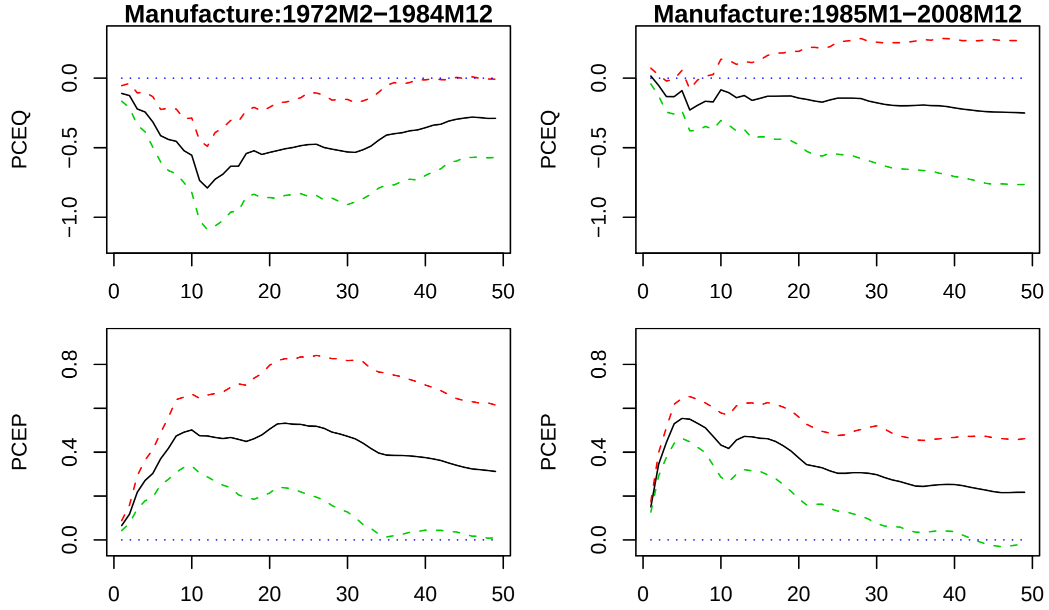

Figure 3.3: Impulse Responses of Manufacturing PCE Price and Quantity Indices

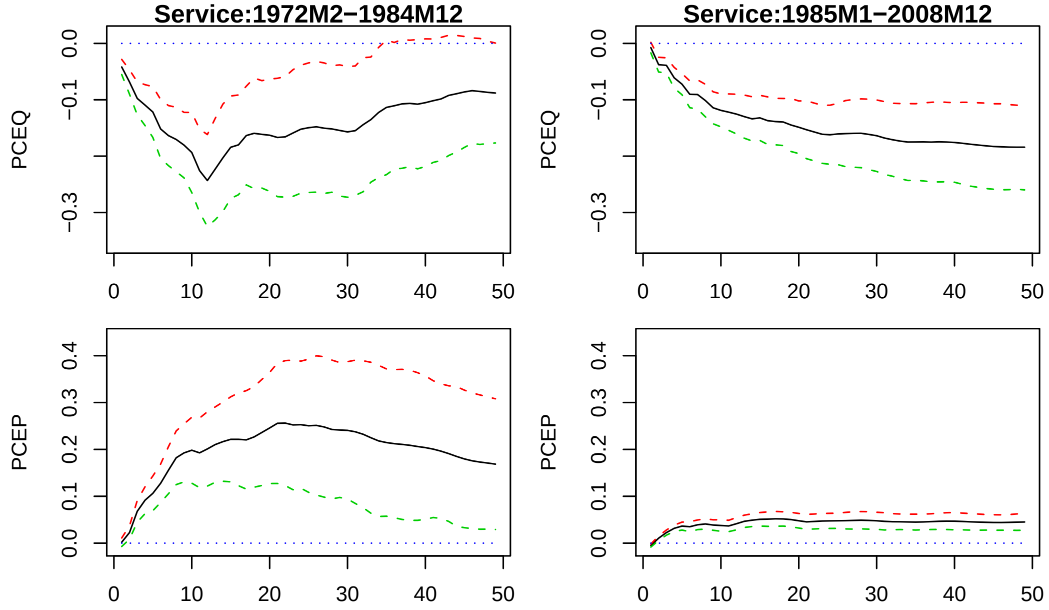

Figure 3.4: Impulse Responses of Service PCE Price and Quantity Indices

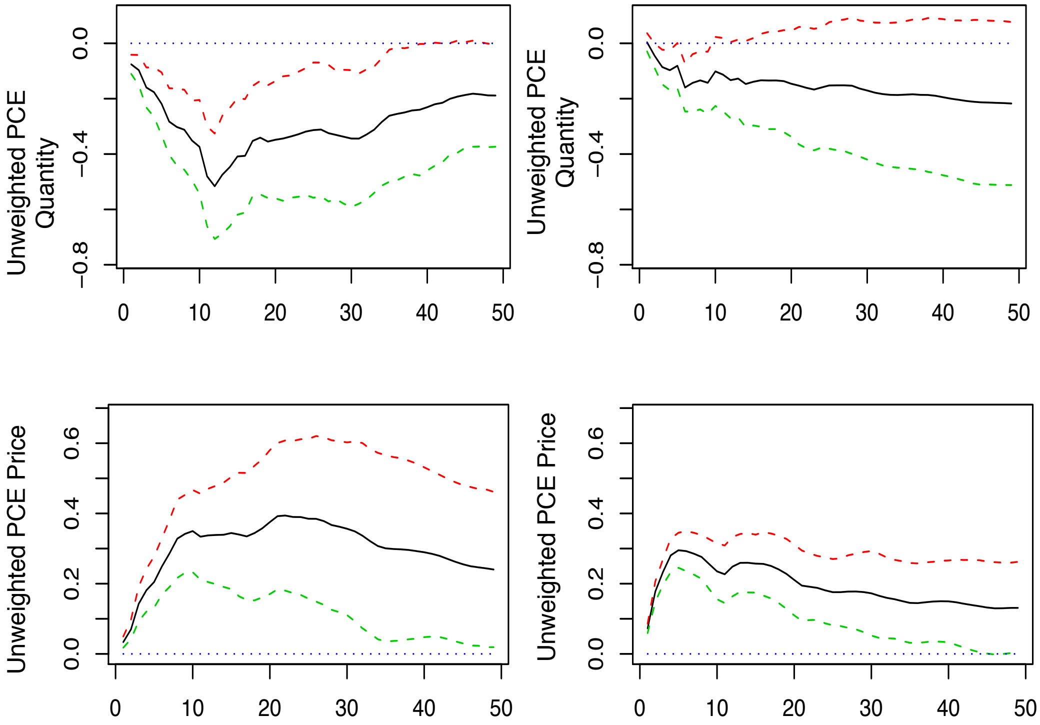

Figure 3.5: Impulse Responses of Aggregate PCE Price and Quantity Indices

3.5.3 Sectoral versus Aggregate Shocks

The U.S. economy's production landscape has shifted dramatically since the mid-1980s. A very high level of import penetration has lead to a rapid increase in U.S. trade linkages with other countries. As a natural byproduct of this development, the U.S. sectors are less integrated with each other. In this section, our objective is to provide an empirical characterization of the reduced linkages among different sectors of the U.S. economy. We seek to answer how the linkages between sectors have evolved over time. We again employ the dynamic factor model to decompose the fluctuations in sectoral output into two factors: (i) economy-wide common factors and (ii) sector-specific components as follows: Let y_t^j denote the growth rate of production (industrial production) in sector j.

$$y_t^j = (\beta_{E'}^j)^T E_t' + e_t^j \tag{3.6}$$

where as defined before

$$\mathbf{E}'_t = \begin{bmatrix} OP_t \\ \mathcal{P}\mathbf{C_t} \end{bmatrix}$$

We denote the transpose of a vector β by β^T. This formulation allows us to disentangle the fluctuations in sectoral output growth rates due to the economy-wide common factors (E_t) and the sector-specific components represented by e_{it}. The β parameters denote the factor loadings and capture the sensitivity of each variable to the latent factors. For each y^j, the estimated factor loadings quantify the extent to which the variable moves with the economy-wide factors, including oil price.

We use variance decompositions to measure the relative contributions of the aggregate economy-wide and sector-specific factors to output fluctuations in each sector. This provides an empirical assessment of how much of a sector's output fluctuations are associated with aggregate fluctuations and how much is attributable to the sectoral factors. We estimate the share of the variance of each macroeconomic variable attributable to each of the three factors and the idiosyncratic component. With orthogonal factors, the variance of the growth rate of the observable quantity y_t^j can be written as follows:

$$var(y_t^j) = (\beta_{E'}^j)^T var(E'_t)\beta_{E'}^j + var(e_t^j) \tag{3.7}$$

If the comovement in sectoral growth rates is driven by aggregate (common) factors, it would follow that these shocks represent the dominant source of variation in the sectoral and aggregate output. However, this calculation is only approximate, since the diagonal elements of the production covariance matrix would themselves partly reflect the effects of aggregate shocks.

We now examine the evolutions of the economy-wide common factors and the sector-specific factors, and how these factors match the actual output growth. Our results show a clear division of the sectors in two groups: high-energy-intensity sectors and low-energy-intensity sectors. The low- energy-intensity sectors have decoupled from the high-energy-intensity sectors. While much of the variability of production in the high-energy-intensity sectors can be explained by the common factors which includes oil, bulk of the variability in the low intensive sectors is explained by sector specific factors. Tables 7 and 8 show the 5-factor model's implied standard deviation of sectoral production as well as the fraction of the variability of sectoral production explained by the common factors $\mathbf{E}_t'$. For the relative high-energy-intensity sectors, e.g., electric and gas utilities, petroleum and coal products, motor vehicles and parts, aerospace and transportation, the R^2 statistic which measures the fraction of variance of output explained by common factors is much higher for the post-mid-1980 sample. These common factors represent not only aggregate shocks but also propagation of sectoral shocks through input-output linkages between sectors. For these sectors, since the input-output linkages are strong, the effects of oil price shocks are transmitted rapidly.

For the low-energy-intensity sectors, e.g., apparel and leather, wood products, food, beverage and tobacco, more than 50% of the variation is attributable to the common factors, and the contribution only increases between the two samples. Thus for the low-energy-intensity sectors, the common factors are more important in explaining output variation than the idiosyncratic sector-specific factors.

To summarize, there are three major results from our analysis of variance decompositions of sectoral production for the two samples 1972:2-1984:12 and 1985:1-2008:12. First, the overall fluctuations in the sectoral growth rates have dampened over time. For most of the series, the fluctuations in the growth rate of output reflected in the sector-specific standard deviations exhibit lower values in the second sample. Second, the common economy-wide factors account for a modest but significant share of macroeconomic fluctuations across all sectors, although they are more important for explaining the fluctuations in the low-energy-intensity sector's output. Third, there appear to be distinct cycles specific to each group, high-energy-intensity sectors and low-energy-intensity sectors. Low-energy-intensity sectors seem to be less affected by the common aggregate shocks post-mid-1980s. Thus effects of oil price shock propagate less to the low-energy-intensive sectors in the post-mid-1980 sample. This shows a convergence of the low-energy-intensity sectors. Because of this evolution of sectoral linkages, the effects of oil price shocks are absorbed by a few sectors of the economy. This might provide a reasonable explanation as to why we see a muted and dampened response of aggregate output post-mid-1980.

Table 3.7: Decomposition of Variance of Sectoral Output: 1972:2-1984:12

Industries	R^2	Sector Specific	Common Factors	Std Dev
Agriculture	0.1939	0.5746	0.2818	0.6399
Manufacturing	0.9891	0.1188	1.1316	1.1378
Durable Manufacturing	0.9566	0.2938	1.3793	1.4102
Non Durable Manufacturing	0.8362	0.3889	0.8786	0.9609
Mining	0.8897	0.6551	1.8605	1.9725
Electric Power Generation, Transmission and Distribution	0.7102	0.8864	1.3876	1.6465
Electric and Gas Utilities	0.8593	0.6584	1.6271	1.7552
Natural Gas Distribution	0.4523	2.871	2.609	3.8793
Food, Beverage and Tobacco	0.4979	0.7582	0.7550	1.070
Textiles and Products	0.5982	1.102	1.3446	1.7385
Apparel and Leather	0.6536	0.9014	1.2381	1.5315

Table 3.7: Decomposition of Variance of Sectoral Output: 1972:2-1984:12

Industries	R^2	Sector Specific	Common Factors	Std Dev
Wood Product	0.4929	2.227	2.1955	3.1273
Paper	0.4849	1.458	1.4146	2.0314
Printing and Support Activities	0.1671	1.26	0.5644	1.3806
Petroleum and Coal Products	0.2095	1.806	0.9297	2.0312
Chemical	0.6444	0.803	1.0809	1.3465
Plastics and Rubber Products	0.4371	2.007	1.7685	2.6750
Non Metallic Mineral	0.6185	1.066	1.3573	1.7258
Primary Metals	0.5955	2.188	2.6547	3.4402
Fabricated Metal Products	0.7839	0.5579	1.0625	1.2001
Machinery	0.6343	1.018	1.3407	1.6833
Computer and Electronic Products	0.5574	1.044	1.1715	1.5692
Electrical Equipments, Appliance, Components	0.6103	1.27	1.5894	2.0344
Motor Vehicles and Parts	0.6593	2.752	3.8282	4.7147
Aerospace and Miscellaneous Transportation	0.1602	1.719	0.7507	1.8758
Furniture and Related Products	0.6029	1.144	1.4096	1.8154
Miscellaneous Manufacturing	0.6467	0.6866	0.9289	1.1551
Other Manufacturing	0.3175	0.8644	0.5895	1.0463

Table 3.8: Decomposition of Variance of Sectoral Output: 1985:1-2008:12

Industries	R^2	Sector Specific	Common Factors	Std Dev
Agriculture	0.0494	0.3631	0.0827	0.3724
Manufacturing	0.9767	0.1064	0.6888	0.6970
Durable Manufacturing	0.9524	0.1992	0.8910	0.9130
Non Durable Manufacturing	0.8784	0.2496	0.6708	0.7157
Mining	0.8010	0.632	1.2679	1.4167
Electric Power Generation, Transmission and Distribution	0.7279	0.977	1.5979	1.8729
Electric and Gas Utilities	0.8830	0.7034	1.9323	2.0564
Natural Gas Distribution	0.5856	3.187	3.7885	4.9507
Food, Beverage and Tobacco	0.5290	0.6354	0.6733	0.9258
Textiles and Products	0.4133	1.03	0.8644	1.3447
Apparel and Leather	0.2819	1.037	0.6497	1.2237
Wood Product	0.4168	1.357	1.1471	1.7769
Paper	0.2829	1.187	0.7455	1.4017
Printing and Support Activities	0.2732	0.8633	0.5292	1.0126
Petroleum and Coal Products	0.5122	1.347	1.3802	1.9286
Chemical	0.6261	0.7022	0.9086	1.1483
Plastics and Rubber Products	0.4816	0.6107	0.5886	0.8481
Non Metallic Mineral	0.4122	0.9575	0.8018	1.2488
Primary Metals	0.3671	2.121	1.6153	2.6660
Fabricated Metal Products	0.5558	0.4799	0.5368	0.7200

Table 3.8: Decomposition of Variance of Sectoral Output: 1985:1-2008:12

Industries	R^2	Sector Specific	Common Factors	Std Dev
Machinery	0.3928	1.13	0.9088	1.4501
Computer and Electronic Products	0.5109	0.8562	0.8750	1.2242
Electrical Equipments, Appliance, Components	0.2663	1.008	0.6072	1.1767
Motor Vehicles and Parts	0.6826	2.343	3.4359	4.1588
Aerospace and Miscellaneous Transportation	0.3221	1.863	1.2841	2.2627
Furniture and Related Products	0.4078	0.8417	0.6984	1.0937
Miscellaneous	0.3849	0.604	0.4777	0.7701
Other Manufacturing	0.2932	0.724	0.4663	0.8611

3.5.4 Price Adjustment Conditional on Oil Shock

We have seen in Section 3.5 that aggregate prices adjust much faster in recent years than in the 1970s and early 1980s. In particular we noted a decline in both the inflation volatility and persistence for the aggregate PCE price indices and also for the disaggregated price indices for manufacturing and services. One possible underlying cause of increased price flexibility is the increased competition among firms following the largescale liberalizations since the 1990s. Because of intense competition, even if firms increase their prices following an oil shock, they bring down the prices faster in the fear of losing market share. If producers know that prices are sufficiently flexible and that they can easily pass on the increase in marginal cost following a oil price increase to the consumers, their markup will in general be lower. Therefore the inflation trigger from the high markups will be dampened.

In order to better understand the resilience of the U.S. economy to large oil shocks post-mid-1980s, it is crucial to see how prices adjust in recent years as compared to the 1970s. The nature of price setting has important implications for a range of issues in macroeconomics, including the welfare consequences of business cycles, the behavior of real exchange rates and optimal monetary policy. Also there is a tremendous amount of sectoral heterogeneity in the frequency of price change. In this section we seek to understand how the frequency of price adjustment varies across sectors and how the frequency has changed since the 1980s. To this end, we estimate the Calvo (1983) style price stickiness parameters for the aggregate producer price index and also the sectoral price indices from the impulse responses of our FAVAR to an oil price shock separately for the pre- and post- mid-1980 period. Our results show that for all sectors, prices adjust much quickly and more frequently when compared to the pre-mid-1980 period.

Measures of price stickiness have been analyzed with micro data Bills and Klenow (2004), and Nakamura and Steinsson (2008). However their estimates are not conditional on any shock. In this section, we investigate the frequency of price adjustment for the different sectors following an oil price shock. We first define a measure of price stickiness [Calvo (1983)] for the aggregate price index as well as the price indices for the 31 sectors. We then estimate the price stickiness for the different sectors by using a maximum likelihood approach separately for the pre- and post-mid-1980 samples to determine if the frequency of price adjustment has changed between the samples.

Let us assume a model similar to the Calvo (1983) framework. We also suppose that the firms know that the shock is permanent and want to set their prices at a new optimal level which we denote by c. This is not a restrictive assumption since in both the sample, pre- and post-mid-1980, the nominal oil price shows a near-random walk response, i.e., it jumps on impact and then stabilizes around a new plateau. However all firms are not able to change the price immediately because of market rigidity. Let λ denote the fraction of firms in sector $i \in \{1, 2, ...31\}$ who cannot reset their prices at period 1. Therefore, a proportion $(1 - \lambda)$ of firms are able to change the price to its new level in the first period, and those who are successful in resetting their price set the price at the new optimal level. These firms do not change their prices again in response to this particular oil shock. In the second time period, $(1 - \lambda)$ proportion of the remaining firms are able to change the price, which is a proportion $\lambda(1 - \lambda)$ of the total. Continuing this argument forward, we get that at time T, $(\lambda^{T-1}(1 - \lambda))$ change their price. So the proportion of firms at time T who have changed their price is $(1 - \lambda^T)$. This implies that the mean change in price from the level prior to the shock to after T periods later is given by $(c(1 - \lambda^T))$. We assume that the observed cumulative impulse response of price in sector i, t time periods after the shock is of the form

$$P_{i,t} = c(1 - \lambda^t) + \epsilon_t, \quad \epsilon_t \sim \text{ iid } N(0, \sigma^2).$$

We estimate the parameters λ, c and standard deviation of ϵ_t, denoted by σ using the maximum likelihood estimation and the results are tabulated in Table 9.

Our results are in line with Nakamura and Steinsson (2008), who also find that the frequency of price change is highest for the energy and gasoline sectors. This result holds true for both the pre- and post-mid-1980 sample. It is also interesting to note that the probability of price change for most of the high-energy-intensity sectors has increased in the post-1980 sample, e.g., following an oil shock the gasoline prices change with a probability of 0.81 in the second sample as compared to 0.15 in the first sample.

The frequency of price change also increases for other energy intensive sectors coal, electric power, motor vehicles and energy services. The increase in the probability of price change for these sectors also leads to increase in flexibility of the aggregate producer price index. We find that the frequency of price adjustment of aggregate producer price index increases significantly in the post-mid-1980 sample. This substantial increase in the frequency of price adjustment could also be instrumental in the dampened response of inflation in the post-mid-1980 sample.

Table 3.9: Measure of Price Stickiness Conditional on Oil

Shock: 1972:2-1984:12

Industries	λ	c	σ
PPI - Total	0.826 (0.814, 0.837)	1.355 (0.753,1.958)	0.080 (0.017, 0.143)
Agriculture	0.998 (0.530, 0.999)	-7.902 (-14.44, -1.368)	0.458 (0.327, 0.589)
Mining	0.904 (0.876, 0.932)	1.49 (0.771, 2.216)	0.059 (0.048, 0.070)
Construction	0.911 (0.891, 0.932)	1.695 (0.860, 2.530)	0.115 (0.080 0.149)
Food	0.651 (0.584, 0.719)	0.919 (0.402,1.436)	0.136 (0.022, 0.251)
Beverage and Materials	0.903 (0.881, 0.926)	1.335 (0.690, 1.979)	0.077 (0.049, 0.106)
Tobacco	0.942 (0.939, 0.944)	0.992 (0.546, 1.438)	0.092 (0.076, 0.109)
Apparel	0.884 (0.861, 0.908)	0.679 (0.351, 1.006)	0.035 (0.0232, 0.048)
Textile Mill Production	0.697 (0.681, 0.712)	0.339 (0.162, 0.515)	0.057 (0.017, 0.096)
Leather	0.946 (0.943 0.949)	-1.37 (-1.882, -0.862)	0.105 (0.075, 0.134)
Fuels, Fuel Products and Power	0.866 (0.848, 0.884)	-3.74 (2.00, 5.48)	0.184 (0.090, 0.277)
Chemicals	0.899 (0.875, 0.924)	2.70 (1.363, 4.050)	0.162 (0.119, 0.206)
Rubber and Plastics	0.888 (0.872, 0.904)	1.48 (0.767, 2.195)	0.019 (0.055, 0.127)

Table 3.9: Measure of Price Stickiness Conditional on Oil

Shock: 1972:2-1984:12

Industries	λ	c	σ
Lumber and Wood	0.919 (0.914, 0.925)	-2.071 (-2.73, -1.41)	0.114 (0.101, 0.127)
Paper	0.886 (0.869, 0.903)	1.64 (0.873, 2.494)	0.099 (0.062, 0.136)
Metal and Metal Products	0.846 (0.814, 0.879)	1.35 (0.753, 1.954)	0.116 (0.030, 0.202)
Machinery and Equipments	0.906 (0.882, 0.930)	1.33 (0.675, 1.993)	0.082 (0.058, 0.106)
Furnitures and Fixtures	0.890 (0.869, 0.910)	0.912 (0.464, 1.359)	0.053 (0.035, 0.071)
Non Metallic Mineral	0.872 (0.835, 0.909)	1.558 (0.808, 2.307)	0.060 (0.045, 0.075)
Transportation Equipments	0.916 (0.896, 0.937)	1.433 (0.735, 2.131)	0.092 (0.063, 0.121)
Misc Manufacturing	0.886 (0.864, 0.908)	1.405 (0.717, 2.092)	0.077 (0.052, 0.102)
Coal	0.893 (0.874, 0.913)	2.259 (1.146, 3.372)	0.140 (0.097, 0.183)
Electric Power	0.903 (0.882, 0.924)	1.774 (0.899, 2.649)	0.116 (0.079, 0.152)
Gasoline	0.861 (0.850, 0.871)	4.441 (2.398, 6.483)	0.235 (0.096, 0.375)
Motor Vehicles and Parts	0.915 (0.893, 0.937)	1.45 (0.747, 2.172)	0.090 (0.063, 0.117)
Stone, Clay and Glass	0.794 (0.760, 0.828)	0.416 (0.256, 0.666)	0.054 (0.014, 0.095)

Table 3.9: Measure of Price Stickiness Conditional on Oil

Shock: 1972:2-1984:12

Industries	λ	c	σ
Electrical Machinery	0.903 (0.877, 0.930)	1.257 (0.633, 1.881)	0.073 (0.054, 0.092)
Transport Utilities	0.928 (0.919, 0.938)	0.784 (0.428, 1.141)	0.048 (0.032, 0.064)
Medical care services	0.925 (0.913, 0.938)	0.593 (0.314, 0.872)	0.043(0.029, 0.056)
Energy	0.863 (0.829, 0.896)	2.485 (1.322, 3.648)	0.093 (0.057, 0.129)
All Services	0.900 (0.874, 0.925)	0.891 (0.462, 1.321)	0.045 (0.029, 0.061)
All Services less energy	0.897 (0.871, 0.923)	0.869 (0.451, 1.288)	0.043 (0.027, 0.060)
Transport Services	0.912 (0.897, 0.928)	0.614 (0.329, 0.899)	0.034 (0.021, 0.047)

Table 3.10: Measure of Price Stickiness Conditional on Oil

Shock: 1985:1-2008:12

Industries	λ	c	σ
PPI - Total	0.25 (0.127, 0.356)	0.798 (0.460,1.136)	0.253 (0.199, 0.308)
Agriculture	0.998 (0.573, 0.999)	-8.304 (-23.51, 6.90)	0.334 (0.279, 0.388)
Mining	0.935 (0.925, 0.946)	0.244 (0.148, 0.339)	0.006 (0.005, 0.006)
Construction	0.853 (0.782, 0.924)	0.046 (0.031, 0.061)	0.003 (0.002, 0.004)
Food	0.280 (0.184, 0.377)	0.142 (0.047, 0.238)	0.077 (0.060, 0.095)
Beverage and Materials	0.962 (0.954, 0.970)	0.162 (0.098, 0.226)	0.020 (0.018, 0.022)
Tobacco	0.160 (0.080, 0.501)	-0.006 (-0.084, 0.070)	0.054 (0.053, 0.056)
Apparel	0.956 (0.952, 0.959)	0.054 (0.030, 0.078)	0.004 (0.004, 0.005)
Textile Mill Production	0.604 (0.561, 0.648)	0.060 (0.040, 0.079)	0.007 (0.007, 0.008)
Leather	0.245 (0.138, 0.352)	0.082 (0.006, 0.159)	0.064 (0.049, 0.079)
Fuels, Fuel Products and Power	0.262 (0.143, 0.380)	3.98 (2.70, 5.27)	0.788 (0.655, 0.921)
Chemicals	0.257 (0.163, 0.350)	0.463 (0.158, 0.768)	0.252 (0.195, 0.310)
Rubber and Plastics	0.585 (0.522, 0.648)	0.131 (0.085, 0.177)	0.019 (0.018, 0.020)

Table 3.10: Measure of Price Stickiness Conditional on Oil

Shock: 1985:1-2008:12

Industries	λ	c	σ
Lumber and Wood	0.998 (0.994, 0.999)	-5.425 (-8.888, -1.962)	0.055 (0.048, 0.062)
Paper	0.277 (0.209, 0.345)	0.057 (0.008, 0.106)	0.041 (0.031, 0.051)
Metal and Metal Products	0.218 (0.109, 0.624)	0.082 (-10.23, 10.40)	0.353 (0.271, 0.435)
Machinery and Equipments	0.903 (0.884, 0.922)	0.104 (0.068, 0.140)	0.003 (0.003, 0.004)
Furnitures and Fixtures	0.936 (0.929, 0.944)	0.100 (0.060, 0.139)	0.003 (0.0035, 0.0036)
Non Metallic Mineral	0.509 (0.436, 0.582)	0.066 (0.035, 0.097)	0.019 (0.017, 0.021)
Transportation Equipments	0.951 (0.950, 0.952)	0.584 (0.359, 0.809)	0.006 (0.004, 0.008)
Misc Manufacturing	0.641 (0.601, 0.682)	0.100 (0.058, 0.141)	0.019 (0.019, 0.020)
Coal	0.828 (0.811, 0.844)	0.214 (0.126, 0.301)	0.041 (0.038, 0.043)
Electric Power	0.495 (0.421, 0.569)	0.187 (0.104, 0.270)	0.047 (0.039, 0.055)
Gasoline	0.196 (0.087, 0.305)	6.86 (4.486, 9.244)	1.735 (0.098, 5.810)
Motor Vehicles and Parts	0.954 (0.953, 0.956)	0.762 (0.456, 1.068)	0.009 (0.008, 0.011)
Stone, Clay and Glass	0.960 (0.958, 0.961)	0.123 (0.070, 0.177)	0.007 (0.0070, 0.0071)

Table 3.10: Measure of Price Stickiness Conditional on Oil

Shock: 1985:1-2008:12

Industries	λ	c	σ
Electrical Machinery	0.808 (0.801, 0.816)	0.024 (0.014, 0.033)	0.003 (0.003, 0.004)
Transport Utilities	0.566 (0.500, 0.631)	0.286 (0.187, 0.385)	0.042 (0.039, 0.045)
Medical care services	0.931 (0.922, 0.941)	0.117 (0.072, 0.161)	0.001(0.001, 0.002)
Energy	0.268 (0.154, 0.382)	1.993 (1.083, 2.903)	0.688 (0.539, 0.838)
All Services	0.754 (0.707, 0.801)	0.082 (0.058, 0.106)	0.003 (0.0035, 0.0041)
All Services less energy	0.877 (0.850, 0.904)	0.043 (0.029, 0.057)	0.001 (0.0014, 0.0022)
Transport Services	0.727 (0.686, 0.769)	0.112 (0.080, 0.144)	0.006 (0.0059, 0.0068)

3.6 Conclusion

In this paper, we have tried to identify the structural changes that have taken place in the U.S. economy during and after the mid-1980s. It is widely accepted that the U.S. economy responds very differently to the oil price shocks post-mid-1980s than in the pre-mid-1980s. This paper is an effort to empirically evaluate what could lead to the differential response. Using a factor augmented vector autoregression framework, we find three major changes in the U.S. economy. U.S. is now mostly a service driven economy where 80% of the GDP comes from services. As a second change, the linkage between the high-energy-intensity industries and low-energy-intensity industries has substantially weakened over time. This result is also in line with the declining oil usage and increase in energy efficiency of the U.S. economy. Finally, our estimation of the probability of price adjustment conditional on an oil shock shows that the aggregate and sectoral price indices adjust much faster in the post-mid-1980 period. This could be due to increase in product competition and increased import penetration. Also because of increased competition and fear of losing market share, producers tend to bring down prices faster after an oil shock. This also leads to a lower persistence of sectoral inflation, as shown in our empirical analysis.

In our current work, we are extending to build a New Keynesian model input-output linkages to analyze the evolution of sectoral interlinkages over time. Our model also includes infrequent price adjustments, allowing us to study the evolution of sectoral price stickiness conditional on an oil price shock both in the pre- and post-mid-1980 period.

CHAPTER 4

EFFECTS OF OIL PRICE SHOCKS ON THE U.S. ECONOMY: ROLE OF OIL INTENSITY AND WAGE PRICE ADJUSTMENTS

Macroeconomic consequences of large increases in the price of oil have been of great concern among economists and policy makers, as well as the general public ever since two major oil-price shocks hit the economy in the 1970s.

Not only that, after World War II, nine out of ten recessions in the U.S. economy were preceded by large increases in the oil price. A general perception is that oil-price increases are instrumental for persistent and deep recession. In fact, a number of studies have tested the relation between economic activity and oil prices and have confirmed that it is not merely a statistical coincidence.

Interestingly in the past five years the price of oil has tripled in nominal units, from \$36 per barrel in 2002 to \$72 per barrel in 2006 and \$140 in June 2008. This has rekindled memories of the sharp oil price rises in the 1970s when the real oil price tripled in 1973 and then again more than doubled in 1979. The oil price hikes of the 1970s coincided with dramatic declines in US GDP growth and led soaring inflation. While post 2000s the oil price build-up has been accompanied with only a modest pick up in inflation and more or less stable GDP growth, it has sparked discussions about the possible causes of the large effects of oil price shocks in the 1970s and early 1980s but the inexplicable and bewildering dampened effect during the post 2000s.

This paper explores possible explanations why we expect to observe the weaker responses of macroeconomic variables to the same size of the oil-price shock. Most of existing studies have focused mainly on recessionary consequences of oil-price shocks [e.g., Kim and Loungani (1991); Rotemberg and Woodford (1996); Finn (2000); Leduc and Sill (2004); Carlstrom and Fuerst (2005); Cavallo and Wu (2006)] but have not addressed the issue of weaker effects of oil-price shocks during the 1990s and later. The only exception is Blanchard and Gali (2007), who ask the same question as this paper does. In order to answer the question, they investigate four different hypotheses; (a) good luck (i.e., lack of concurrent adverse shocks), (b) smaller share of oil in production, (c) more flexible labor markets, and (d) improvements in monetary policy. They conclude that all four factors have played an important role in accounting for the mild effects on inflation and economic activity. In this paper, we will take a similar stance. We will offer four possible explanations of the muted effect of oil price shocks in the post 1990s. The first factor investigated is the improvement in oil efficiency in of the U.S. economy. After the two oil-price shocks in the 1970s, technological advances enabled the economy to utilize petroleum more efficiently. For example, vehicles' miles per gallon improved dramatically. According to the Energy Information Administration (2006), from 1973 to 1991, miles per gallon (all motor vehicles) improved by 42%. This more efficient use of oil is apparent in terms of the oil expenditure share in value added. While average oil expenditure share relative to GDP was 3.65% in the pre-1984 periods, the average share declines in the post-1984 periods to 2.75%. This point is similar to one of factors considered in Blanchard and Gali (2007). The second possibility that we will examine is the decline in labor market rigidities. Adjustments in the labor market take place both on the intensive (hours of work) and extensive margin (employment). Besides the high levels of union membership during the 1970s and early 1980s lead to a generally rigid labor markets. Thus the assumption of a cleared labor market neglecting unemployment might be a misleading assumption. In contrast, our model incorporates matching frictions that generate equilibrium unemployment as in Gertler, Sala and Trigari (2008). Moreover, workers and firms bargain over wages in a collective wage bargaining manner. We employ a model with nominal price rigidities that incorporates both real wage rigidities and matching frictions in the labor market. This model framework will allow us to analyze how labor market dynamics and particularly the adjustment of wages translate into marginal cost and inflation dynamics.

Next we analyze the change in the monetary policy of the Federal Reserve. Orphanides (2001) argues that monetary policy by the Fed definitely improved after the appointment to Paul Volcker as Chairman of the Federal Reserve in 1979. In his view, policy was excessively activist during the 1970s and early 1980s, a result of policymaker overconfidence in their ability to stabilize deviations of output from the economys output gap. Therefore according to his view, the inflationary episodes of the 1970s and 80s were because of the extremely activist policies of the Fed targeting output gap. By the beginning of the 1980s, the inflationary outcome of the activist policies was finally recognized and policies moved to targeting inflation than output gap.

Finally, we analyze the impact of a change in the degree of price stickiness after the mid 1980s. Recent research and policy discussions have noted that the potentially increased competition among firms and also increased openness of the U.S. economy since the 1990s may affect inflation and economic activity. In the light of these, it is interesting to see increased price flexibility induced by increased competitiveness among firms and increased openness of the economy can shed light on the dampened effects of inflation and economic activity in U.S. mid-1980s onwards.

The goal of the paper is not just to investigate the role of these four factors but also to see how much each factor accounts for the changes observed in the time series data for inflation and GDP i.e. weaker responses of output and inflation. We will argue and show that all four factors outlined are instrumental for the decrease in the response of output, employment and inflation to an oil price shock in the after the mid-1980s.

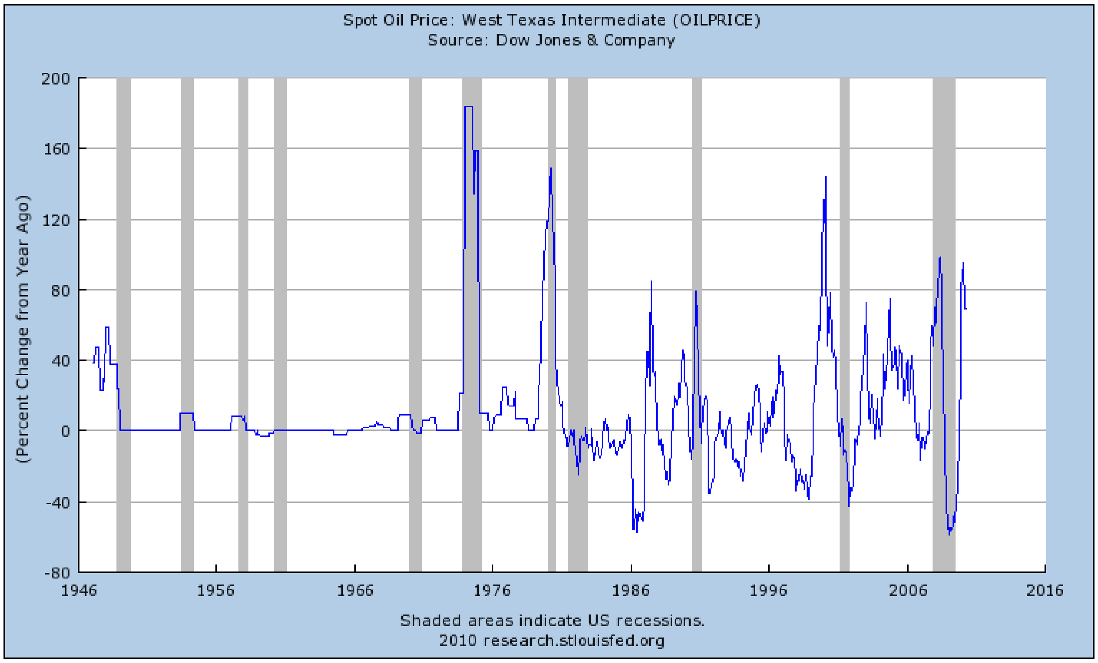

Figure 4.1: Nominal Oil Price of West Texas Intermediate Crude

The model is based on a standard New Keynesian model with price and nominal wage adjustment costs. We extend the standard sticky-price model to include the role of oil prices into the economy in two ways. As in Blanchard and Gali (2007), we introduce oil as an input in the production process as also in household consumption basket. We modify the labor market along the lines of Gertler, Sala and Trigari (2008). We introduce labor market frictions with a variant of the Mortensen and Pissarides (1994) search and matching framework. This variant allows for staggered Nash wage bargaining, as in Gertler, Sala and Trigari (2008).

The rest of the paper is organized as follows: Section 4.1 presents the structural VAR, Section 4.2 presents the model. Model evaluations are presented in section 4.3, Section 4.4 discusses the role of monetary policy, Section 4.5 is a brief on extensions. Finally Section 4.6 concludes.

4.1 Empirical Evidence

The purpose of this section is to provide a structural evidence of the macroeconomic effects of oil price shocks and explore the nature and causes of the apparent changing consequences of the oil price shocks on the US economy. To answer this question, we use the Vector Autoregression (VAR) approach to analyze how the oil price shocks on the aggregate U.S. economy.

The VAR modeling introduced by Sims (1980) is now very standard in applied macroeconomics literature. This approach conceives of fluctuations in economic activity as arising from impulses or shocks (oil price shock in our case) through a complex dynamic propagation mechanism. Our objective in this section is to develop a statistical model in order to identify the major oil price shocks from 1970s through today and to understand the dynamic response of the U.S. economy to these shocks. Using the estimated VAR system, we trace out the dynamic responses of output, prices and other macroeconomic variables to an oil price innovation. This gives quantitative estimates of how an exogenous oil price shock affect the economy. Our data (except energy intensity) runs monthly from January 1960 to December 2008. All data are seasonally adjusted. The variables and the corresponding data sources are given below. All the data above (except oil price and CPI) are at quarterly frequency. We interpolated these quarterly data to monthly frequency by following the interpolation method outlined in Bernanke, Gertler and Watson, (1997). The details of the interpolation method is given in this section.

Following Bernanke, Gertler and Watson, (1997), we designate quarterly series by uppercase letters and monthly series by lower case letters. Quarters are indexed by $T = 1, 2, ..., N$, and months by $t = 1, 2, ..., n$. Let Y_T be an observed quarterly variable

Table 4.1: Variables, Definitions and Sources of Baseline VAR

Variable	Definition	Source
Oil Price	Nominal Spot Oil Price of West Texas Intermediate Crude obtained as dollars per barrel	FRB St Louis
CPI	Prices paid by urban consumers for a representative basket of goods and services	BLS
GDP Deflator	GDP deflator (implicit price deflator for GDP) is a measure of the level of prices of all new, domestically produced, final goods and services in an economy	FRB St Louis & BLS
Wages	Non Farm Business Sector Compensation Per Hour	BLS
Employment	Non Farm Business Hours of all Persons	BLS
GDP	Quarterly Real Gross Domestic Product in Billions of Chained 2005 Dollars at Seasonally Adjusted Annual Rate (SAAR)	FRB
FFR	Rate at which a depository institution lends immediately available funds to another depository institution	FRB St. Louis

which we want to interpolate. Consider for example GDP. Correspondingly let y_t be the unobserved monthly series, which for our example is the monthly GDP. Therefore Y_T and y_t are related by the identity

$$Y_T = \frac{1}{3}\sum_{i=0}^{2} y_{3T-i} \tag{4.1}$$

Interpolation by done by the same state space method as in Bernanke, Gertler and Watson, (1997). Suppose $\mathbf{x_t}$ be a vector of observable interpolator variable at monthly frequency, eg. industrial production. This monthly variable evidently provides information about quarterly movements in real GDP. We assume [Bernanke, Gertler and Watson, (1997)] that the unobserved monthly variable y_t is related to its corresponding interpolator variables $\mathbf{x_t}$ according to the "causal" equation

$$y_t = \mathbf{x}_t'\beta + u_t \tag{4.2}$$

where $u_t \sim N(0, \sigma^2)$. Note that we include a constant and a trend term in all our "causal" equations.

Let z_t be a monthly variable that equals $Y_{t/3}$ in the third month of each quarter and is zero otherwise. Then the measurement equations are given by

$$\begin{aligned} z_t &= \frac{1}{3}\sum_{i=0}^{2} y_{t-i}, t = 3, 6, 9, 12, ..., n \\ z_t &= 0 \times y_t, o.w \end{aligned} \tag{4.3}$$

The parameters β and σ^2 are estimated by maximum likelihood. Conditional on the estimated parameters, we assume $y_{t/T} = E_T y_t$, where E is the expectations operator. Thus given the full information set, $y_{t/n}$ gives the set of interpolated values.

To estimate the accuracy of the interpolation, we used the R^2 goodness of fit, which in levels is given by

Table 4.2: Interpolators and Goodness of Fit

Quarterly Series Interpolated	Monthly Interpolators	R^2
GDP	IPBUSEQ, IPCONGD	0.9997
GDPDEF	PPIACO, PPICPE, PPIFCG, PPIITM	0.9997
WAGES	AHECONS, AHEMAN	0.9931
EMP	AWHMAN, AWHNONAG	0.9998

$$R^2_{levels} = var(y^2_{t|n})/var(y^2_t) \tag{4.4}$$

Table 2 lists the quarterly series we interpolate, the corresponding monthly interpolators, and the measures of fit. The variables are defined in more details below.

The monthly interpolator variables along with their data sources are defined below:

(a) IPBUSEQ - Seasonally adjusted data on Industrial Production Index for business equipments (Index 2002=100). Source: Board of Governors of the Federal Reserve System (G17 Industrial Production and Capacity Utilization).

(b) IPCONGD - Seasonally adjusted data on Industrial Production Index for Consumer Goods (Index 2002=100). Source: Board of Governors of the Federal Reserve System (G17 Industrial Production and Capacity Utilization).

(c) PPIACO - Seasonally adjusted data on Producer Price Index for all commodities (Index 1982=100). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(d) PPICPE - Seasonally adjusted data on Producer Price Index Finished Goods Capital Equipment (Index 1982=100). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(e) PPIFCG - Seasonally adjusted data on Producer Price Index for Finished Consumer Goods (Index 1982=100). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(f) PPIITM - Seasonally adjusted data on Producer Price Index: Intermediate Materials: Supplies and Components (Index 1982=100). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(g) AHECONS - Seasonally adjusted data on Average Hourly Earnings: Construction (Dollars per Hour). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(h) AHEMAN - Seasonally adjusted data on Average Hourly Earnings: Manufacturing (Dollars per Hour). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(i) AWHMAN - Seasonally adjusted data on Average Weekly Hours: Manufacturing (Units=Hours). Source: U.S. Department of Labor: Bureau of Labor Statistics.

(j) AWHNONAG - Seasonally adjusted data on Average Weekly Hours: Total Private Industries (Units = Hours). Source: U.S. Department of Labor: Bureau of Labor Statistics.

4.1.1 Structural VAR Model for the US Economy

As noted earlier our aim is to provide a structural evidence on the macroeconomic effects of oil price shocks on the U.S. economy and also analyze the nature and causes of the changes in the effects of those shocks. The choice of variables is influenced by insights from Blanchard and Gali (2007), Bernanke, Gertler and Watson, (1997). In our baseline

VAR, we carry out the specification in Blanchard and Gali (2007), with the variables described before.

Assuming that the economy is described by a structural system of linear stochastic dynamic form

$$A(L)y_t = a + bt + \epsilon_t, \tag{4.5}$$

where y_t is a $(K \times 1)$ vector of endogenous variables given by

$$y_t = \left[OP_t, GDP_t, EMP_t, DEF_t, CPI_t, W_t, FFR_t\right]$$

Precise denitions of the variables and data sources are given in Table 1.

$A(L)$ is a matrix polynomial in the lag operator L, and ϵ_t is an $(K \times 1)$ vector of structural innovations or disturbances. ϵ_t is serially uncorrelated and $var(\epsilon_t) = \Sigma_\epsilon$ and Σ_ϵ is a diagonal matrix where the diagonal elements are the variances of structural disturbances. Hence the structural disturbances are assumed to be mutually uncorrelated. Note that we just consider the stochastic part of the data generating process because it is the part of interest from the point of view of structural modeling and impulse response analysis.

We estimate a reduced form equation (VAR)

$$y_t = a + bt + \sum_{i=1}^{p} B_i y_{t-i} + u_t, \tag{4.6}$$

where B represents matrix of polynomial and $var(u_t) = \Sigma_u$.

4.1.2 Lag Length Selection

The standard results about the properties of the *VAR* coefficients and *VAR* estimation (Hamilton (1994), Chapter 11) depend on the lag length of the *VAR*. There are two main approaches used for selecting or testing for lag length in *VAR* models. The first consists of rules of thumb based on the periodicity of the data and past experience, regarding cyclicality of economic data. The second is based on formal hypothesis tests.

Two classical test statistics can be used to evaluate the lag length of a *VAR* model. The first is based on a likelihood ratio test. The likelihood ratio test compares the maximum value of the likelihood achieved for a model with p lags to a model with $p-1$ lags. The likelihood ratio function for a *VAR* model can be written as

$$L(\hat{\Sigma}, B, p) = -\frac{TK}{2} log(2\pi) + \frac{T}{2} log|\hat{\Sigma}^{-1}| - \frac{TK}{2}, \tag{4.7}$$

where $\hat{\Sigma}^{-1}$ is the matrix inverse of the estimated error covariance matrix and $log|\hat{\Sigma}^{-1}|$ is the logarithm of the determinant of $\hat{\Sigma}^{-1}$, the inverse of the error covariance matrix.

A second type of measure used to determine lag length in *VAR* models is the information criteria such as Akaike's information criterion (AIC), the Bayesian (or Schwarz) information criterion (BIC or SC), and the Hannan-Quinn criterion. Information criteria measures are an effort to determine the trade-off between model fit and parsimony. They are based on the likelihood function for a model, penalized by the number of parameters. For two models that fit the data equally well (i.e., they have the same likelihood value), the more parsimonious model pays a smaller penalty and is thus superior based on an information criteria measure. According to Ivanov and Killian (2001), for monthly *VAR* models, the AIC tends to produce the most accurate structural and semi-structural impulse response estimates for realistic sample sizes. Thus with our monthly *VAR*, we were tempted to use the AIC to determine lag length, which suggested the optimal lag length of 5. However there is always the issue of the potential sensitivity of the point estimates to assumptions about lag length as in Hamilton and Herrera (2001). While including too many lags and hence an excessive number of parameters introduces sampling uncertainty in estimating a 5-7 variable *VAR* as in our case, we cannot at the same time afford to overlook the fact that fewer lags also introduce omitted variable bias. Carrying out the F - tests also confirms that the extra lags (at least the 8th and 9th) enter significantly. Thus we decided to use the rule of thumb so that our *VAR* models include enough lags to capture the full cycle of the data, this means for our seasonally adjusted monthly data, we included 12 lags for all the endogenous variables.

4.1.3 Identification Issues

There are several ways of recovering the parameters in the structural form equations from the estimated parameters in the reduced form equation. Some methods give restrictions on only contemporaneous structural parameters. Others impose restrictions on the lag structure as well. A popular and convenient method is to orthogonalize reduced form disturbances by Cholesky decomposition of the white noise covariance matrix, $\Sigma_u = PP'$ (as in Sims (1980) among others), where P is a lower triangular matrix with positive elements on the main diagonal. Ofcourse, such a method makes most sense when there is theoretical reason for a recursive structure or a Wold causal ordering. We will use the recursive identification scheme and justify why this is a satisfactory identification approach in our case.

Following Blanchard and Gali (2007), we identify oil shocks by assuming that unexpected variations in the nominal spot price of oil are completely exogenous relative to the contemporaneous values of the remaining macroeconomic variables included in the *VAR*. The theoretical justification of this recursive structure is as follows: oil price shock can instantaneously affect the block of U.S. macroeconomic variables, but the U.S. macroeconomic block cannot affect the world oil price instantaneously or in the same month.[1] Thus in this specification, oil price is Wold casually prior to the remaining macroeconomic variables in the system i.e., we place nominal oil price as the first variable in our ordering. Since we are interested only in oil price shock, the ordering of the remaining variables does not matter. The ordering of the federal funds rate after the oil price captures the idea that U.S. Fed will tighten monetary policy in response to inflationary oil price shocks. We do not impose any restrictions on the lag structure of the variables.

Our identification assumption outlined above allows us to recover the structural innovations ϵ_t directly from the forecast errors or the reduced form residuals, u_t. We can write the reduced form equation (4.6) in such a way that the residuals of the different equations are uncorrelated. Writing the forecast errors as linear functions of the structural innovations, we have $u_t = P\epsilon_t$. Hence $\Sigma_u = P\Sigma_\epsilon P'$. Normalizing the variances of the structural innovations to one, i.e., assuming $\epsilon_t \sim (0, I_K)$, gives $\Sigma_u = PP'$. Hence choosing P by a Choleski decomposition solves our identification problem.

4.1.4 Impulse Responses

This section reports the estimated impulse responses from our *VAR* model specified above. We begin our analysis by seeking to replicate Banchard and Gali's results for USA and checking whether they are robust to the use of monthly data (rather than quarterly data).

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[1] See discussion in Blanchard and Gali (2007)

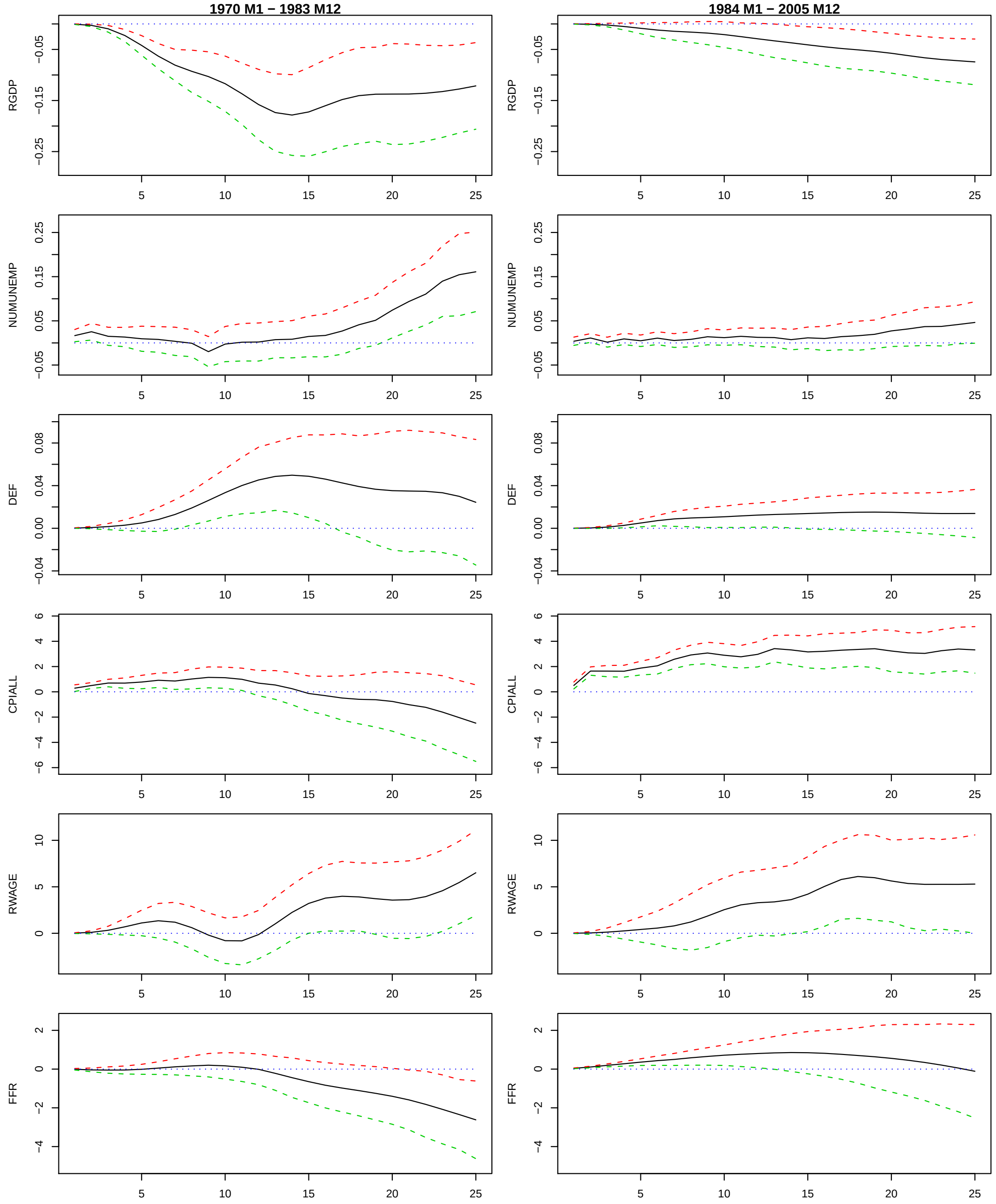
We estimate monthly *VAR* models with 12 lags for different time horizons. It is interesting to note that different horizons give different qualitative results of impulse responses. The choice of variables is also the same as in Blanchard and Gali (2007). However instead of the nominal price of oil, we use the real price of oil which is the nominal oil price deflated by the GDP deflator and then expressed in log differences, CPI inflation, GDP deflator inflation, wage inflation (wage is the non farm business compensation per hour) and log changes in real GDP and employment (non farm business sector hours). Each equation in the *VAR* includes a constant term and a linear trend (unlike the quadratic trend in BG). Figure 2 shows the estimated impulse response functions for the variables to an oil price shock, where the oil price shock is identified as an innovation to the oil price equation. Estimates are reported for two different sample periods: 1970:1-1983:12 and 1984:1-2005:12. The left hand side panel shows impulse responses for the sample 1970:1-1983:12 and the right hand side shows impulse responses for the sample 1984:1-2005:12. The break date chosen corresponds roughly to the beginning of the Great Moderation in the United States, as identified by several authors [e.g.McConnell and Pérez-Quirós (2000)]. Note that each subperiod contains two of the four large oil shock episodes identified in the previous section.

The results of the impulse responses are similar to Blanchard and Gali (2007) which means the shift to a low frequency data does not affect BG's basic findings.

The VAR predicts a tighter monetary policy reflected in an increase in the federal funds rate in the second sample, possibly aimed at curbing inflation. In the 1970:1-1983:12 sample, after two years, the cumulative change in output is -0.016%. In contrast, during the post 1984 period, the same percentage increase in oil prices results in a smaller (-0.010%) and shorter-lived drop in output. In the first period, the contractionary effect of the oil price shock reaches a trough a year after the shock, whereas in the post-1984 period, we see a monotonic decline of output although at a much lower magnitude.

An interesting result is the change in the response of prices across subsamples. Note that in the pre-Volcker era the oil price shock generates an increase in the price level and a slowdown in output growth. During the second period, the shock still generates a slowdown in GDP growth but the increase in prices, particularly of the GDP deflator is considerably smaller. The change in the magnitude suggests that the less accommodative monetary policy of the Volcker-Greenspan era may has been more effective in controlling the expectations of higher inflation that follow an oil price shock. However not much is reflected from the headline inflation in since the increase in oil and food prices directly feeds in to that part of inflation.

Figure 3 displays the impulse responses when the dataset is extended till 2008:M12. It is interesting to note that the impulse responses change significantly when the dataset is extended, which means when the sky rocketing of the oil price in June 2008 is included, we no longer get the muted response of oil price shock in the post 1984 episode. Hence it is fitting to put a disclaimer here about the paper - this paper is not an argument for not studying the effects of oil price increases anymore. By extending the dataset sufficiently, it is clear that there could still be situations in which the effects of oil shock is large. This is an attempt to try and ascertain what led to the large responses in the past, and what are the conditions under which the US economy could be subject to such problematic responses in the future.


1970 M1 – 1983 M12

1984 M1 – 2005 M12

Figure 4.2: Impulse Responses to Real Oil Price Shock: 1970:1-2005:12

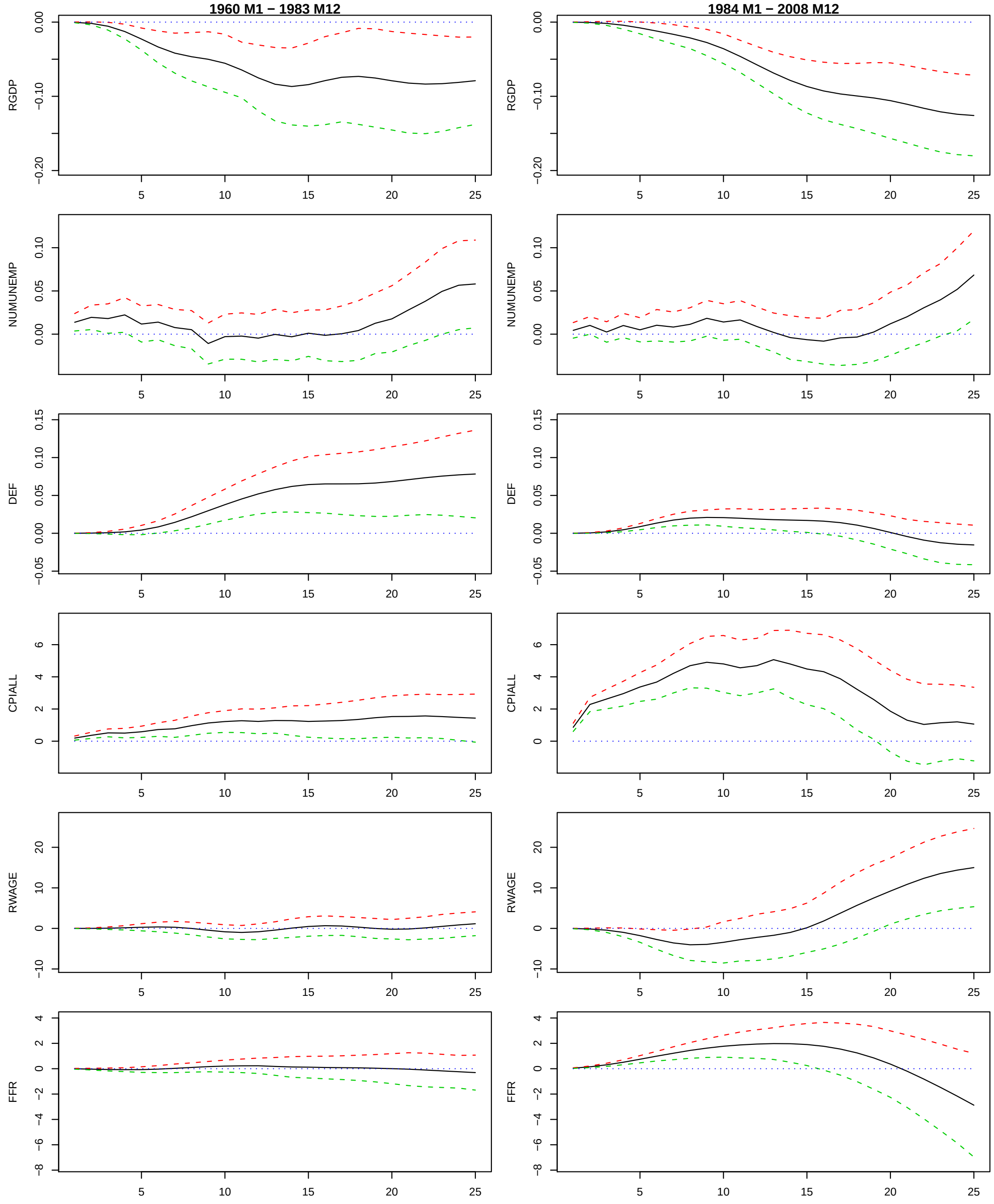


Figure 4.3: Impulse Responses to Real Oil Price Shock: 1970:1-2008:12

4.2 The Model

In this section we will develop a model to study the macroeconomic effects of oil price shocks. The main focus is to see the significant difference in the response of major macroeconomic variables after the mid 1980s.

We start with a standard monetary DSGE model and introduce two modifications. First, following Blanchard and Gali (2008), we take oil both as an input in the production as well as a good in the household consumption basket. We assume that the country is an importer of oil. But we will abstract from the explicit modeling of the foreign sector. Secondly, to study the role of real rigidities, we introduce search and matching frictions and staggered wage bargaining as in Gertler, Sala and Trigari (2008) in this otherwise standard new-Keynesian model. The model has the key features useful for capturing data. These include cost of adjusting the flow of investment, variable capacity utilization, nominal price rigidities, both nominal and real wage rigidities.

The model has three types of agents: households, wholesale firms, and retail firms. We use a representative family construct, similar to Gertler, Sala and Trigari (2008) in order to introduce complete consumption insurance. Production takes place at wholesale competitive firms. They hire workers and negotiate wage contracts with them and in the process enter into staggered wage bargaining with the workers. Monopolistically competitors retail firms buy goods from wholesale firms, differentiate them into a continuum of varieties and then repackage them as final goods and sell them back to the households. Retailers set prices on a staggered (Calvo) basis. The separation of retail firms from wholesale firms is purely to keep the wage bargaining process simple.

4.2.1 Households

There is a representative household with a continuum of members of measure unity. The number of family members currently employed is N_t. Employment is determined through a search and matching process to be described in the following section. The family provides perfect consumption insurance for its members. Thus consumption is the same for each person, regardless of whether he or she is currently employed or unemployed. The treatment of labor supply is exactly similar to Gertler, Sala and Trigari (2008). Households vary labor along the extensive margin instead of the intensive margin. The reason for this assumption being the fact that in USA, most of the variation in hours is on the extensive margin and as Gertler, Sala and Trigari (2008) say "intensive margin in unimportant for cyclical variation." Households do not receive any utility gains from leisure. Individuals not currently working are searching for jobs.

Conditional on N_t, the representative household chooses consumption C_t, one period nominally riskless government bonds B_t, capacity utilization v_t, investment I_t, and physical capital K_t^P to maximize the present discounted value of the utility stream

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(C_t), \tag{4.8}$$

where $C_t = \Theta_{\chi_c} C_{O,t}^{\chi_c} C_{Q,t}^{1-\chi_c}$ and where $C_{O,t}$ denotes consumption of imported oil and

$$C_{Q,t} \equiv \left(\int_0^1 C_{Q,t}(i)^{1-\frac{1}{\epsilon_Q}}\right)^{\frac{\epsilon_Q}{\epsilon_Q-1}} \tag{4.9}$$

is the CES index of the domestically produced differentiated by retail goods and $\Theta_{\chi_c} = \chi_c^{-\chi_c}(1-\chi_c)^{-(1-\chi_c)}$, where χ_c is the share of oil in the consumption basket.

Let Π_t be the lumpsum profits, $P_{C,t}$ be the price of the consumption basket, R_t be the one period nominal interest rate (central bank policy instrument). Household's budget constraint is then given by

$$P_{Q,t}C_{Q,t} + P_{O,t}C_{O,t} + \frac{B_t}{P_{C,t}R_t} = \mathcal{Y}_t + \frac{B_{t-1}}{P_{C,t}} \tag{4.10}$$

where $P_{Q,t} \equiv \left(\int_0^1 P_{Q,t}(i)^{1-\epsilon_Q}di\right)^{\frac{1}{1-\epsilon_Q}}$ is the price index of domestic goods, $P_{O,t}$ is the price of oil in domestic currency, B_t denotes the quantity of one period bonds purchased in period t which is purchased at the price $1/R_t$. For simplicity we also assume no access to international financial markets.

The optimal allocation of expenditures between imported and domestically produced goods implies

$$P_{Q,t}C_{Q,t} = (1-\chi_c)P_{C,t}C_t, \tag{4.11}$$

$$P_{O,t}C_{O,t} = \chi_c P_{C,t}C_t \tag{4.12}$$

where $P_{C,t} \equiv P_{O,t}^{\chi_c}P_{Q,t}^{1-\chi_c}$ is the headline CPI index. Also note that $P_{Q,t}$ is the core CPI index which does not include the price of oil. Further $P_{C,t} = P_{Q,t}S_{O,t}^{\chi_c}$, where $S_{O,t} = \frac{P_{O,t}}{P_{Q,t}}$ denotes the real price of oil, expressed in terms of domestically produced goods.

Furthermore conditional on an optimal allocation between the two types of goods, we have $P_{Q,t}C_{Q,t} + P_{O,t}C_{O,t} = P_{C,t}C_t$, which can be substituted in the budget constraint (4.10).

Let $\mathcal{Y}_t$ denote the income of the household defined below. Households own capital and choose the capital utilization rate, v_t, which transforms physical capital into effective capital according to

$$K_t = v_t K_{t-1}^P \tag{4.13}$$

Effective capital is rented to the firms at the rate r_t. The cost of capital utilization per unit of physical capital is $\mathcal{A}(\nu_t)$. We assume that $\nu_t = 1$ in the steady state. Also $\mathcal{A}(1) = 0$ and $\mathcal{A}'(1)/\mathcal{A}''(1) = \eta_\nu$.

Therefore the income of the household is given by the following equation

$$\mathcal{Y}_t = W_t N_t + (1 - N_t)b_t + [r_t \nu_t - \mathcal{A}(\nu_t)]K_t^P + \Pi_t \tag{4.14}$$

$W_t N_t$ is the household's labor income, $(1 - N_t)b_t$ is the unemployment benefits, $[r_t \nu_t - \mathcal{A}(\nu_t)]K_t^P$ is the income from capital and Π_t denotes the profit income, where we assume $\mathcal{S}(\gamma_z) = S'(\gamma_z) = 0$, and $\mathcal{S}''(\gamma_z) = \eta_k > 0$. $\gamma_z = 1$ is the economy's steady state growth rate.

The physical capital accumulation equation is

$$K_t^P = (1 - \delta)K_{t-1}^P + [1 - \mathcal{S}(\frac{I_t}{I_{t-1}})]I_t \tag{4.15}$$

The first order necessary conditions for the households is given below:

$$\beta E_t\Big[\frac{C_t}{C_{t+1}}.\frac{P_{C,t}}{P_{C,t+1}}\Big] = \frac{1}{R_t} \tag{4.16}$$

$$r_t = \mathcal{A}'(\nu_t) \tag{4.17}$$

$$q_t^k[1 - \mathcal{S}(\frac{I_t}{I_{t-1}})] = q_t^k.\mathcal{S}'(\frac{I_t}{I_{t-1}})\frac{I_t}{I_{t-1}} - \beta E_t q_{t+1}^k \frac{\lambda_{t+1}}{\lambda_t} S'(\frac{I_{t+1}}{I_t})(\frac{I_{t+1}}{I_t})^2 + 1 \tag{4.18}$$

$$q_t^k = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\Big[(1 - \delta)q_{t+1}^k + r_{t+1}\nu_{t+1} - \mathcal{A}(\nu_{t+1})\Big] \tag{4.19}$$

Here $\lambda_t = U'(C_t)$ and q_t^k is the real price of capital or value of installed capital in terms of the consumption good.

4.2.2 Search and Matching

In the following section we lay out the search and matching model of Mortensen-Pissarides that is incorporated into a New Keynesian style business cycle model to explicitly model labor market frictions in the form of equilibrium unemployment, Mortensen and Pissarides (1994) Mortensen and Pissarides (1999), Pissarides (2000). At each time t, each firm posts $v_t(i)$ vacancies in order to attract new workers and employs $N_t(i)$ workers. The total number of vacancies and unemployed workers are $v_t = \int_0^1 v_t(i)$ and $N_t = \int_0^1 N_t(i)$. All unemployed workers at t look for jobs. The timing assumptions are such that unemployed workers who find a match go to work immediately within the same period. Hence the pool of unemployed workers searching for jobs at time t is given by

$$u_t = 1 - N_{t-1} \tag{4.20}$$

Trade in the labor market is an uncoordinated, time consuming and costly activity that introduces frictions which lead to imperfect outcomes in the labor market. Jobs are constantly created and destroyed and unemployed workers look for new jobs generating unemployment in equilibrium. The process through which workers and firms find and match each other is represented by a matching function accounting for the imperfections and transaction cost in the labor market. This function summarizes the entire search and matching process in a single relation where the number of matches is a function of the number of unemployed persons, u_t, and the number of vacant jobs, v_t, in the labor market. The number of new hires or "matches", m_t is a function of searching workers and vacancies, as follows:

$$m_t = \sigma_m u_t^{\sigma} v_t^{1-\sigma} \tag{4.21}$$

The probability a firm fills a vacancy in period t, q_t is given by

$$q_t = \frac{m_t}{v_t} \tag{4.22}$$

Similarly, the probability a searching worker finds a job, s_t is given by

$$s_t = \frac{m_t}{u_t} \tag{4.23}$$

Both firms and workers take q_t and s_t as given. At each period, firms exogenously detach themselves from a fraction $1 - \rho$ of their existing workforce $N_{t-1}(i)$. Workers who lose jobs at time t cannot search until next period. Thus within this framework, fluctuations in unemployment are due to cyclical variations in hiring as opposed to separations. Hall (2005a) and **?** present evidence in support of this phenomenon.

4.2.3 Wholesale Firms

At each period t, wholesale firms produce Q_{it} using capital K_{it}, labor N_{it} and oil O_{it} according to the Cobb-Douglas production function given below:

$$Q_{it} = Z_t N_{it}^{\alpha_N} K_{it}^{\alpha_K} O_{it}^{\alpha_O} \tag{4.24}$$

where Q_{it} is the output produced by firm i, where Z_t is the exogenous common productivity shock, N_{it} is the labor employed, K_{it} is the capital employed, and O_{it} is the quantity of imported oil used in production. α_N, α_K and α_O denote the share of labor, capital and oil respectively in the production process, where $\alpha_N + \alpha_K + \alpha_O \leq 1$. For simplicity, we assume that capital and oil are perfectly mobile across firms and that there is a competitive rental market in capital and oil. These assumptions ensure constant returns to scale at the firm level, which greatly simplifies the wage bargaining problem. The hiring rate x_{it} as defined as the ratio of new hires $q_t v_{it}$ to the existing workforce $N_{t-1}(i)$:

$$x_{it} = \frac{q_t v_{it}}{N_{it-1}} \tag{4.25}$$

It is interesting to note that due to the law of large numbers the firm knows x_{it} with certainty at time t since it knows the likelihood q_t that each vacancy it posts will be filled. The hiring rate is thus effectively the firm's control variable. The total workforce, in turn, is the sum of the number of surviving workers ρN_{it-1} and new hires $x_{it} N_{it-1}$:

$$N_{it} = (\rho + x_{it}) N_{it-1} \tag{4.26}$$

Equation (4.26) reflects the timing assumption that new hires go to work immediately. Let P_t^W denote the relative price of the intermediate goods produced by the wholesale firms, W_t denotes the nominal wage, r_t denotes the rental rate of capital, and $\beta E_t \Lambda_{t,t+1}$ be the firm's stochastic discount factor, β being the household's subjective discount factor and $\Lambda_{t,t+1} = \lambda_{t+1}/\lambda_t$. The value of the firm i given by $F_t(W_{it}, N_{it-1})$ may be expressed as:

$$\begin{aligned} F_t(W_{it}, N_{it-1}) &= P_t^W Q_{it} - r_t K_{it} - P_{ot} O_{it} - \frac{W_{it}}{P_t} N_{it} - \frac{\kappa_t}{2} x_{it}^2 N_{it-1} \\ &\quad + \beta E_t \Lambda_{t,t+1} F_{t+1}(W_{it+1}, N_{it}) \end{aligned} \tag{4.27}$$

with $\kappa_t = \kappa Z_t$. Because of the presence of wage dispersion, Gertler, Sala and Trigari (2008) replace the standard assumption of fixed costs of posting a vacancy with quadratic adjustment costs, given by $\frac{\kappa_t}{2} x_{it}^2 N_{it-1}$. As in Gertler, Sala and Trigari (2008), we have quadratic costs of hiring as opposed to fixed costs of post a vacancy for purely technical reasons. Because the contract structure leads to temporary wage dispersion and because (to simplify the bargaining problem) we have constant returns at the firm level, quadratic costs are required to keep capital and labor from shifting to the low wage firms. Lastly as in Gertler, Sala and Trigari (2008), we allow adjustment costs to drift proportionately with productivity in order to maintain a balanced steady state growth path (otherwise adjustment costs become relatively less important as the economy grows.)

At each time t, a representative firm i maximizes its total value $F_t(W_{it}, N_{it-1})$ by choosing the hiring rate x_{it} and capital stock K_{it}, given its existing employment stock, the probability of filling a vacancy, the rental rate on capital and the current and expected path of wages. If it is a firm that is able to renegotiate the wage, it bargains with its workforce over a new contract. If it is not renegotiating, it takes as given the wage at the previous periods level, as well the likelihood it will be renegotiating in the future. We next consider the firm's hiring and capital rental decisions, and defer a bit the description of the wage bargain. The first order condition for oil and capital are given below:

$$P_{o,t} = \alpha_O P_t^W \frac{Q_{it}}{O_{it}} = \alpha_O P_t^{WS} \frac{Q_t}{O_t} \tag{4.28}$$

$$r_t = \alpha_K P_t^W \frac{Q_{it}}{K_{it}} = \alpha_O P_t^{WS} \frac{Q_t}{K_t} \tag{4.29}$$

Given Cobb-Douglas technology and perfect capital mobility, all firms choose the same capital-output ratio and also oil-output ratio. Firms choose N_{it} by setting x_{it} or equivalently v_{it}. The firm's hiring decision gives us the following condition:

$$\kappa_t x_{it} = P^W a_{it} - \frac{W_{it}}{P_{C,t}} + \beta E_t \Lambda_{t,t+1} \partial F_{t+1}(W_{it+1}, N_{it}) / \partial N_{it} \tag{4.30}$$

where $a_{it} = \alpha_N \frac{Q_{it}}{N_{it}} = \alpha_N \frac{Q_t}{N_t} = a_t$. By making use of the envelope theorem to obtain $\partial F_t(W_{it}, N_{it-1}) / \partial N_{it-1}$ and combining equations, we obtain

$$\kappa_t x_{it} = P_t^W a_t - \frac{W_{it}}{P_{C,t}} + \beta E_t \Lambda_{t,t+1} \frac{\kappa_t}{2} x_{it+1}^2 + \rho \beta E_t \Lambda_{t,t+1} \kappa_{t+1} x_{it+1} \tag{4.31}$$

The hiring rate thus depends on the discounted stream of earnings and savings on adjustment costs. Finally, for the purpose of the wage bargain it is useful to define $J_t(W_{it})$, which is the marginal value to firm i or the value to the firm from hiring another worker at time t after adjustment costs have been incurred. Differentiating $F_t(W_{it}, N_{it-1})$ with respect to N_{it}, taking x_{it} as given yields:

$$J_t(W_{it}) = P^W a_{it} - \frac{W_{it}}{P_{C,t}} + \beta E_t \Lambda_{t,t+1} \partial F_{t+1}(W_{it+1}, N_{it}) / \partial N_{it} \tag{4.32}$$

By making use of the hiring rate condition (4.25) and the relation for the evolution of the workforce (4.26), $J_t(W_{it})$ may be expressed as expected average profits per worker net of the first period adjustment costs, with the discount factor accounting for future changes in workforce size:

$$J(W_{it}) = P_t^W a_t - \frac{W_{it}}{P_t} - \beta E_t \Lambda_{t,t+1} \frac{\kappa_{t+1}}{2} x_{it+1}^2 + E_t[\rho + x_{it+1}] \beta \Lambda_{t,t+1} J_{t+1}(W_{it+1}) \tag{4.33}$$

4.2.4 Problem of the workers

In this section we develop an expression for a worker's surplus from employment, which is the most important determinant of the outcome of the wage bargain. Let $V_t(W_{it})$ be the value to a worker of employment at firm i and let U_t be the value of unemployment. These values are defined after hiring decisions have been made at time t and are in units of consumption good Q_{it}. The value from employment of a worker working in firm i at time t is given by

$$V_t(W_{it}) = \frac{W_{it}}{P_t} + \beta E_t \Lambda_{t,t+1} \Big[\rho V_{t+1}(W_{it+1}) + (1-\rho) U_{t+1} \Big] \tag{4.34}$$

To define the value of unemployment, we will first define $V_{x,t}$ as the average value of employment conditional on being a new worker at time t as $V_{x,t} = \int_0^1 V_t(W_{it}) \frac{x_{it} N_{it-1}}{x_t N_{t-1}} di$, where $x_{it} N_{it-1}$ is total new workers at firm i and $x_t N_{t-1}$ is total number of new workers at time t. Next let b_t be the flow value from unemployment, including unemployment benefits, as well as other factors that can be measured in units of consumption goods. As defined before, let s_t be the probability of finding a job for the subsequent period. Then U_t may be expressed as

$$U_t = b_t + \beta E_t \Lambda_{t,t+1} \Big[s_{t+1} V_{x,t+1} + (1 - s_{t+1}) U_{t+1} \Big] \tag{4.35}$$

with $b_t = b K_t^P$, K_t^P being the economy wide stock of physical capital. We also assume like Gertler, Sala and Trigari (2008) that b_t grows proportionately to K_t^P in order to maintain a balanced growth. The value of unemployment thus depends on the current flow value b_t and the likelihood of being employed versus unemployed next period. Note that the value of finding a job next period for a worker that is currently unemployed is $V_{x,t+1}$, the average value of working next period conditional on being a new worker. Unemployed workers do not have a priori knowledge of which firms might be paying higher wages next period. They instead just randomly flock to firms posting vacancies. Correspondingly $H_t(W_{it})$ and $H_{x,t}$ defined as surplus from employment are given by:

$$H_t(W_{it}) = V_t(W_{it}) - U_t \tag{4.36}$$

$$H_{x,t} = V_{x,t} - U_t \tag{4.37}$$

and

$$H_t(W_{it}) = \frac{W_{it}}{P_{C,t}} - b_t + \beta E_t \Lambda_{t,t+1}[\rho H_{t+1}(W_{it+1}) - s_{t+1} H_{x,t+1}] \tag{4.38}$$

4.2.5 Staggered Nash Wage Bargaining

In this section, we introduce staggered Nash wage bargaining as in Gertler, Sala and Trigari (2008). We introduce nominal wage contracting and simultaneously allow for the possibility of indexing to past inflation.

The staggered multi-period contracting on this model is introduced so as to simplify aggregation. In each period a firm has a probability $1 - \lambda_w$ that it may renegotiate the wage.[2] This adjustment probability is independent of its history, which makes it unnecessary to keep track of individual firms' wage histories. While how long an individual wage contract lasts is uncertain, the average duration of the wage contract is fixed at $1/(1 - \lambda_w)$. The coefficient λ_w is effectively the measure of the degree of wage stickiness.

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[2] λ_w is effectively the Calvo parameter for wage setting

Since we allow for the possibility of indexing to past CPI inflation, $\pi_{C,t-1}$, the fraction λ_w of firms that cannot renegotiate their contract set their nominal wages W_{it} according to the indexation rule:

$$W_{it} = W_{it-1}(\pi_{C,t-1})^{\gamma} \tag{4.39}$$

where $\pi_{C,t} = P_{C,t}/P_{C,t-1}$ and $\gamma \in [0, 1]$ reflects the degree of indexing to past inflation.

Firms that enter into a new wage contract at time t negotiate the wage with the existing laborforce and also with the newly hired workforce. Due to the assumption of constant returns, all workers are the same at the margin. The wage bargaining rule is such that the negotiating firm and the worker share the surplus from the marginal match. After the wage bargain and renegotiation takes place, all workers, both existing and the newly employed labor force receive the same renegotiated wage. When firms cannot renegotiate the wage, all existing and newly hired workers employed at the firm receive the existing contracting wage indexed by last period's inflation.

Let W_t^* denote the wage of a firm that is able to renegotiate at time t. Given constant returns, all sets of firms and workers at time t fact the same problem, and therefore set the same wage. Under the assumption of Nash bargaining the contract wage W_t^* is chosen to solve

$$W_t^* = \arg\max_{W_t} H_t(W_{it})^{\eta} J_t(W_{it})^{1-\eta} \tag{4.40}$$

s.t

$$W_{it+j} = \begin{cases} W_{it+j-1}\pi^{\gamma}_{C,t+j-1} & \text{with prob} \quad \lambda_w \\ W^*_{t+j} & \text{with prob} \quad 1-\lambda_w \end{cases}$$

$\forall j \geq 1$, where $\eta \in [0, 1]$ is the worker's relative bargaining power, and $J_t(W_{it})$ and $H_t(W_{it})$ are as defined by equations (4.32) and (4.38). As in the conventional search and matching model, we assume that the bargaining power parameter η is constant. The wage in this model is determined by the two "threat" points of employers and employees, i.e. the marginal product and the reservation wage, respectively. The stronger the bargaining power of the worker, the closer the wage is to the marginal product and vice versa. The first order necessary condition for the Nash bargaining equation is given by

$$\eta\epsilon_t J_t(W_t^*) = (1-\eta)\mu_t(W_t^*)H_t(W_t^*), \tag{4.41}$$

where $\epsilon_t = P_t \partial H_t / \partial W_{it}$ is the effect of a rise in the real wage on the worker's surplus, and $\mu_t(W_{it}) = -P_t \partial J_t / \partial W_{it}$ is the negative of the effect of a rise in the real wage on the firms surplus, and where

$$\epsilon_t = 1 + E_t \Lambda_{t,t+1}(\rho\lambda\beta)\frac{p_t}{p_{t+1}}\bar{\gamma}\pi_t^{\gamma}\epsilon_{t+1} \tag{4.42}$$

$$\mu_t(W_{it}) = 1 + E_t \Lambda_{t,t+1}[\rho + x_{t+1}(\bar{\gamma}\pi_t)^{\gamma} W_{it})](\lambda\beta)\frac{p_t}{p_{t+1}}\bar{\gamma}\pi_t^{\gamma}\mu_{t+1}(\bar{\gamma}\pi_t)^{\gamma} W_{it})) \tag{4.43}$$

In effect ϵ_t is the cumulative the cumulative discount factor the worker uses to value the contract wage stream, while $\mu_t(W_{it})$ is the same thing for the firm. Because of the non-negativity of the hiring rate x_{it}, it must be always true that $\mu_t(W_{it}) \geq \epsilon_t$. This implies that a firm has a longer horizon than the worker, since the worker cares only about the effect of the current wage contract only on itself. However the firm cares about the effect of the current wage contracts on payments to both the existing workforce and also on the workforce slated to come in the future.

The first order condition for wages, therefore can be rewritten as:

$$\chi_t(W_t^*)J_t(W_t^*) = [1 - \chi_t(W_t^*)]H_t(W_t^*), \tag{4.44}$$

where

$$\chi_t(W_t^*) = \frac{\eta}{\eta + (1-\eta)\mu_t(W_{it})/\epsilon_t} \tag{4.45}$$

$\chi_t(W_t^*)$ is the effective bargaining power of the worker. $\chi_t(W_t^*)$ depends not only on the bargaining power but also on the different horizon over which the worker and the firm value the impact of the contract wage. In the limiting case of $\lambda_w = 0$, $\chi_t(W_t^*) = \eta$ as in the conventional period-by-period bargaining case. When $\lambda_w > 0$, $\chi_t(W_t^*) < \eta$, Intuitively, because it makes firms effectively more patient than workers, the "horizon effect" works to raise the effective bargaining power of firms from $1 - \eta$ to $1 - \chi_t(W_t^*)$.

4.2.6 Wage Dynamics

The key features of the model that differentiates it from the conventional new Keynesian models is the wage and hiring dynamics. In this section, we will derive log linear relationship for these variables. Let $W_t^0(W_t^*)$ be the target nominal wage at time t, i.e., the wage the firm and its workers would agree to under period-by-period bargaining, given that firms and workers elsewhere remain on staggered multi-period wage contracts. Loglinearizing the first order condition for Nash bargaining (4.41), we obtain the following loglinear difference equation for real contract wage W_t^*:

$$W_t^* = \left[(1-\tau)W_t^0(W_t^*) + \tau E_t(\hat{\pi}_{C,t+1} - \gamma\hat{\pi}_{C,t}) + \tau E_t \hat{W}_{t+1}^*\right] \tag{4.46}$$

Note: hat above a certain variable denotes the percent deviation of a variable from its steady state value and $\psi = \chi\beta\lambda_w\mu + (1-\chi)\rho\beta\lambda_w\epsilon$ and $\tau = \psi/(1+\psi)$. The contract wage thus depends on the current and expected future path of the target wage $W_t^0(W_t^*)$ and terms that reflect adjustments for indexing. As shown in the appendix for GST (2008), we have:

$$\begin{aligned} W_t^0(W_t^*) &= \varphi_a(\hat{P}_t^W + \hat{a}_t) + \varphi_x E_t\left[\hat{x}_{t+1}(W_{t+1}^*) + (1/2)\hat{\Lambda}_{t,t+1})\right] \\ &\quad \varphi_s E_t\left[\hat{s}_{t+1} + \hat{\bar{}}H_{xt+1} + \hat{\Lambda}_{t,t+1}\right] + \varphi_b\hat{b}_t + \varphi_\chi\left[\hat{\chi}_t(W_t^*) - (\rho\beta)E_t\hat{\chi}_{t+1}(W_{t+1}^*)\right] \end{aligned} \tag{4.47}$$

where the coefficients $\varphi_a, \varphi_x, \varphi_s, \varphi_b$ and φ_χ depend on the primitive model parameters and are defined as follows $\varphi_a = \chi P^W \bar{a}\bar{W}^{-1}$, $\varphi_x = \chi\beta\kappa x^2\bar{W}^{-1}$, $\varphi_b = (1-\chi)\bar{b}\bar{W}^{-1}$, $\varphi_s = (1-\chi)s\beta\bar{H}\bar{W}^{-1}$, $\varphi_\chi = \chi(1-\chi)^{-1}\kappa x\bar{W}^{-1}$.

Let $\hat{W}_t^0$ be the wage that would arise if all firms and workers negotiate wages period by period[3]. The link between $\hat{W}_t^0(W_t^*)$ and $\hat{W}_t^0$ is given by:

$$\hat{W}_t^0(W_t^*) = W_t^0 + \frac{\tau_1}{1-\tau}E_t(\hat{W}_{t+1} - \hat{W}_{t+1}^*) + \frac{\tau_2}{1-\tau}(\hat{W}_t - \hat{W}_t^*), \tag{4.48}$$

where τ_1 and τ_2 are given as: $\tau_1 = \left[\varkappa_w\mu\varphi_x + \varphi_\chi(1-\chi)(x\beta\lambda_w)(\varkappa_w\mu)\mu(\rho\beta) + \varphi_s\Gamma\right](1-\tau)$, $\tau_2 = -(\varkappa\mu)\varphi_\chi(1-\chi)(x\beta\lambda_w)\mu(1-\tau)$ and $\Gamma = (1-\eta x\beta\lambda_w\mu)\eta^{-1}\mu\varkappa_w$.

The expression for $\hat{W}_t^0$ is given by

$$\begin{aligned} \hat{W}_t^0 &= \varphi_a(\hat{P}_t^W + \hat{a}_t) + (\varphi_s + \varphi_x)E_t\hat{x}_{t+1} + \varphi_s\hat{s}_{t+1} \\ &\quad +\varphi_b\hat{b}_t + (\varphi_s + \varphi_x/2)E_t\hat{\Lambda}_{t,t+1} + \varphi_\chi[\hat{\chi}_t - (\rho - s)\beta E_t\hat{\chi}_{t+1}] \end{aligned} \tag{4.49}$$

There is both a direct effect and also an indirect spillover effect on the target wage. The direct effect, captured by the second term in equation (4.48), reflects the impact of market wages on the worker's outside option. If $E_t\hat{W}_{t+1} > E_t\hat{W}_{t+1}^*$, opportunities are prospective for workers expecting to move into employment next period, and vice versa if $E_t\hat{W}_{t+1} < E_t\hat{W}_{t+1}^*$, average market wage at $t+1$ induces a direct spillover effect on the wage bargain. By influencing the worker's outside option in this way, the expected average market wage at $t+1$ induces a direct spillover effect on the wage bargain. The indirect effect, captured by the third term, depends on several factors. Overall, it is much smaller in absolute magnitude than the direct effect. The loglinearized[4] real wage index is in turn given by

$$\hat{W}_t = (1-\lambda_w)\hat{W}_t^* + \lambda_w(\hat{W}_{t-1} - \hat{\pi}_{C,t} + \gamma\hat{\pi}_{C,t-1}) \tag{4.50}$$

Combining the equations above yields the following second order difference equation for wage inflation:

$$\hat{W}_t = \gamma_b(\hat{W}_{t-1} - \hat{\pi}_{C,t} + \gamma\hat{\pi}_{C,t-1}) + \gamma_0\hat{W}_t^0 + \gamma_f E_t(\hat{W}_{t+1} + \hat{\pi}_{C,t+1} - \gamma\hat{\pi}_t) \tag{4.51}$$

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[3] See Gertler, Sala and Trigari (2008) appendix for the details of the derivations

[4] Details of log linearization is provided in Appendix

where $\gamma_b = (1 + \tau_2)\phi^{-1}$, $\gamma_0 = (1 - \lambda_w)(1 - \tau)\lambda_w^{-1}\phi^{-1}$, $\gamma_f = (\tau\lambda_w^{-1} - \tau_1)\phi^{-1}$, $\phi = (1 + \tau_2 + (1 - \lambda_w)(1 - \tau)\lambda_w^{-1} + (\tau\lambda^{-1} - \tau_1)$ with $\gamma_b + \gamma_0 + \gamma_f = 1$.

Due to staggered wage contracting, $\hat{W}_t$ depends on the lagged wage $\hat{W}_{t-1}$ as well as the expected future wage $E_t\hat{W}_{t+1}$. The spillover effects measured by τ_1 and τ_2 work to reduce the relative importance of the expected future wage. Thus the spillovers effects work in a similar (though not identical) way as to how real relative price rigidities enhance nominal price stickiness in monetary models with time-dependent pricing. Also in the case when $\lambda_w = 0$ (the case of period by period wage bargaining), both γ_b and γ_f go to zero, implying that $\hat{W}_t$ converges to $\hat{W}_t^0$, which is the wage in the flexible wage case. The model thus nests the conventional period-by-period wage bargaining setup.

Finally, loglinearizing the equation for the hiring rate (4.31) yields

$$\hat{x}_t = \varkappa_a(\hat{P}_t^W + \hat{a}_t) - \varkappa_w\hat{W}_t + \varkappa_{\lambda_w}E_t\hat{\Lambda}_{t,t+1} + \beta E_t\hat{x}_{t+1} \tag{4.52}$$

where the expressions for the coefficients are given as $\varkappa = (\kappa x)^{-1}$, $\varkappa_a = \varkappa P^W\bar{a}$, $\varkappa_w = \varkappa\bar{w}$ and $\varkappa_{\lambda_w} = \beta(1 + \rho)/2$. The hiring rate thus depends on current and expected movements of the marginal product of labor relative to the wage. The stickiness in the wage due to staggered contracting, everything else equal, implies that current and expected movement in the marginal product of labor will have a greater impact on the hiring rate than would have been the case otherwise.

4.2.7 Retail Firms

There is a continuum of monopolistically competitive retailers indexed by i on the unit interval. Retailers buy intermediate goods from the wholesale firms described before at the wholesale price P_t^W. They in turn differentiate them with a technology that transforms one unit of intermediate goods into one unit of retail goods, then resell them to the households. In addition, they set prices on a staggered basis. All retail firms face an identical isoelastic demand schedule given by $C_{Q,t}(i) = \left(\frac{P_{Q,t}(i)}{P_{Q,t}}\right)^{-\epsilon_Q} C_{Q,t}$ and take the aggregate price level $P_{Q,t}$ and aggregate consumption index $C_{Q,t}$ as given.

Following Calvo (1983), each firm may reset its price with a constant probability $(1 - \lambda_p)$ in any given period, independent of the time elapsed since the last adjustment. Thus each period a measure $(1 - \lambda_p)$ of retailers reset their prices, while the remaining λ_p keep their prices unchanged at the last period's price with some indexation. Thus the average duration of the price is given by $1/(1 - \lambda_p)$. We assume the following partial price indexation rule (assuming zero inflation steady state),

$$P_{Q,t+k} = P_{Q,t+k-1}(\pi_{Q,t+k-1})^{\gamma}, \tag{4.53}$$

where γ as defined before is the degree of indexation.

Now we describe the optimal price setting. A firm reoptimizing in period t will choose the price $P^*_{Q,t}$ that maximizes the current market value of the profits generated while that price remains effective. Formally a price resetting firm solves the following problem

$$\max_{\{P^*_{Q,t}\}} = E_t\Big\{ \sum_{k=0}^{\infty} \lambda_p^k \Lambda_{t,t+k} Q_{t+k|t}(P^*_{Q,t} - \mathcal{M}^p \Psi_{t+k|t})\Big\} \tag{4.54}$$

subject to the sequence of demand constraints $Q_{t+k} = (\frac{P_{Q,t}}{P_{Q,t+k}})^{-\epsilon_Q} C_{Q,t+k}$ for $k = 0, 1, 2, ...$ and $\Lambda_{t,t+k} = \beta^k(\frac{C_t}{C_{t+k}} \frac{P_{Q,t}}{P_{Q,t+k}})$ is the stochastic discount factor, $\Psi_t(.)$ is the cost function and $Q_{t+k|k}$ denotes output in period $t + k$ for a firm that last reset its price in period t. The first order condition associated with the problem above takes the form

$$\sum_{k=0}^{\infty} \lambda_p^k \{\Lambda_{t,t+k} Q_{t+k|k}(P^*_{Q,t} - \mathcal{M}.\Psi_{t+k}) = 0 \tag{4.55}$$

where $\psi_{t+k|t} \equiv \Psi'_{t+k}(Q_{t+k|t})$ denotes the nominal marginal cost in period $t + k$ for a firm that last reset its price in period t and $\mathcal{M} = \frac{\epsilon_Q}{\epsilon_Q - 1}$. The real marginal cost of a retail firm is obtained by inverting the hiring rate condition given by (4.31), so that the real marginal cost is

$$P_t^W = \frac{1}{a_t}\Big[\frac{W_{it}}{P_{C,t}} + \kappa_t x_{it} - \beta E_t \Lambda_{t,t+1}\frac{\kappa_{t+1}}{2}x_{it+1}^2 - \rho\beta E_t \Lambda_{t,t+1}\kappa_{t+1}x_{it+1}\Big] \tag{4.56}$$

Real marginal costs thus depend on unit labor costs, plus terms that correct for the adjustment costs of hiring workers. Observe that since we have normalized the relative price of final output at unity, the retailer's markup is given by $\mu_t^p = 1/P_t^W$. Since final goods prices are sticky and wholesale prices are flexible, this markup will in general exhibit cyclical behavior, with the direction depending on the nature of the disturbances hitting the economy, as well as other features of the model. Finally as shown in the appendix, by log linearizing expressions for the price index and the optimal reset price equation (4.55), we obtain a relation for the consumer price inflation which is the core inflation (that does not include oil price) as follows

$$\hat{\pi}_{Q,t} = \iota_b \hat{\pi}_{Q,t-1} + \iota_o \hat{P}_t^W + \iota_f E_t \hat{\pi}_{Q,t+1} \tag{4.57}$$

where $\iota_b = \frac{\gamma}{1+\beta\gamma}$, $\iota_o = \frac{(1-\beta\lambda_p)(1-\lambda_p)}{\lambda_p}$, $\iota_f = \frac{\beta}{1+\beta\gamma}$. Since real marginal cost P_t^W feed into the determination of prices through the new Keynesian Phillips curve, this in turn establishes a direct channel of real wage rigidities to translate to aggregate inflation. Also note that because of the partial indexation rule in the optimal price resetting equation of the retailers, there is a substantial backward looking component included in the Phillips curve relation.

4.2.8 GDP and Deflator

Let us now define the Value added or GDP, Y_t as follows:

$$P_{Y,t}Y_t = P_{Q,t}Q_t - P_{O,t}O_t \tag{4.58}$$

Correspondingly the GDP deflator $P_{Y,t}$ is implicitly defined as

$$P_{Q,t} \equiv (P_{y,t})^{\alpha_N+\alpha_K}(P_{o,t})^{\alpha_O} \tag{4.59}$$

4.2.9 Monetary Policy Rule

We assume that the monetary policy follows a simple forward looking rule given by the equation below:

$$\frac{R_t}{\bar{R}} = \Big(\frac{R_{t-1}}{\bar{R}}\Big)^{\rho_R}\Big[\Big(\frac{E_t\pi_{Q,t+1}}{\pi_Q}\Big)^{\phi_\pi}\Big(\frac{Y_t}{Y_{nt}}\Big)^{\phi_y}\Big]^{1-\rho_R} \tag{4.60}$$

where π_Q and $\bar{R}$ denote the steady state values of inflation, and Y_{nt} denotes the potential level of output of the economy i.e, the value of output when there are no frictions and all prices are flexible. Note that the monetary policy rule is such that the Federal Reserve targets the core inflation defined before as $\pi_{Q,t}$.

4.3 Quantitative Analysis of Effects of Oil Price Shocks

Having described the model and the equilibrium dynamics of prices and quantities, given the exogenous process for technology and the real price of oil, and the description for the monetary policy rule. We will now use these conditions to characterize the economy's response to an oil price shock.

We will assume that in the steady state $Z = 0$ i.e., we abstract from technology shocks. Further we assume that the real price of oil follows an AR(1) process

$$s_{o,t} = \rho_{so}s_{t-1} + \epsilon_t \tag{4.61}$$

Next we will assess quantitatively the four hypothesis of the changing effects of oil price shocks.

4.3.1 Calibration

We divide our simulation exercise in two different parts. First, we will examine the ability of the model described above to see how it can reproduce the impulse responses of the effects of oil shock on the U.S. economy. In the second stage, we will vary our important parameter values to see how the impulse responses of output and inflation changed in the post 1984 period. Table 4.3 displays the value of the parameters that are kept unchanged through the various model variants in the simulation exercise. In order to properly assess the high rate of job finding that characterizes the US labor market, we opt for a monthly calibration. The key parameters of the business cycle literature are calibrated at conventional values: the chosen discount factor is chosen at 0.99 which implies an annual steady state real interest rate of 4%, capital depreciates by 10% on an annual basis, the labor share is equal to 0.7. The share of oil in the production and consumption are set at their high value (pre 1984 value) such that $\alpha_O = 0.05$ and $\chi_c = 0.023$. Further, we assume that the elasticity of substitution between the different varieties of retail products if set at 10, such that the steady state markup is close to 10%. The parameter for the elasticity of the capital utilization rate to the rental rate of capital η_v is taken to be equal to 0.4285 from the estimates of Gertler, Sala and Trigari (2008).

There are six parameters that are specific to the conventional search and matching framework: the job survival rate ρ, the elasticity of matches to unemployment σ, the matching function constant σ_m, the worker's bargaining power parameter η, the labor adjustment cost parameter κ, and the unemployment flow value $\bar{b}$. We choose the average monthly separation rate $1 - \rho$ based on the observation that jobs last about two years and a half. Therefore we set $\rho = 1 - 0.035$. We choose the elasticity of matches to unemployment $\sigma = 0.5$, the midpoint of the values typically used in the literature.[5] The

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[5] The values for σ used in the literature are: 0.24 in Hall (2005a), 0.4 in Blanchard and Diamond (1989), Andolfatto (1994) and Merz (1995), 0.45 in Mortensen and Nagypal (2007), 0.5 in Hagedorn and

parameter σ_m is chosen to be equal to 1. To maintain comparability with much of the existing literature, we set the bargaining power parameter η to be equal to 0.5. One of the few studies that provides direct estimates is Flinn (2006), who finds a point estimates of 0.4, close to the value we use. We then use the adjustment cost parameter, κ, and the flow unemployment value, $\bar{b}$, to target the average job finding probability, $s = 0.45$ and the value of $\tilde{b}$ defined as the ratio of the unemployment flow value $\bar{b}$ to the steady state contribution of the worker to the match, given by

$$\tilde{b} = \frac{\bar{b}}{P^W \bar{a} + \beta(\kappa/2)x^2}$$

We follow much of the literature by assuming that the value of non work activities is far below what workers produce on the job (see Hall, NBER Macroannual, 2005, p. 121, for a brief discussion). In particular, we specifically follow Shimer (2005a) and Hall (2005c) and choose $\tilde{b} = 0.4$. This requires setting $\bar{b} = 1.46$ and $\kappa = 148.2$. This parameterization implies a ratio of adjustment costs to output equal to 1%. In addition, under the interpretation of $\bar{b}$ as unemployment benefits, it implies a steady state replacement ratio of 0.42 (since the steady state ratio of the wage to the workers contribution to the job is 0.956.)

Next we have to calibrate the parameters of wage renegotiation frequency λ_w and the price stickiness parameter λ_p. For the wage stickiness parameter λ_w, we take the estimate in Gertler, Sala and Trigari (2008) which is equal to 0.72 for quarterly data, which implies the monthly wage stickiness parameter is equal to 0.889. Regarding the price stickiness parameter, we take the estimated reported in Gertler, Sala and Trigari (2008) which says that for quarterly data the price rigidity parameter is $\lambda_p = 0.72$, which gives a monthly value of about 0.95. Finally for the monetary policy parameters, we choose the parameters reported in Orphanides (2001) for the pre-Volcker period. The details on this is provided on the section on monetary policy.

Manovskii (2006), 0.5 in Farmer (2004), 0.72 in Shimer (2005a).

4.3.2 Calibration Results and Model Evaluation

The benchmark impulse responses are done with the parameter values calibrated for the first sample 1960:1-1983:12. Figures 4.4 and 4.5 shows the impulse response functions to a negative oil shock of 10% in an economy described above with staggered wage bargaining and nominal price rigidity. It is clear that the presence of real wage rigidity introduces a trade-off between inflation and output stabilization: inflation goes up and output decreases, the nominal interests rate increases more than proportionately with respect to the inflation rate. Moreover, in this staggered price economy unemployment increases and the output gap increases. Given that firms cannot adjust real wages they are forced to reduce their demand for labor. Therefore unemployment increases. The qualitative features of the responses presented in Figure 4.4 and 4.5 are broadly in line with those obtained in the literature. The oil price shock generates inflationary and recessionary pressures as well as a reduction in real wages and an increase in the markup.

The model is able to replicate most of the responses observed in the empirical impulse responses provided in Section 3. GDP Y_t falls and employment N_t falls. Both core CPI inflation ($\pi_{Q,t}$) and headline CPI inflation ($\pi_{C,t}$) show a rise. While the headline CPI (which includes both oil and food prices) rises immediately due to a permanent rise in the price of oil. However it takes about two months for this oil price rise to feed into core CPI. Both the price markup and the wage markup exhibit countercyclicality which is in line with Rotemberg and Woodford (1999).

The tables below give the 3 and 6 months impulse responses for GDP Y_t, employment N_t and core CPI $\pi_{Q,t}$ along with their two-standard deviation error bands. The responses of employment N_t is closer to the data than the Blanchard and Gali (2007). The elaborate labor market with search and matching frictions is better able to capture the data. Also the impulse responses of core CPI inflation $\pi_{Q,t}$ better matches the data

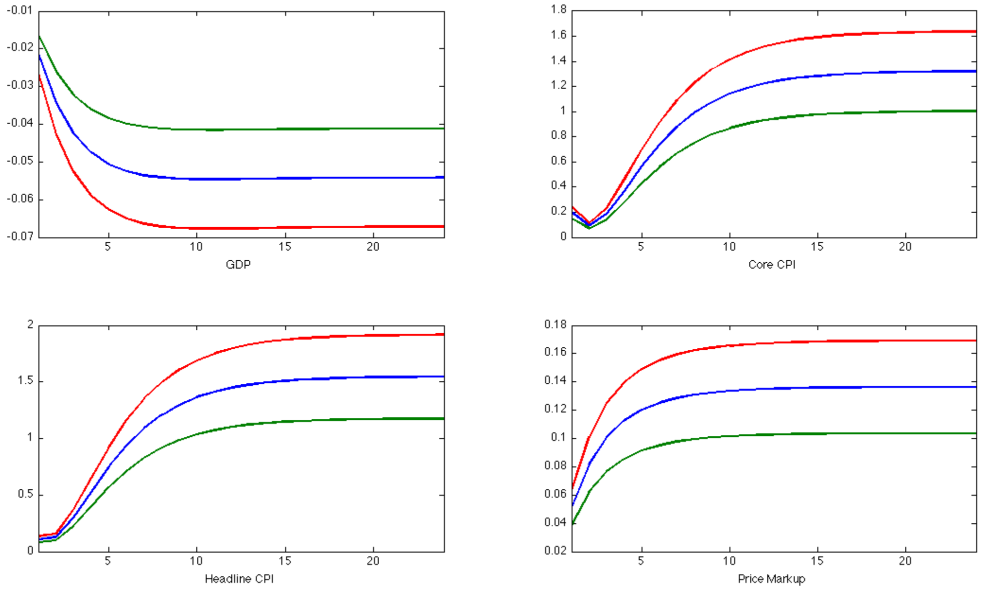


Figure 4.4: Model Impulse Responses

since we also have a forward looking monetary policy rule that incorporates the inflation expectations and output gap.

4.3.3 Testing the Hypothesis

What are the factors that account for the rather small impulse responses of GDP, employment and inflation in the post 1984 period? In the previous sections, we have offered four hypotheses of the declining effect of oil price fluctuations. The first is the decline in oil intensity, second is the decline in real wage rigidity, third is the decline in aggregate price stickiness and the fourth is the change in the monetary policy stance of the Federal

Table 4.3: Benchmark Calibration

Parameter	Mechanism	Value
	Conventional Parameters	
β	Discount Factor	$(0.99)^{1/3}$
α_N	Labor share in production	0.7
α_O	Oil share in production	0.04
χ_c	Oil share in consumption	0.023
δ	Depreciation rate	$0.025/3$
ϵ_Q	elasticity of subs between varieties	10
	Labor Market Parameters	
s	Job finding rate	0.45
$1-\rho$	Job Separation rate	0.035
σ	elasticity of matches to unemployment	0.5
η	worker's bargaining power	0.5
λ_w	wage stickiness	0.889
γ	Indexation	0.5
	Monetary Policy Parameters	
$\bar{R}$	Steady state interest rate	1.53
ϕ_π	Weight on expected future inflation	1.64
ϕ_y	Weight on output gap	0.57
ρ_R	Interest Rate Smoothing Parameter	0.68
	Other Parameters	
λ_p	Price Stickiness	0.95
σ_o	Standard deviation of oil shock	0.012
ρ_{so}	Persistence of oil shock	$(0.97)^{1/3}$
η_v	Elasticity of capital utilization	0.4285

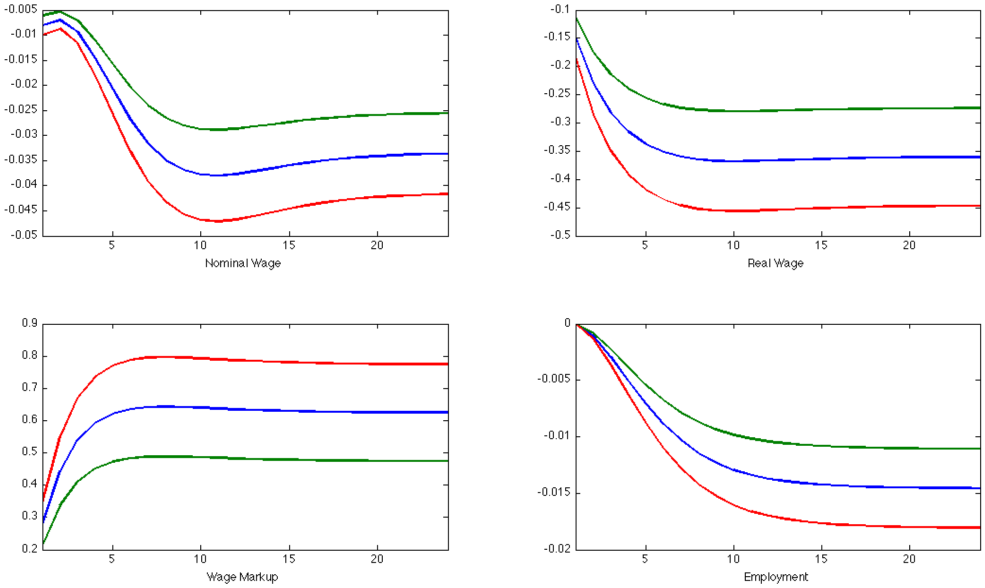


Figure 4.5: Model Impulse Responses

Table 4.4: Benchmark Impulse Responses of GDP (Y_t)

	1960-1983		1984-2005	
	3 Months	6 Months	3 Months	6 Months
Data	-0.0095	-0.0631	-0.0023	-0.0120
	(-0.016, -0.003)	(-0.093, -0.034)	(-0.005, 0.001)	(-0.025, 0.003)
BG	-0.0623	-0.1192	-0.0480	-0.0765
Model	-0.0425	-0.0525	-0.0154	-0.0173
	(-0.032, -0.053)	(-0.039, -0.063)	(-0.012, 0.019)	(-0.013, -0.021)

Table 4.5: Benchmark Impulse Responses of Employment (N_t)

	1960-1983		1984-2005	
	3 Months	6 Months	3 Months	6 Months
Data	0.0150	0.0079	0.0018	0.0108
	(-0.006, 0.036)	(-0.022, 0.038)	(-0.011, 0.013)	(-0.006, 0.025)
BG	0.0623	0.1192	0.0480	0.0765
Model	0.0029	0.0087	0.0010	0.0021
	(0.002, 0.004)	(0.007, 0.011)	(0.001, 0.001)	(0.002, 0.003)

Table 4.6: Benchmark Impulse Responses of Core Inflation ($\pi_{Q,t}$)

	1960-1983		1984-2005	
	3 Months	6 Months	3 Months	6 Months
Data	0.6949	0.9144	1.6404	2.0568
	(0.275, 1.115)	(0.353, 1.476)	(1.271, 2.087)	(1.523, 2.703)
BG	0.0266	0.0509	0.0480	0.0765
Model	0.2986	0.9362	0.1790	0.6932
	(0.227, 0.370)	(0.712, 1.161)	(0.136, 0.222)	(0.527, 0.860)

Reserve. In this section, we will consider one factor at a time. First we calibrate the parameters of oil share in production and consumption to their post 1984 values (as in Blanchard and Gali (2008)). The table below shows the change in the values of the impulse responses of GDP after we reduce the oil share in production $\alpha_O = 0.025$ and the oil share in consumption to $\chi_c = 0.017$ in the first line. In the second line, we reduce both the nominal and the real wage rigidity, by reducing the nominal wage stickiness parameter from its benchmark value of $\lambda_w = 0.889$ to $\lambda_w = 0.833$ and the value of the worker's bargaining power parameter from $\eta = 0.5$ to $\eta = 0.4$. In the third line, we alter the value of nominal price stickiness from $\lambda_p = 0.95$ to $\lambda_p = 0.90$. We can see that in all the three cases, the response of output decline is reduced. It is seen that as much as 50% of the decline in output response in the 3, 6 and 12 months case is accounted for by the increase in oil efficiency. The next most important cause of decline in the response of output in both the 3 and 6 months cases is the decline in real rigidity in the form of bargaining power of the union η., while for the 12 months case, the next most important cause of the decline in output response in the decline in the aggregate price rigidity.

For the core inflation, for both the 3 and 12 months case, the largest decline in the response of inflation is caused by the decrease in real wage rigidity. About 12% of the decline in the inflation response in the 3 month case is accounted for by the decline in real wage rigidity, whereas about 47% of the decline in the inflation response is accounted for by the decline in real wage rigidity. The increase in oil efficiency is the next most important factor that is instrumental for the muted response of inflation. However increase in the aggregate price flexibility understandably leads to a greater short run pass through of oil price increase to the core inflation. Thus the hypotheses advanced in the paper seem to have good explanatory power in explaining the reduced impact of oil price shocks.

4.4 Role of Monetary Policy

A number of alternative hypotheses for how a monetary policy change may have contributed to the improvement in macroeconomic performance during the post 1990s have been advanced. One widely known view is the result of recent influential studies on monetary policy rules, notably Clarida, Gali and Gertler (2000) and Taylor (1999).

Table 4.7: Experiments with GDP

	3 Months	6 Months	12 Months
Benchmark	-0.0425	-0.0525	-0.0546
Oil Efficiency			
($\alpha_O = 0.025, \chi_C = 0.017$)	-0.0205	-0.0252	-0.0261
Real Wage Rigidity			
($\lambda_w = 0.833, \eta = 0.4$)	-0.0342	-0.0395	-0.0402
Price Rigidity			
($\lambda_p = 0.9$)	-0.0340	-0.0385	-0.0386

Table 4.8: Experiments with Core Inflation

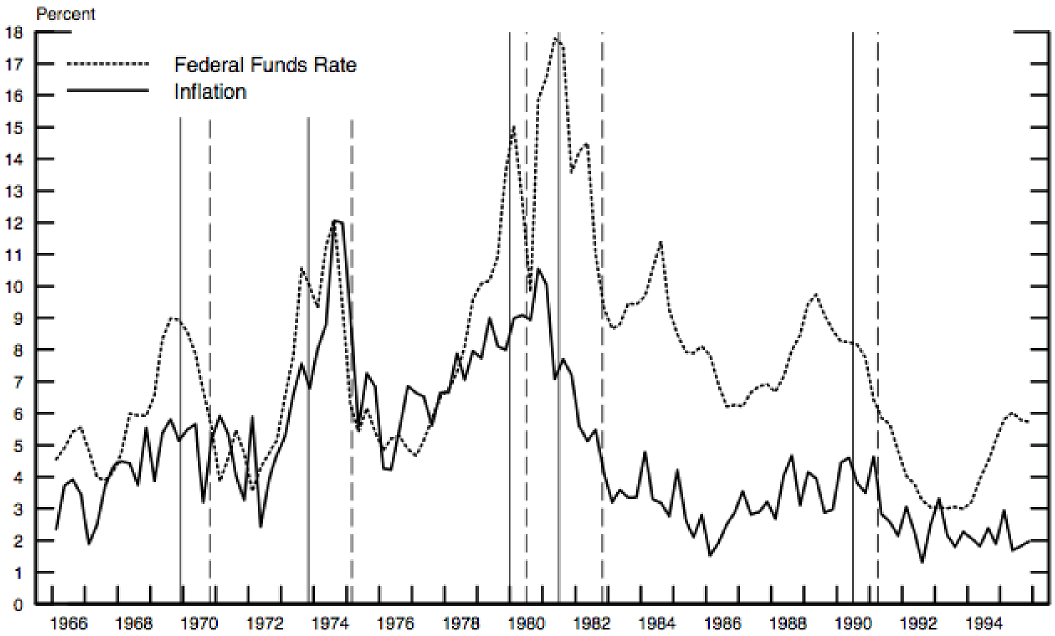
	3 Months	6 Months	12 Months
Benchmark	0.2986	0.9362	1.4494
Oil Efficiency			
($\alpha_O = 0.025, \chi_C = 0.017$)	0.2908	0.5855	0.8182
Real Wage Rigidity			
($\lambda_w = 0.833, \eta = 0.4$)	0.2629	0.6013	0.7753
Price Rigidity			
($\lambda_p = 0.9$)	0.3280	0.1.4576	2.1094

This view emphasizes the important insight that successful monetary policy requires a strong response to expected inflation, such that an increase in expected inflation prompts a more than proportional increase of short-term nominal interest rates. CGG and Taylor argue that the difference in performance from the pre 1984 to the post 1984 can be squarely traced to a shift in this response associated with Paul Volcker's appointment as Chairman of the Federal Reserve in 1979. In essence, these authors argue that during the Great Inflation the Federal Reserve pursued a policy that accommodated inflation and induced instability in the economy by lowering real interest rates when expected inflation increased and vice versa. This perverse practice, they suggest, ended with Volcker's appointment as Chairman, thus restoring monetary stability in the economy. An alternative view on how policy may have improved since 1984 onwards identifies changes in the response of policy to economic activity, as opposed to expected inflation. In this view, policy was excessively activist during the Great Inflation, a result of policymaker overconfidence in their ability to stabilize deviations of output from the economys potential supplythe output gap. As shown by Orphanides (1998), if policymakers mistakenly adopt policies that are optimal under the presumption that their understanding of the state of the economy is accurate when, in fact, such accuracy is lacking, they inadvertently induce instability in both inflation and economic activity. According to this view, the instability associated with the pre 1984 period was the unintended outcome of excessively activist policies chasing output targets that proved overambitious, retrospectively. By the end of the 1970s, the instability and inflationary impetus of these activist policies was finally recognized and policy subsequently improved by becoming less activist.

The behavior of inflation since the 1960s offers indisputable evidence that monetary policy was highly accommodative during the Great Inflation but much less so afterwards. Figure 4.5 compares the behavior of inflation and the federal funds rate from 1966 to 1995. As is evident, the federal funds rate was consistently much higher than inflation since the late 1970s than it was earlier. This change is suggestive of a dramatic reversal in policy at that time. To identify more precisely whether and how monetary policy differed before and after Volcker's appointment, CGG estimate and compare forward-looking monetary policy rules responding to the outlook of inflation and economic activity for each era. Their estimation also suggests that, even after controlling for policy responses to economic activity, the Federal Reserve adjusted real interest rates in a perverse manner prior to Volcker's appointment but not after. In their estimation, however, CGG do not employ information that was available to the Federal Open Market Committee (FOMC) when monetary policy decisions were made but instead rely on ex post constructed data as proxies. As they carefully acknowledge, this raises some questions regarding the interpretation of the results. Indeed, CGG conclude that the fundamental problem they raise for the pre 1984 inflationary episode is that the Federal Reserve maintained persistently low short-term real interest rates in the face of high inflation. Orphanides (2001) revisits the issue and examine the evolution of monetary policy from the 1960s to the 1990s using exclusively information that was available to the FOMC when policy decisions were made. Specifically he estimated a forward-looking monetary policy reaction function such as proposed by CGG for the periods before and after Paul Volckers appointment as Chairman in 1979 using this real-time information.

Estimation results suggest broad similarities in policy over the two periods. In particular, and in contradiction to findings based on the ex post constructed data, the evidence points to a forward looking approach to policy consistent with a strong reaction to inflation forecasts both before and after Volckers appointment as Chairman. This suggests that policymakers during the Great Inflation did not commit an error as egregious as the perverse response to inflation would suggest. The evidence, however, does not absolve monetary policy from the macroeconomic instability experienced during the pre 1984 era. As we discuss, the policy rule describing policy during the Great Inflation was excessively activist in its response to the output gap, especially in light of the outsized misperceptions regarding potential output that were only understood much later. By contrast, the evidence suggests that policy after 1979 did not exhibit the same degree of activism, resulting in a reduction of emphasis to the output gap relative to inflation

Federal Funds Rate and Inflation



Notes: Inflation reflects the quarterly change in the chain-weighted GDP price index (January 2001 data, percent annual rate). The federal funds rate is the quarterly average of daily effective rates. The solid and dashed vertical lines represent NBER business cycle peaks and troughs, respectively.

Figure 4.6: FFR and Inflation Rate

in setting policy. Contemporaneous accounts provide additional support for the view that an intentional reduction in policy activism along these lines followed Paul Volckers appointment as Federal Reserve Chairman. The policy record suggests that rapidly changing economic developments during 1979 forced a critical reconsideration of policy that year. This subtle policy improvement in the aftermath of the Great Inflation contributed to the improved macroeconomic performance of the Long

Orphanides (2001) also estimates a forward-looking Taylor rule but uses real-time data on forecasts of GDP deflator inflation and the output gap made by Federal Reserve Board staff for FOMC meetings. His estimates suggest that the Fed had a strong reaction

Table 4.9: Baseline Estimates from Orphanides (2001)

	$\bar{R}$	ϕ_π	ϕ_y	ρ_R
Pre-Volcker	1.53	1.64	0.57	0.68
Volcker-Greenspan	1.31	1.80	0.27	0.79

to inflation forecasts both before and after 1979. The weight on the output gap in rules estimated using pre-1979 data is higher because of real-time uncertainty about the level of potential GDP. Federal Reserve Board staff forecasts did not correctly perceive that potential output growth slowed in the early 1970s, and so the perceived output gap was larger than the actual output gap.

Monetary policy rule postulated by Orphanides (2001) estimates the following forward looking Taylor equation

$$R_t = \rho_R R_{t-1} + \phi_\pi(1-\rho_R)(E_t\pi_{t+1} - \pi^*) + \phi_y(1-\rho_R)(y_t - y_t^*) + \eta_t \qquad (4.62)$$

where R_t denote the nominal interest rate (Federal Funds Rate). In estimating a policy reaction function such as (4.62), the objective is to describe how policy responded over time to the outlook of inflation and economic activity as understood when policy decisions were made. Ideally, to capture the intent of policy as closely as possible, estimation of (4.62) is based on consistent forecasts of inflation and the output gap, as formed by policymakers themselves (using real time data), and reflecting concepts of these variables with uniform meanings over time.

The tables and below presents the estimation results for equation (4.62).

We will now see the model impulse responses for 3, 6 and 12 months for the estimated parameter values in the benchmark case (pre-Volcker period) and the impulse

Table 4.10: Impulse Responses to Oil Price Shock on Y_t

	3 Months	6 Months	12 Months
Benchmark	-0.0699	-0.0966	-0.0992
Monetary Policy (V-G)	-0.0678	-0.0933	-0.0951

Table 4.11: Impulse Responses to Oil Price Shock on $\pi_{Q,t}$

	3 Months	6 Months	12 Months
Benchmark	0.2465	0.3558	0.7416
Monetary Policy (V-G)	0.2391	0.3325	0.7033

responses for the estimated parameters in the Volcker-Greenspan (V-G) period. It is clear from the values of the impulse responses that under the estimated parameters [provided by Orphanides (2001)] of the V-G period, the impulses are significantly lower - decline in output for 3, 6 and 12 months are close to 3% and the decline for core inflation $\pi_{Q,t}$ for 3, 6 and 12 months are about 4-6% respectively. This decline in the responses for both GDP and inflation suggests a clear role of the change in the stance of the Federal Reserve's monetary policy. These impulse response estimates are in line with our story of the role of the change in the monetary policy in reducing the impact of oil price shock in the post 1984 episode.

4.5 Multisector Extension

Currently we are working on a multisector extension of the single sector model described above. The idea is to see how the change in the sectoral composition of the

U.S. economy (economy becoming more service oriented) leads to a much smaller response of oil price shocks post 1984s. Not only that the sectors differ significantly in terms of energy intensities. Various studies have shown that sectoral heterogeneity in price stickiness, energy intensity, cost shares play important role in determining the aggregate impulse responses. While the cost share of energy may be small in aggregate economic activity, energy inputs are of considerable importance to individual sectors of the economy and therefore identifying these sectors and studying whether these were responsible for the recessions of the 1970s looks to be an important agenda in the study of oil shocks.

4.5.1 Changes in the share of energy

An explanation that we have offered in this study is that there has been a change in the economy's underlying structure and that has induced a reduction in the importance of energy in the US economy. There is sufficient evidence of this decline in energy intensity, with the US Energy Information Administration reporting a drop in "energy intensity" of GDP from an index value of 100 in 1980 to a value of about 62 in 2000. However calibrating the importance of this factor is nontrivial. In this work, following Blanchard and Gali (2008), we suppose that production function for domestic output takes the Cobb-Douglas form given in (4.24). Here the technological parameter α_O is taken to be equal to the value of energy inputs to the value of domestic output, and this ratio is always independent of the price of energy. However it is well known that increase in the price of energy raise the ratio of energy inputs over the value of produced output. This clearly suggests that the elasticity of demand for energy is less than one and therefore constant shares model is not ideal. Hence we are trying the nested CES production function of the following form used quite extensively in the energy literature:

$$Q_t = Z_t N^{\alpha_N}[(\alpha)^{\frac{1}{e}}(K_t)^{\frac{e-1}{e}} + (1-\alpha)^{\frac{1}{e}}(O_t)^{\frac{e-1}{e}}]^{(\frac{e}{e-1})(1-\alpha_N)}$$

where e denotes the elasticity of substitution between oil and capital.

4.6 Conclusion

We have shown in the paper that the effects of oil price shocks have changed over time, with steadily smaller effects on prices and wages, as well as on output and employment. We have seen that the stories offered at the start of the paper are each responsible for a more muted response of oil shock on the US economy in the post 1984 period. The first and most important factor seem to be the decline in the oil intensity in both consumption and production side. The decline is large enough to have significant quantitative implications. The second plausible cause for these changes is a decrease in real wage rigidities. The development of a richer labor market model than the one in Blanchard and Gali (2008) helps understanding of the real wage rigidities and its decline in the post 1984 episode much better, and therefore its quantitative implications are also better. Thirdly there is a huge literature on the increased competitiveness of the manufacturing sector. Therefore prices are more flexible today than it was in the pre 1984 period. Although there is no available estimates for the degree of price stickiness separately for the pre and post 1984 period, we can see that increasing the price flexibility of the aggregate price index leads to a substantial decline in the response of GDP and prices. This makes us hopeful that an estimation of the price stickiness parameters for the two sample will give us better quantitative results with respect to the model impulses. Finally with regards to monetary policy, it is widely accepted that the Federal Reserve now targets core CPI inflation, and thus inflation expectations are anchored much better today than it was in the pre 1984 period. Using estimates from Orphanides (2001), we see that the estimated coefficients of the monetary policy rule in the post 1984 period makes inflation much lower as compared to the pre 1984 period.

APPENDIX A

CHAPTER 1: EQUATIONS AND THEIR DERIVATIONS

Derivation of U.S. Household's first order conditions

At time t, households in the oil importing country U.S. maximize the present discounted value of their utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) = E_0 \sum_{t=0}^{\infty} \beta^t [A_t \log C_t - \zeta_t \frac{N_t^{1+\gamma}}{1+\gamma}] \tag{A1}$$

subject to

$$C_t(j) + I_t(j) + \tau_t + \frac{d_t(j)}{R_t P_t} + \frac{e_{F,t} B_{F,t}(j)}{P_t R_t^* \phi_{F,t}} + \frac{e_{o,t} B_{o,t}(j)}{P_t R_t^o \phi_{o,t}} = \frac{W_t(j) N_t(j)}{P_t} + S_t(j) \tag{A2}$$

$$+ \Big[\frac{r_t u_t(j) K_t^p(j)}{P_t} - a(u_t(j)) K_t^p(j)\Big] + \frac{d_{t-1}(j)}{P_t} + \frac{e_{F,t} B_{F,t-1}(j)}{P_t} + \frac{e_{o,t} B_{o,t-1}(j)}{P_t} + \frac{\Pi_t(j)}{P_t}$$

$$K_{t+1}^p = (1-\delta) K_t^p + s_{It}\Big[1 - \mathcal{S}\Big(\frac{I_t}{I_{t-1}}\Big)\Big] I_t \tag{A3}$$

Let λ_{1t} denote the Lagrangian multiplier associated with (A2) and λ_{2t} denote the Lagrangian multiplier associated with (A3). The household maximizes (A1) subject to (A2) and (A3) with respect to $(C_t, B_t, u_t, K_{t+1}^p, I_t)$. The first order conditions are given by:

$$C_t : \frac{A_t}{C_t} - \lambda_{1t} = 0 \tag{A4}$$

$$B_{H,t} : \lambda_{1t} = \beta R_t E_t\Big(\frac{\lambda_{1t+1} P_t}{P_{t+1}}\Big) \tag{A5}$$

$$B_{F,t} : \lambda_{1t} = \beta \phi_{F,t} R_t^* E_t\Big(\frac{\lambda_{1t+1} P_t}{P_{t+1}} \frac{e_{F,t}}{e_{F,t+1}}\Big) \tag{A6}$$

$$B_{o,t} : \lambda_{1t} = \beta \phi_{o,t} R_t^o E_t \Big(\frac{\lambda_{1t+1} P_t}{P_{t+1}} \frac{e_{o,t}}{e_{o,t+1}} \Big) \tag{A7}$$

$$u_t : \frac{r_t}{P_t} = a'(u_t) \tag{A8}$$

$$K_{t+1}^p : q_t^k = \beta E_t \frac{\lambda_{1t+1}}{\lambda_{1t}} \Big[r_{t+1} u_{t+1} - a(u_{t+1}) + (1-\delta) q_{t+1}^k \Big] \tag{A9}$$

$$I_t : s_{It} q_t^k \Big[1 - \mathcal{S}\Big(\frac{I_t}{I_{t-1}}\Big) \Big] = s_{It} q_t^k \mathcal{S}'\Big(\frac{I_t}{I_{t-1}}\Big)\Big(\frac{I_t}{I_{t-1}}\Big) - \beta E_t s_{It+1} q_{t+1}^k \frac{\lambda_{1t+1}}{\lambda_{1t}} \mathcal{S}'\Big(\frac{I_{t+1}}{I_t}\Big)\Big(\frac{I_{t+1}}{I_t}\Big)^2 + 1 \tag{A10}$$

where $q_t^k = \frac{\lambda_{1t}}{\lambda_{2t}}$ is the price of installed capital in consumption units.

U.S. Firms' Price Setting Equations

A domestic firm reoptimizing in period t will choose the price $\tilde{P}_{H,t}$ that maximizes the current market value of profits generated while that price remains effective. Therefore it solves the problem

$$\max_{\tilde{P}_{H,t}} \sum_{k=0}^{\infty} \lambda_p^k E_t \Big\{ \Lambda_{t,t+k} \Big(\tilde{P}_{H,t} Q_{t+k|t} - \Psi_{t+k}(Q_{t+k|t}) \Big) \Big\} \tag{A11}$$

subject to the sequence of demand functions

$$Q_{t+k|t} = \Big(\frac{\tilde{P}_{H,t}}{P_{H,t+k}} \Big)^{-\Theta_{pt}} Q_{t+k} \tag{A12}$$

$$P_{H,t} = \Big[(1-\lambda_p) \tilde{P}_{H,t}^{1-\Theta_{pt}} + \lambda_p P_{H,t-1}^{1-\Theta_{pt}} \Big]^{1/1-\Theta_{pt}} \tag{A13}$$

$$\Delta_t = \int_0^1 \Big(\frac{P_{H,t}(i)}{P_{H,t}} \Big)^{-\Theta_{pt}} di \tag{A14}$$

$$\Delta_t = \lambda_p \pi_t^{\Theta_{pt}} \Delta_{t-1} + (1-\lambda_p) \Big(\frac{\tilde{P}_{H,t}}{P_{H,t}} \Big)^{-\Theta_{pt}} \tag{A15}$$

The first order condition associated with the problem above takes the following form:

$$\sum_{k=0}^{\infty} \lambda_p^k E_t \Big\{ \Lambda_{t,t+k} Q_{t+k|t} \Big(\tilde{P}_{H,t} (\Theta_{pt+k} - 1) - \Theta_{pt+k} \psi_{t+k|t} \Big) \Big\} = 0 \tag{A16}$$

Derivation of OPEC's Markup

$P^o_t O_t = \alpha_O \psi_t Q_t \Delta_t$ and $\psi_t = \frac{(W_t)^{\alpha_N}(r_t)^{\alpha_K}(P^o_t)^{\alpha_O}}{Z_t \alpha_N^{\alpha_N} \alpha_K^{\alpha_K} \alpha_O^{\alpha_O}}$ imply

$$P^o_t = \frac{\alpha_O(\mathcal{K}_t)^{\frac{1}{1-\alpha_O}}}{O_t} \tag{A17}$$

where $\mathcal{K}_t = \frac{W_t^{\alpha_N} r_t^{\alpha_K} N_t^{\alpha_N} K_t^{\alpha_K}}{\alpha_N^{\alpha_N} \alpha_K^{\alpha_K}}$

The definition of markup implies the following equation for OPEC's markup

$$\mu^o_t = \frac{\alpha_O \mathcal{K}_t^{\frac{1}{1-\alpha_O}} Z_{o,t}}{O_t \delta P_t^{opec}} = \frac{\alpha_O^* (\mathcal{K}_t^*)^{\frac{1}{1-\alpha_O^*}} Z_{o,t}}{O_t^* \delta P_t^{opec}} \tag{A18}$$

Steady State Equations

1. U.S. Economy

1. Consumption Euler Equation: $1 = R\beta = R^*\beta$
2. Consumption and Savings: $1 = \beta(1 - \delta + r)$
3. Investment: $q^k = 1; \delta K = I$
4. Capital Utilization: $u = 1, \frac{r}{P} = a'(1) = a_1$
5. GDP Deflator Inflation: $\pi_H = 1$
6. CPI Inflation: $\pi = 1$
7. Price Dispersion: $\Delta = 1$
8. Marginal Cost: $\psi = \frac{(W)^{\alpha_N}(r)^{\alpha_K}(P^o)^{\alpha_o}}{(\alpha_N)^{\alpha_N}(\alpha_K)^{\alpha_K}(\alpha_O)^{\alpha_o}}$
9. Price Setting: $\tilde{P}_H = \frac{\Theta_p}{\Theta_p - 1}\psi$
10. Wage Setting: $\frac{W^*}{P} = \frac{\Theta_w}{\Theta_w - 1} MRS$
11. Oil Demand: $P^o = \frac{\alpha_O \psi Q}{O}$
12. Labor Demand: $W = \frac{\alpha_N \psi Q}{N}$

13. Capital Demand: $r = \frac{\alpha_K \psi Q}{K}$

14. Consumer Price: $P = \left[b(P_H)^{1-\eta} + (1-b)(P_F)^{1-\eta} \right]^{\frac{1}{1-\eta}}$

15. Government Budget Balance: $G = \tau$

2. Rest of the World

16. Production: $Q^* = Z^* O^*$

17. Marginal Cost: $\psi^* = \frac{P^o}{Z^*}$

18. Price Setting: $\tilde{P}_F = \frac{\Theta_p}{\Theta_p - 1} \psi^*$

19. Foreign CPI: $P^* = \left[(1-b)(P^*_H)^{1-\eta} + b(P^*_F)^{1-\eta} \right]^{\frac{1}{1-\eta}}$

20. Law of One Price: $P_H = eP^*_H, P_F = eP^*_F$

3. OPEC

21. Oil Production: $Q_o = Z_o K_o$

22. OPEC Price: $P^{opec} = \left[1/2(P_H)^{1-\eta} + 1/2(P_F)^{1-\eta} \right]^{\frac{1}{1-\eta}}$

23. Consumption Euler Equation: $1 = \beta \left[\frac{P^o}{P^{opec}} Z_o + (1-\delta) \right]$

4. Market Clearing

24. Oil Market: $Q_o = O + O^*$

25. U.S. Goods Market Equilibrium: $Q = C_H + I_H + G_H + C^*_H + C^o_H + I^o_H$

26. Foreign Importing Country Goods Market Equilibrium: $Q^* = C_F + I_F + C^*_F + C^o_F + I^o_F$

27. U.S. GDP: $Y = P_H \big(C_H + I_H + G_H \big) + P_H \big(C^*_H + C^o_H + I^o_H \big) - P^o O - P_F \big(C_F + I_F \big)$

28. Net Foreign Assets: $e_F B_F + P_H C_H^* = P_F\Big(C_F + I_F\Big) + \frac{e_F B_F}{R^*}$

29. U.S. OPEC Trade Balance: $e_o B_o + P^o O = P_H\Big(C_H^o + I_H^o\Big) + \frac{e_o B_o}{R_o}$

30. OPEC ROW Trade Balance: $e_o B_o^* + P^o O^* = P_F\Big(C_F^o + I_F^o\Big) + \frac{e_o B_o^*}{R_o}$

31. Bonds Market Equilibrium: $B_F + B_F^* = 0$ and $B_o + B_o^* + B^o = 0$

32. Interest Rate: $R = R^* = R_o$

The Log Linearized Model

1. U.S. Firms

1. $\hat{\pi}_{H,t} = E_t[\hat{P}_{H,t+1}] - \hat{P}_{H,t}$

2. $\hat{\tilde{P}}_{H,t} = (1 - \beta\lambda_p)(\hat{\psi}_t - (\Theta_p - 1)^{-1}\hat{\Theta}_{p,t}) + \beta\lambda_p E_t[\hat{\tilde{P}}_{H,t+1}]$

3. $\hat{P}_{H,t} = \lambda_p \hat{P}_{H,t-1} + (1 - \lambda_p)\hat{\tilde{P}}_{H,t}$

4. $\hat{\Delta}_t - \Theta_p \hat{P}_{H,t} = \lambda_p(\hat{\Delta}_{t-1} - \Theta_p \hat{P}_{H,t-1}) - (1 - \lambda_p)\Theta_p \hat{\tilde{P}}_{H,t}$

5. $\hat{P}_t^o = \hat{\psi}_t + \hat{Q}_t + \hat{\Delta}_t - \hat{O}_t$

6. $\hat{W}_t = \hat{\psi}_t + \hat{Q}_t + \hat{\Delta}_t - \hat{L}_t$

7. $\hat{r}_t = \hat{\psi}_t + \hat{Q}_t + \hat{\Delta}_t - \hat{K}_t$

8. $\hat{Q}_t = \hat{Z}_t + \alpha_N \hat{L}_t + \alpha_o \hat{O}_t + \alpha_K \hat{K}_t - \hat{\Delta}_t$

9. $\hat{\mu}_{p,t} = \hat{P}_{H,t} - \hat{\psi}_t - \hat{\Delta}_t$

10. $\bar{\mu}_p \hat{\mu}_{p,t} = \mu_1 \frac{X}{Q}(\hat{X}_t - \hat{Q}_t)$

11. $\alpha^{-1} X(\hat{X}_t - \hat{\pi}_t) = E_t\Big[(P_H \hat{P}_{H,t} - \psi(\hat{\psi}_t + \hat{\Delta}_t))Q - (P_H - \psi)Q\hat{Q}_t + X\hat{X}_{t+1}\Big]$

2. U.S. Households

12. $K^p \hat{K}_t^p = (1 - \delta)K^p \hat{K}_{t-1}^p + I(\hat{I}_t + \hat{s}_{It})$

13. $\hat{K}_{t+1} = \hat{u}_t + \hat{K}_t^p$

14. $\hat{R}_t + \hat{C}_t + E_t[\hat{A}_{t+1} - \hat{C}_{t+1}] - \hat{A}_t - \hat{\pi}_t = 0$

15. $\hat{\pi}_t = E_t[\hat{P}_{t+1}] - \hat{P}_t$

16. $P^{1-\eta}\hat{P}_t = bP_H^{1-\eta}\hat{P}_{H,t} + (1-b)P_F^{1-\eta}\hat{P}_{F,t}$

17. $\hat{C}_{H,t} = \eta(\hat{P}_t - \hat{P}_{H,t}) + \hat{C}_t$

18. $\hat{C}_{F,t} = \eta(\hat{P}_t - \hat{P}_{F,t}) + \hat{C}_t$

19. $\hat{I}_{H,t} = \eta(\hat{P}_t - \hat{P}_{H,t}) + \hat{I}_t$

20. $\hat{I}_{F,t} = \eta(\hat{P}_t - \hat{P}_{F,t}) + \hat{I}_t$

21. $\hat{r}_t = \hat{P}_t + \frac{a''(1)}{a'(1)}\hat{u}_t$

22. $q^k\hat{q}_t^k = \hat{\pi}_t + E_t\big[r(\hat{r}_{t+1} + \hat{u}_{t+1}) - a'(1)\hat{u}_{t+1} + (1-\delta)q^k\hat{q}_{t+1}^k\big]$

23. $\hat{I}_t = \frac{1}{1+\beta}I_{t-1} + \frac{1/S''(1)}{1+\beta}(\hat{q}_t^k + \hat{s}_{It}) + \frac{\beta}{1+\beta}E_t(I_{t+1})$

24. $\hat{q}_t^k = \beta(1-\delta)E_t q_{t+1}^k + (1-\beta(1-\delta))E_t\hat{r}_{t+1}^k - (\hat{r}_t - E_t\hat{\pi}_{t+1})$

25. $\hat{\tilde{W}}_t = \frac{1-\beta\lambda_w}{1+\gamma\Theta_w}\Big(-\frac{\hat{\Theta}_{w,t}}{\Theta_w - 1} + \hat{P}_t + \hat{C}_t - \hat{A}_t + \hat{\zeta}_t + \gamma\hat{L}_t + \gamma\Theta_w\hat{W}_t\Big) + \beta\lambda_w E_t[\hat{W}_{t+1}]$

26. $\hat{W}_t = \lambda_w\hat{W}_{t-1} + (1-\lambda_w)\hat{\tilde{W}}_t$

3. Rest of the World

27. $\hat{Q}_t^* = \hat{Z}_t^* + \alpha_o^*\hat{O}_t^* - \hat{\Delta}_t^*$

28. $\hat{P}_t^o = \hat{\psi}_t + \hat{Q}_t + \hat{\Delta}_t - \hat{O}_t + \hat{e}_t$

29. $\hat{\pi}_{F,t} = E_t[\hat{P}_{F,t+1}] - \hat{P}_{F,t}$

30. $(P^*)^{1-\eta}\hat{P}_t = (1-b)(P_H^*)^{1-\eta}\hat{P}_{H,t}^* + b(P_F^*)^{1-\eta}\hat{P}_{F,t}^*$

31. $\hat{R}_t^* + \hat{C}_t^* - E_t[\hat{C}_{t+1}^*] - \hat{\pi}_t^* = 0$

32. $\hat{C}_{H,t}^* = \eta(\hat{P}_t^* - \hat{P}_{H,t}) + \hat{C}_t^*$

33. $\hat{C}^{*}_{F,t} = \eta(\hat{P}^{*}_{t} - \hat{P}_{F,t}) + \hat{C}^{*}_{t}$

34. $\hat{\tilde{P}}^{*}_{F,t} = (1 - \beta\lambda_p)\hat{\psi}^{*}_{t} + \beta\lambda_p E_t[\hat{\tilde{P}}^{*}_{F,t+1}]$

35. $\hat{P}^{*}_{F,t} = \lambda_p \hat{P}^{*}_{F,t-1} + (1 - \lambda_p)\hat{\tilde{P}}^{*}_{F,t}$

36. $\hat{\Delta}^{*}_{t} - \Theta_p \hat{P}^{*}_{F,t} = \lambda_p(\hat{\Delta}^{*}_{t-1} - \Theta_p \hat{P}^{*}_{F,t-1}) - (1 - \lambda_p)\Theta_p \hat{\tilde{P}}^{*}_{F,t}$

37. $\hat{P}_{H,t} = \hat{e}_t + \hat{P}^{*}_{H,t} + \hat{\varkappa}_t$

38. $\hat{P}_{F,t} = \hat{e}_t + \hat{P}^{*}_{F,t} + \hat{\varkappa}_t$

4. OPEC

39. $\hat{Q}_{o,t} = \hat{Z}_{o,t} + \hat{K}_{o,t-1}$

40. $K_o \hat{K}_{o,t} = (1 - \delta)K_o \hat{K}_{o,t-1} + I_o \hat{I}_{o,t}$

41. $(P^{opec})^{1-\eta}\hat{P}^{opec}_{t} = \frac{1}{2}P_H^{1-\eta}\hat{P}_{H,t} + \frac{1}{2}P_F^{1-\eta}\hat{P}_{F,t}$

42. $\hat{C}^{o}_{H,t} = \eta(\hat{P}^{opec}_{t} - \hat{P}_{H,t}) + \hat{C}^{o}_{t}$

43. $\hat{C}^{o}_{F,t} = \eta(\hat{P}^{opec}_{t} - \hat{P}_{F,t}) + \hat{C}^{o}_{t}$

44. $\hat{I}^{o}_{H,t} = \eta(\hat{P}^{opec}_{t} - \hat{P}_{H,t}) + \hat{I}^{o}_{t}$

45. $\hat{I}^{o}_{F,t} = \eta(\hat{P}^{opec}_{t} - \hat{P}_{F,t}) + \hat{I}^{o}_{t}$

46. $P^{opec}(E_t[\hat{C}^{o}_{t+1}] - \hat{C}^{o}_{t} + \hat{P}^{opec}_{t}) = \beta(P^{o}Z_o(E_t[\hat{P}^{o}_{t+1}] + \hat{Z}_{o,t}) - (1 - \delta)P^{opec}\hat{P}^{opec}_{t})$

47. $\hat{R}_{o,t} + \hat{C}^{o}_{t} - E_t[\hat{C}^{o}_{t+1}] - \hat{\pi}^{o}_{t} = 0$

5. Market Clearing

48. $Q_o \hat{Q}_{o,t} = O\hat{O}_t + O^{*}\hat{O}^{*}_{t}$

49. $Q\hat{Q}_t = C_H \hat{C}_{H,t} + I_H \hat{I}_{H,t} + b\left(\frac{P_H}{P}\right)^{-\eta} a'(1)K^{p}u\hat{u}_t + G_H \hat{G}_{H,t} + C^{*}_{H}\hat{C}^{*}_{H,t} + C^{o}_{H}\hat{C}^{o}_{H,t} + I^{o}_{H}\hat{I}^{o}_{H,t}$

50. $Q^{*}\hat{Q}^{*}_{t} = C_F \hat{C}_{F,t} + I_F \hat{I}_{F,t} + (1 - b)\left(\frac{P_F}{P}\right)^{-\eta} a'(1)K^{p}u\hat{u}_t + C^{*}_{F}\hat{C}^{*}_{F,t} + C^{o}_{F}\hat{C}^{o}_{F,t} + I^{o}_{F}\hat{I}^{o}_{F,t}$

51. $e_oB_o(\hat{e}_{o,t} + \hat{B}_{o,t-1}) + P^oO(\hat{P}^o_t + \hat{O}_t) = P_HC^o_H(\hat{P}^o_t + \hat{C}^o_{H,t}) + P_HI^o_H(\hat{P}^o_t + \hat{I}^o_{H,t}) + \frac{e_oB_o}{R_o}(\hat{e}_{o,t} + \hat{B}_{o,t} - \hat{\phi}_{o,t} - \hat{R}_{o,t})$

52. $e_oB^*_o(\hat{e}_{o,t} + \hat{B}^*_{o,t-1}) + P^oO^*(\hat{P}^o_t + \hat{O}^*_t) = P_FC^o_F(\hat{P}^o_t + \hat{C}^o_{F,t}) + P_FI^o_F(\hat{P}^o_t + \hat{I}^o_{F,t}) + \frac{e_oB^*_o}{R_o}(\hat{e}_{o,t} + \hat{B}^*_{o,t} - \hat{\phi}_{o,t} - \hat{R}_{o,t})$

53. $0 = -e_FB_F(\hat{e}_{F,t} + \hat{B}_{F,t-1}) - P_HC^*_H(\hat{P}_{H,t} + \hat{C}^*_{H,t})P_FC_F(\hat{P}_{F,t} + \hat{C}_{F,t}) + P_FI_F(\hat{P}_{F,t} + \hat{I}_{F,t}) + (1-b)P_F\left(\frac{P_F}{P}\right)^{-\eta}a'(1)K^pu\hat{u}_t + \frac{e_FB_F}{R^*}(\hat{e}_{F,t} + \hat{B}_{F,t} - \hat{\phi}_{F,t} - \hat{R}^*_t)$

54. $Y\hat{Y}_t = C_H\hat{C}_{H,t} + I_H\hat{I}_{H,t} + G_H\hat{G}_{H,t} + C^*_H\hat{C}^*_{H,t} + C^o_H\hat{C}^o_{H,t} + I^o_H\hat{I}^o_{H,t} - \frac{P^o}{P_H}O(\hat{P}^o_t - \hat{P}_{H,t} + \hat{O}_t) - \frac{P_F}{P_H}(C_F + I_F)(\hat{P}_{F,t} - \hat{P}_{H,t}) - (1-b)\frac{P_F}{P_H}\left(\frac{P_F}{P}\right)^{-\eta}a'(1)K^pu\hat{u}_t$

55. $E_t[\hat{e}_{F,t+1}] - \hat{e}_{F,t} = \hat{\phi}_{F,t} + \hat{R}^*_t - \hat{R}_t$

56. $E_t[\hat{e}_{o,t+1}] - \hat{e}_{o,t} = \hat{\phi}_{o,t} + \hat{R}_{o,t} - \hat{R}_t$

57. $\hat{\phi}_{F,t} = \phi\frac{e_F}{Y}\hat{B}_{F,t}$

58. $\hat{\phi}_{o,t} = \phi\frac{e_F}{Y}\hat{B}_{F,t}$

6. Monetary policy and Phillips curve

59. $\hat{R}_t = \phi_R\hat{R}_{t-1} + (1-\phi_R)(\phi_\pi\hat{\pi}_t + \phi_y\hat{Y}_t)$

60. $\pi_{H,t} = \beta E_t\pi_{H,t+1} + \frac{(1-\beta\lambda_p)(1-\lambda_p)}{\lambda_p}\hat{mc}_t$

Table A.1: Variables, definitions and sources of data Used in Estimation

Variable	**Definition**	**Source**
Oil Price	Nominal Spot Oil Price of West Texas Intermediate Crude obtained as dollars per barrel	EIA & FRB St Louis
CPI	Prices paid by urban consumers for a representative basket of goods and services	Bureau of Labor Statistics
GDP Deflator	Implicit price deflator for GDP - measure of the level of prices of all new, domestically produced, final goods and services	Bureau of Economic Analysis
Wages	Non Farm Business Sector Compensation Per Hour	Bureau of Labor Statistics
Employment	Non Farm Business Hours of all Persons	Bureau of Labor Statistics
GDP	Quarterly Real Gross Domestic Product in Billions of 2005 Dollars	Federal Reserve Board
Consumption	Real Personal Consumption Expenditure Billions of 2005 Dollars	Bureau of Economic Analysis
Investment	Real Gross Private Domestic Investment Billions of 2005 Dollars	Bureau of Economic Analysis
Government	Federal Consumption Expenditures and Gross Investment	Bureau of Economic Analysis
FFR	Rate at which a depository institution lends funds to each other	Federal Reserve Bank of St Louis
Exchange Rate	US: Nominal Effective Exchange Rate Index	International Monetary Fund
Oil Imports	U.S. Imports of Crude Oil (Thousand Barrels)	Energy Information Administration

APPENDIX B

CHAPTER 2: DATASET DESCRIPTION AND SOURCE

The data are taken from various sources. The series names, data span, respective sources and transformation codes along with a short description is given here. The transformation codes are: 1 - no transformation; 2 - first difference; 4 - logarithm; 5 - first difference of logarithm. Second differencing of logarithms was not used. The data are monthly and the span for all series is 1972:2-2008:12.

Aggregate Dataset

Table B.1: Aggregate Data

	Variable	Span	Code	Source
	Output, Income & Capacity			
1	IPI: Total	1972:2-2008:12	5	FRB G.17
2	IPI: Final products & non industrial supplies	1972:2-2008:12	5	FRB G.17
3	IPI: Final Products	1972:2-2008:12	5	FRB G.17
4	IPI: Consumer Goods	1972:2-2008:12	5	FRB G.17
5	IPI: Durable Consumer Goods	1972:2-2008:12	5	FRB G.17
6	IPI: Non Durable Consumer Goods	1972:2-2008:12	5	FRB G.17
7	IPI: Energy Goods	1972:2-2008:12	5	FRB G.17
8	IPI: Non Energy Goods	1972:2-2008:12	5	FRB G.17
9	IPI: Business Equipments	1972:2-2008:12	5	FRB G.17
10	IPI: Non Industrial Supplies	1972:2-2008:12	5	FRB G.17
11	IPI: Materials	1972:2-2008:12	5	FRB G.17
12	IPI: Energy	1972:2-2008:12	5	FRB G.17

Table B.1: Continued

	Variable	Span	Code	Source
13	IPI: Construction VIP	1972:2-2008:12	5	U.S Census Bureau
14	IPI: Crude Processing	1972:2-2008:12	5	FRB G.17
15	IPI: Finished Processing	1972:2-2008:12	5	FRB G.17
16	IPI: Primary and Semifinished Products	1972:2-2008:12	5	FRB G.17
17	Personal Income	1972:2-2008:12	5	BEA
18	Industrial Production: Diffusion Indexes (1 month earlier)	1972:2-2008:12	5	FRB G.17
19	Real PCE Quantity Index - Total	1972:2-2008:12	5	BEA (2005=100)
20	Real PCE Quantity Index - Durable Goods	1972:2-2008:12	5	BEA (2005=100)
21	Real PCE Quantity Index - Non Durable Goods	1972:2-2008:12	5	BEA (2005=100)
22	ISM Manufacturing: PMI Composite Index	1972:2-2008:12	5	Institute of Supply Management
23	Capacity Utilization: Total	1972:2-2008:12	5	FRB G.17
24	Capacity Utilization: Manufacturing	1972:2-2008:12	5	FRB G.17
25	Capacity Utilization: Durable manufacturing	1972:2-2008:12	5	FRB G.17
26	Capacity Utilization: Non Durable Manufacturing	1972:2-2008:12	5	FRB G.17

Table B.1: Continued

	Variable	Span	Code	Source
27	Capacity Utilization: Mining	1972:2-2008:12	5	FRB G.17
	Employment & Earnings			
28	U.S employment index	1972:2-2008:12	5	IMF (2005=100)
29	U.S unemployment rate	1972:2-2008:12	5	BLS
30	U.S employment Non Farm - Total	1972:2-2008:12	5	BLS (Persons Th)
31	U.S employment - Private	1972:2-2008:12	5	BLS (Persons Th)
32	U.S employment - Goods Producing	1972:2-2008:12	5	BLS (Persons Th)
33	U.S employment - Natural Resources and Mining	1972:2-2008:12	5	BLS (Persons Th)
34	U.S employment - Mining	1972:2-2008:12	5	BLS (Persons Th)
35	U.S employment - Construction	1972:2-2008:12	5	BLS (Persons Th)
36	U.S employment - Manufacturing	1972:2-2008:12	5	BLS (Persons Th)
37	U.S employment - Service Providing	1972:2-2008:12	5	BLS (Persons Th)
38	U.S employment - Retail Trade	1972:2-2008:12	5	BLS (Persons Th)
39	U.S employment - Utilities	1972:2-2008:12	5	BLS (Persons Th)

Table B.1: Continued

	Variable	**Span**	**Code**	**Source**
40	U.S employment - Transportation and Warehousing	1972:2-2008:12	5	BLS (Persons Th)
41	U.S employment - Finance activities	1972:2-2008:12	5	BLS (Persons Th)
42	U.S employment - Government	1972:2-2008:12	5	BLS (Persons Th)
43	Average Hourly Earnings - Construction	1972:2-2008:12	5	BLS (Dollars per hour)
44	Average Hourly Earnings -Manufacturing	1972:2-2008:12	5	BLS (Dollars per hour)
45	Average Hourly Earnings-Private industries	1972:2-2008:12	5	BLS (Dollars per hour)
46	Civilian Employment	1972:2-2008:12	5	BLS (persons Ths)
47	Civilian Participation rate	1972:2-2008:12	5	BLS (in percent)
48	Civilian Labor Force	1972:2-2008:12	5	BLS (persons Ths)
49	Median Duration of Unemployment	1972:2-2008:12	5	BLS (weeks)
50	Unemployment Duration: less than 5 weeks	1972:2-2008:12	5	BLS
51	Unemployment Duration: 5-14 weeks	1972:2-2008:12	5	BLS
52	Unemployment Duration: 15 weeks and over	1972:2-2008:12	5	BLS
53	Average Weekly Hours: Manufacturing	1972:2-2008:12	5	BLS

Table B.1: Continued

	Variable	Span	Code	Source
54	Average Weekly Hours: Private Industries	1972:2-2008:12	5	BLS
	Housing			
55	Housing Starts: Total: New privately owned housing units	1972:2-2008:12	4	US Census Bureau
56	Housing Starts: 2-4 units	1972:2-2008:12	4	US Census Bureau
57	New Private Housing Units authorized by building permits	1972:2-2008:12	4	US Census Bureau
	Exchange Rates			
58	Exchange Rate: Canada (Canadian $ per US $)	1972:2-2008:12	5	Federal Reserve System G.5
59	Exchange Rate: Japan (Yen per US $)	1972:2-2008:12	5	Federal Reserve System G.5
60	Exchange Rate: Switzerland (Swiss Franc per US $)	1972:2-2008:12	5	Federal Reserve System G.5
61	Exchange Rate: UK (cents per US $)	1972:2-2008:12	5	Federal Reserve System G.5
	Interest Rates			
62	Federal Funds Rate (% per annum)	1972:2-2008:12	1	Federal Reserve System H.15
63	U.S Treasury Bill Rate: Government Securities	1972:2-2008:12	1	IMF (in percent)
64	U.S Government Bonds Yield 3-5 Years	1972:2-2008:12	1	IMF (in percent)

Table B.1: Continued

	Variable	Span	Code	Source
65	U.S Government Bonds Yield Long Term	1972:2-2008:12	1	IMF (in percent)
66	1-Year Treasury Constant Maturity Rate (GS1)	1972:2-2008:12	1	FRB H.15 (in percent)
67	5-Year Treasury Constant Maturity Rate (GS5)	1972:2-2008:12	1	FRB H.15 (in percent)
68	Corporate Bonds Yield (Aaa rated)	1972:2-2008:12	1	FRB H.15 (in percent)
69	Corporate Bonds Yield (Baa rated)	1972:2-2008:12	1	FRB H.15 (in percent)
	Money and Credit			
70	U.S Money Supply (Base Money)	1972:2-2008:12	5	IMF (USD Bn)
71	U.S Money Supply (M1)	1972:2-2008:12	5	IMF (USD Bn)
72	U.S Money Supply (M2)	1972:2-2008:12	5	IMF (USD Bn)
73	Total Borrowings of Depository Institutions from Federal Board	1972:2-2008:12	5	FRB H.3 (Billions of Dollars)
74	Demand Deposits at Commercial Banks	1972:2-2008:12	5	FRB H.6 (Billions of Dollars)
75	Total Investments at all Commercial Banks	1972:2-2008:12	5	FRB H.8 (Billions of Dollars)
	Stock Market			

Table B.1: Continued

	Variable	Span	Code	Source
76	Price-Earnings Ratio	1972:2-2008:12	5	S&P (% monthly avg.)
77	U.S Index of Share Price	1972:2-2008:12	5	IMF (2005=100)
78	Dow Jones Average: Industrial	1972:2-2008:12	5	Dow Jones (monthly)
79	Equity Market Index	1972:2-2008:12	5	NYSE (monthly, 12/2002=500)
	Price Indices			
80	Producer Price Index: Total	1972:2-2008:12	5	BLS (1982=100)
81	Producer Price Index: Manufacturing	1972:2-2008:12	5	BLS (1982=100)
82	Producer Price Index: Durable Manufacturing	1972:2-2008:12	5	BLS (1982=100)
83	Producer Price Index: Non Durable Manufacturing	1972:2-2008:12	5	BLS (1982=100)
84	Producer Price Index: Intermediate Materials	1972:2-2008:12	5	BLS (1982=100)
85	Producer Price Index: Finished Goods	1972:2-2008:12	5	BLS (1982=100)
86	Producer Price Index: Consumer Durable Goods	1972:2-2008:12	5	BLS (1982=100)
87	Producer Price Index: Consumer Non Durable Goods	1972:2-2008:12	5	BLS (1982=100)

Table B.1: Continued

	Variable	Span	Code	Source
88	Producer Price Index: Finished Consumer Goods	1972:2-2008:12	5	BLS (1982=100)
89	Producer Price Index: Industrial Commodities	1972:2-2008:12	5	BLS (1982=100)
90	CPI: All Urban Consumers: All items less food energy	1972:2-2008:12	5	BLS (1982=100)
91	CPI: All Urban Consumers: All items	1972:2-2008:12	5	BLS (1982=100)
92	PCE Price Index - All items	1972:2-2008:12	5	BLS (1982=100)
93	PCE Price Index - Durable Goods	1972:2-2008:12	5	BLS (1982=100)
94	PCE Price Index - Non Durable Goods	1972:2-2008:12	5	BLS (1982=100)
95	PCE Price Index - Energy Goods and Services	1972:2-2008:12	5	BLS (1982=100)
	Energy			
96	Spot Oil Price: West Texas Intermediate	1972:2-2008:12	5	Dow Jones (Dollars Per Barrel)
97	Producer Price Index: Fuel and Power	1972:2-2008:12	5	BLS (1982=100)
98	Consumer Price Index for Energy	1972:2-2008:12	5	BLS (1982=100)
99	Consumer Price Index for Transportation	1972:2-2008:12	5	BLS (1982=100)
100	Total Primary Energy Consumption	1973:2-2008:12	5	EIA (Quadrillion BTU)

Table B.1: Continued

	Variable	Span	Code	Source
101	Total Energy Consumption by Industrial Sector	1973:2-2008:12	5	EIA (Trillion BTU)
102	U.S Field Production of Crude Oil	1972:2-2008:12	5	EIA (Thousand barrels)
103	U.S Net Imports of Crude Oil	1972:2-2008:12	5	EIA (Thousand barrels per day)

Price Data Set

Table B.2: Price Data

	Variable	Span	Code	Source
1	Producer Price Index: Agriculture	1972:2-2008:12	5	BLS (1982=100)
2	Producer Price Index: Mining	1972:2-2008:12	5	BLS (1982=100)
3	Producer Price Index: Construction	1972:2-2008:12	5	BLS (1982=100)
4	Producer Price Index: Food	1972:2-2008:12	5	BLS (1982=100)

Table B.2: Continued

	Variable	Span	Code	Source
5	Producer Price Index: Beverage and & Materials	1972:2-2008:12	5	BLS (1982=100)
6	Producer Price Index: Tobacco	1972:2-2008:12	5	BLS (1982=100)
7	Producer Price Index: Apparel	1972:2-2008:12	5	BLS (1982=100)
8	Producer Price Index: Textile Mills Products & Services	1972:2-2008:12	5	BLS (1982=100)
9	Producer Price Index: Hides, Skin & Leather	1972:2-2008:12	5	BLS (1982=100)
10	Producer Price Index: Fuels, Fuel Products & Power	1972:2-2008:12	5	BLS (1982=100)
11	Producer Price Index: Chemicals & Allied Products	1972:2-2008:12	5	BLS (1982=100)
12	Producer Price Index: Rubber & Plastics	1972:2-2008:12	5	BLS (1982=100)
13	Producer Price Index: Lumber & Wood	1972:2-2008:12	5	BLS (1982=100)
14	Producer Price Index: Pulp, Paper & Allied Products	1972:2-2008:12	5	BLS (1982=100)
15	Producer Price Index: Metal and Metal Products	1972:2-2008:12	5	BLS (1982=100)
16	Producer Price Index: Machinery and Equipments	1972:2-2008:12	5	BLS (1982=100)
17	Producer Price Index: Furnitures and Fixtures	1972:2-2008:12	5	BLS (1982=100)
18	Producer Price Index: Non-metallic Mineral	1972:2-2008:12	5	BLS (1982=100)

Table B.2: Continued

	Variable	Span	Code	Source
19	Producer Price Index: Miscellaneous Manufacturing	1972:2-2008:12	5	BLS (1982=100)
20	Producer Price Index: Producer Price Index: Fuel: Coal	1972:2-2008:12	5	BLS (1982=100)
21	Producer Price Index: Fuel: Natural Gas	1972:2-2008:12	5	BLS (1982=100)
22	Producer Price Index: Fuel: Gasoline	1972:2-2008:12	5	BLS (1982=100)
23	Producer Price Index: Motor Vehicles and & Equipments	1972:2-2008:12	5	BLS (1982=100)
24	Producer Price Index: Stone, Clay and Glass	1972:2-2008:12	5	BLS (1982=100)
25	Producer Price Index: Electrical Machinery	1972:2-2008:12	5	BLS (1982=100)
26	Consumer Price Index: Utilities and Public Transportation	1972:2-2008:12	5	BLS (1982=100)
27	Consumer Price Index: Medical Care Services	1972:2-2008:12	5	BLS (1982=100)
28	Consumer Price Index: Energy	1972:2-2008:12	5	BLS (1982=100)
29	Consumer Price Index: All Services	1972:2-2008:12	5	BLS (1982=100)
30	Consumer Price Index: All Services less Energy	1972:2-2008:12	5	BLS (1982=100)
31	Consumer Price Index: Transport Services	1972:2-2008:12	5	BLS (1982=100)

Production Data Set

Table B.3: Production Data

	Variable	Span	Code	Source
1	Production Index: Agriculture	1972:2-2008:12	5	USDA
2	Industrial Production Index: Manufacturing	1972:2-2008:12	5	FRB G.17
3	Industrial Production Index: Durable Manufacturing	1972:2-2008:12	5	FRB G.17
4	Industrial Production Index: Non Durable Manufacturing	1972:2-2008:12	5	FRB G.17
5	Industrial Production Index: Mining	1972:2-2008:12	5	FRB G.17
6	Industrial Production Index: Electric Power Generation	1972:2-2008:12	5	FRB G.17
7	Industrial Production Index: Electric and Gas Utilities	1972:2-2008:12	5	FRB G.17
8	Industrial Production Index: Natural Gas Distribution	1972:2-2008:12	5	FRB G.17
9	Industrial Production Index: Food Beverage and Tobacco	1972:2-2008:12	5	FRB G.17
10	Industrial Production Index: Textiles and Products	1972:2-2008:12	5	FRB G.17
11	Industrial Production Index: Apparel and Leather Goods	1972:2-2008:12	5	FRB G.17

Table B.3: Continued

	Variable	**Span**	**Code**	**Source**
12	Industrial Production Index: Wood	1972:2-2008:12	5	FRB G.17
13	Industrial Production Index: Paper	1972:2-2008:12	5	FRB G.17
14	Industrial Production Index: Printing and Publishing	1972:2-2008:12	5	FRB G.17
15	Industrial Production Index: Petroleum and Coal Products	1972:2-2008:12	5	FRB G.17
16	Industrial Production Index: Chemical	1972:2-2008:12	5	FRB G.17
17	Industrial Production Index: Plastics and Rubber	1972:2-2008:12	5	FRB G.17
18	Industrial Production Index: Non Metallic Mineral Products	1972:2-2008:12	5	FRB G.17
19	Industrial Production Index: Primary Metals	1972:2-2008:12	5	FRB G.17
20	Industrial Production Index: Fabricated Metals	1972:2-2008:12	5	FRB G.17
21	Industrial Production Index: Machinery	1972:2-2008:12	5	FRB G.17
22	Industrial Production Index: Computer and Electronic Products	1972:2-2008:12	5	FRB G.17
23	Industrial Production Index: Electrical equipment, appliance, and component	1972:2-2008:12	5	FRB G.17
24	Industrial Production Index: Motor Vehicles and Parts	1972:2-2008:12	5	FRB G.17
25	Industrial Production Index: Aerospace and Miscellaneous	1972:2-2008:12	5	FRB G.17

Table B.3: Continued

	Variable	**Span**	**Code**	**Source**
26	Industrial Production Index: Furnitures and Fixtures	1972:2-2008:12	5	FRB G.17
27	Industrial Production Index: Miscellaneous Manufacturing	1972:2-2008:12	5	FRB G.17
28	Industrial Production Index: Other Manufacturing	1972:2-2008:12	5	FRB G.17

APPENDIX C

CHAPTER 3: EQUATIONS AND THEIR DERIVATIONS

Steady State Computations

Let $\bar{y}$ denote the steady state value of a variable y. We assume that in steady state $\bar{y} = y_t \forall t$.

1. Production Function

$$Q = N^{\alpha_N} K^{\alpha_K} O^{\alpha_O}$$

2. Marginal Product of labor

$$\bar{a} = \alpha_N \frac{Q}{N}$$

3. Rental rate of capital

$$r = P^W \alpha_K \frac{Q}{K}$$

4. Oil Price

$$P_O = P^W \alpha_O \frac{Q}{O}$$

5. Consumption and Savings

$$1 = \beta(1 - \delta + r)$$

6. Investment

$$q^k = 1$$

7. Hiring rate

$$x = 1 - \rho$$

8. Flow

$$xN = su$$

9. Unemployment

$$u = 1 - N$$

10. Matching

$$su = \sigma_m u^{\sigma} v^{1-\sigma}$$

11. Hiring Condition

$$\kappa x = P^W \bar{a} - \bar{W} + \beta \frac{\kappa}{2} x^2 + \beta \rho \kappa x$$

12. Wages

$$\bar{W} = \chi(\bar{a} + \beta \frac{\kappa}{2} x^2 + \beta \kappa s x) + (1 - \chi)\bar{b}$$

$$\chi = \frac{\eta}{\eta + (1 - \eta)\mu/\epsilon}, \mu = \frac{1}{1 - \lambda_w \beta}, \epsilon = \frac{1}{1 - \rho \lambda_w \beta}$$

13. Resource Constraints

$$P_Y Y = P_C C$$

$$P_C C = P_Q Q - P_O O$$

14. Prices and Inflation

$$P_C = P_O^{\chi_c} P_Q^{1-\chi_c}$$

15. Real Oil Price

$$S_O = \frac{P_O}{P_Q}$$

16. Markup

$$\frac{P_Q}{P_W} = \frac{\epsilon_Q}{\epsilon_Q - 1}$$

17. Consmption

$$C = [\chi_c^{-\chi_c} (1 - \chi_c)^{-(1-\chi_c)}] C_O^{\chi_c} C_Q^{1-\chi_c}$$

18. Consumption Share

$$P_Q C_Q = (1 - \chi_c) P_c C$$

$$P_O C_O = \chi_c P_C C$$

The Loglinearized Model

I **Production, Consumption and Investment**

(1) Production Function

$$\hat{Q}_t = \alpha_N \hat{N}_t + \alpha_K \hat{K}_t + \alpha_O \hat{O}_t$$

(2) Consumption-Savings

$$E_t \hat{\Lambda}_{t,t+1} + (\hat{R}_t - E_t \hat{\pi}_{C,t+1}) = 0$$

(3) Capital Utilization

$$\hat{\nu}_t = \eta_\nu \hat{r}_t$$

(4) Investment

$$\hat{I}_t = \frac{1}{1+\beta} \hat{I}_{t-1} + \frac{1}{\eta_k (1+\beta)} \hat{q}_t^k + \frac{\beta}{1+\beta} E_t(\hat{I}_{t+1})$$

$$\eta_k = S''(\gamma_z) = S''(1)$$

(5) Capital Renting

$$\hat{r}_t = \hat{P}_t^W + \hat{Q}_t - \hat{K}_t$$

(6) Oil Import

$$\hat{P}_{O,t} = \hat{P}_t^W + \hat{Q}_t - \hat{O}_t$$

(7) Tobin's q

$$\hat{q}_t^k = \beta(1-\delta) E_t \hat{q}_{t+1}^k + [1 - \beta(1-\delta)] E_t \hat{r}_{t+1} - (\hat{R}_t - E_t \hat{\pi}_{C,t+1})$$

II **Search, Matching and Employment**

(1) Matching

$$\hat{m}_t = \sigma\hat{u}_t + (1-\sigma)\hat{v}_t$$

(2) Employment Dynamics

$$\hat{N}_t = \hat{N}_{t-1} + (1-\rho)\hat{x}_t$$

$$\hat{s}_t = \hat{m}_t - \hat{u}_t$$

(3) Transition Probabilities

$$\hat{u} = -(\frac{N}{u})\hat{N}_{t-1}$$

(4) Working capital

$$\hat{K}_t = \hat{v}_t + \hat{K}^P_{t-1}$$

(5) Physical capital

$$\hat{K}^P_t = (1-\delta)\hat{K}^P_{t-1} + \delta\hat{I}_t$$

(6) Vacancies

$$\hat{x}_t = \hat{q}_t + \hat{v}_t - \hat{N}_{t-1}$$

III **Bargaining**

(1) Hiring rate

$$\hat{x}_t = \varkappa_a(\hat{P}^W_t + \hat{a}_t) - \varkappa_w\hat{W}_t + \varkappa_{\lambda_w}E_t\hat{\Lambda}_{t,t+1} + \beta E_t\hat{x}_{t+1}$$

$$\varkappa = (\kappa x)^{-1}, \varkappa_a = \varkappa P^W\bar{a}, \varkappa_w = \varkappa\bar{W}, \varkappa_{\lambda_w} = \beta(1+\rho)/2$$

(2) Marginal Product of Labor

$$\hat{a}_t = \hat{Q}_t - \hat{N}_t$$

(3) Weight in Nash Bargaining

$$\hat{\chi}_t = -(1-\chi)(\hat{\mu}_t - \hat{\epsilon}_t)$$

$$\hat{\epsilon}_t = (\rho\lambda_w\beta)E_t\Big[\hat{\Lambda}_{t,t+1} - \hat{\pi}_{C,t+1} + \gamma\hat{\pi}_{C,t} + \hat{\epsilon}_{t+1}\Big]$$

$$\begin{aligned}\hat{\mu}_t \quad = \quad & (x\lambda_w\beta)E_t\hat{x}_{t+1} - (x\lambda_w\beta)(\varkappa_w\mu)\mu E_t(\hat{W}_t + \gamma\hat{\pi}_{C,t} - \hat{\pi}_{C,t+1} - \hat{W}_{t+1}) \\ & +(\lambda_w\beta)E_t(\hat{\mu}_{t+1}\hat{\Lambda}_{t,t+1} + \gamma\hat{\pi}_{C,t} - \hat{\pi}_{C,t+1})\end{aligned}$$

IV **Wages**

(1) Spillover free wage

$$\begin{aligned}\hat{W}_t^0 \quad = \quad & \varphi_a(\hat{P}_t^W + \hat{a}_t) + (\varphi_s + \varphi_x)E_t\hat{x}_{t+1} + \varphi_s\hat{s}_{t+1} \\ & +\varphi_b\hat{b}_t + (\varphi_s + \varphi_x/2)E_t\hat{\Lambda}_{t,t+1} + \varphi_\chi[\hat{\chi}_t - (\rho - s)\beta E_t\hat{\chi}_{t+1}]\end{aligned}$$

$$\varphi_a = \chi P^W\bar{a}\bar{W}^{-1}, \varphi_x = \chi\beta\kappa x^2\bar{W}^{-1}$$

$$\varphi_b = (1-\chi)\bar{b}\bar{W}^{-1}, \varphi_s = (1-\chi)s\beta\bar{H}\bar{W}^{-1}, \varphi_\chi = \chi(1-\chi)^{-1}\kappa x\bar{W}^{-1}$$

(2) Wage

$$\hat{W}_t = \gamma_b(\hat{W}_{t-1} - \hat{\pi}_{C,t} + \gamma\hat{\pi}_{C,t-1}) + \gamma_0\hat{W}_t^0 + \gamma_f E_t(\hat{W}_{t+1} + \hat{\pi}_{C,t+1} - \gamma\hat{\pi}_t)$$

$$\gamma_b = (1+\tau_2)\phi^{-1}$$

$$\gamma_0 = (1-\lambda_w)(1-\tau)\lambda_w^{-1}\phi^{-1}$$

$$\gamma_f = (\tau\lambda_w^{-1} - \tau_1)\phi^{-1}$$

$$\phi = (1 + \tau_2 + (1-\lambda_w)(1-\tau)\lambda_w^{-1} + (\tau\lambda^{-1} - \tau_1)$$

$$\gamma_b + \gamma_0 + \gamma_f = 1$$

$$\tau_1 = \Big[\varkappa_w\mu\varphi_x + \varphi_\chi(1-\chi)(x\beta\lambda_w)(\varkappa_w\mu)\mu(\rho\beta) + \varphi_s\Gamma\Big](1-\tau)$$

$$\tau_2 = -(\varkappa\mu)\varphi_\chi(1-\chi)(x\beta\lambda_w)\mu(1-\tau)$$

$$\Gamma = (1 - \eta x\beta\lambda_w\mu)\eta^{-1}\mu\varkappa_w.$$

V Inflation

(1) Phillips Curve

$$\hat{\pi}_{Q,t} = \frac{\gamma}{(1+\beta)\gamma}\hat{\pi}_{Q,t-1} + \frac{(1-\beta\lambda_p)(1-\lambda_p)}{\lambda_p}\hat{P}_t^W + \frac{\beta}{1+\beta\gamma}E_t\hat{\pi}_{Q,t+1}$$

(2) Taylor Rule

$$\hat{R}_t = \rho_R\hat{R}_{t-1} + \phi_\pi(1-\rho_R)(E_t\pi_{t+1} - \pi^*) + \phi_y(1-\rho_R)(y_t - y_{nt}^*)$$

VI Prices, GDP and GDP Deflator

(1) GDP

$$\bar{P}_Y\bar{Y}(\hat{P}_{Y,t} - \hat{Y}_t) = \bar{P}_Q\bar{Q}(\hat{P}_{Q,t} + \hat{Q}_t) - \bar{P}_O\bar{O}(\hat{P}_{O,t} + \hat{O}_t)$$

(2) GDP Deflator

$$\hat{P}_{Q,t} = (\alpha_N + \alpha_K)\hat{P}_{Y,t} + \alpha_O\hat{P}_{O,t}$$

(3) Real Price of Oil

$$\hat{S}_{o,t} = \hat{P}_{O,t} - \hat{P}_{Q,t}$$

(4) Headline CPI

$$\hat{P}_{C,t} = \chi_c\hat{P}_{O,t} + (1-\chi_c)\hat{P}_{Q,t}$$

$$\hat{\pi}_{C,t+1} = \hat{P}_{C,t+1} - \hat{P}_{C,t}$$

$$\hat{\pi}_{Q,t+1} = \hat{P}_{Q,t+1} - \hat{P}_{Q,t}$$

$$\hat{\pi}_{Y,t+1} = \hat{P}_{Y,t+1} - \hat{P}_{Y,t}$$

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