Energy Shocks

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Abstract

The paper incorporates endogenous energy sector composed of coal, gas and oil in a Dynamic Stochastic General Equilibrium (DSGE) model and estimates using Bayesian methodology, providing evidence that energy shocks are the main contributor to the latest post-pandemic inflation episode and the variance of the monetary policy. The model augmented with financial frictions corrects counterfactual response of positive investment. An intriguing finding is that while the short run responses of output, consumption, and investment are negative but in the medium run swing to positive, not uncovered in any other relevant paper in literature. The substitution effect improves the productivity of capital and labor leading to positive medium term growth. Question is how policy makers can leverage these insights of positive dynamic response for transition towards a low-carbon economy? The paper also shows that well functioning financial markets can reduce the policy burden by stabilising the macro aggregates.

1. Introduction

The recent post-pandemic inflation in the US and globally can be attributed to several factors: easy monetary policy, pandemic induced fiscal stimuli, and labour market tightness. Energy supply shocks, particularly those in the summer of 2021 and the 2022 Ukraine war, cannot be ignored as significant contributing factors. This coincidence has reignited an interest in research of energy shocks, their sources, and their effects on macroeconomic aggregates.

Dynamics within the energy sector impact real economic activity, inflation, unemployment, household welfare, carbon emissions, terms of trade, and most importantly for macro economists the monetary policy. Historically, the disruptions within the energy sector were more characterised by supply side disturbances in the oil market, particularly in 1970s. Hence, traditionally focus of literature is on the oil shocks. Baumeister and Peersman (2013) presented evidence on the unstable relationship between oil prices and US macro performance since 1974 and cited changes in the regulation of energy markets, sector composition, and in the capacity utilization rate and variation in the oil intensity as reasons for such unstable relationship. Macro economists have viewed changes in oil price not only as an important source of economic fluctuations but also as a paradigm of a global shock likely to affect many economies simultaneously(Blanchard and Gali (2007)). Backus and Crucini (2000) accounts oil for much of the variation in the terms of trade over the last 25 years and its quantitative role varied significantly. Nakov and Nuño (2013) analysed welfare impacts of dominant oil supplier on the oil importing countries and how policy interventions can improve welfare by reducing monopolistic rent. Abbritti, Equiza-Goñi, Gracia, and Trani (2020) suggested that oil price

shocks have a large and significant effect not only on production, interest rates, and unemployment but also on credit spreads and hence on the health of banking and financial sector. Its after Ukraine-Russia war the focus is shifted to gas but still it rarely covers coal, another primary source of energy. There are few papers covering energy as a factor of productivity. For instance, Punzi (2019) showed energy price shocks cause economic slowdown due to higher cost for consumers and firms. Energy price volatility influence households to cut consumption for precautionary savings and in turn increase investment, a counter intuitive conclusion as higher volatility can lead to lower investment. I have addressed these gaps in literature not only covering oil and gas but also coal and addressing the counter intuitive response of investment to volatility caused by energy price shocks.

International Energy Agency (IEA) Government Energy Spending Tracker June 2023 issue [1] tracks almost 1600 government financial measures from 68 countries to find US$ 1.34 trillion allocation for clean energy investment support since 2020. Since the start of the recent global energy crisis, governments have also allocated US$ 900 billion to short-term consumer affordability measures. These are a few examples to demonstrate the importance of studying the interaction between the energy sector and the macroeconomy. With increasing global risks of energy security, affordability, and climate change, research on these interactions is required more than before.

I have developed a DSGE model in a staged approach for structural analysis of energy shocks and its impact on macro aggregates. Initially, I incorporated an endogenous oil sector into a basic New Keynesian (NK) model with nominal price and wage frictions. Subsequently, I integrated this sector into a model with financial frictions. Finally, I extended the model to include coal and gas shocks in addition to oil as these three commodities constitute significant share in energy mix and renewable share can be abstracted without losing key insights about the energy sector. Considering the complexity of developing a model rich in financial frictions and shocks, my research strategy is to find an existing model with financial frictions and augment it by adding an endogenous energy sector. The recent model by Becard and Gauthier (2022) proved to be very useful. I worked backward that is after integrating the oil shocks, I simplified the model into a basic NK model with oil shocks.

Section 2 covers the literature review. Sector 3 analyses the relevant data to present stylised facts. Section 4 summarises the institutional insights used to develop the specifications of endogenous oil sector. Section 5 describes the basic NK model with oil shocks. Section 6 explains how the model can be adapted simply to analyse energy shocks. Section 7 presents the main results. In section 8, I compare the results with relevant literature. Finally, section 9 concludes.

2. Literature Review

The relevant literature has several strands. Recently, Gagliardone and Gertler (2023), Baba and Lee (2022), Conflitti and Luciani (2019), Vlieghe (2024) and Guerrieri, Marcussen, Reichlin, and Tenreyro (2023) showed significant role of oil and energy shocks on inflation. Blanchard and Bernanke (2023) underestimated overheated labour markets and attributed pandemic-era inflation surge to prices given wages, particularly energy and commodities prices, and sectoral shortages.

Hamilton (1983) and Bernanke, Gertler, and Watson (1997) used empirical models. According to Hamilton (1983), oil price shocks had significant correlations with US recessions whereas Bernanke, Gertler, and Watson (1997) showed that oil shocks were not a major cause of US recessions but the tightening of the monetary policy following oil shocks. Barsky and Kilian (2001) also dissented from conventional view concluding that 1970s stagflation was unlikely due to oil supply disturbances. Kilian (2008) found that

[1] IEA website

exogenous oil supply disruptions were important oil price determinants in the 1970s but did not help to explain subsequent oil price increases during 1979/80.

Kim and Loungani (1992) and Rotemberg and Woodford (1996) used structural theoretical models. Rubaszek (2021) categorised the oil incorporating DSGE models into three main groups: assumptions that both oil prices and production are exogenous; treatment of oil prices as an endogenous variable but oil production remains exogenous or vice versa and; assumptions that both oil prices and oil production are endogenous, allowing a two way feedback. The third category has further two distinct frameworks of dominant oil producers and the two-stage production setup.

Fuerst and Carlstrom (2006) incorporated NK frictions to show that output decline following oil shocks cannot be attributed to Monetary policy, a different view from that of Bernanke, Gertler, and Watson (1997). Using NK model, Blanchard and Gali (2007) highlighted that four different hypothesis of "good luck", smaller share of oil in production, more flexible labour markets, and improvement in monetary policy played an important role in macroeconomic stability to the oil shocks. Bodenstein, Erceg, and Guerrieri (2011) used endogenously determined oil prices but exogenous oil supply in a two country DSGE model, finding lack of a close relationship between oil prices and the overall trade balances.

According to Kilian (2005), assumption that either the oil price or oil supply was exogenous were not only unappealing from a theoretical point of view but also inconsistent with the economic evidence. Motivated by this critique, Nakov and Pescatori (2007a), Nakov and Pescatori (2010), Balke, Brown, and Yucel (2010), and Balke and Brown (2018) developed DSGE models with endogenous oil sectors. Nakov and Pescatori (2007a) emphasised the importance of endogenous oil sector for policy analysis. With an endogenous oil sector, stabilizing inflation does not necessarily stabilize the efficient output gap, thereby exposing monetary policy to a trade-off between these two goals.

Economic research not only differs in the way energy employed in the economy — either as a consumption good, a standard factor of productivity, or a factor linked to capital utilization—but also in addressing different research questions. Argentiero, Bollino, Micheli, and Zopounidis (2018) assessed the effectiveness of a comprehensive strategy for renewable sources, between carbon tax and subsidy measures. Rubaszek (2021) investigated the competition in oil price forecasting among a set of structural models. Çakır Melek, Plante, and Yücel (2021) used a two-country DSGE model to show that the shale oil boom boosted US real GDP by about 1 percentage point from 2010 to 2015, led to a decline in oil and fuel prices, and caused a domestic fall in US light oil imports. The most interesting features of their model are the heterogeneity of oil and a refining sector, which were not utilized in any other research.

To the best of my knowledge, Gelain and Lorusso (2022) is the only paper, in addition to my paper, which has explicitly taken the financial accelerator into account to estimate the effect of oil price shocks on macroeconomic variables. They modelled oil using bivariate vector auto-regression (VAR) outside US economy, a counterfactual assumption as US has become one of the largest oil producer recently. Accordingly, I have specified the oil sector within the US economy. Despite difference in modelling approach, it can still serve as a valuable reference for my research.

3. Data and Stylised Facts

Figure 1 shows US primary energy consumption by source since 1984 based on data from the US Energy Information Administration (EIA). Since 2008, coal consumption has been trending downwards, mainly being substituted by natural gas and a renewable mix of wind, solar, geothermal, and biomass. Oil consumption has remained quite stable, but the oil and energy intensity of the overall economy has been drastically decreased as shown in figure 2. The energy consumption pattern highlights the dominant role of three

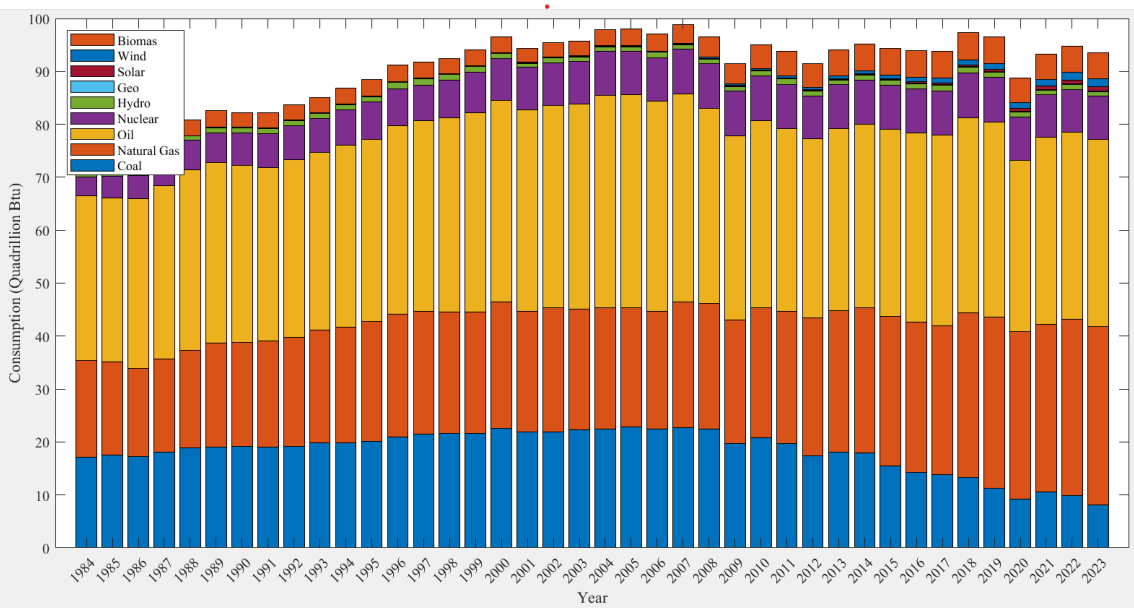


Figure 1: US Primary Energy Consumption by Source (Source: EIA)

commodities — coal, oil, and gas — which I will consider in this paper and abstract renewable energy technologies. In addition to lower share in energy mix, another reason for omitting renewable technologies is the difficulty to get price data of renewable energy , not only its not easily available but modern renewable technologies are intermittent and their pricing is highly complex and affected by fossil fuel prices.

Figure 3 shows a strong positive correlation between energy prices and inflation, also calculated in table 1, strongest for coal and followed by natural gas and oil. The correlations between per capita real GDP growth and these prices are negative.

Table 1: Correlation of real energy prices with inflation and per capita GDP growth

	Correlation with inflation	Correlation with per capita real GDP growth
Oil, WTI	0.17	-0.09
Natural Gas, US Henry Hub	0.19	-0.08
Global Coal Price	0.50	-0.09

4. Oil and Gas Sector Details

4.1. Sectors Overview

Globally, oil-producing firms can be divided into two groups: OPEC (Organization of the Petroleum Exporting Countries) and non-OPEC. 60% of the oil production is in non-OPEC countries, which include North America, regions of Soviet Union, and the North Sea. Non-OPEC producers are owned by private investors, whereas OPEC producers are mostly state-owned. OPEC producers are in 12 countries: Algeria, Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, the U.A.E, and Venezuela. Similarly, the demand can be distributed into two groups: OECD (Organisation for Economic Cooperation and Development) and non-OECD.

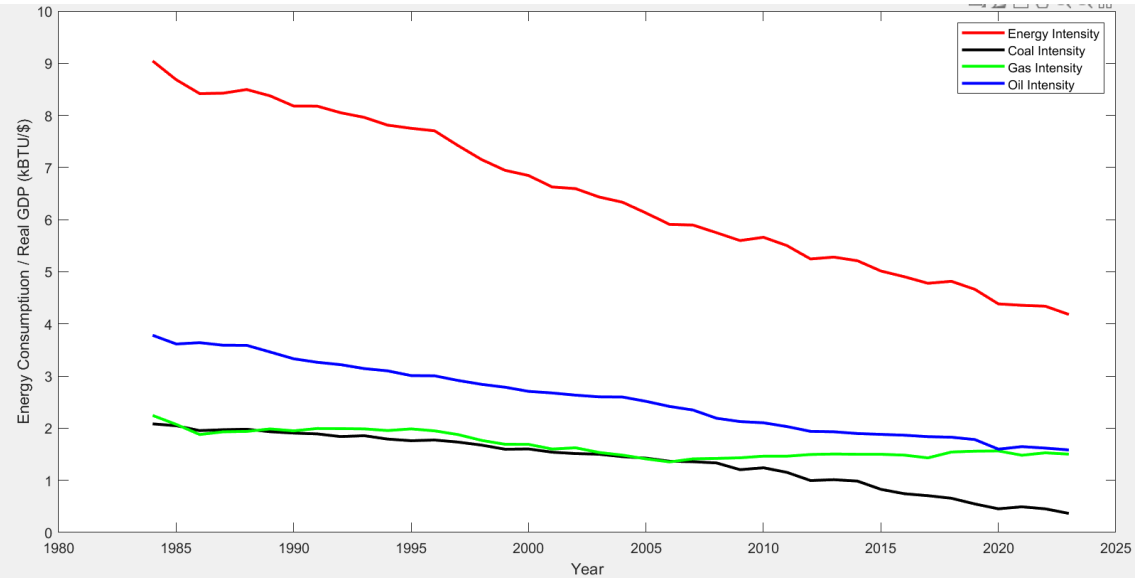


Figure 2: US Energy Intensity Trend (Source: EIA)

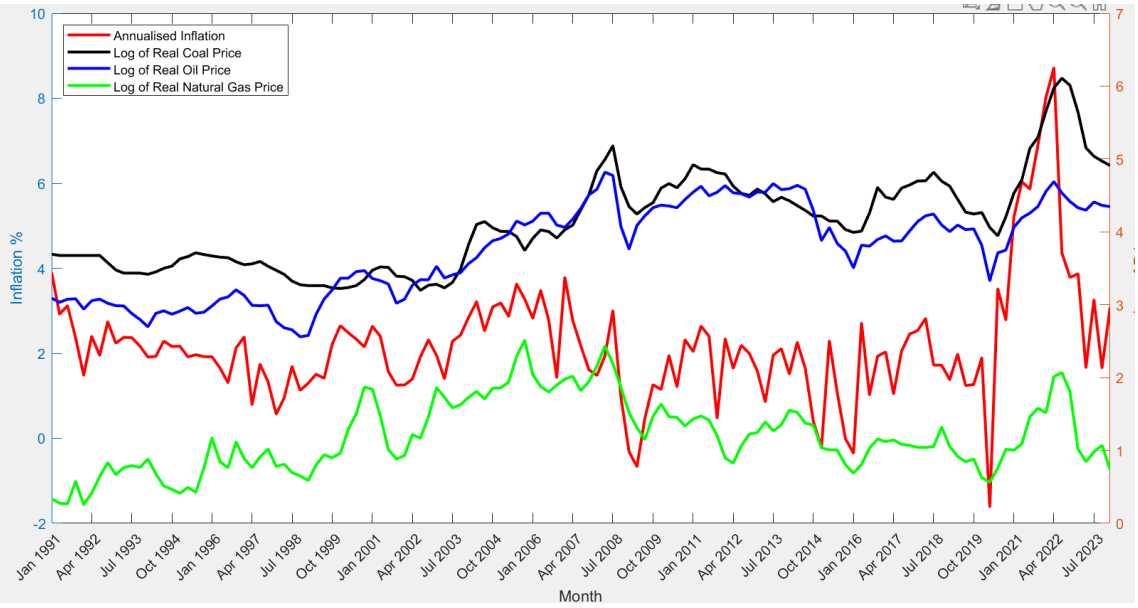


Figure 3: Log Real Prices and US Inflation Quarterly Data (Source:https://fred.stlouisfed.org)

The oil and gas production infrastructure are located both onshore and offshore. Both sectors can be segmented into upstream, midstream, and downstream as shown in figures 4 and 5. While oil and gas producing firms operate in all three segments, to manage internal governance and business operations competitively, these segments can be organised as different legal entities. Firms in the upstream segment specialize in exploring, developing, and constructing oil and gas fields to make them operational. Fully operational fields produce crude oil or gas, which is transported via pipelines, vessels, and vehicles. The crude oil is transported to midstream segment refineries, which refine it into petroleum products such as gasoline, distillate, jet fuel, and others, as shown in figure 6.

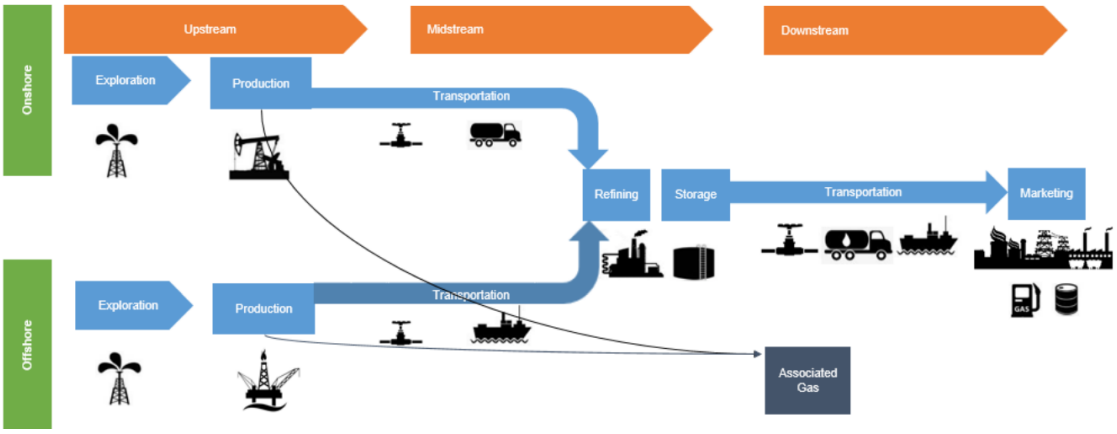


Figure 4: Oil Sector Overview (Source: Dutch Banking Sector Agreement)

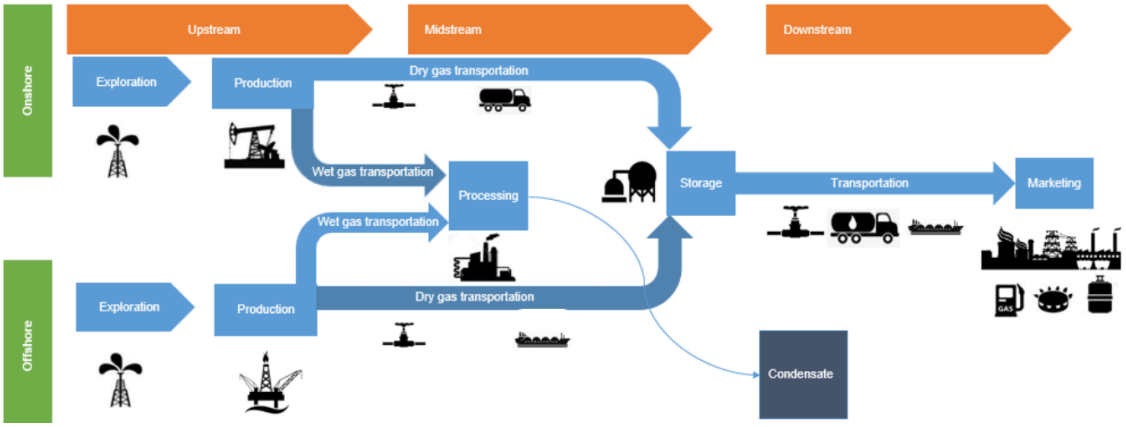


Figure 5: Gas Sector Overview (Source: Dutch Banking Sector Agreement)

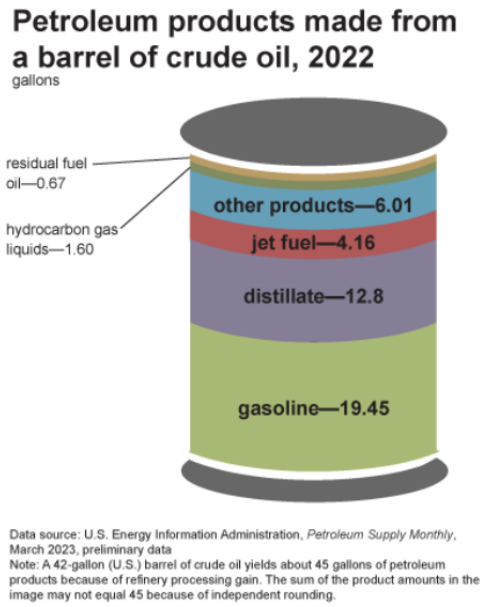


Figure 6: Petroleum Products from Crude Oil (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

Refineries store either the crude oil before refining or the refined petroleum products, depending on market supply and demand. Downstream firms transport and distribute petroleum products from refineries to end consumers. The gas value chain does not include refineries but has processing plants for condensation.

4.2. Historical Oil Price Swings

Figure 7 shows historical price swings. It started with exhausted spare capacity in US in 1973 and later followed by the political events of war and embargoes. In 1986, Saudis abandon their role of swing producer, cutting oil production to keep oil prices high and stable, that resulted in oil price collapse representing structural shift in the oil industry. Late 1990s oil price rise was coincided by cut in OPEC production targets. By mid 2000s spare capacity was lowered again shooting the oil price to unprecedented high levels until it collapse due to global financial crisis around 2008. Last episodes of oil price increases around 2010 was again due to OPEC target production cuts. Overall, such trajectory of oil price in the last five decades show that a number of supply and demand factors impact the oil prices but most of the time its supply rather than demand impacting the price. Hence, in this paper I have focused on the supply side disruptions, particularly when interest is to expand it to other commodities of gas and coal. The recent disruptions are also due to supply issues so this approach aligns with the context.

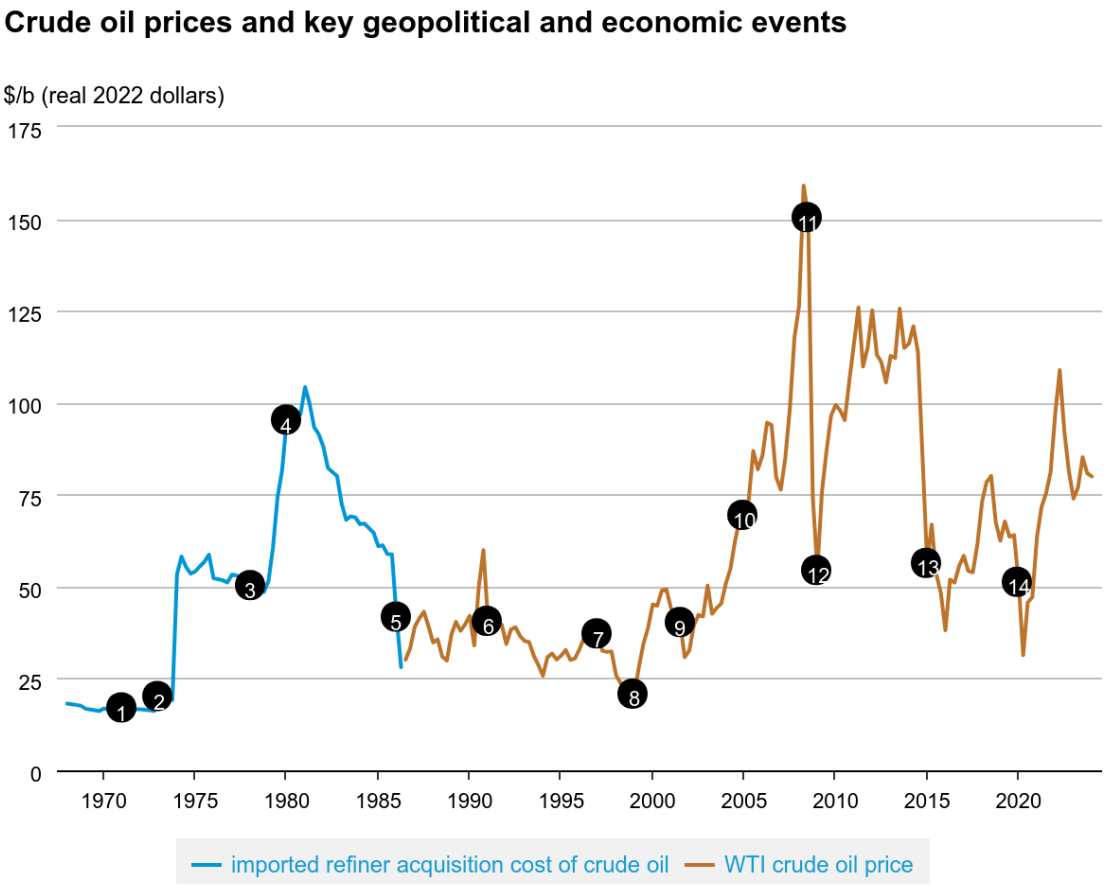


Figure 7: Historical Oil Price Swings (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

4.3. Drivers of Oil Prices

Oil prices are driven by many physical, political, and financial factors which are assessed by EIA. While prices of crude oil are visible, prices of petroleum products are not so much visible except of gasoline and distillate. As shown in figure 6 crude oil is refined into different petroleum products, figure 8 shows that crude oil price is the primary driver of gasoline and same can be assumed for other petroleum product prices. I have used this insight in developing and estimating the model by using the crude oil price data.

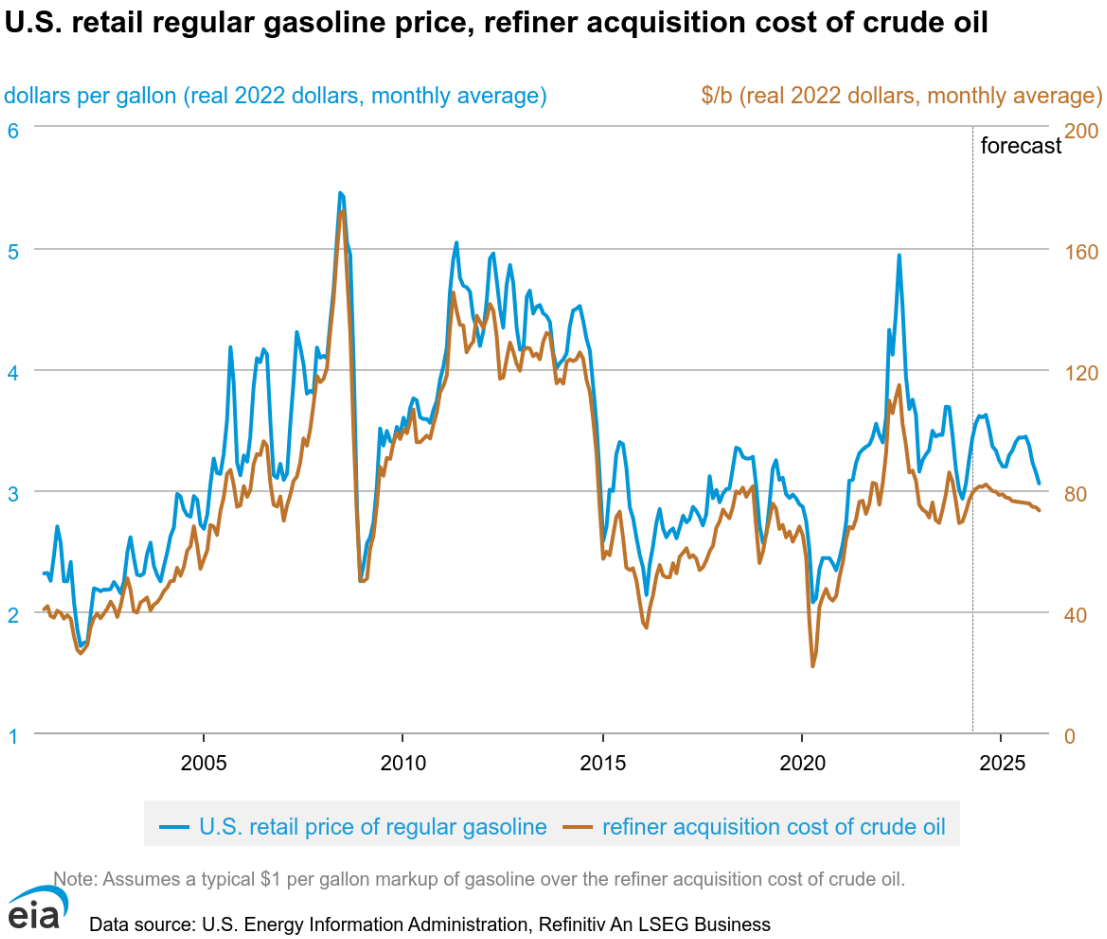


Figure 8: Crude Oil Primary Driver of Petroleum Prices (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

Crude oil and petroleum products are traded globally and at various markets around the world that are integrated. In the long run, prices of crude oil, gasoline (most widely used petroleum product in USA), and distillate in different regions of the world tend to move together because of transportation channels which eliminate the arbitrage opportunities. Differences between the short term prices and the absolute price levels arise because of different composition specifications (quality of oil), refinery maintenance schedules, unplanned refinery outages, transportation constraints, peak consumption seasons, and regional inventory levels.

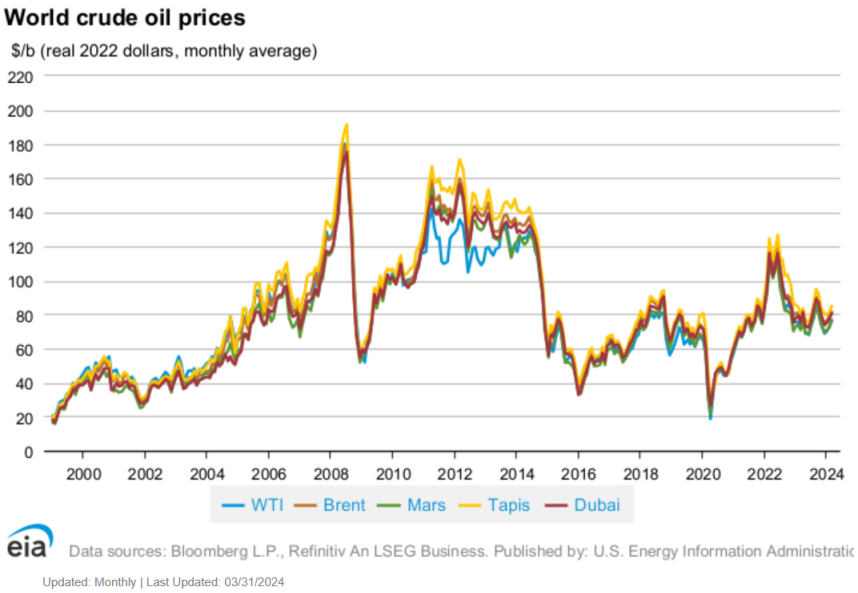


Figure 9: World Crude Oil Prices (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

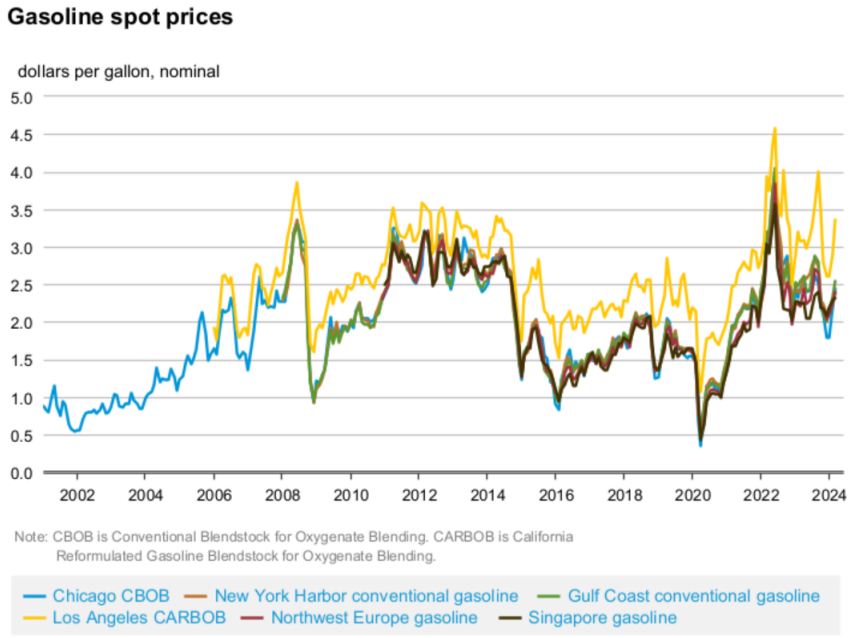


Figure 10: Gasoline Spot Prices (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

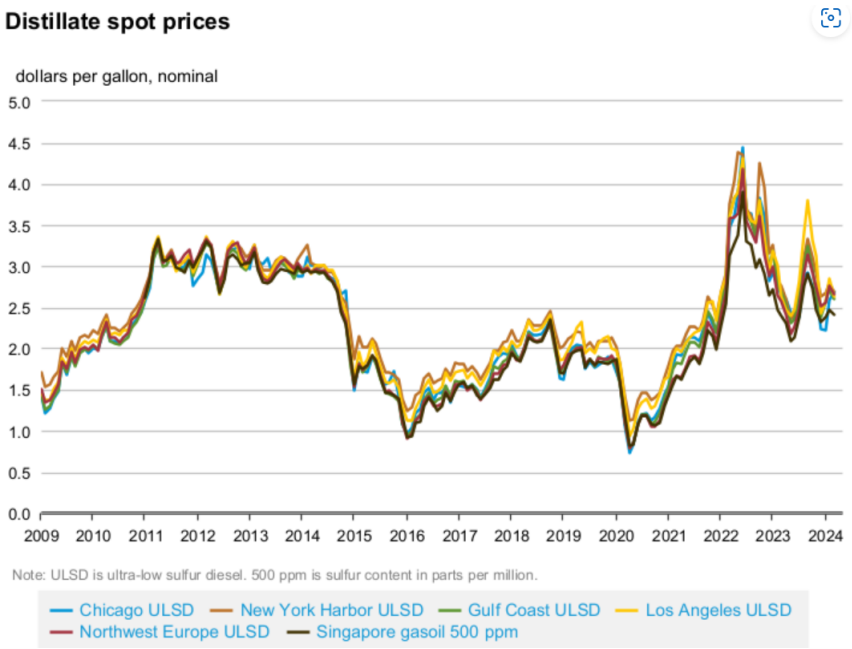


Figure 11: Distillate Spot Prices (Source: EIA https://www.eia.gov/finance/markets/crudeoil/)

Events which have potential to disrupt the flow of oil and petroleum products to market affect prices of both crude oil and petroleum products. Usually such events are geo-political dynamics and weather-related disruptions. Mainly, the low responsiveness or inelasticity of demand and supply to supply or demand shocks in the short run is responsible for the volatility of the oil prices. Both oil production capacity and the equipment using petroleum products as main source of energy are relatively fixed in the near-term. Significant time and resources are required either to develop new supply resources or to vary production. Similarly, it's hard for consumers to substitute petroleum products with other sources of energy in the near-term. Hence, a large price change is necessary to re-balance demand and supply following a shock to the system. In contrast to NK nominal frictions, the oil and gas prices are flexible and swing to re-balance the rigid supply and demand. I have used this fact in deriving the oil price equation by setting Calvo price friction parameter to zero for all the commodities of oil, gas, and coal.

Non-OPEC oil producers owned by private investors are price-takers and tend to respond more readily to changes in the market conditions and to market prices rather than influencing prices by managing production. They operate close to full capacity and have little spare capacity. Crude oil prices are affected not only by actual non-OPEC production but also by changes in expectations about future non-OPEC oil supply.

Crude oil prices are affected by the oil production targets of OPEC countries which set production targets based on current and future expectations of supply and demand. OPEC spare capacity also affect the oil prices. When spare capacity of OPEC countries are low, oil prices increase by incorporating a rising risk premium.

Inventories are the balancing point and also the precautionary measures given the uncertainty of supply and demand. An expectation of higher future prices increases inventories whereas current high oil price results in inventory draw downs. In addition to inventories countries maintain strategic oil reserves for responding to the supply shocks. 1.6 billion barrel of oil stocks are held by IEA members including USA.

Financial markets with commercial and non-commercial oil traders also influence crude oil prices. Commercial participants have a direct interest in physical oil production, consumption, or trade and non-

commercial participants interest is to invest for diversification and to hedge inflation risks. Banks, hedge funds, commodity trading advisors, and other money-managers trade energy derivatives to profit from price volatility. Financial markets offer both futures and option contracts which allow investment with limited exposure to potential losses and provide an insurance-like instrument against adverse commodity price movements.

Demand has a key role in affecting the oil prices. Oil consumption has increased in non-OECD countries due to rapid economic growth particularly in Saudi Arabia, India, and China. Manufacturing sector which is bigger in the non-OECD countries is energy intensive and require more oil. OECD countries have a larger service sector relative to manufacturing so strong economic growth in these countries may not have the same impact on oil consumption as it is in non-OECD countries.

5. The Model

The basic model is developed by simplifying Becard and Gauthier (2022) model which has a number of frictions and shocks widely used in the literature. Mainly, these are covered in Christiano, Eichenbaum, and Evans (2005); Smets and Wouters (2007); and Christiano, Motto, and Rostagno (2014). The complete derivation of the basic model is in appendix A.

5.1. Households

A representative household contains a large number of workers who supply differentiated labour $l_{j,t}$ where $j \in [0, 1]$. The household objective is to maximize the utility by controlling consumption C_t, deposits D_t, and investment I_t .

$$\max_{C_t, I_t, D_t} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln(C_t - b_c C_{t-1}) - \psi_l \int_0^1 \frac{l_{j,t}^{1+\sigma_l}}{(1+\sigma_l)} dj \right\}, b_c, \psi_l, \sigma_l > 0,$$

where β is a discount factor. The household budget constraint is:

$$(1+\tau^c)P_t C_t + P_t D_t + \frac{P_t}{\Upsilon^t} I_t \leq (1-\tau^l) \int_0^1 W_{j,t} l_{j,t} dj + R_t P_{t-1} D_{t-1} + \Upsilon^{-t} P_t K_{t-1} \left\{ (u_t r_t^k - a(u_t))(1-\tau^k) + \tau^k \delta \right\} + T_t + \Delta_t,$$

where τ^c, τ^l, and τ^k are consumption, labour, and capital tax rates respectively; P_t is the price of final goods, $W_{j,t}$ is the nominal wage of worker j and Υ^t is the rate at which final goods are converted into investment goods, with $\Upsilon > 1$. The household is the owner of capital and chooses capital utilization rate u_t, pays utilization adjustment cost $a(u_t)$, and rents out capital services $u_t K_{t-1}$ to intermediate firms at rental rate r_t^k. The household benefits from tax deduction due to depreciation δ. The household allocates revenues to consumption, investments, and deposits in each period. The household revenues are from labour income, previous period deposits financial income, capital income, dividends from firms Δ_t, and a transfer from the government T_t.

The equation for the capital accumulation K_t is:

$$K_t = (1-\delta)K_{t-1} + [1 - S^k(\zeta_{i,t} \frac{I_t}{I_{t-1}})]I_t$$

where $S^k(\zeta_{i,t} \frac{I_t}{I_{t-1}})$ is the investment adjustment cost defined in below section and $\zeta_{i,t}$ is a shock to marginal efficiency of investment (MEI).

5.2. Capital Utilization Rate

Household j determines the utilization rate of capital $u_{j,t}$. A competitive market condition is that the user cost function must equal to return on capital services i.e.

$$P_t \Upsilon^{-t} a(u_{j,t}) K_{j,t-1} = P_t \tilde{r}_t^k u_{j,t} K_{j,t-1}$$

5.3. Final Goods Producer

A representative, competitive final good firm combines intermediate goods $Y_{j,t}$, $j \in [0,1]$ to produce final output Y_t using the technology:

$$Y_t = \Big[\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj \Big]^{\lambda_{p,t}}$$

where $\lambda_{p,t}$ is a price markup shock and $\lambda_{p,t} \geq 1$. The budget constraint is:

$$\int_0^1 P_{j,t} Y_{j,t} dj = P_t Y_t$$

5.4. Oil Producers

According to Kilian and Lewis (2011) critique, DSGE models with exogenous sector cannot help to understand the monetary policy response that should not respond to the energy price shocks but to the underlying demand and supply shocks, driving the real price of energy along with the other macroeconomic variables. With an exogenous energy price shock occurring in isolation, there is no reason for the monetary policy to raise the interest rates in the face of recessionary and deflationary forces. Hence, a structural model which takes account of endogeneity of the real price of energy is valuable.

Motivated by Kilian's critique, I have developed an endogenous oil sector in a closed economy. The oil firms whether separated in different segments or integrated as one firm operating in all the three segments are making primarily four economic decisions. First, how much to invest in developing the oil fields, transportation infrastructure, refineries, storage facilities, and the oil inventories. All these assets can be called as oil capital or reserves. The firms operating in the upstream and midstream segments are taking these investment decisions, collectively called as upstream firm in the model. Similar to non-OPEC producers, the upstream firm investing in the oil capital is competitive. Second, upstream firm decide how much capital to utilise in each period. As non-OPEC firms operate close to full capacity and have little spare capacity, the endogenous utilization rate in the steady state is equal to one.

Third, how much capital reserves employed for producing petroleum products. These production decisions are primarily taken by refiners that I abstracted as taken by the downstream firm. Hence, the midstream investment decision is merged in upstream and production decision in downstream. The marginal cost of the downstream firm is similar to the refiner acquisition cost which includes crude oil price, rental rate of the oil capital, and the supply shocks. The downstream firm has monopoly power and set the price of oil to intermediate firms, the fourth economic decision.

5.4.1. Upstream Firm

Similar to Balke, Brown, and Yucel (2010), Nakov and Nuño (2013), and Balke and Brown (2018), a representative, competitive producer of upstream reserves accumulates oil reserves as per the following technology.

$$X_t^o = X_{t-1}^o(1-\delta) + [1 - S^o(\frac{I_t^o}{I_{t-1}^o})]I_t^o, \delta \in (0,1)$$

where X_t^o is the upstream reserves or oil capital, I_t^o is the investment in the upstream reserves, and S^o is the investment adjustment cost function defined below. δ is the depreciation rate of the upstream reserves, similar to the capital depreciation rate.

Similar to Balke, Brown, and Yucel (2010), the upstream firm optimizes the reserves supply decision which introduces an inter-temporal element. However, my methodology of capital investment optimization has simplified the mechanics. Since the firm is owned by households so the discount rate is similar to the households.

$$\max_{I_t^o} E_t \sum_{t=0}^{\infty} \beta^t \Lambda_{z,t}\{u_t^o X_{t-1}^o \tilde{r}_t^o - [\Upsilon^t]^{-1} I_t^o\},$$

where $\tilde{r}_t^o$ is the user cost (or rental rate) of the oil capital and u_t^o is the oil capital utilization rate. Appendix A derives FOC for the upstream firm showing that the present oil price and capital are determined not only by the current economic state but also by future expectations of the economy and oil supply productivity.

5.4.2. Oil Reserves Utilization Rate

Similar to Nakov and Pescatori (2007a), upstream oil firm determines the utilization rate of oil capital or reserves u_t^o. But they did not assume any utilisation rate adjustment cost which I have assumed similar to the capital utilization adjustment cost. A competitive market condition is that the user cost function must equal the return on renting out capital services i.e.

$$P_t \Upsilon^{-t} a(u_t^o) X_{t-1}^o = P_t \tilde{r}_t^o u_t^o X_{t-1}^o,$$

where $a(u_t^o)$ is the oil capital utilization rate adjustment cost as defined below.

5.4.3. Downstream Firm

Nakov and Pescatori (2007a) oil production technology employs intermediate good and exogenous productivity shifter. Nakov and Nuño (2013) used intermediate goods purchased from oil importing countries in addition to oil capital. In Balke and Brown (2018) and Balke, Brown, and Yucel (2010), oil production technology depends on both capital and labour services. I have assumed that only oil capital is required and labour can be abstracted because its role in the oil production is relatively negligible. A representative downstream firm produces oil O_t utilising the available upstream capital $u_t^o X_{t-1}^o$:

$$O_t = \epsilon_t^o u_t^o X_{t-1}^o$$

where ϵ_t^o is the oil technology or supply shock representing the events having potential to disrupt the flow of oil and petroleum products. Such events include unexpected shutdowns, geopolitical tensions, natural disasters, environmental damages, and weather-related disruptions. My model does not have any external sector so any influence of external demand or supply is captured in this shock. The downstream firm objective function is to minimise the rental cost $\tilde{r}_t^o$, by controlling $u_t^o X_{t-1}^o$:

$$\min_{u_t^o X_{t-1}^o} \tilde{r}_t^o u_t^o X_{t-1}^o + \frac{S_t^o}{P_t}[O_t - \epsilon_t^o u_t^o X_{t-1}^o],$$

where S_t^o is the nominal marginal cost of acquiring or renting oil reserves incurred by the downstream firm, similar to the refiner acquisition cost or price of crude oil.

FOC w.r.t $u_t^o X_{t-1}^o$ is:

$$\frac{S_t^o}{P_t} = \frac{\tilde{r}_t^o}{\epsilon_t^o}$$

5.4.4. Downstream Firm Oil Price Setting

In the beginning, I determined downstream firm oil price FOC using Nakov and Pescatori (2007a) and Balke, Brown, and Yucel (2010) approaches. Same is explained in the appendix. However, I also used Dixit and Stiglitz (1977) approach which provided similar results. Since later methodology is more aligned with widely accepted economic theory, so main model is based on it. Consider more than one downstream firms in a monopolistic competition and production function for each firm j is:

$$O_{j,t} = \epsilon_t^o u_t^o X_{j,t-1}^o$$

The downstream firm j objective function is to minimise the rental cost $\tilde{r}_t^o$, by controlling $u_t^o X_{j,t-1}^o$:

$$\min_{u_t^o X_{j,t-1}^o} \tilde{r}_t^o u_t^o X_{j,t-1}^o + \frac{S_{j,t}^o}{P_t}[O_{j,t} - \epsilon_t^o u_t^o X_{j,t-1}^o],$$

where $S_{j,t}^o$ is the nominal marginal cost of renting oil reserves incurred by the downstream firm j.

FOC w.r.t $u_t^o X_{j,t-1}^o$ is:

$$\frac{S_{j,t}^o}{P_t} = \frac{\tilde{r}_t^o}{\epsilon_t^o}$$

If the downstream firms pay the same factor prices, receive the same aggregate shocks then choose the same proportion of inputs and have the same marginal cost $S_{j,t}^o = S_t^o$ as explained in the previous section.

$$\frac{S_t^o}{P_t} = \frac{\tilde{r}_t^o}{\epsilon_t^o}$$

A representative competitive oil contractor aggregates oil produced by downstream firms by choosing input $O_{j,t}$ to minimise the total cost of oil input $\int_0^1 P_{j,t}^o O_{j,t} dj$ subject to the following constraint:

$$O_t = [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{\lambda_{o,t}}{\lambda_{o,t-1}}}$$

where $\lambda_{o,t} \geq 1$ is the downstream firm markup. The objective function is:

$$\min_{O_{j,t}} \int_0^1 P_{j,t}^o O_{j,t} dj + x\left\{O_t - [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{\lambda_{o,t}}{\lambda_{o,t-1}}}\right\}$$

Section h of Appendix A shows derivation of FOC w.r.t $O_{j,t}$ which is:

$$O_{j,t} = O_t[\frac{P_{j,t}^o}{P_t^o}]^{-\lambda_{o,t}}$$

The downstream firm maximise profits subject to its demand function constraint:

$$\max_{P_{j,t}^o} [P_{j,t}^o - S_{j,t}^o] O_{j,t}$$

FOC w.r.t $P_{j,t}^o$ is derived in section h of Appendix A which is:

$$P_{j,t}^o = S_{j,t}^o(\frac{\lambda_{o,t}}{\lambda_{o,t}-1})$$

Since every downstream firm experiences the same marginal cost equal to the aggregate marginal cost, so it charges the same price equal to the aggregate price. As $S^o_{j,t} = S^o_t$, so $P^o_{j,t} = P^o_t$.

$$P^o_t = P_t \frac{\tilde{r}^o_t}{\epsilon^o_t}\left(\frac{\lambda_{o,t}}{\lambda_{o,t} - 1}\right)$$

5.5. Intermediate goods producers

Kim and Loungani (1992) presented first DSGE model incorporating energy shocks. They modified Hansen's Real Business Cycle model by explicitly including energy as a factor of productivity in both nested constant elasticity of substitution (CES) and Cobb-Douglas productivity functions. Subsequent papers which studied energy or oil shocks within a DSGE framework followed either of the two approaches. My approach is more aligned with Nakov and Pescatori (2007a) who included oil as a factor of productivity in addition to capital and labour in the Cobb-Douglas productivity function.

Each intermediate good j is produced by a monopolist according to the following production function:

$$Y_{j,t} = max\left\{\epsilon_t (z_t l_{j,t})^{\alpha_l} (u_t K_{j,t-1})^{\alpha_k} O^{1-\alpha_l-\alpha_k}_{j,t} - \theta z^*_t; 0\right\}, \alpha_l, \alpha_k \in (0,1)$$

where $K_{j,t-1}$ denotes capital services, $l_{j,t}$ is a homogeneous labour input, u_t is the aggregate utilization rate of capital, $O_{j,t}$ is the oil consumed in producing output, ϵ_t is a stationary technology shock, and θ is a fixed cost. As in Becard and Gauthier (2022) model, there are two sources of growth, the trend rise in technology z_t and an investment-specific shock $\mu_{\Upsilon,t}$ which changes the rate at which final goods are converted into $\Upsilon^t \mu_{\Upsilon,t}$ investment goods, with $\Upsilon > 1$. However, in the basic model without banking channels I removed the second source of growth for simplicity. In equilibrium, the price of investment goods is $\frac{P_t}{\Upsilon^t}$. The fixed cost θ is proportional to z^*_t which combines the two trends, $z^*_t = z_t \Upsilon^{(\frac{1-\alpha_l}{\alpha_l})t}$. The intermediate firms face standard Calvo frictions, only a fraction of intermediate firms $1 - \xi_p$ set its price $P_{j,t}$ optimally. The remaining fraction follows an indexation rule $P_{j,t} = \pi^{i_p} \pi^{1-i_p}_{t-1} P_{j,t-1}$, where $i_p \in (0,1)$ and $\pi_t = \frac{P_t}{P_{t-1}}$ is inflation.

5.6. Labor Market

A representative competitive labour contractor aggregates specialised labor services $l_{k,t}$, where $k \in [0,1]$ into homogeneous labor l_t using the technology:

$$\max_{l_{k,t}} l_t = \left[\int_0^1 l^{\frac{1}{\lambda_w}}_{k,t} dk\right]^{\lambda_w}, \quad \lambda_w \geq 1.$$

subject to the budget constraint

$$W_t l_t = \int_0^1 W_{k,t} l_{k,t} dk$$

Union k set wage $W_{k,t}$ to maximize sum of future utilities from t to t+s and discounts the future in the same way as the household it represents. All monopoly unions are subject to Calvo frictions similar to the intermediate firms with a fraction $1 - \xi_w$ monopoly unions setting the wage optimally. The remaining fraction follows an indexation rule $W_{k,t} = \mu_{z^*} \pi^{i_w} \pi^{1-i_w}_{t-1} W_{k,t-1}$ where $i_w \in (0,1), \mu_{z^*} = \frac{z^*}{z^*_{-1}}$ is the steady state growth rate.

5.7. Government

The monetary authority follows a standard Taylor rule:

$$R_t - R = \rho_\rho (R_{t-1} - R) + (1 - \rho_\rho)[\alpha_\pi (E_t \pi_{t+1} - \pi) + \alpha_{\Delta y}(g_{y,t} - \mu_{z^*})] + \epsilon^p_t$$

where $\alpha_\pi, \alpha_{\Delta y} > 0$ are weights, $g_{y,t}$ is the quarterly GDP growth in deviation from its steady state, and ϵ_t^p is a monetary policy shock. The fiscal authority finance public expenditures $G_t = z_t^* g_t$ and transfer payments T_t by taxes. g_t is an exogenous spending shock. The government budget constraint is:

$$G_t + T_t = [u_t r_t^k - a(u_t)]\Upsilon^{-t} P_t K_{t-1} \tau^k - \delta \Upsilon^{-t} P_t K_{t-1} \tau^k + W_t l_t \tau^l + P_t C_t \tau^c$$

5.8. Goods Market Clearing

Clearing in the goods market imposes:

$$Y_t = G_t + C_t + \Upsilon^{-t}(I_t + I_t^o) + a(u_t)\Upsilon^{-t} K_{t-1} + a(u_t^o)\Upsilon^{-t} X_{t-1}^o$$

5.9. Adjustment Costs and Shocks

Adjustment costs on capital investment and oil capital investment are similar:

$$S^i(x_t^i) = exp[\sqrt{S^{i\prime\prime}/2}(x_t^i - x^i)] + exp[-\sqrt{S^{i\prime\prime}/2}(x_t^i - x^i)] - 2, i \in \{k, o\}$$

where $x_t^k = \zeta_{i,t} I_t / I_{t-1}$ and $x_t^o = I_t^o / I_{t-1}^o$. Its assumed that $S^i(x^i) = S^{i\prime}(x^i) = 0$ for $i \in \{k, o\}$ and $S^{k\prime\prime}$ and $S^{o\prime\prime}$ are parameters. The utilization adjustment cost functions for capital and oil reserves are:

$$a(u_t) = r^k(exp[\sigma_a(u_t - 1)] - 1)/\sigma_a, \sigma_a > 0$$
$$a(u_t^o) = r^o(exp[\sigma_o(u_t^o - 1)] - 1)/\sigma_o, \sigma_o > 0$$

There are 7 structural shocks in the basic model: $\epsilon_t, \epsilon_t^o, \epsilon_t^p, g_t, \lambda_{p,t}, \mu_{z^*,t}$, and $\zeta_{i,t}$. All have the same structure and follow a standard AR(1) process. If x_t is a generic shock, then

$$ln(x_t/x) = \rho_x ln(x_{t-1}/x) + \epsilon_t^x, \epsilon_t^x \; N(0, \sigma_x^2)$$

The model is solved by stationarizing and log-linearizing around the steady-state.

5.10. Model with Banking Channels

The oil sector explained above in subsections 5.4 and 5.5 is added to Becard and Gauthier (2022) model which can be referred for the details. Without covering the details, its important to highlight the key differences. In the banking channel model, households are heterogenous, patient and impatient. Patient households are savers with deposits which are used for lending by banks. Impatient households are workers, real estate brokers, and homeowners. Capital is owned by entrepreneurs who provide capital services to the intermediate firms. Both housing and capital assets are traded in the market and have nominal market value. There are two type of borrowers: entrepreneurs and impatient households who borrow against capital and housing collaterals respectively. The default is introduced using Bernanke, Gertler, and Gilchrist (1999) for each type of borrower. Banks lending to the borrowers is determined by endogenous loan to value ratios which are impacted by the collateral shocks.

6. Model with Energy Shocks

I have developed specifications to extend the model to incorporate not only oil shocks but also other energy technology shocks. Coal and gas are only other technologies which constitute significant share in US primary energy consumption. Not only the renewable technologies of nuclear, hydro, solar, wind, geothermal, and biomass do not have significant share in the energy mix but also its not possible to get price time series for these technologies to estimate the model. Hence, I have considered coal, oil, and gas

only in the energy bundle. The investment and production decisions within these technologies are similar to the investment and production decisions for the oil technology. Following is the capital accumulation technology:

$$X_t^e = X_{t-1}^e(1-\delta) + [1 - S^e(\frac{I_t^e}{I_{t-1}^e})]I_t^e, \delta \in (0,1), e \in \{c,g,o\}$$

The upstream firms within each technology sector optimise investment as follows:

$$\max_{I_t^e} E_t \sum_{t=0}^{\infty} \beta^t \Lambda_{z,t}\{u_t^e X_{t-1}^e \tilde{r}_t^e - [\Upsilon^t]^{-1} I_t^e\}, e \in \{c,g,o\}$$

The upstream firms within each technology sector set the reserves utilisation rate as follows:

$$P_t \Upsilon^{-t} a(u_t^e) X_{t-1}^e = P_t \tilde{r}_t^e u_t^e X_{t-1}^e, e \in \{c,g,o\}$$

The downstream firms production function for each technology is:

$$O_t = \epsilon_t^o u_t^o X_{t-1}^o$$

$$C_t = \epsilon_t^c u_t^c X_{t-1}^c$$

$$G_t = \epsilon_t^g u_t^g X_{t-1}^g$$

The marginal costs for these technologies are:

$$\frac{S_t^e}{P_t} = \frac{\tilde{r}_t^e}{\epsilon_t^e}, e \in \{c,g,o\}$$

The price setting of these technologies are:

$$P_t^c = P_t \frac{\tilde{r}_t^c}{\epsilon_t^c}(\frac{\lambda_{c,t}}{\lambda_{c,t}-1})$$

$$P_t^o = P_t \frac{\tilde{r}_t^g}{\epsilon_t^g}(\frac{\lambda_{g,t}}{\lambda_{g,t}-1})$$

$$P_t^o = P_t \frac{\tilde{r}_t^o}{\epsilon_t^o}(\frac{\lambda_{o,t}}{\lambda_{o,t}-1})$$

A competitive final energy producer aggregate the energy produced from all these technologies of coal, gas, and oil to minimise the total cost of the energy bundle. The aggregate energy production function is similar to CES production function used by Argentiero, Bollino, Micheli, and Zopounidis (2018) :

$$E_t = [\omega_c C_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_g G_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_o O_t^{\frac{\sigma_e-1}{\sigma_e}}]^{\frac{\sigma_e}{\sigma_e-1}}$$

where σ_e is constant elasticity of substitution and ω_c, ω_g, and ω_o are weights of coal C, gas G, and oil O in energy bundle E. Price of energy bundle p_t^e is based on prices p_t^c, p_t^g, p_t^o of coal, gas, and oil and is given as:

$$P_t^e = [\omega_c P_t^{c,1-\sigma_e} + \omega_g P_t^{g,1-\sigma_e} + \omega_o P_t^{o,1-\sigma_e}]^{\frac{1}{1-\sigma_e}}$$

The optimisation of final energy producer is given as follows:

$$\min_{C_t,G_t,O_t} P_t^c C_t + P_t^g G_t + P_t^o O_t + \lambda_t^e\{E_t - [\omega_c C_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_g G_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_o O_t^{\frac{\sigma_e-1}{\sigma_e}}]^{\frac{\sigma_e}{\sigma_e-1}}\}$$

7. Model Estimation

As the time series available for coal and gas prices are from 1990, I have estimated my model using US quarterly data covering the period from 1990:I to 2024:I. These include eight standard macroeconomic variables: GDP, consumption, investment, hours worked, inflation (based on GDP deflator), the federal funds rate, and the relative price of investment goods. In addition, I have used four financial series: credit to households, credit to nonfinancial businesses, interest rate on household mortgage loans, and interest rate on business loans; and three energy price series: WTI spot crude oil price, global price of natural gas, and global price of coal. The two rates enter as spreads relative to the federal funds rate. In case of GDP, consumption, investment, household credit, and business credit, these are expressed in real, per capita terms and the logarithmic first difference. The price of investment goods is expressed in real terms and the log first difference. The energy prices are also in real terms and the first logarithmic difference. The hours are expressed in log levels and inflation, the federal funds rate, and the two spreads are in levels. All the variables are demeaned to prevent low-frequency movements from interfering with the higher business cycle frequencies. Appendix provides full description of the data and the measurement equations.

The basic model with oil technology shock and no banks (OSNB) has 41 parameters, 28 structural and 13 related to shocks. The 17 structural parameters (including endogenous parameter of disutility of labor to normalise labor hours to one to simplify solution of the steady state as per Becard and Gauthier (2022) (CS)) in table 2 are calibrated based on data set mean and literature and other targets. The calibrated parameters for oil shock model with banks (OS) and energy shocks model with banks (ES) are also listed in the table. The share of labor is average of the sample as per macroeconomic series LABSHPUSA156NR, share of labor compensation in GDP. The shares of coal, oil, and gas are calibrated as per paper Nakov and Pescatori (2007b) (NP) and accordingly the share of capital is calibrated. Similarly, the steady state inflation is calculated as per sample mean. Oil reserves utilization rate adjustment cost σ_a^o is calibrated to match the estimated σ_a. All other parameters are assumed as per Becard and Gauthier (2022).

The model remaining 11 structural and 13 shock parameters are estimated using Dynare Bayesian methodology as per Adjemian, Bastani, Juillard, Karamé, Maih, Mihoubi, Mutschler, Perendia, Pfeifer, Ratto, and Villemot (2011). These parameters are in the tables 3 and 4. The priors for non-oil parameters are same as in the model Becard and Gauthier (2022). The priors for investment adjustment costs in energy assets of coal, gas, and oil are similar to the capital investment adjustment cost considering these assets are equivalent to capital. The priors for energy technology and investment shocks are based on stationary technology and capital investment shocks. The estimated parameters for models with banks are in the tables 15, 16, 12, and 13 in appendices.

8. Main Results

The developed models are analysed using Adjemian, Bastani, Juillard, Karamé, Maih, Mihoubi, Mutschler, Perendia, Pfeifer, Ratto, and Villemot (2011) methodology.

8.1. Oil Technology Shock in Models With and Without Banks

Figure 12 shows the impulse response functions (IRFs) of different variables to negative one standard deviation oil technology shock in models with banks and without banks. A negative one standard deviation oil technology shock would reduce oil supply and increase oil price. Due to substitution effect the demand for labor would increase. Firms due to the marginal cost channel, charge higher prices pushing up inflation rate. The central bank would respond by increasing the policy rate. Households would consume less due to higher prices and higher savings because of higher monetary policy rates and precautionary motives.

Table 2: Calibrated Structural Parameters of Models with Different Specifications

Description	Parameter	OSNB	OS	ES	Based on
Share of capital in output	α_k	0.3457	0.3457	0.2261	Sample mean
Share of labor in output	α_l	0.6081	0.6081	0.6081	Sample mean
Impatient hh discount factor	β^i	–	0.9750	0.9750	CS
Patient hh discount factor	β^p	0.9993	0.9993	0.993	CS
Depreciation rate of capital	δ	0.025	0.025	0.025	CS
Entrepre. dividend share	δ^e	–	0.0256	0.0158	$L^e = 1.7479$
Gov. spending to GDP ratio	η_g	0.1580	0.1580	0.1580	Sample mean
Firms' price markup	λ_p	1.20	1.20	1.20	CS
Wage markup	λ_w	1.025	1.025	1.025	CS
Coal markup	λ_c	–	–	1.20	Firms markup
Gas markup	λ_g	–	–	1.7753	Oil markup
Oil markup	λ_o	2.00	2.00	1.7753	Steady state solution
Growth rate of the economy	μ_{z^*}	1.0036	1.0036	1.0036	Sample mean
Weight of coal in energy	ω_c	–	–	0.1852	NP
Weight of gas in energy	ω_g	–	–	0.5359	NP
Weight of oil in energy	ω_o	–	–	0.2789	NP
Steady-state inflation	π	1.0056	1.0056	1.0056	Sample mean
Disutility weight on labour	ψ_l	0.5440	0.7595	0.7165	Hours $l = 1$
Inverse Frisch elasticity	σ_l	1.00	1.00	1.00	CS
Coal utilization adj. cost	σ_a^c	–	–	0.2603	σ_a^o
Gas utilization adj. cost	σ_a^g	–	–	0.2603	σ_a^o
Oil utilization adj. cost	σ_a^o	0.2603	0.2603	0.2603	Estimated σ_a in OSNB
Energy bundle CES	σ_e	–	–	0.0118	EIA
Tax rate on consumption	τ^c	0.0476	0.0476	0.0476	CS
Tax rate on labor income	τ^l	0.2005	0.2005	0.2005	CS
Tax rate on capital income	τ^k	0.2290	0.2290	0.2290	CS
Trend rate of IST change	Υ	1.0023	1.0023	1.0023	CS

Table 3: Estimated Structural Parameters of Model with Oil Shocks and No Banks

			Prior		Posterior	
Description	Parameter	Distribution	Mean	SD	Mode	SD
Taylor rate output	α_{Δ_y}	Normal	0.2	0.05	0.2103	0.0460
Taylor rate inflation	α_π	Normal	1.5	0.25	1.4594	0.1793
Consumption habit	b_c	Beta	0.6	0.1	0.5755	0.0520
Price indexation on inflation	ι_p	Beta	0.5	0.2	0.8030	0.0868
Price indexation on wage	ι_w	Beta	0.5	0.2	0.6227	0.1715
Taylor rate smoothing	ρ_p	Beta	0.8	0.15	0.8036	0.0385
Capital utilization rate adjustment cost	σ_a	Normal	0.9	0.5	0.2992	0.2029
Capital investment adjustment cost	$S^{k\prime\prime}$	Normal	2	1	2.2302	0.7818
Oil investment adjustment cost	$S^{o\prime\prime}$	Normal	2	1	1.9928	0.8134
Calvo price stickiness	ξ_p	Beta	0.75	0.15	0.6166	0.0661
Calvo wage stickiness	ξ_w	Beta	0.75	0.15	0.7218	0.0571

Table 4: Estimated Shock Parameters of Model with Oil Shocks and No Banks

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode	SD
Persistence of stationary technology shock	ρ_{ϵ}	Beta	0.5	0.2	0.6743	0.0870
Persistence of oil technology shock	ρ_{ϵ^o}	Beta	0.5	0.2	0.7283	0.0682
Persistence of gov. spending shock	ρ_g	Beta	0.5	0.2	0.8539	0.0657
Persistence of price markup shock	ρ_{λ_p}	Beta	0.5	0.2	0.6776	0.0956
Persistence of technology trend shock	$\rho_{\mu_{z^*}}$	Beta	0.5	0.2	0.9110	0.0345
Persistence of MEI shock	$\rho_{\zeta_i^k}$	Beta	0.5	0.2	0.3634	0.0952
SD of stationary technology shock	σ_{ϵ}	invg2	0.01	1	0.0179	0.0023
SD of oil technology shock	σ_{ϵ^o}	invg2	0.01	1	0.2995	0.0396
SD of monetary policy shock	σ_{ϵ^p}	invg2	0.01	1	0.0033	0.0004
SD of gov. spending shock	σ_g	invg2	0.01	1	0.0579	0.0079
SD of price markup shock	σ_{λ_p}	invg2	0.01	1	0.0256	0.0193
SD of technology trend shock	$\sigma_{\mu_{z^*}}$	invg2	0.01	1	0.0040	0.0016
SD of MEI shock	$\sigma_{\zeta_i^k}$	invg2	0.01	1	0.0594	0.0068

Demand driven output would fall while inflation increases showing stagflation. In the model without banks, the investment would increase to balance falling consumption in the budget constraint. Such increase in investment during higher macro volatility period is counterfactual that can be corrected by adding banking channels. In the model with banks, net worth maximising entrepreneurs would start reducing debt on the balance sheet resulting in lower investment. Except the response of investment, the response of other macro aggregates is quite similar in the two models. The financial frictions or the financial accelerator have amplified the negative impact of the oil technology shock on the output and investment. The financial channels also reduced inflation by correcting the response of investment but the monetary policy response is stronger with banks. It can be inferred that banking channels require more policy effort to stabilise the macro fluctuations.

The negative impact on output, consumption, and investment (only in the case of model with banking channels) would last for first five quarters only. The inflation would return to normal after first five quarters but not oil price and oil demand that would be half way on recovery and take five more quarters to return to the steady state level. Substitution of oil with labor and capital would continue after five quarters increasing households labor and financial incomes resulting in increased investment, consumption, and output for rest of the quarters. Output, consumption, and investment would experience a swing from negative to positive response that is missing for other macro aggregates. To sum, the short run response of oil technology shock is stag-flationary but medium run dynamic response is positive. Surprisingly, in the medium run the impact of oil technology is positive by increasing the productivity of factor resources.

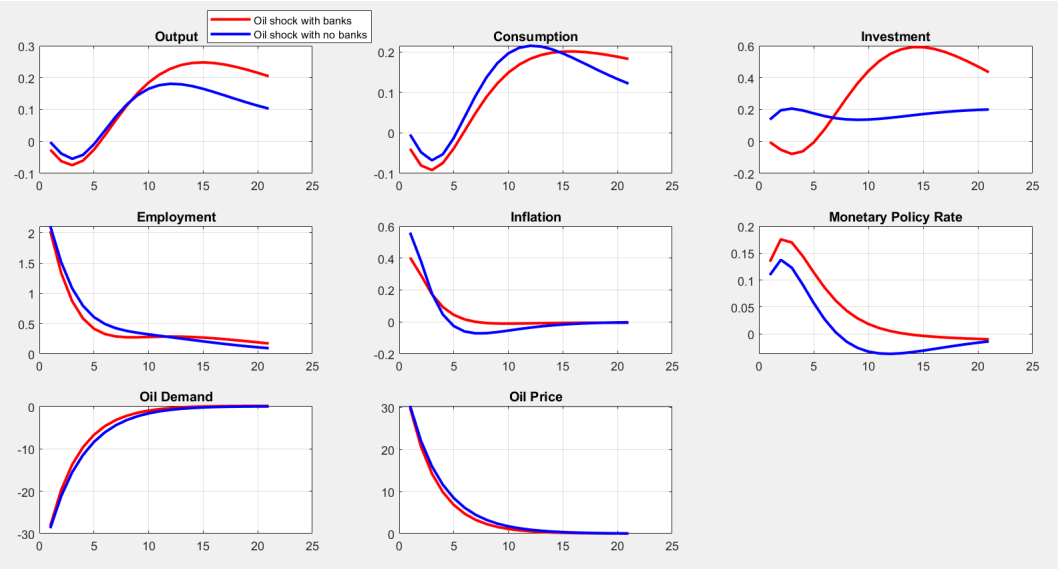


Figure 12: IRFs to negative one standard deviation oil technology shock in models with and without banks

Its worth mentioning that adding the financial channels not only correct the investment response but also correct the dynamic properties of the model. Table 5 shows that model with financial channels correct the correlation of output, consumption, and investment from positive in OSNB model to negative in OS model. Although, its not a big quantitative correction but qualitatively it makes a difference. Further, the model with financial channels reduce the volatility of macro aggregates as can be seen from the reduced standard deviation of these variables in OS model. The mean value of the MP response is slightly higher showing that in presence of financial channels a stronger MP is required to stabilise the macro fluctuations but the standard deviation is lower. Based on this it can be inferred that well functioning financial markets can reduce the policy burden by stabilising the macro aggregates. Presumably, financial markets play this role by easing the liquidity constraint of the households and by regulating the net worth maximising entrepreneurs.

Table 5: Model Dynamic Properties

	OSNB		OS		Correlation with Oil Price	
Description	Mean	SD	Mean	SD	OSNB	OS
Output	−133.90	14.27	45.37	3.48	0.03	−0.03
Consumption	−152.16	14.36	0.74	2.24	0.01	−0.06
Investment	−614.07	54.43	−114.95	12.80	0.01	−0.01
Employment	−0.17	12.28	0	5.65	0.26	0.40
Inflation	100.00	1.69	100.00	1.36	0.37	0.35
Monetary Policy	99.98	1.30	100.00	0.78	0.17	0.29

8.2. Energy Shocks in Model with Banks

Figure 13 shows IRFs of different variables to negative one standard deviation shocks to different energy technologies of coal, gas, and oil. The shock mechanism is same for all these technologies as explained in the previous section. However, the dynamic responses of output, consumption, investment, inflation, and monetary policy rates are stronger to coal than oil and the strongest for gas. Gas has the largest share in the energy mix with parameter value of $\omega_g = 0.5359$ whereas coal share of $\omega_c = 0.1852$ is lower than oil $\omega_o = 0.2789$, as shown in table 2. Hence, this may not explain stronger responses to coal and gas technology

shocks. The gas technology shock parameter has the highest volatility of 0.3634 compare to all other shocks as listed in table 13. The volatility of coal is slightly higher than oil, 0.2892 for coal compare to 0.2827 for oil. The persistence of coal and gas technology shocks, 0.7469 and 0.7499 respectively, are higher than persistence of oil technology shock of 0.6803. Hence, higher volatility and higher persistence of these shocks may explain stronger responses of macro aggregates to these shocks . The response of employment to gas technology shock is stronger than coal and oil shocks. Inflation is highest for the gas shock followed by coal and oil and accordingly the response of monetary policy. The responses of consumption, investment, and output to coal and gas are negative for longer, for ten business quarters, after which these responses also become positive. Hence, the short run responses of macro aggregates to energy shocks are stag-flationary but medium run responses are positive. The dynamic positive response to coal technology shocks is an important finding for energy transition policy making.

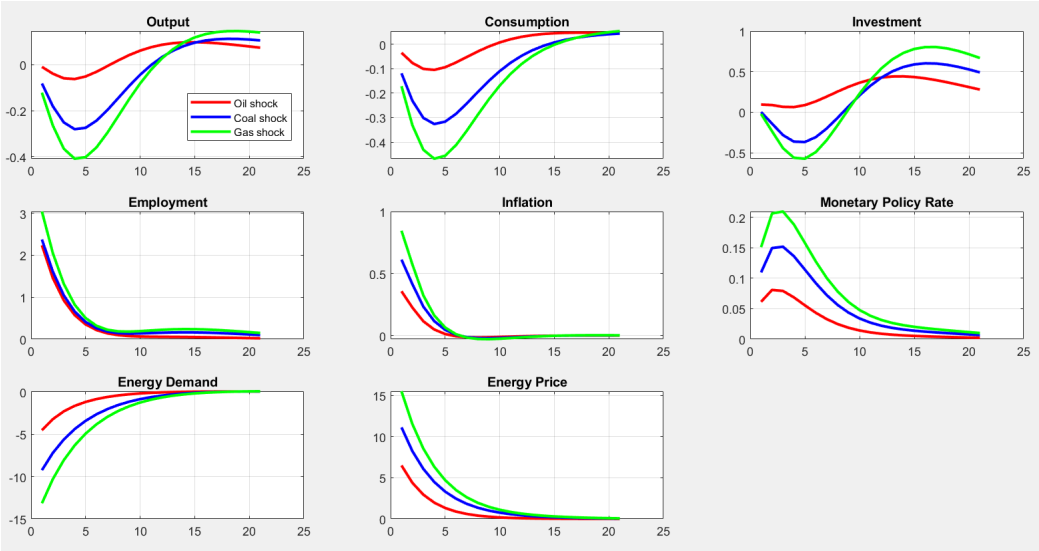


Figure 13: IRFs to negative one standard deviation energy technology shocks in model with banks

8.3. Energy Shocks Major Contributor to recent Post-pandemic Inflation

Figure 14 decomposes historical inflation variance around its steady state (which is annual average of 2.25% during 1990 - 2024 period) into the contribution of the model's different shocks. There are two key take ways. First, energy shocks i.e. coal, gas, and oil technology shocks are the major contributor to recent post-pandemic inflation particularly during years 2021, year of easing of the COVID lock down, and 2022, the year of Ukraine-Russia war. Other shocks which played key role in this inflationary episode are markup and monetary policy shocks. Collateral shock which represents financial market sentiment has been contributing to inflation that didn't change before and during the pandemic period. Stationary technology shock to large extent and household preferences, housing redeployment, and entrepreneur equity to minor extent have negative impact on inflation during this period. Second, stationary technology shocks and energy shocks are major contributor to variance in inflation during the period 1990 - 2024. Other shocks having obvious role in the inflation variance is markup shock and recently monetary policy shock. Impact of technology growth or total factor productivity and other shocks is insignificant.

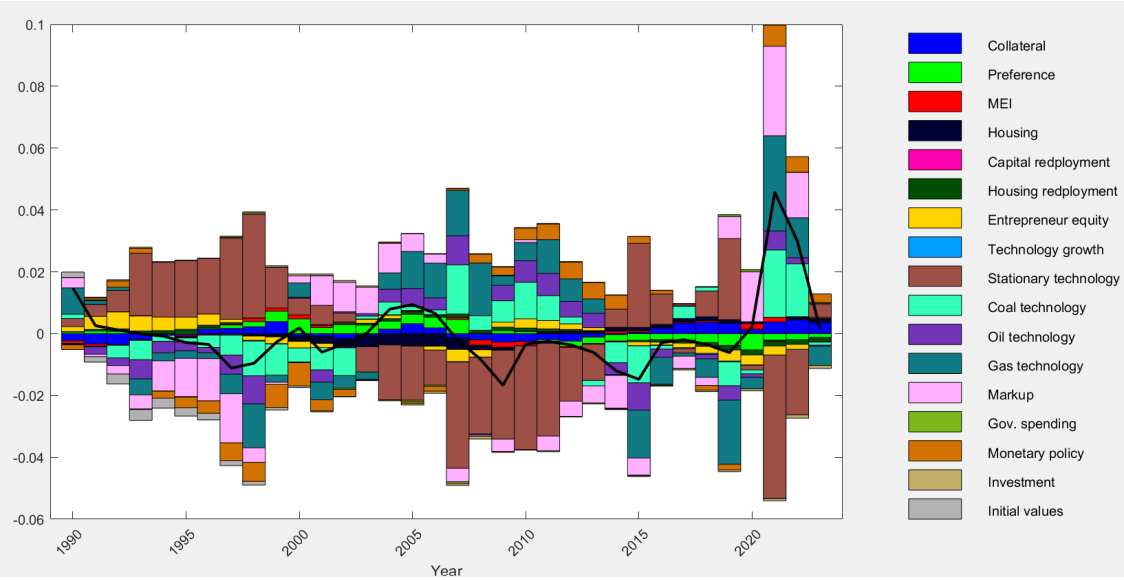


Figure 14: Shock Decomposition of inflation

8.4. Role of Energy Shocks in Macro Fluctuations

Table 6: Energy Shocks Model Variance Decomposition at Business Cycle Frequency

Variable	Collateral (ν_t)	Technology ($\epsilon_t, \mu_{z^*,t}, \lambda_{p,t}$)	Investment ($\zeta_{i,t}, \mu_{\Upsilon,t}$)	Household ($\zeta_{c,t}$ $\zeta_{h,t}, \eta_t^l$)	Firm (γ_t^e, η_t^e)	Policy (g_t, ϵ_t^p)	Energy ($\epsilon_t^{c,g,o}$)
Output	32	4	10	22	9	16	7
Consumption	11	4	1	65	1	9	9
Investment	36	3	22	0	26	11	2
Hours	2	66	2	4	1	2	23
Inflation	1	60	0	1	1	2	35
Monetary Policy	11	28	1	5	6	19	30
Energy Demand	0	8	0	1	0	0	91
Energy Price	0	0	0	0	0	0	100

Table 7 shows that contribution of energy shocks in driving variance is non-negligible for all macro variables except for investment which is primarily driven by collateral, investment and firm shocks and secondarily by policy shocks. Output variance is mainly driven by collateral and household shocks with secondary level of contribution by policy, investment, firm, and energy shocks in descending order. Consumption variance is mainly driven by households with secondary level of contribution by collateral, energy, and policy shocks. Technology shocks are the major contributors in variance of labor and inflation followed by energy shocks with negligible contribution from other shocks. Monetary policy variance is mainly driven by energy shocks followed by technology and policy shocks with secondary level of contribution by collateral shock. This shows how significant energy shocks are for the monetary policy making. Energy shocks are primary drivers of energy demand and price variances with minor role of technology shocks in variance of energy demand.

9. Results Comparison with the Literature

As stated in the introduction, there are more research papers on oil shocks than on energy shocks and accordingly I have compared results of my paper. Balke, Brown, and Yucel (2010) highlighted contradictory

evidence about the relationship between oil price movements and aggregate US economic activity. In 1970s and 1980s oil prices rose sharply and US economic activity contracted. However, throughout 2000s oil prices rose strongly but US economic activity continued to expand until 2008 financial crisis. The model was estimated using Bayesian methodology for period between 1970 and 2009 providing evidence that oil supply and efficiency shocks were the primary drivers of oil prices but such shocks had relatively little effect on US GDP, mainly driven by total factor productivity (TFP), preference, and investment efficiency shocks. No role of oil efficiency shocks on US output was accounted. They defined oil supply shocks when both oil production and oil reserve shocks occurred at the same time generating a negative relationship between oil prices and U.S. economic activity, estimating oil price elasticity of US real GDP with a mean of -0.016. Similarly, Balke and Brown (2018) showed no major contribution of US originated and rest of world originated oil shocks on US real output, between 1991 and 2005, and estimated elasticity of US real GDP with respect to oil price shock in the range between -0.022 and -0.017. I have estimated oil shock model (with banks) from 1973 to 2024 and results are included in appendix H. The negative oil technology shock alone can generate negative relation between oil prices and US economic activity. While output is mainly driven by total factor productivity and MEI shocks, oil shocks still have a significant impact on output and much more significant impact on consumption, hours, inflation and monetary policy rates. The estimated oil price elasticity of US real GDP is -0.0174 for model using sample between 1973 and 2024 and -0.0013 for model between 1990 and 2024. My models also show similar results of falling real GDP to oil price elasticity from 1990s and less sensitivity of US real GDP to oil price shocks between 1990 and 2024 as per table 18.

Blanchard and Gali (2007) also identified changes between the macroeconomic effects of oil price shocks of 1970s and the late 1990s, investigating the factors behind such changes. The developed model was calibrated and not estimated. They explained time-variation in the effects of oil price shocks because of decrease in real wage rigidities, increased credibility of monetary policy, and the decrease in share of oil in consumption and production. The research objective of my paper is not to investigate such a time varying effect but its evident in figures 18 and 19 showing variance of inflation and per capita real GDP growth around its sample period mean values of 3.36% and 1.48% respectively.

Blanchard and Bernanke (2023) estimated that one standard deviation shock to energy prices increases inflation by 2.5%. In my model, there is no energy price shock but coal, gas, and oil technology shocks driving variance in energy price. A negative one standard deviation shock to coal, gas, and oil technology increases inflation by 0.61%, 0.85%, and 0.35% respectively.

Contrary to results in my model, Baba and Lee (2022) showed oil supply shocks played a smaller role in driving the real oil price compared to oil-specific demand shocks and aggregate demand shocks. Nakov and Nuño (2013) estimated that a one standard deviation shock to oil supply reduces oil output by 2% and raises oil prices by 8% whereas results in my model are much stronger, around 30% as per figures 12 and 17. Nakov and Pescatori (2007a) showed asymptotic variance decomposition of macro variables using structural composition of dominant oil producer and competitive fringe. Oil shocks originating from dominant oil producer (OPEC) contribute significantly to the volatility of output and inflation, 26% for output and 16% for inflation. Whereas those originating from competitive fringe (non-OPEC) contribute 5% to output volatility and 1% to inflation volatility. The estimated oil shock model between 1973 and 2024 show variance of 10% for output and 40% for inflation, higher volatility to inflation than output.

Bjørnland, Larsen, and Maih (2018) specified structural composition of oil sector differently as an external oil sector rather than a sector within the economy. They allowed the change in volatility of the oil shocks showing that contribution of the shocks increases with shock volatility in the medium term. The contribution of high volatility oil shocks to output growth is between 9% and 13% and to inflation is around 65% after 1 - 2 years. They suggested that when analyzing the oil shocks impact on the economy, one needs to separate periods of low and high volatility. Estimating the relationship with constant parameters may lead one to

underestimate the impact of energy shocks on the economy. However, even with the constant parameters, I have shown the impact of oil shocks on the economy in similar range. Most importantly, none of the papers in the literature have identified a macroeconomic response which swing from negative to positive.

10. Conclusion

Models in this paper with endogenous oil and energy sectors do not consider two key factors of external sector and the change in volatility of energy shocks, highlighted by Bjørnland, Larsen, and Maih (2018). Despite these two missing factors, I have shown that energy shocks contribution to the historic variance of the macro variables is not insignificant. Large and open economies, like US, China, and EU are not independent in meeting their energy needs and depend significantly on the imports. Further, a small open economy which depends on external sources to meet its energy demand can be significantly impacted by global energy shocks. Hence, the change in structural composition of the energy sector to reflect energy dependence or interdependence can help to further uncover the relationship between energy sector and the macro fluctuations. This can also help to resolve the puzzle of time-variation in the impact of oil shocks.

The analysis shows that energy security is key to a stable economy and any threat to it leads to macro volatility and impact household welfare. As the energy shocks have contributed the most to the historic variance of the monetary policy rate, these shocks have a key role in the monetary policy making. However, monetary policy in isolation cannot help to mitigate the impact of these shocks and needs to be coordinated with the energy security policy. Such a coordination can deliver better outcome for household welfare and the macro stability.

Inflation Reduction Act signed by President Biden on 16 August 2022 is such a policy which can be explained by adding shocks to marginal efficiency of investment for energy assets. The act had two dozen tax provisions intending to reduce energy bills and to accelerate investment on clean energy infrastructure. The act is analogous to a negative energy MEI shock which reduces the investment adjustment cost for the energy capital, easing supply side frictions. The increased investment in the energy capital not only increases the gdp growth, consumption, aggregate investment, and employment but also reduces inflation. The firms anticipating lower cost of energy and the marginal cost would price less pushing down the prices. This shows the importance of coordination between energy policy and monetary policy to mitigate inflation induced by such energy shocks.

Energy sector has a critical role in enabling the development and operation of Artificial Intelligence (AI) agents that can substitute for or complement labor. The developed framework can be used to analyse how AI adoption can affect the labor market, macroeconomic outcomes, and associated policy implications. The model can be also extended by adding renewable energy technology. This extension would help to identify the optimal energy mix and to formulate an effective energy transition policy. Climate change or environmental policy measures aim to reduce green house gas emissions. Figure 15 shows that historically three-quarters of global emissions are contributed by the energy sector. Hence, for designing and implementing effective climate change policies, research on the energy sector and its relationship with macro economy is vital.

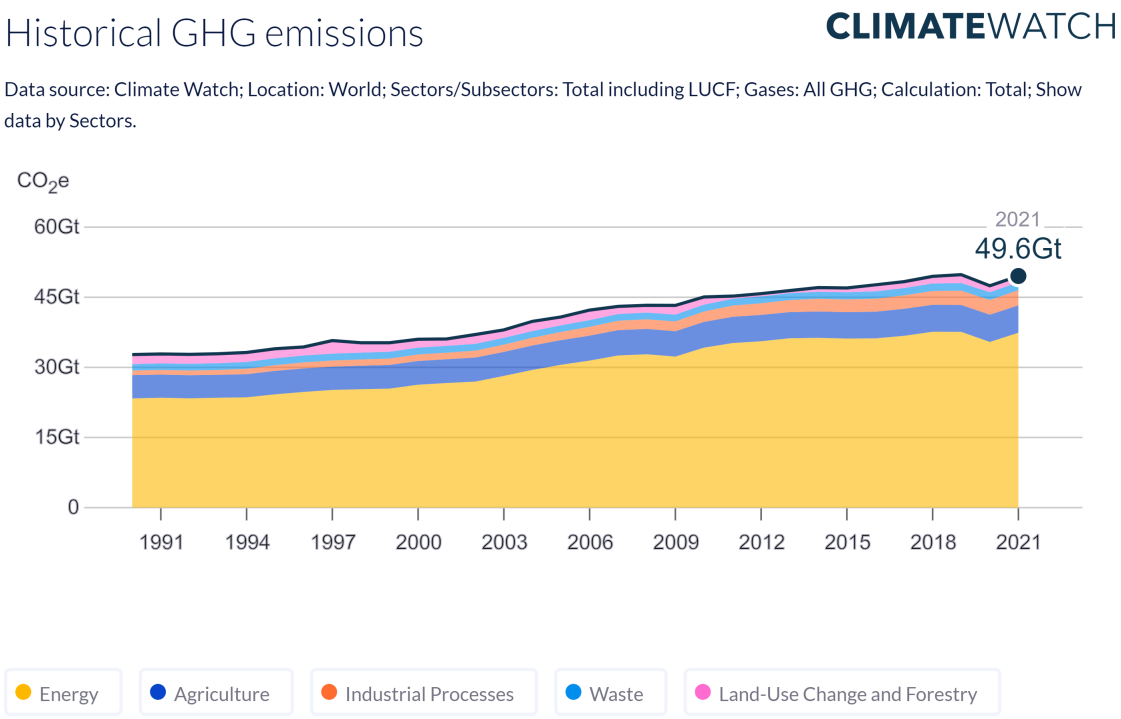


Figure 15: Historical Green House Gas Emissions by Sector (Source: CLIMATEWATCH website)

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A Derivation of the Baseline Model

My baseline model is a NK model with an endogenous oil sector and without banks as explained in section 5.

a) Households

The equation for the capital accumulation K_t is:

$$K_t = (1-\delta)K_{t-1} + [1 - S^k(\zeta_{i,t}\frac{I_t}{I_{t-1}})]I_t$$

$\frac{dK_t}{dI_t}$:

$$\frac{dK_t}{dI_t} = 1 - S^k(\zeta_{i,t}\frac{I_t}{I_{t-1}}) - \frac{I_t}{I_{t-1}}\zeta_{i,t}S^{k\prime}(\zeta_{i,t}\frac{I_t}{I_{t-1}})$$

$$K_{t+1} = (1-\delta)\bar{K}_t + [1 - S^k(\zeta_{i,t+1}\frac{I_t+1}{I_t})]I_{t+1}$$

$\frac{dK_{t+1}}{dI_t}$:

$$\frac{dK_{t+1}}{dI_t} = (\frac{I_{t+1}}{I_t})^2\zeta_{i,t+1}S^{k\prime}(\zeta_{i,t+1}\frac{I_{t+1}}{I_t})$$

FOC w.r.rt investment

$$-\Lambda_{z,t}\frac{P_t}{\Upsilon^t} + \beta E_t\Lambda_{z,t+1}\Upsilon^{-(t+1)}P_{t+1}\{(1-\tau^k)(u_{t+1}r^k_{t+1} - a(u_{t+1})) + \tau^k\delta\}\frac{dK_t}{dI_t}$$

$$+\beta^2 E_t\Lambda_{z,t+2}\Upsilon^{-(t+2)}P_{t+2}\{(1-\tau^k)(u_{t+2}r^k_{t+2} - a(u_{t+2})) + \tau^k\delta\}\frac{dK_{t+1}}{dI_t} = 0$$

$$-\Lambda_{z,t}\frac{P_t}{\Upsilon^t} + \beta E_t\Lambda_{z,t+1}\Upsilon^{-(t+1)}P_{t+1}\{(1-\tau^k)(u_{t+1}r^k_{t+1} - a(u_{t+1})) + \tau^k\delta\}\{1 - S^k(\zeta_{i,t}\frac{I_t}{I_{t-1}}) - \frac{I_t}{I_{t-1}}\zeta_{i,t}S^{k\prime}(\zeta_{i,t}\frac{I_t}{I_{t-1}})\}$$

$$+\beta^2 E_t\Lambda_{z,t+2}\Upsilon^{-(t+2)}P_{t+2}\{(1-\tau^k)(u_{t+2}r^k_{t+2} - a(u_{t+2})) + \tau^k\delta\}\{(\frac{I_{t+}}{I_t})^2\zeta_{i,t+1}S^{k\prime}(\zeta_{i,t+1}\frac{I_{t+1}}{I_t})\} = 0$$

where $\Lambda_{z,t}$ is household's marginal utility of consumption.

FOC w.r.t Consumption

$$\Lambda_{z,t}(1+\tau^c)P_t - \frac{1}{C_t - b_cC_{t-1}} + E_t\frac{\beta b_c}{C_{t+1} - b_cC_t} = 0$$

FOC w.r.t deposits

$$-P_t\Lambda_{z,t} + \beta P_t E_t\Lambda_{z,t+1}R_{t+1} = 0$$

b) Capital Utilization Rate

Competitive market condition for capital utilization rate:

$$P_t \Upsilon^{-t} a(u_{j,t}) K_{j,t-1} = P_t \tilde{r}_t^k u_{j,t} K_{j,t-1}$$

FOC w.r.t $u_{j,t}$ is:

$$\Upsilon^{-t} a'(u_{j,t}) = \tilde{r}_t^k$$

All households choose same utilization rate, $u_{j,t} = u_t$ as optimal utilization depends on the aggregate variables. The cost function is:

$$a'(u_t) = r^k exp(\sigma_a[u_t - 1])$$

$$\Upsilon^{-t} r^k exp(\sigma_a[u_t - 1]) = \tilde{r}_t^k$$

FOC for the Utilization rate

$$\Upsilon^t \tilde{r}_t^k = r^k exp(\sigma_a[u_t - 1])$$

c) Final Goods Producer

Final good firm objective function:

$$Y_t = \Big[\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj \Big]^{\lambda_{p,t}}$$

The budget constraint is:

$$\int_0^1 P_{j,t} Y_{j,t} dj = P_t Y_t$$

FOC wrt $Y_{j,t}$ is:

$$\lambda_{p,t} [\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}-1} \frac{1}{\lambda_{p,t}} Y_{j,t}^{\frac{1}{\lambda_{p,t}}-1} - x P_{j,t} = 0$$

$$[\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}-1} Y_{j,t}^{\frac{1-\lambda_{p,t}}{\lambda_{p,t}}} = x P_{j,t}$$

From

$$Y_t = [\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}}$$

we can deduce

$$\frac{Y_t^{\frac{1}{\lambda_{p,t}}}}{Y_t} = \frac{\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj}{Y_t}$$

$$\frac{Y_t^{\frac{1}{\lambda_{p,t}}}}{Y_t} = \frac{\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj}{[\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}}}$$

$$Y_t^{\frac{1-\lambda_{p,t}}{\lambda_{p,t}}} = [\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{1-\lambda_{p,t}}$$

$$Y_t^{\frac{\lambda_{p,t}-1}{\lambda_{p,t}}} = [\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}-1}$$

FOC would become:

$$Y_t^{\frac{\lambda_{p,t}-1}{\lambda_{p,t}}} Y_{j,t}^{\frac{1-\lambda_{p,t}}{\lambda_{p,t}}} = xP_{j,t}$$

$$(\frac{Y_{j,t}}{Y_t})^{\frac{1-\lambda_{p,t}}{\lambda_{p,t}}} = xP_{j,t}$$

$$(\frac{Y_{j,t}}{Y_t}) = (xP_{j,t})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}$$

$$Y_{j,t} = Y_t(xP_{j,t})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}$$

Putting above value of $Y_{j,t}$ into

$$Y_t = [\int_0^1 Y_{j,t}^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}}$$

$$Y_t = [\int_0^1 [Y_t[xP_{j,t}]^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}]^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}}$$

$$Y_t = [Y_t^{\frac{1}{\lambda_{p,t}}} \int_0^1 [[x^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}} P_{j,t}^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}]^{\frac{1}{\lambda_{p,t}}} dj]^{\lambda_{p,t}}$$

$$Y_t = Y_t[x^{\frac{1}{1-\lambda_{p,t}}} \int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{\lambda p,t}$$

$$1 = x^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}} [\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{\lambda p,t}$$

$$x^{\frac{\lambda_{p,t}}{\lambda_{p,t}-1}} = [\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{\lambda p,t}$$

$$x = [\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{\lambda p,t}]^{\frac{\lambda_{p,t}-1}{\lambda_{p,t}}}$$

$$x = [\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{\lambda_{p,t}-1}$$

$$x = \frac{1}{[\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{1-\lambda_{p,t}}}$$

$$\int_0^1 P_{j,t}^{\frac{1}{1-\lambda_{p,t}}} dj]^{1-\lambda_{p,t}} = P_t$$

This implies that

$$x = \frac{1}{P_t}$$

Hence, the below equation would become:

$$Y_{j,t} = Y_t(xP_{j,t})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}$$

$$Y_{j,t} = Y_t(\frac{P_{j,t}}{P_t})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}}$$

Above is the demand for good j.

d) Upstream Firm

Upstream firm objective function is:

$$\max_{I_t^o} E_t \sum_{t=0}^{\infty} \beta^t \Lambda_{z,t} \{u_t^o X_{t-1}^o \tilde{r}_t^o - [\Upsilon^t]^{-1} I_t^o\},$$

subject to the constraint

$$X_t^o = X_{t-1}^o(1-\delta) + [1 - S^o(\frac{I_t^o}{I_{t-1}^o})]I_t^o, \delta \in (0,1)$$

FOC w.r.t I_t^o:

$$-\frac{\Lambda_{z,t}}{\Upsilon^t} + \beta \Lambda_{z,t+1} u_{t+1}^o \tilde{r}_{t+1}^o \frac{dX_t^o}{dI_t^o} + \beta^2 \Lambda_{z,t+2} u_{t+2}^o \tilde{r}_{t+2}^o \frac{dX_{t+1}^o}{dI_t^o} = 0$$

$$X_t^o = X_{t-1}^o(1-\delta) + [1 - S^o(\frac{I_t^o}{I_{t-1}^o})]I_t^o$$

$$X_{t+1}^o = X_t^o(1-\delta) + [1 - S^o(\frac{I_{t+1}^o}{I_t^o})]I_{t+1}^o$$

$$\frac{dX_t^o}{dI_t^o} = 1 - S^o(\frac{I_t^o}{I_{t-1}^o}) - \frac{I_t^o}{I_{t-1}^o} S^{o\prime}(\frac{I_t^o}{I_{t-1}^o})$$

$$\frac{dX_{t+1}^o}{dI_t^o} = (\frac{I_{t+1}^o}{I_t^o})^2 S^{x\prime}(\frac{I_{t+1}^o}{I_t^o})$$

Hence, FOC becomes:

$$-\frac{\Lambda_{z,t}}{\Upsilon^t} + \beta E_t \Lambda_{z,t+1} u_{t+1}^o \tilde{r}_{t+1}^x [1 - S^o(\frac{I_t^o}{I_{t-1}^o}) - \frac{I_t^o}{I_{t-1}^o} S^{o\prime}(\frac{I_t^o}{I_{t-1}^o})] + \beta^2 E_t \Lambda_{z,t+2} u_{t+2}^o \tilde{r}_{t+2}^o (\frac{I_{t+1}^o}{I_t^o})^2 S^{o\prime}(\zeta_{o,t+1} \frac{I_{t+1}^o}{I_t^o}) = 0$$

e) Oil Reserves Capital Utilisation Rate

A competitive market condition is that the user cost function must equal the return on renting out capital services i.e.

$$P_t \Upsilon^{-t} a(u_t^o) X_{t-1}^o = P_t \tilde{r}_t^x u_t^o X_{t-1}^o,$$

FOC w.r.t u_t^o is:

$$a'(u_t^o) = \Upsilon^t \tilde{r}_t^o$$

$$a'(u_t^o) = r^o exp(\sigma_a[u_t^o - 1])$$

$$\Upsilon^t \tilde{r}_t^o = r^o exp(\sigma_a[u_t^o - 1])$$

f) Downstream Firm

Downstream firm FOC w.r.t $u_t^o \bar{X}_{t-1}$ is:

$$\frac{S_t^o}{P_t} = \frac{\tilde{r}_t^x}{\epsilon_t^o}$$

g) Downstream Firm Oil Price Equation

$$\min_{O_{j,t}} \int_0^1 P^o_{j,t} O_{j,t} dj + x \left\{ O_t - [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{\lambda_{o,t}}{\lambda_{o,t-1}}} \right\}$$

F.O.C w.r.t $O_{j,t}$:

$$P^o_{j,t} - x \frac{\lambda_{o,t}}{\lambda_{o,t}-1} [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{1}{\lambda_{o,t-1}}} \frac{\lambda_{o,t}-1}{\lambda_{o,t}} O_{j,t}^{\frac{-1}{\lambda_{o,t}}} = 0$$

$$P^o_{j,t} - x [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{1}{\lambda_{o,t-1}}} O_{j,t}^{\frac{-1}{\lambda_{o,t}}} = 0$$

$$P^o_{j,t} - x O_t^{\frac{1}{\lambda_{o,t}}} O_{j,t}^{\frac{-1}{\lambda_{o,t}}} = 0$$

$$P^o_{j,t} = x O_t^{\frac{1}{\lambda_{o,t}}} O_{j,t}^{\frac{-1}{\lambda_{o,t}}}$$

$$P^o_{j,t} = x [\frac{O_t}{O_{j,t}}]^{\frac{1}{\lambda_{o,t}}}$$

$$[\frac{P^o_{j,t}}{x}]^{\lambda_{o,t}} = \frac{O_t}{O_{j,t}}$$

$$O_{j,t} = O_t [\frac{P^o_{j,t}}{x}]^{-\lambda_{o,t}}$$

From:

$$O_t = [\int_0^1 O_{j,t}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{\lambda_{o,t}}{\lambda_{o,t-1}}}$$

$$O_t = [\int_0^1 \{O_t [\frac{P^o_{j,t}}{x}]^{-\lambda_{o,t}}\}^{\frac{\lambda_{o,t}-1}{\lambda_{o,t}}} dj]^{\frac{\lambda_{o,t}}{\lambda_{o,t-1}}}$$

$$x = [\int_0^1 [P^o_{j,t}]^{1-\lambda_{o,t}} dj]^{\frac{1}{1-\lambda_{o,t}}}$$

$$x = P^o_t$$

Hence,

$$O_{j,t} = O_t [\frac{P^o_{j,t}}{P^o_t}]^{-\lambda_{o,t}}$$

The downstream firm maximise profits subject to the constraint of its demand function:

$$\max_{P^o_{j,t}} [P^o_{j,t} - S^o_{j,t}] O_{j,t}$$

$$\max_{P^o_{j,t}} [P^o_{j,t} - S^o_{j,t}] O_t [\frac{P^o_{j,t}}{P^o_t}]^{-\lambda_{o,t}}$$

FOC w.r.t $P^o_{j,t}$:

$$O_t(\frac{P^o_{j,t}}{P^o_t})^{-\lambda_{o,t}} + O_t[P^o_{j,t} - S^o_{j,t}](\frac{1}{P^o_t})^{-\lambda_{o,t}}(-\lambda_{o,t})(P^o_{j,t})^{-1-\lambda_{o,t}} = 0$$

$$O_t(\frac{P^o_{j,t}}{P^o_t})^{-\lambda_{o,t}} - \lambda_{o,t}O_t(\frac{P^o_{j,t}}{P^o_t})^{-\lambda_{o,t}}(P^o_{j,t})^{-1}[P^o_{j,t} - S^o_{j,t}] = 0$$

$$1 = \frac{\lambda_{o,t}}{P^o_{j,t}}[P^o_{j,t} - S^o_{j,t}]$$

$$\frac{P^o_{j,t}}{\lambda_{o,t}} = P^o_{j,t} - S^o_{j,t}$$

$$S^o_{j,t} = P^o_{j,t} - \frac{P^o_{j,t}}{\lambda_{o,t}}$$

$$S^o_{j,t} = P^o_{j,t}(1 - \frac{1}{\lambda_{o,t}})$$

$$S^o_{j,t} = P^o_{j,t}(\frac{\lambda_{o,t} - 1}{\lambda_{o,t}})$$

$$P^o_{j,t} = S^o_{j,t}(\frac{\lambda_{o,t}}{\lambda_{o,t} - 1})$$

As $S^o_{j,t} = S^o_t$, so $P^o_{j,t} = P^o_t$ as it these depends on the aggregate variables. Hence,

$$P^o_t = S^o_t(\frac{\lambda_{o,t}}{\lambda_{o,t} - 1})$$

$$\frac{S^o_t}{P_t} = \frac{\tilde{r}^o_t}{\epsilon^o_t}$$

$$P^o_t = P_t\frac{\tilde{r}^o_t}{\epsilon^o_t}(\frac{\lambda_{o,t}}{\lambda_{o,t} - 1})$$

h) Intermediate Good Producers - Production

The intermediate firms maximize profit by minimising the marginal cost subject to the intermediate firm production function. Intermediate firms profit function is:

$$P_{j,t}Y_{j,t} - W_t l_{j,t} - P_t\tilde{r}^k_t u_t\bar{K}_{j,t-1} - P^o_t O_{j,t},$$

where $P_t\tilde{r}^k_t$ is the nominal rental rate of capital.

FOC w.r.t capital services

$$P_t\tilde{r}^K_t = S_{j,t}\alpha_k\epsilon_t(z_t l_{j,t})^{\alpha_l}(u_t K_{j,t-1})^{\alpha_k - 1}O^{1-\alpha_l-\alpha_k}_{j,t}$$

FOC w.r.t oil

$$P^o_t = S_{j,t}(1 - \alpha_l - \alpha_k)\epsilon_t(z_t l_{j,t})^{\alpha_l}(u_t K_{j,t-1})^{\alpha_k}O^{-\alpha_l-\alpha_k}_{j,t}$$

FOC w.r.t labour

$$W_t l_{j,t} = S_{j,t}\alpha_l \epsilon_t (z_t l_{j,t})^{\alpha_l} (u_t K_{j,t-1})^{\alpha_k} O_{j,t}^{1-\alpha_l-\alpha_k}$$

We can find out capital to labor,capital to oil, and oil to labor ratios.

Capital to labor ratio

$$\frac{u_t K_{j,t-1}}{l_{j,t}} = \frac{\alpha_k}{\alpha_l}\frac{W_t}{P_t \tilde{r}_t^k}$$

Capital to oil ratio:

$$\frac{u_t K_{j,t-1}}{O_{j,t}} = \frac{\alpha_k}{1-\alpha_l-\alpha_k}\frac{P_t^o}{P_t \tilde{r}_t^k}$$

Oil to labor ratio:

$$\frac{O_{j,t}}{l_{j,t}} = \frac{1-\alpha_l-\alpha_k}{\alpha_l \kappa}\frac{W_t}{P_t^o}$$

From FOC of capital:

$$S_{j,t} = \frac{P_t \tilde{r}_t^k}{\alpha_k \epsilon_t (z_t l_{j,t})^{\alpha_l} (u_t K_{j,t-1})^{\alpha_k - 1} O_{j,t}^{1-\alpha_l-\alpha_k}}$$

From labor to capital ratios:

$$l_{j,t} = u_t K_{j,t-1}\left(\frac{\alpha_l P_t \tilde{r}_t^k}{\alpha_k W_t}\right)$$

Above FOC of capital becomes:

$$S_{j,t} = \frac{1}{\epsilon_t}\left(\frac{P_t \tilde{r}_t^k}{\alpha_k}\right)^{1-\alpha_l}\left(\frac{W_t^{p,\kappa} W_t^{i,(1-\kappa)}}{z_t \alpha_l \kappa (1-\kappa)}\right)^{\alpha_l} \frac{1}{(u_t K_{j,t-1})^{\alpha_l+\alpha_k-1} O_{j,t}^{1-\alpha_l-\alpha_k}}$$

From capital to oil ratio:

$$O_{j,t} = \left(\frac{1-\alpha_l-\alpha_k}{\alpha_k}\right)\left(\frac{P_t \tilde{r}_t^k}{P_t^o}\right) u_t K_{j,t-1}$$

The FOC of capital becomes:

$$S_{j,t} = \frac{1}{\epsilon}\left(\frac{P_t \tilde{r}_t^k}{\alpha_k}\right)^{\alpha_k}\left(\frac{P_t^o}{1-\alpha_l-\alpha_k}\right)^{1-\alpha_l-\alpha_k}\left(\frac{W_t}{z_t \alpha_l}\right)^{\alpha_l}$$

All above ratios depend only on aggregate quantities and are therefore common to all the intermediate producers. If firms pay the same factor prices, receive the same aggregate shocks and choose the same proportion of inputs then they have the same marginal cost $S_{j,t} = S_t$.

$$S_t = \frac{1}{\epsilon}\left(\frac{P_t \tilde{r}_t^k}{\alpha_k}\right)^{\alpha_k}\left(\frac{P_t^o}{1-\alpha_l-\alpha_k}\right)^{1-\alpha_l-\alpha_k}\left(\frac{W_t}{z_t \alpha_l}\right)^{\alpha_l}$$

Intermediate Good Producers - Aggregate Production

The aggregate production function is:

$$Y_t = max\{\epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{1-\alpha_l-\alpha_k} - \theta z_t^*; 0\}, \alpha_l, \alpha_k \in (0,1)$$

The aggregate cost function is:

$$W_t l_t + P_t \tilde{r}_t^k u_t K_{t-1} + P_t^o O_t$$

Aggregated FOCs are:

$$P_t \tilde{r}_t^K = S_t \alpha_k \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k - 1} O_t^{1-\alpha_l-\alpha_k}$$
$$P_t^o = S_t (1-\alpha_l-\alpha_k) \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{-\alpha_l-\alpha_k}$$
$$W_t l_t = S_t \alpha_l \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{1-\alpha_l-\alpha_k}$$

i) Intermediate Good Producers - Prices

Intermediate goods producers set price $P_{j,t}$ to maximise the sum of future discounted profits from period t to t+s. The firms discount the future similar to the households who are dominantly owner of these firms

$$\max_{P_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} [P_{j,t} \tilde{\pi}_{t,t+s} Y_{j,t+s} - W_{t+s} l_{j,t+s} - P_t^o O_{j,t+s} - P_{t+s} \tilde{r}_{t+s}^k u_{j,t+s} \bar{K}_{j,t+s-1}]$$

subject to demand faced by the producer

$$Y_{j,t+s} = [\frac{\tilde{\pi}_{t,t+s} P_{j,t}}{P_{t+s}}]^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} Y_{t+s}$$

where

$$\tilde{\pi}_{t,t+s} = \Pi_{k=1}^{s} \tilde{\pi}_{t+s}$$

and

$$\tilde{\pi} = \pi^{i_p} \pi_{t-1}^{1-i_p}$$

ϵ_p is the probability of firm to adjust its price.Above function becomes:

$$\max_{P_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} [Y_{j,t+s} P_{j,t} \tilde{\pi}_{t,t+s} - S_{j,t+s} Y_{j,t+s}]$$

$$= \max_{P_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{j,t+s} [P_{j,t} \tilde{\pi}_{t,t+s} - S_{j,t+s}]$$

$$= \max_{P_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} [\frac{\tilde{\pi}_{t,t+s} P_{j,t}}{P_{t+s}}]^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} Y_{t+s} [P_{j,t} \tilde{\pi}_{t,t+s} - S_{j,t+s}]$$

$$= \max_{P_{j,t}} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} [\frac{\tilde{\pi}_{t,t+s}}{P_{t+s}}]^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} [P_{j,t}^{\frac{1}{1-\lambda_{p,t+s}}} \tilde{\pi}_{t,t+s} - (P_{j,t})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} S_{j,t+s}]$$

FOC w.r.t $P_{j,t}$

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{P_{t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} [P_{j,t}^{\frac{\lambda_{t,t+s}}{1-\lambda_{p,t+s}}} \frac{\tilde{\pi}_{t,t+s}}{1-\lambda_{p,t+s}} - \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} (P_{j,t})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}-1} S_{j,t+s}] = 0$$

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{P_{t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} P_{j,t}^{\frac{\lambda_{t,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} [\tilde{\pi}_{t,t+s} - \lambda_{p,t+s} (P_{j,t})^{-1} S_{j,t+s}] = 0$$

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{P_{j,t} \tilde{\pi}_{t,t+s}}{P_{t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} [\tilde{\pi}_{t,t+s} - \lambda_{p,t+s} \frac{S_{j,t+s}}{P_{j,t}}] = 0$$

Considering:

$$P_{j,t} = \tilde{P}_t$$

because the optimal price depends only on aggregate variables and similar for all the producers.

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{P}_t \tilde{\pi}_{t,t+s}}{P_{t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} [\tilde{\pi}_{t,t+s} - \lambda_{p,t+s} \frac{S_{j,t+s}}{\tilde{P}_t}] = 0$$

$$P_{t+s} = P_t \pi_{t,t+s}$$

where

$$\pi_{t,t+s} = \Pi_{k=1}^{s} \pi_{t+k}$$

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{P}_t \tilde{\pi}_{t,t+s}}{P_t \pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} [\tilde{\pi}_{t,t+s} - \lambda_{p,t+s} \frac{S_{j,t+s}}{\tilde{P}_t}] = 0$$

The exponent terms $\lambda_{p,t+s}$ for $\tilde{P}_t$ and P_t would disappear in the log-linearized equilibrium and hence can be ignored for $\frac{\tilde{P}}{P_t}$. The marginal cost $S_{j,t}$ is same S_t for all the intermediate producers.

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\tilde{P}_t}{P_t} \frac{1}{1-\lambda_{p,t+s}} [\tilde{\pi}_{t,t+s} - \lambda_{p,t+s} \frac{S_{t+s}}{\tilde{P}_t}] = 0$$

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{\tilde{P}_t}{P_t} \frac{S_{t+s}}{\tilde{P}_t} = \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\tilde{P}_t}{P_t} \frac{\tilde{\pi}_{t,t+s}}{1-\lambda_{p,t+s}}$$

$$\frac{\tilde{P}_t}{P_t} = \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{P_{t+s}}{P_t} \frac{S_{t+s}}{P_{t+s}}}{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s P_{t+s} \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} \frac{\tilde{\pi}_{t,t+s}}{P_{t+s}}}$$

$$\frac{\tilde{P}_t}{P_t} = \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{P_{t+s}}{P_t} \frac{S_{t+s}}{P_{t+s}}}{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s P_{t+s} \Lambda_{z,t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} \frac{\tilde{\pi}_{t,t+s}}{P_t \pi_{t,t+s}}}$$

$$\frac{\tilde{P}_t}{P_t} = \frac{\frac{1}{P_t} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{S_{t+s}}{P_{t+s}}}{\frac{1}{P_t} \mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}} \frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}}}$$

$$\frac{\tilde{P}_t}{P_t} = \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{S_{t+s}}{P_{t+s}}}{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{1}{1-\lambda_{p,t+s}}} \frac{1}{1-\lambda_{p,t+s}}}$$

Ignoring $\lambda_{p,t+s}$ exponents for $(\frac{\tilde{\Pi}_{t,t+s}}{\Pi_{t,t+s}})$

$$\frac{\tilde{P}_t}{P_t} = \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}} \frac{\lambda_{p,t+s}}{1-\lambda_{p,t+s}} \frac{S_{t+s}}{P_{t+s}}}{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \Lambda_{z,t+s} P_{t+s} Y_{t+s} (\frac{\tilde{\pi}_{t,t+s}}{\pi_{t,t+s}})^{\frac{1}{1-\lambda_{p,t}}} \frac{1}{1-\lambda_{p,t+s}}}$$

$$\frac{\tilde{P}_t}{P_t} = \frac{K_{p,t}}{F_{p,t}}$$

$$K_{p,t} = \Lambda_{z,t} P_t Y_t \frac{S_t}{P_t} \frac{\lambda_{p,t}}{1-\lambda_{p,t}} (\frac{\tilde{\pi}_t}{\pi_t})^{\frac{\lambda_{p,t}}{1-\lambda_{p,t}}} + \xi_p \beta \mathbb{E}_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1}$$

Since $\tilde{\pi}_t = \pi_t$ so

$$K_{p,t} = \Lambda_{z,t} P_t Y_t \frac{S_t}{P_t} \frac{\lambda_{p,t}}{1-\lambda_{p,t}} + \xi_p \beta \mathbb{E}_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1}$$

Similarly,

$$F_{p,t} = \Lambda_{z,t} P_t Y_t \frac{1}{1-\lambda_{p,t}} + \xi_p \beta \mathbb{E}_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1}$$

Above are the equilibrium equations 1 and 2.

j) Labour Contractor

A representative competitive labour contractor aggregates specialised labor services $l_{k,t}$, where $k \in [0,1]$ into homogeneous labor l_t using the technology:

$$\max_{l_{k,t}} l_t = [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w}, \lambda_w \geq 1.$$

subject to the budget constraint

$$W_t l_t = \int_0^1 W_{k,t} l_{k,t} dk$$

$$\max_{l_{k,t}} [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w} + x[W_t l_t - \int_0^1 W_{k,t} l_{k,t} dk]$$

FOC wrt $l_{k,t}$:

$$\lambda_w [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w - 1} \frac{1}{\lambda_w} l_{k,t}^{\frac{1}{\lambda_w} - 1} - x W_{k,t} = 0$$

$$[\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w - 1} \frac{1}{\lambda_w} l_{k,t}^{\frac{1}{\lambda_w} - 1} = x W_{k,t}$$

From the first equation:

$$l_t = [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w}$$

$$l_t^{-\frac{1}{\lambda_w}} = [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{-1}$$

FOC would become:

$$l_t^{1-\frac{1}{\lambda_w}} l_{k,t}^{\frac{1}{\lambda_w} - 1} = x W_{k,t}$$

$$l_t^{\frac{\lambda_w - 1}{\lambda_w}} l_{k,t}^{\frac{1-\lambda_w}{\lambda_w}} = x W_{k,t}$$

$$l_{k,t}^{\frac{1-\lambda_w}{\lambda_w}} = [x W_{k,t}] l_t^{\frac{1-\lambda_w}{\lambda_w}}$$

$$l_{k,t} = [x W_{k,t}]^{\frac{\lambda_w}{1-\lambda_w}} l_t$$

Above is substituted in the first equation

$$l_t = [\int_0^1 l_{k,t}^{\frac{1}{\lambda_w}} dk]^{\lambda_w}$$

$$l_t = [\int_0^1 [[xW_{k,t}]^{\frac{\lambda_w}{1-\lambda_w}} l_t]^{\frac{1}{\lambda_w}} dk]^{\lambda_w}$$

$$l_t = [\int_0^1 l_t^{\frac{1}{\lambda_w}} x^{\frac{1}{1-\lambda_w}} (W_{k,t}^{\frac{\lambda_w}{1-\lambda_w}})^{\frac{1}{\lambda_w}} dk]^{\lambda_w}$$

$$l_t = l_t x^{\frac{\lambda_w}{1-\lambda_w}} [\int_0^1 (W_{k,t}^{\frac{1}{1-\lambda_w}}) dk]^{\lambda_w}$$

$$x^{\frac{\lambda_w}{\lambda_w - 1}} = [\int_0^1 (W_{k,t}^{o,\frac{1}{1-\lambda_w}}) dk]^{\lambda_w}$$

$$x^{\frac{1}{\lambda_w - 1}} = [\int_0^1 (W_{k,t}^{\frac{1}{1-\lambda_w}}) dk]$$

$$x = [\int_0^1 (W_{k,t}^{\frac{1}{1-\lambda_w}}) dk]^{\lambda_w - 1}$$

$$x = \frac{1}{[\int_0^1 (W_{k,t}^{\frac{1}{1-\lambda_w}}) dk]^{1-\lambda_w}} = \frac{1}{W_t}$$

$$[\int_0^1 (W_{k,t}^{\frac{1}{1-\lambda_w}}) dk]^{1-\lambda_w} = W_t$$

Putting

$$x = \frac{1}{W_t}$$

in

$$l_{k,t} = [xW_{k,t}]^{\frac{\lambda_w}{1-\lambda_w}} l_t$$

$$l_{k,t} = [\frac{W_{k,t}}{W_t}]^{\frac{\lambda_w}{1-\lambda_w}} l_t$$

The labor demand function can be plugged into the Dixit-Stiglitz aggregator to obtain the aggregate wage index.

$$W_t = [\int_0^1 W_{k,t}^{\frac{1}{1-\lambda_w}} dk]^{1-\lambda_w}$$

k) Monopoly Unions

Monopoly Union k objective function is:

$$\max_{W_{k,t}} E_t \sum_{s=0}^{\infty} \xi_w^s \beta^s [\Lambda_{z,t+s}(1-\tau_l) W_{k,t} \tilde{\pi}_{t,t+s}^w l_{k,t+s} - \psi_l \int_0^1 \frac{l_{k,t+s}^{1+\sigma_l}}{1+\sigma_l} dk]$$

subject to the demand function

$$l_{k,t+s} = [\frac{W_{k,t} \tilde{\pi}_{t,t+s}^w}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}} l_{t+s}$$

where

$$\tilde{\pi}_{t,t+s}^w = \Pi_{k=1}^s \mu_{z*} \pi_{w,t+k}$$

and

$$\tilde{\pi}_{w,t} = \pi^{i_w} \pi_{t-1}^{1-i_w}$$

$$\pi^w_{t,t+s} = \Pi^s_{k=1}\pi_{w,t+k}$$

FOC can be found as follows: First term:

$$W_{k,t}\tilde{\pi}^w_{t,t+s}l_{k,t+s} = W_{k,t}\tilde{\pi}^w_{t,t+s}[\frac{W_{k,t}\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}$$

$$= \frac{l_{t+s}}{(W_{t+s})^{\frac{\lambda_w}{1-\lambda_w}}}[W_{k,t}\tilde{\pi}^w_{t,t+s}]^{\frac{1}{1-\lambda_w}}$$

Differential of the first term wrt $W_{k,t}$

$$= \frac{l_{t+s}}{(W_{t+s})^{\frac{\lambda_w}{1-\lambda_w}}}\frac{1}{1-\lambda_w}[W_{k,t}\tilde{\pi}^w_{t,t+s}]^{\frac{1}{1-\lambda_w}-1}\tilde{\pi}^w_{t,t+s}$$

$$= \frac{l_{t+s}\tilde{\pi}^w_{t,t+s}}{(W_{t+s})^{\frac{\lambda_w}{1-\lambda_w}}}\frac{1}{1-\lambda_w}[W_{k,t}\tilde{\pi}^w_{t,t+s}]^{\frac{\lambda_w}{1-\lambda_w}}$$

$$= \frac{l_{t+s}\tilde{\pi}^w_{t,t+s}}{(1-\lambda_w)}[\frac{W_{k,t}\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}$$

Second term:

$$\int_0^1 \frac{l^{1+\sigma_l}_{k,t+s}}{1+\sigma_l}dk$$

Differential of the second term wrt $W_{k,t}$

$$\frac{1+\sigma_l}{1+\sigma_l}l^{o,\sigma_l}_{k,t+s}\frac{d}{dW_{k,t}}l_{k,t+s} = l^{\sigma_l}_{k,t+s}\frac{d}{dW_{k,t}}[\frac{W^o_{k,t}\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}$$

$$\{[\frac{W_{k,t}\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}\}^{\sigma_l}l_{t+s}\frac{\lambda_w}{1-\lambda_w}[\frac{W_{k,t}\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}-1}\frac{\tilde{\pi}^w_{t,t+s}}{W_{t+s}}$$

The optimal wage depends on the aggregate variables and same for all the workers union. Hence,

$$W_{k,t} = \tilde{W}_t$$

Complete FOC is as follows:

$$E_t\sum_{s=0}^{\infty}\xi^s_w\beta^s\left\{\Lambda_{z,t+s}\frac{1-\tau_l}{1-\lambda_w}[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}\tilde{\pi}^w_{t,t+s} - \psi_l\{[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}\}^{\sigma_l}l_{t+s}\frac{\lambda_w}{1-\lambda_w}[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}-1}\frac{\tilde{\pi}^w_{t,t+s}}{W_{t+s}}\right\} = 0$$

$$E_t\sum_{s=0}^{\infty}\xi^s_w\beta^s[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}l_{t+s}\left\{\Lambda_{z,t+s}(1-\tau_l)\tilde{\pi}^w_{t,t+s} - \psi_l[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w\sigma_l}{1-\lambda_w}}l^{\sigma_l}_{t+s}\lambda_w[\frac{W^o_{t+s}}{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}][\frac{\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]\right\} = 0$$

$$E_t\sum_{s=0}^{\infty}\xi^s_w\beta^s l_{t+s}[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}\{\Lambda_{z,t+s}(1-\tau_l)\tilde{\pi}^w_{t,t+s} - \psi_l\frac{\lambda_w}{\tilde{w}_t}[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W_{t+s}}]^{\frac{\lambda_w\sigma_l}{1-\lambda_w}}l^{\sigma_l}_{t+s} = 0$$

$$W_{t+s} = W_t\pi^w_{t,t+s}$$

$$E_t\sum_{s=0}^{\infty}\xi^s_w\beta^s l_{t+s}\Lambda_{z,t+s}(1-\tau_l)\tilde{\pi}^w_{t,t+s}[\frac{\tilde{W}_t\tilde{\pi}^w_{t,t+s}}{W^o_t\pi^w_{t,t+s}}]^{\frac{\lambda_w}{1-\lambda_w}} = E_t\sum_{s=0}^{\infty}\xi^s_w\beta^s l^{\sigma_l+1}_{t+s}\psi_l\frac{\lambda_w}{\tilde{w}_t}[\frac{\tilde{W}^o_t\tilde{\pi}^w_{t,t+s}}{W_t\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$(1-\tau_l)E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\Lambda_{z,t+s}[\frac{\tilde{W}_t}{W_t}]^{\frac{\lambda_w}{1-\lambda_w}}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}\tilde{\pi}^w_{t,t+s}=\psi_l\frac{\lambda_w}{\tilde{w}_t}E_t\sum_{s=0}^{\infty}\epsilon_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{W}_t}{W_t}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$(1-\tau_l)[\frac{\tilde{W}_t}{W_t}]^{\frac{\lambda_w}{1-\lambda_w}}E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\Lambda_{z,t+s}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w}{1-\lambda_w}}\tilde{\pi}^w_{t,t+s}=\psi_l\frac{\lambda_w}{\tilde{w}_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}}E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$(1-\tau_l)\tilde{W}_t[\frac{\tilde{W}_t}{W_t}]^{\frac{-\lambda_w\sigma_l}{1-\lambda_w}}E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\Lambda_{z,t+s}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+1-1}{1-\lambda_w}}\tilde{\pi}^w_{t,t+s}=\psi_l\lambda_w E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$(1-\tau_l)W_t\frac{\tilde{W}_t}{W_t}\frac{P_t}{P_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{-\lambda_w\sigma_l}{1-\lambda_w}}E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\Lambda_{z,t+s}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{1}{1-\lambda_w}}[\frac{\pi^w_{t,t+s}}{\tilde{\pi}^w_{t,t+s}}]\tilde{\pi}^w_{t,t+s}=\psi_l\lambda_w E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$\frac{W_t}{P_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{1-\lambda_w(1+\sigma_l)}{1-\lambda_w}}\frac{1}{\psi_l\lambda_w}E_t[\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}(1-\tau_l)[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{1}{1-\lambda_w}}\Lambda_{z,t+s}\pi^w_{t,t+s}]P_t=E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$P_{t+s}=P_t\Pi_{t,t+s}$$

$$\frac{W_t}{P_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{1-\lambda_w(1+\sigma_l)}{1-\lambda_w}}\frac{1}{\psi_l\lambda_w}E_t[\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}(1-\tau_l)[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{1}{1-\lambda_w}}\Lambda_{z,t+s}[\frac{\pi^w_{t,t+s}}{\pi_{t,t+s}}]P_{t+s}=E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$\frac{W_t}{P_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{1-\lambda_w(1+\sigma_l)}{1-\lambda_w}}\frac{1}{\psi_l}E_t[\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\frac{(1-\tau_l)}{\lambda_w}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{1}{1-\lambda_w}}\Lambda_{z,t+s}[\frac{\Pi^w_{t,t+s}}{\pi_{t,t+s}}]P_{t+s}=E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w+\lambda_w\sigma_l}{1-\lambda_w}}$$

$$\frac{W_t}{P_t}[\frac{\tilde{W}_t}{W_t}]^{\frac{1-\lambda_w(1+\sigma_l)}{1-\lambda_w}}\frac{1}{\psi_l}=\frac{E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}^{\sigma_l+1}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}}}{E_t\sum_{s=0}^{\infty}\xi_w^s\beta^s l_{t+s}\frac{(1-\tau_l)}{\lambda_w}[\frac{\tilde{\pi}^w_{t,t+s}}{\pi^w_{t,t+s}}]^{\frac{1}{1-\lambda_w}}\Lambda_{z,t+s}[\frac{\pi^w_{t,t+s}}{\pi_{t,t+s}}]P_{t+s}}=\frac{K_{w,t}}{F_{w,t}}$$

Infinite sums can be expressed in recursive form:

$$K_{w,t}=l_t^{1+\sigma_l}+\xi_w\beta E_t(\tilde{\pi}^w_{t,t+1}\pi^{-1}_{w,t+1}\mu_{z*})^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}}K_{w,t+1}$$

$$F_{w,t}=\frac{1-\tau_l}{\lambda_w}l_tP_t\Lambda_{z,t}+\xi_w\beta E_t[\tilde{\pi}^w_{t,t+1}\mu_{z*}]^{\frac{1}{1-\lambda_w}}\pi^{\frac{\lambda_w}{\lambda_w-1}}_{w,t+1}\pi^{-1}_{t+1}F_{w,t+1}$$

$$\frac{\tilde{W}_t}{W_t}=[\psi_l\frac{K_{w,t}}{F_{w,t}}\frac{P_t}{W_t}]^{\frac{1-\lambda_w}{1-\lambda_w(1+\sigma_l)}}$$

B Equilibrium Equations - Oil Shock Model without Banks

a) Scaled Variables

In order to solve the model, the variables need to be stationarize as follows:

$$c_t = \frac{C_t}{z_t^*}$$

$$F_{w,t} = F_{W,t} z_t^*$$

$$g_t = \frac{G_t}{z_t^* P_t}$$

$$i_t = \frac{I_t}{z_t^* \Upsilon^t}$$

$$i_t^o = \frac{I_t^o}{z_t^* \Upsilon^t}$$

$$k_t = \frac{K_t}{z_t^* \Upsilon^t}$$

$$x_t^o = \frac{X_t^o}{z_t^* \Upsilon^t}$$

$$\lambda_{z,t} = \Lambda_{z,t} P_t z_t^*$$

$$o_t = \frac{O_t}{z_t^* \Upsilon^t}$$

$$\tilde{p}_t = \frac{\tilde{P}_t}{P_t}$$

$$p_t^o = \frac{\Upsilon^t P_t^o}{P_t}$$

$$r_t^k = \Upsilon^t \tilde{r}_t^k$$

$$r_t^o = \Upsilon^t \tilde{r}_t^o$$

$$s_t = \frac{S_t}{P_t}$$

$$s_t^o = \frac{\Upsilon^t S_t^o}{P_t}$$

$$t_t = \frac{T_t}{z_t^* P_t}$$

$$w_t = \frac{W_t}{z_t^* P_t}$$

$$x_t = \frac{X_t}{z_t^* \Upsilon^t}$$

$$y_{z,t} = \frac{Y_t}{z_t^*}$$

$$y_t = \frac{Y_t^{gdp}}{z_t^*}$$
$$\mu_{z^*,t} = \frac{z_t^*}{z_{t-1}^*}$$
$$z_t^* = z_t \Upsilon^{(\frac{1-\alpha_l}{\alpha_l})t}$$

b) Optimal Price Equilibrium Equations

$$F_{p,t} = \Lambda_{z,t} P_t Y_t \frac{1}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1}$$
$$F_{p,t} = \Lambda_{z,t} P_t Y_t (\frac{z_t^*}{z_t^*}) \frac{1}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1}$$
$$F_{p,t} = (z_t^* \Lambda_{z,t} P_t)(\frac{Y_t}{z_t^*}) \frac{1}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1}$$
$$F_{p,t} = \lambda_{z,t} y_{z,t} \frac{1}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1}$$
$$F_{p,t} = \lambda_{z,t} y_{z,t} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F_{p,t+1} \tag{1}$$
$$K_{p,t} = \Lambda_{z,t} P_t Y_t \frac{S_t}{P_t} \frac{\lambda_{p,t}}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1}$$
$$K_{p,t} = (\Lambda_{z,t} P_t z_t^*) \frac{Y_t}{z_t^*} \frac{S_t}{P_t} \frac{\lambda_{p,t}}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1}$$
$$K_{p,t} = \lambda_{z,t} y_{z,t} s_t \frac{\lambda_{p,t}}{1-\lambda_{p,t}} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1}$$
$$K_{p,t} = \lambda_{z,t} y_{z,t} s_t \lambda_{p,t} + \xi_p \beta E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K_{p,t+1} \tag{2}$$

Above two equations can be related by:

$$K_{p,t} = \{[1 - \xi_p (\frac{\tilde{\pi}_t}{\pi_t})^{\frac{1}{1-\lambda_{p,t}}}](1-\xi_p)^{-1}\}^{1-\lambda_{p,t}} F_{p,t} \tag{3}$$

c) Wages Equilibrium Equations

$$F_{W,t} = \frac{1-\tau_l}{\lambda_w} l_t P_t \Lambda_{z,t} + \xi_w \beta E_t [\tilde{\pi}_{t,t+1}^w \mu_{z*}]^{\frac{1}{1-\lambda_w}} \pi_{w,t+1}^{\frac{\lambda_w}{\lambda_w - 1}} \pi_{t+1}^{-1} F_{W,t+1}$$
$$z_t^* F_{W,t} = \frac{1-\tau_l}{\lambda_w} l_t P_t \Lambda_{z,t} z_t^* + \xi_w \beta E_t [\tilde{\pi}_{t,t+1}^w \mu_{z*}]^{\frac{1}{1-\lambda_w}} \pi_{w,t+1}^{\frac{\lambda_w}{\lambda_w - 1}} \pi_{t+1}^{-1} F_{W,t+1} z_t^* \frac{z_{t+1}^*}{z_{t+1}^*}$$
$$F_{w,t} = \frac{1-\tau_l}{\lambda_w} l_t \lambda_{z,t} + \xi_w \beta E_t \mu_{z_{t+1}^*}^{-1} [\tilde{\pi}_{t,t+1}^w \mu_{z*}]^{\frac{1}{1-\lambda_w}} \pi_{w,t+1}^{\frac{\lambda_w}{\lambda_w - 1}} \pi_{t+1}^{-1} F_{w,t+1}$$
$$F_{w,t} = (1-\tau_l)\lambda_w^{-1} l_t \lambda_{z,t} + \xi_w \beta \mu_{z*}^{\frac{1}{1-\lambda_w}} E_t \mu_{z^*,t+1}^{-1} \pi_{w,t+1}^{\frac{\lambda_w}{\lambda_w - 1}} \tilde{\pi}_{w,t+1}^{\frac{1}{1-\lambda_w}} \pi_{t+1}^{-1} F_{w,t+1} \tag{4}$$
$$K_{w,t} = l_t^{1+\sigma_l} + \xi_w \beta E_t (\tilde{\pi}_{w,t+1} \pi_{w,t+1}^{-1} \mu_{z*})^{\frac{\lambda_w (1+\sigma_l)}{1-\lambda_w}} K_{w,t+1} \tag{5}$$

Above two equations can be related as:

$$K_{w,t} = \psi_l^{-1} [(1 - \xi_w (\tilde{\pi}_{w,t} \pi_{w,t}^{-1} \mu_{z^*})^{\frac{1}{1-\lambda_w}})(1-\xi_w)^{-1}]^{1-\lambda_w(1+\sigma_l)} w_t F_{w,t} \tag{6}$$

d) Production Equilibrium Equations

FOC from the utilization rate is:

$$\Upsilon^t \tilde{r}_t^k = r^k exp(\sigma_a[u_t - 1])$$

The scaling variable is

$$r_t^k = \Upsilon^t \tilde{r}_t^k$$

Hence, above equation becomes:

$$r_t^k = r^k exp(\sigma_a[u_t - 1]) \tag{7}$$

Capital services FOC is:

$$P_t \tilde{r}_t^k = S_t \alpha_k \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k - 1} O_t^{1-\alpha_l-\alpha_k}$$

$$\Upsilon^t \tilde{r}_t^k = \frac{S_t}{P_t} \alpha_k \epsilon_t (\frac{z_t^*}{[\Upsilon^{\frac{\alpha_l}{1-\alpha_l} t}]} l_t)^{\alpha_l} \Upsilon^t (u_t \frac{K_{t-1}}{z_t^* \Upsilon^{t-1}})^{\alpha_k - 1} (z_t^* \Upsilon^{t-1})^{\alpha_k - 1} [\frac{O_t}{z_t^* \Upsilon^t}]^{1-\alpha_l-\alpha_k} [z_t^* \Upsilon^t]^{1-\alpha_l-\alpha_k}$$

$$r_t^k = s_t \alpha_k \epsilon_t l_t^{\alpha_l} (\frac{z_t^{*\alpha_l}}{[\Upsilon^{\frac{\alpha_l}{1-\alpha_l} t}]})^{\alpha_l} \Upsilon^t (u_t k_{t-1})^{\alpha_k - 1} o_t^{1-\alpha_l-\alpha_k} z_t^{*,\alpha_k - 1} z_t^{*,1-\alpha_l-\alpha_k} \Upsilon^{(t-1)(\alpha_k-1)} \Upsilon^{t(1-\alpha_l-\alpha_k)}$$

$$r_t^k = s_t \alpha_k \epsilon_t l_t^{\alpha_l} (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k - 1} o_t^{1-\alpha_l-\alpha_k} \tag{8}$$

Similarly, FOC for labor demand can be stationarized as below:

$$W_t l_t = S_t \alpha_l \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{1-\alpha_l-\alpha_k}$$

$$w_t l_t = \alpha_l s_t \epsilon_t l_t^{\alpha_l} (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k} \tag{9}$$

FOC for oil can be stationarized as:

$$P_t^o = S_t (1 - \alpha_l - \alpha_k) \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{-\alpha_l-\alpha_k}$$

$$p_t^o = (1 - \alpha_l - \alpha_k) s_t \epsilon_t l_t^{\alpha_l} (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} o_t^{-\alpha_l-\alpha_k} \tag{10}$$

Following is the capital producer technology:

$$K_t = (1 - \delta) K_{t-1} + [1 - S^k(\zeta_{i,t} \frac{I_t}{I_{t-1}})] I_t$$

$$K_t = (1 - \delta) \frac{K_{t-1}(z_{t-1}^* \Upsilon^{t-1})}{(z_{t-1}^* \Upsilon^{t-1})} + [1 - S^k(\zeta_{i,t} \frac{I_t}{I_{t-1}} \frac{z_{t-1}^* \Upsilon^{t-1}}{z_{t-1}^* \Upsilon^{t-1}} \frac{z_t^* \Upsilon^t}{z_t^* \Upsilon^t})] \frac{z_t^* \Upsilon^t}{z_t^* \Upsilon^t} I_t$$

$$\frac{K_t}{z_t^* \Upsilon^t} = (1 - \delta) k_{t-1} \frac{(z_{t-1}^* \Upsilon^{t-1})}{(z_t^* \Upsilon^t)} + [1 - S^k(\zeta_{i,t} \frac{i_t}{i_{t-1}} \mu_{z^*,t} \Upsilon)] \frac{z_t^* \Upsilon^t}{z_t^* \Upsilon^t} i_t$$

$$k_t = (1 - \delta) k_{t-1} \mu_{z^*,t}^{-1} \Upsilon^{-1} + [1 - S^k(\zeta_{i,t} \frac{i_t}{i_{t-1}} \mu_{z^*,t} \Upsilon)] i_t \tag{11}$$

The aggregate production function can be stationarize as follows:

$$Y_t = \epsilon_t (z_t l_t)^{\alpha_l} (u_t K_{t-1})^{\alpha_k} O_t^{1-\alpha_l-\alpha_k} - \theta z_t^*$$

$$y_{z,t} = \epsilon_t l_t^{\alpha_l} (\frac{u_t k_{t-1}}{\Upsilon \mu_{z_t^*}})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k} - \theta \tag{12}$$

where θ is:

$$\theta = l_t^{\alpha_l} (\Upsilon^{-1} \mu_{z_t^*}^{-1} u_t k_{t-1})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k} [1 - \frac{1}{\lambda_p}]$$

e) Resource Constraints

The output is used for the government expenditures, consumption, investment, entrepreneur utilization adjustment and banks agency cost to monitor defaulting borrowers. The resource constraint is:

$$Y_t = G_t + C_t + \Upsilon^{-t}(I_t + I_t^o) + a(u_t)\Upsilon^{-t}K_{t-1} + a(u_t^o)\Upsilon^{-t}X_{t-1}^o$$

$$\frac{Y_t}{z_t^*} = \frac{G_t}{z_t^*} + \frac{C_t}{z_t^*} + \Upsilon^{-t}\frac{(I_t + I_t^o)}{z_t^*} + a(u_t)\Upsilon^{-t}\frac{K_{t-1}}{z_t^*} + a(u_t^o)\Upsilon^{-t}\frac{X_{t-1}^o}{z_t^*}$$

$$y_{z,t} = g_t + c_t + (i_t + i_t^o) + a(u_t)\Upsilon^{-t}\frac{z_{t-1}^*\Upsilon^{t-1}}{z_t^*}\frac{K_{t-1}}{z_{t-1}^*\Upsilon^{t-1}} + a(u_t^o)\Upsilon^{-t}\frac{z_{t-1}^*\Upsilon^{t-1}}{z_t^*}\frac{X_{t-1}}{z_{t-1}^*\Upsilon^{t-1}}$$

$$y_{z,t} = g_t + c_t + (i_t + i_t^o) + a(u_t)\Upsilon^{-1}{\mu_{z^*,t}}^{-1}k_{t-1} + a(u_t^o)\Upsilon^{-1}{\mu_{z^*,t}}^{-1}x_{t-1}^o \tag{13}$$

The stationarized GDP is:

$$Y_t^{GDP} = G_t + C_t + \Upsilon^{-t}(I_t + I_t^o)$$

$$\frac{Y_t^{GDP}}{z_t^*} = \frac{G_t}{z_t^*} + \frac{C_t}{z_t^*} + \Upsilon^{-t}\frac{I_t + I_t^o}{z_t^*}$$

$$y_t = g_t + c_t + i_t + i_t^o \tag{14}$$

f) Government

Government monetary policy is:

$$R_t - R = \rho_p(R_{t-1} - R) + (1 - \rho_p)[\alpha_\pi(E_t\pi_{t+1} - \pi) + \alpha_{\Delta Y}(g_{y,t} - \mu_z)] + \epsilon_t^p \tag{15}$$

Government fiscal policy is:

$$G_t + T_t = [u_t r_t^k - a(u_t)]\Upsilon^{-t}P_tK_{t-1}\tau^k - \delta\Upsilon^{-t}P_tK_{t-1}\tau^k + W_tl_t\tau^l + P_tC_t\tau^c$$

$$G_t + T_t = \{[u_t r_t^k - a(u_t)] - \delta\}\Upsilon^{-t}P_tK_{t-1}\tau^k + W_tl_t\tau^l + P_tC_t\tau^c$$

$$\frac{G_t}{P_tz_t^*} + \frac{T_t}{P_tz_t^*} = \{[u_t r_t^k - a(u_t)] - \delta\}\Upsilon^{-t}P_t\frac{K_{t-1}}{P_tz_t^*}\tau^k + \frac{W_t}{P_tz_t^*}l_t\tau^l + P_t\frac{C_t}{P_tz_t^*}\tau^c$$

$$g_t + t_t = \{[u_t r_t^k - a(u_t)] - \delta\}k_{t-1}\mu_{z^*,t}^{-1}\Upsilon^{-1}\tau^k + w_tl_t\tau^l + c_t\tau^c \tag{16}$$

g) Oil Producer

The oil production function is stationarized as:

$$O_t = \epsilon_t^o[u_t^oX_{t-1}^o]$$

$$\frac{O_t}{z_t^*\Upsilon^t} = \epsilon_t^o[u_t^o\frac{X_{t-1}^o}{z_t^*\Upsilon^t}]$$

$$o_t = \epsilon_t^o u_t^o x_{t-1}^o\frac{z_{t-1}^*\Upsilon^{t-1}}{z_t^*\Upsilon^t}$$

$$o_t = \epsilon_t^o u_t^o x_{t-1}^o[\mu_{z^*,t}\Upsilon]^{-1} \tag{17}$$

Stationarize marginal cost for the downstream oil firm:

$$\frac{S_t^o}{P_t} = \frac{\tilde{r}_t^o}{\epsilon_t^o}$$

$$\Upsilon^t \frac{S_t^o}{P_t} = \Upsilon^t \frac{\tilde{r}_t^o}{\epsilon_t^o}$$

$$s_t^o = \frac{r_t^o}{\epsilon_t^o} \tag{18}$$

Stationarize oil price is:

$$\Upsilon^t \frac{P_t^o}{P_t} = \Upsilon^t \frac{\tilde{r}_t^o}{\epsilon_t^o}(\frac{\lambda_{o,t}}{\lambda_{o,t}-1})$$

$$p_t^o = \frac{r_t^o}{\epsilon_t^o}(\frac{\lambda_{o,t}}{\lambda_{o,t}-1}) \tag{19}$$

The upstream oil producer technology is:

$$X_t^o = X_{t-1}^o(1-\delta) + [1 - S^o(\frac{I_t^o}{I_{t-1}^o})]I_t^x, \delta \in (0,1)$$

$$\frac{X_t^o}{z_t^* \Upsilon^t} = \frac{X_{t-1}^o}{z_{t-1}^* \Upsilon^{t-1}} \frac{z_{t-1}^* \Upsilon^{t-1}}{z_t^* \Upsilon^t}(1-\delta) + [1 - S^o(\frac{I_t^o}{I_{t-1}^o} \frac{z_t^* \Upsilon^t}{z_t^* \Upsilon^t} \frac{z_{t-1}^* \Upsilon^{t-1}}{z_{t-1}^* \Upsilon^{t-1}})] \frac{I_t^o}{z_t^* \Upsilon^t}$$

$$x_t^o = \frac{x_{t-1}^o}{\mu_{z^*,t} \Upsilon}(1-\delta) + [1 - S^o(\frac{i_t^o}{i_{t-1}^o} \mu_{z^*,t} \Upsilon)] i_t^o \tag{20}$$

Upstream reserves rental cost is:

$$\Upsilon^t \tilde{r}_t^o = r^x exp(\sigma_a[u_t^o - 1])$$

$$r_t^o = r^o exp(\sigma_a[u_t^o - 1]) \tag{21}$$

Optimal capital investment in the upstream is stationarized as follows:

$$-\frac{\Lambda_{z,t}}{\Upsilon^t} + \beta E_t \Lambda_{z,t+1} u_{t+1}^o \tilde{r}_{t+1}^o [1 - S^o(\frac{I_t^o}{I_{t-1}^o}) - \frac{I_t^o}{I_{t-1}^o} \zeta_{o,t} S^{o\prime}(\frac{I_t^o}{I_{t-1}^o})] + \beta^2 E_t \Lambda_{z,t+2} u_{t+2}^o \tilde{r}_{t+2}^o (\frac{I_{t+1}^o}{I_t^o})^2 S^{o\prime}(\frac{I_{t+1}^o}{I_t^o}) = 0$$

$$-\frac{\lambda_{z,t}}{P_t z_t^*} \frac{1}{\Upsilon^t} + \beta E_t \frac{\lambda_{z,t+1}}{P_{t+1} z_{t+1}^*} u_{t+1}^o \tilde{r}_{t+1}^o [1 - S^o(\frac{I_t^o}{I_{t-1}^o}) - \frac{z_t^* \Upsilon^t}{z_t^* \Upsilon^t} \frac{z_{t-1}^* \Upsilon^{t-1}}{z_{t-1}^* \Upsilon^{t-1}} \frac{I_t^o}{I_{t-1}^o} \zeta_{o,t} S^{o\prime}(\frac{I_t^o}{I_{t-1}^o})]$$
$$+\beta^2 E_t \frac{\lambda_{z,t+2}}{P_{t+2} z_{t+2}^*} u_{t+2}^o \tilde{r}_{t+2}^o (\frac{I_{t+1}^o}{I_t^o})^2 S^{o\prime}(\frac{I_{t+1}^o}{I_t^o}) = 0$$

$$-\lambda_{z,t} + \frac{\beta}{\Upsilon} E_t \frac{\lambda_{z,t+1}}{\pi_{t+1} \mu_{z_{t+1}^*}} u_{t+1}^o r_{t+1}^o [1 - S^o(\frac{i_t^o}{i_{t-1}^o} \Upsilon \mu_{z_t^*}) - \frac{i_t^o}{i_{t-1}^o} \Upsilon \mu_{z_t^*} S^{o\prime}(\frac{i_t^o}{i_{t-1}^o} \Upsilon \mu_{z_t^*})]$$
$$+\frac{\beta^2}{\Upsilon^2} \frac{\lambda_{z,t+2}}{\pi_{t+1} \pi_{t+2} \mu_{z_{t+1}^*} \mu_{z_{t+2}^*}} u_{t+2}^o r_{t+2}^o (\frac{i_{t+1}^o}{i_t^o} \mu_{z_{t+1}^*} \Upsilon)^2 \zeta_{o,t+1} S^{x\prime}(\frac{I_{t+1}^o}{I_t^o}) = 0$$

$$-\lambda_{z,t} + \frac{\beta}{\Upsilon} E_t \frac{\lambda_{z,t+1}}{\pi_{t+1} \mu_{z_{t+1}^*}} u_{t+1}^o r_{t+1}^o [1 - S^x(.) - \frac{i_t^o}{i_{t-1}^o} \Upsilon \mu_{z_t^*} S^{o\prime}(.)] + \frac{\beta^2}{\Upsilon^2} \frac{\lambda_{z,t+2}}{\pi_{t+1} \pi_{t+2} \mu_{z_{t+1}^*} \mu_{z_{t+2}^*}} u_{t+2}^o r_{t+2}^o (\frac{i_{t+1}^o}{i_t^o} \mu_{z_{t+1}^*} \Upsilon)^2 S^{o\prime\prime}(\frac{i_{t+1}^o}{i_t^o}) = 0 \tag{22}$$

h) Household Equilibrium Equations

FOC wrt consumption:

$$\Lambda_{z,t}(1+\tau^c)P_t - \frac{1}{C_t - b_c C_{t-1}} + \mathbb{E}_t \frac{\beta b_c}{C_{t+1} - b_c C_t} = 0$$

$$\frac{-1}{C_t - b_c C_{t-1}} + \Lambda_{z,t}(1+\tau^c)P_t + \beta \frac{E_t b_c}{C_{t+1} - b_c C_t} = 0$$

$$\frac{-1}{z_t^* c_t - b_c z_{t-1}^* c_{t-1}} + \frac{\lambda_{z,t}}{P_t z_t^*}(1+\tau^c)P_t + \beta \frac{E_t b_c}{z_t^*[\mu_{z^*,t+1} c_{t+1} - b_c c_t]} = 0$$

$$\frac{-1}{z_{t-1}^*[\mu_{z^*,t}^* c_t - b_c c_{t-1}]} + \frac{\lambda_{z,t}}{z_t^*}(1+\tau^c) + \beta \frac{E_t b_c}{z_t^*[\mu_{z^*,t+1} c_{t+1} - b_c c_t]} = 0$$

$$\frac{-\mu_{z^*,t}}{[\mu_{z^*,t} c_t - b_c c_{t-1}]} + \lambda_{z,t}(1+\tau^c) + \beta \frac{E_t b_c}{[\mu_{z^*,t+1} c_{t+1} - b_c c_t]} = 0 \tag{23}$$

FOC w.r.t investment:

$$-\Lambda_{z,t}\frac{P_t}{\Upsilon^t} + \beta E_t \Lambda_{z,t+1} \Upsilon^{-(t+1)} P_{t+1}\{(1-\tau^k)(u_{t+1} r_{t+1}^k - a(u_{t+1})) + \tau^k \delta\}\{1 - S^k(\zeta_{i,t}\frac{I_t}{I_{t-1}}) - \frac{I_t}{I_{t-1}}\zeta_{i,t} S^{k\prime}(\zeta_{i,t}\frac{I_t}{I_{t-1}})\}$$

$$+\beta^2 E_t \Lambda_{z,t+2} \Upsilon^{-(t+2)} P_{t+2}\{(1-\tau^k)(u_{t+2} r_{t+2}^k - a(u_{t+2})) + \tau^k \delta\}\{(\frac{I_{t+}}{I_t})^2 \zeta_{i,t+1} S^{k\prime}(\zeta_{i,t+1}\frac{I_{t+1}}{I_t})\} = 0$$

$$-\Lambda_{z,t}\frac{P_t}{\Upsilon^t} + \beta E_t \Lambda_{z,t+1} \Upsilon^{-(t+1)} P_{t+1}\{(1-\tau^k)(u_{t+1} r_{t+1}^k - a(u_{t+1})) + \tau^k \delta\}\{1 - S^k(\zeta_{i,t}\frac{I_t}{I_{t-1}}) - \frac{I_t}{I_{t-1}}\zeta_{i,t} S^{k\prime}(\zeta_{i,t}\frac{I_t}{I_{t-1}})\}$$

$$+\beta^2 E_t \Lambda_{z,t+2} \Upsilon^{-(t+2)} P_{t+2}\{(1-\tau^k)(u_{t+2} r_{t+2}^k - a(u_{t+2})) + \tau^k \delta\}\{(\frac{I_{t+}}{I_t})^2 \zeta_{i,t+1} S^{k\prime}(\zeta_{i,t+1}\frac{I_{t+1}}{I_t})\} = 0$$

$$-\lambda_{z,t} + \beta E_t \frac{\lambda_{z,t+1}}{\mu_{z_{t+1}^*}} \Upsilon^{-1}\{(1-\tau^k)(u_{t+1} r_{t+1}^k - a(u_{t+1})) + \tau^k \delta\}\{1 - S^k(\zeta_{i,t}\frac{i_t}{i_{t-1}}\Upsilon\mu_{z_t^*}) - \zeta_{i,t}\frac{i_t}{i_{t-1}}\Upsilon\mu_{z_t^*} S^{k\prime}(\zeta_{i,t}\frac{i_t}{i_{t-1}}\Upsilon\mu_{z_t^*})\}$$

$$+\beta^2 E_t \frac{\lambda_{z,t+2}}{\mu_{z_{t+1}^*}\mu_{z_{t+2}^*}} \Upsilon^{-2}\{(1-\tau^k)(u_{t+2} r_{t+2}^k - a(u_{t+2})) + \tau^k \delta\}\{\zeta_{i,t+1}(\frac{i_{t+1}}{i_t}\Upsilon\mu_{z_t^*})^2 S^{k\prime}(\zeta_{i,t+1}\frac{i_{t+1}}{i_t}\Upsilon\mu_{z_{t+1}^*})\} = 0 \tag{24}$$

FOC w.rt deposits:

$$-P_t\Lambda_{z,t} + \beta P_t E_t \Lambda_{z,t+1} R_{t+1} = 0$$

$$P_t \frac{\lambda_{z,t}}{z_t^* P_t} - P_t \beta E_t \frac{\lambda_{z,t+1}}{z_{t+1}^* P_{t+1}} R_{t+1} = 0$$

$$\frac{\lambda_{z,t}}{z_t^*} - \beta E_t \frac{\lambda_{z,t+1}}{\mu_{z^*,t+1}\pi_{t+1}} R_{t+1} = 0$$

$$\lambda_{z,t} - \beta E_t \lambda_{z,t+1}[\mu_{z^*,t+1}\pi_{t+1}]^{-1} R_{t+1} = 0 \tag{25}$$

i) Auxiliary Equations

Price and wage indexation and wage inflation:

$$\tilde{\pi}_t = \pi^{i_p} \pi_{t-1}^{1-i_p}$$

$$\tilde{\pi}_{w,t} = \pi^{i_w} \pi_{t-1}^{1-i_w}$$

$$\pi_{w,t} = \pi_t \mu_{z^*,t} \frac{w_t}{w_{t-1}}$$

Adjustment cost for the utilization of capital and upstream reserves are:

$$a(u_t) = r^k (exp[\sigma_a (u_t - 1)] - 1)/\sigma_a$$

$$a(u_t^o) = r^o (exp[\sigma_a (u_t^o - 1)] - 1)/\sigma_a$$

Adjustment costs for the capital investment, housing and upstream investments are:

$$S^k(\zeta_{i,t}\mu_{z^*,t}\Upsilon i_t/i_{t-1}) = e^{\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} + e^{-\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} - 2$$

$$S^o(\mu_{z^*,t}\Upsilon i_t^o/i_{t-1}^o) = e^{\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} + e^{-\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} - 2$$

C Equilibrium Equations - Oil Shock Model with Banks

a) Prices

$$F^p_{p,t} = \lambda^p_{z,t} y_{z,t} + \xi_p \beta^p E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F^p_{p,t+1} \tag{1}$$

$$K^p_{p,t} = \lambda^p_{z,t} y_{z,t} s_t \lambda_{p,t} + \xi_p \beta^p E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K^p_{p,t+1} \tag{2}$$

$$K^p_{p,t} = \{[1 - \xi_p (\frac{\tilde{\pi}_t}{\pi_t})^{\frac{1}{1-\lambda_{p,t}}}](1-\xi_p)^{-1}\}^{1-\lambda_{p,t}} F^p_{p,t} \tag{3}$$

b) Wages

$$F^p_{w,t} = (1-\tau_l)\lambda_w^{-1} l^p_t \lambda^p_{z,t} + \xi_w \beta^p \mu_{z*}^{\frac{1}{1-\lambda_w}} E_t \mu^{-1}_{z^*,t+1} \pi^{\frac{\lambda_w}{\lambda_w - 1}}_{w,t+1} \tilde{\pi}^{\frac{1}{1-\lambda_w}}_{w,t+1} \pi^{-1}_{t+1} F^p_{w,t+1} \tag{4}$$

$$K^p_{w,t} = l^{p,1+\sigma_l}_t + \xi_w \beta^p E_t (\tilde{\pi}_{w,t+1} \pi^{-1}_{w,t+1} \mu_{z*})^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}} K^p_{w,t+1} \tag{5}$$

$$K^p_{w,t} = \psi_l^{-1} [(1 - \xi_w (\tilde{\pi}_{w,t} \pi^{-1}_{w,t} \mu_{z^*})^{\frac{1}{1-\lambda_w}})(1-\xi_w)^{-1}]^{1-\lambda_w(1+\sigma_l)} w^p_t F^p_{w,t} \tag{6}$$

$$F^i_{w,t} = (1-\tau_l)\lambda_w^{-1} l^i_t \lambda^i_{z,t} + \xi_w \beta^i \mu_{z*}^{\frac{1}{1-\lambda_w}} E_t \mu^{-1}_{z^*,t+1} \pi^{\frac{\lambda_w}{\lambda_w - 1}}_{w,t+1} \tilde{\pi}^{\frac{1}{1-\lambda_w}}_{w,t+1} \pi^{-1}_{t+1} F^i_{w,t+1} \tag{7}$$

$$K^i_{w,t} = l^{i1+\sigma_l}_t + \xi_w \beta^i E_t (\tilde{\pi}_{w,t+1} \pi^{-1}_{w,t+1} \mu_{z*})^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}} K^i_{w,t+1} \tag{8}$$

$$K^i_{w,t} = \psi_l^{-1} [(1 - \xi_w (\tilde{\pi}_{w,t} \pi^{-1}_{w,t} \mu_{z^*})^{\frac{1}{1-\lambda_w}})(1-\xi_w)^{-1}]^{1-\lambda_w(1+\sigma_l)} w^i_t F^i_{w,t} \tag{9}$$

$$w_t = \kappa w^p_t + (1-\kappa) w^i_t \tag{10}$$

c) Production

$$r^k_t = r^k exp(\sigma_a [u_t - 1]) \tag{11}$$

$$r^k_t = s_t \alpha_k \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k - 1} o^{1-\alpha_l-\alpha_k}_t \tag{12}$$

$$w^p_t l^p_t = \alpha_l \kappa s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} o^{1-\alpha_l-\alpha_k}_t \tag{13}$$

$$w^i_t l^i_t = \alpha_l (1-\kappa) s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} o^{1-\alpha_l-\alpha_k}_t \tag{14}$$

$$p^o_t = (1-\alpha_l-\alpha_k) s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} o^{-\alpha_l-\alpha_k}_t \tag{15}$$

$$k_t = (1-\delta) k_{t-1} {\mu_{z^*,t}}^{-1} \Upsilon^{-1} + [1 - S^k(\zeta_{i,t} \frac{i_t}{i_{t-1}} \mu_{z^*,t} \Upsilon)] i_t \tag{16}$$

$$R^k_t = \{(1-\tau^k)[u_t r^k_t - a(u_t)] + (1-\delta) q^k_t\} \pi_t \Upsilon^{-1} q^{k,-1}_{t-1} + \tau^k \delta \tag{17}$$

$$R_t^h = \frac{q_t^h}{q_{t-1}^h}\pi_t \tag{18}$$

$$y_{z,t} = \epsilon_t l_t^{\alpha_l}(\frac{u_t k_{t-1}}{\Upsilon \mu_{z_t^*}})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k} - \theta \tag{19}$$

where θ is:

$$\theta = l_t^{\alpha_l}(\Upsilon^{-1}\mu_{z_t^*}^{-1}u_t k_{t-1})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k}[1 - \frac{1}{\lambda_p}]$$

d) Resource Constraint

$$y_{z,t} = g_t + c_t + \mu_{\Upsilon,t}^{-1} i_t + i_t^o + a(u_t)\Upsilon^{-1}\mu_{z^*,t}{}^{-1}k_{t-1} + a(u_t^o)\Upsilon^{-1}\mu_{z^*,t}{}^{-1}x_{t-1}^o + d_t^b \tag{20}$$

where

$$d_t^b = \phi_{t-1}^i \mu^i G^i(\bar{\omega}_t^i) R_t^h Q_{t-1}^h \frac{\bar{H}_{t-1}^i}{P_t} + \phi_{t-1}^e \mu^e G^e(\bar{\omega}_t^e) R_t^k Q_{t-1}^k \frac{\bar{K}_{t-1}^i}{P_t}$$

$$c_t = c_t^p + c_t^i \tag{21}$$

$$l_t = l_t^{p,\kappa} l_t^{i,1-\kappa} \tag{22}$$

$$h_t = h_t^p + h_t^i \tag{23}$$

$$y_t = g_t + c_t + \mu_{\Upsilon,t}^{-1} i_t + i_t^o \tag{24}$$

e) Government Monetary Policy and Budget Constraint

$$R_t - R = \rho_p(R_{t-1} - R) + (1-\rho_p)[\alpha_\pi(E_t\pi_{t+1} - \pi) + \alpha_{\Delta Y}(g_{y,t} - \mu_z)] + \epsilon_t^p \tag{25}$$

$$g_t + t_t = ([u_t r_t^k - a(u_t)]\Upsilon^{-1} - \delta q_{t-1}^k \pi_t^{-1})k_{t-1}\mu_{z^*,t}^{-1}\tau^k + (w_t^i l_t^i + w_t^p l_t^p)\tau^l + c_t\tau^c \tag{26}$$

f) Optimal Capital Investment

$$\lambda_{z,t}^p q_t^k[1 - S^k(.) - \zeta_{i,t}\mu_{z^*,t}\Upsilon i_t i_{t-1}^{-1} S^{k\prime}(.)] - \mu_{\Upsilon,t}^{-1}\lambda_{z,t}^p + \beta^p E_t \lambda_{z,t+1}^p (\Upsilon\mu_{z^*,t})^{-1} q_{t+1}^k \zeta_{i,t+1}(\frac{i_{t+}\mu_{z^*,t+1}\Upsilon}{i_t})^2 S^{k\prime}(.) = 0 \tag{27}$$

g) Oil Producer

$$o_t = \epsilon_t^o u_t^o x_{t-1} [\mu_{z^*,t} \Upsilon]^{-1} \tag{28}$$

$$s_t^o = \frac{r_t^o}{\epsilon_t^o} \tag{29}$$

$$p_t^o = \frac{r_t^o}{\epsilon_t^o} (\frac{\lambda_{o,t}}{\lambda_{o,t} - 1}) \tag{30}$$

$$x_t^o = \frac{x_{t-1}^o}{\mu_{z^*,t} \Upsilon} (1 - \delta) + [1 - S^o(\zeta_{o,t} \frac{i_t^o}{i_{t-1}^o} \mu_{z^*,t} \Upsilon)] i_t^o \tag{31}$$

$$r_t^o = r^o exp(\sigma_a [u_t^o - 1]) \tag{32}$$

$$-\lambda_{z,t}^p + \frac{\beta^p}{\Upsilon} E_t \frac{\lambda_{z,t+1}^p}{\pi_{t+1} \mu_{z_{t+1}^*}} u_{t+1}^o r_{t+1}^o [1 - S^o(.) - \frac{i_t^o}{i_{t-1}^o} \Upsilon \mu_{z_t^*} S^{o\prime}(.)] + \frac{\beta^{p,2}}{\Upsilon^2} \frac{\lambda_{z,t+2}^p}{\pi_{t+1} \pi_{t+2} \mu_{z_{t+1}^*} \mu_{z_{t+2}^*}} u_{t+2}^o r_{t+2}^o (\frac{i_{t+1}^o}{i_t^o} \mu_{z_{t+1}^*} \Upsilon)^2 S^{o\prime}(\frac{i_{t+1}^o}{i_t^o}) = 0 \tag{33}$$

h) Patient Household

$$\frac{-\mu_{z^*,t} \zeta_{c,t}}{[\mu_{z^*,t} c_t^p - b_c^p c_{t-1}^p]} + \lambda_{z,t}^p (1 + \tau^c) + \beta^p \frac{b_c^p E_t \zeta_{c,t+1}}{[\mu_{z^*,t+1} c_{t+1}^p - b_c^p c_t^p]} = 0 \tag{34}$$

$$\frac{1}{h_t^p} - \lambda_{z,t}^p q_t^h + \beta^p E_t \lambda_{z,t+1}^p q_{t+1}^h \mu_{z^*,t+1}^{-1} = 0 \tag{35}$$

$$\lambda_{z,t}^p - \beta^p E_t \lambda_{z,t+1}^p [\mu_{z^*,t+1} \pi_{t+1}]^{-1} R_{t+1} = 0 \tag{36}$$

i) Impatient Household

$$\lambda_{z,t}^i (1 + \tau^c) - \frac{\zeta_{c,t} \mu_{z^*,t}}{\mu_{z^*,t} c_t^i - b_c^i c_{t-1}^i} + \beta^i b_c^i \frac{E_t \zeta_{c,t+1}}{\mu_{z^*,t+1} c_{t+1}^i - b_c^i c_t^i} = 0 \tag{37}$$

$$\frac{1}{h_t^i} - \lambda_{z,t}^i r_t^h = 0 \tag{38}$$

$$\lambda_{z,t}^i (r_t^h h_t^i + b_t^i) - \lambda_{z,t}^i q_t^h h_t^i [1 + S^h(.) + \zeta_{h,t} \frac{h_t^i}{h_{t-1}^i} \mu_{z^*,t} S^{h\prime}(.)] + \beta^i \mathbb{E}_t \lambda_{z,t+1}^i q_{t+1}^h \frac{h_t^i}{\mu_{z^*,t+1}} \zeta_{h,t+1} (\frac{h_{t+1}^i \mu_{z^*,t+1}}{h_t^i})^2 S^{h\prime}(.)$$

$$+\beta^i E_t \frac{\lambda_{z,t+1}^i}{(\pi_{t+1} \mu_{z^*,t+1})} [1 - \phi_t^i \Gamma^i(\bar{\omega}_{t+1}^i)] R_{t+1}^h q_t^h h_t^i = 0 \tag{39}$$

$$\lambda_{z,t}^i - \beta^i \mathbb{E}_t \frac{1}{\pi_{t+1} \mu_{z^*,t+1}} \lambda_{z,t+1}^i \{R_{t+1} - (1 - \mu^i) R_{j,t+1}^i G^{i\prime}(\bar{\omega}_{j,t+1}^i) +$$

$$F^{i\prime}(\bar{\omega}_{j,t+1}^i) \bar{\omega}_{j,t+1}^i [1 - F^i(\bar{\omega}_{j,t+1})]^{-1} [R_{t+1} - (1 - \mu^i) G^i(\bar{\omega}_{j,t+1}^i) R_{t+1}^h \phi_t^i Q_t^h \frac{\bar{H}_{j,t}^i}{B_{j,t}^i}]\} = 0 \tag{40}$$

$$w_t^i l_t^i (1-\tau^l) + (\pi_t \mu_{z^*,t})^{-1}[1-\phi_{t-1}^i \Gamma^i(\bar{\omega}_t^i)] R_t^h q_{t-1}^h h_{t-1}^i + b_t^i + t_t^i - (1+\tau^c) c_t^i - q_t^h h_t^i = 0 \tag{41}$$

$$R_t b_{t-1}^i - [1-F^i(\bar{\omega}_t^i)] R_t^i b_{t-1}^i - (1-\mu^i) G^i(\bar{\omega}_t^i) R_t^h \phi_{t-1}^i q_{t-1}^h h_{t-1}^i = 0 \tag{42}$$

$$\bar{\omega}_t^i = \frac{R_t^i b_{t-1}^i}{R_t^h \phi_{t-1}^i q_{t-1}^h h_{t-1}^i} \tag{43}$$

$$n_t^i = (\pi_t \mu_{z^*,t})^{-1}[1-\phi_t^i \Gamma^i(\bar{\omega}_t^i)] R_{t+1}^h q_{t-1}^h h_{t-1}^i \tag{44}$$

$$L_t^i = \frac{q_t^h h_t^i}{n_t^i} \tag{45}$$

$$S_t^i = \frac{R_t^i}{R_t} \tag{46}$$

j) Entrepreneur

$$\mathbb{E}_t\{[1-\phi_t^e \Gamma^e(\bar{\omega}_{t+1}^e)] \frac{R_{t+1}^k}{R_{t+1}} + \frac{\Gamma^{e\prime}(\bar{\omega}_{t+1}^e)}{[\Gamma^{e\prime}(\bar{\omega}_{t+1}^e) - \mu^e G^{e\prime}(\bar{\omega}_{t+1}^e)]} \{\frac{R_{t+1}^k}{R_{t+1}} \phi_t^e [\Gamma^e(\bar{\omega}_{t+1}^e) - \mu^e G^e(\bar{\omega}_{t+1}^e)] - 1\}\} = 0 \tag{47}$$

$$[1-F^e(\bar{\omega}_t^e)] R_t^e b_{t-1}^e + (1-\mu^e) G^e(\bar{\omega}_t^e) R_t^k \phi_{t-1}^e q_{t-1}^k k_{t-1} = R_t b_{t-1}^e \tag{48}$$

$$\bar{\omega}_t^e = \frac{R_t^e b_{t-1}^e}{\phi_t^e R_t^k q_{t-1}^k k_{t-1}} \tag{49}$$

$$n_t^e = \gamma_t^e [\pi_t \mu_{z^*,t}]^{-1}[1-\phi_{t-1}^e \Gamma^e(\bar{\omega}_t^e)] R_t^k q_{t-1}^k k_{t-1} - \delta^e n_t^e \tag{50}$$

$$L_t^e = \frac{q_t^k k_t}{n_t^e} \tag{51}$$

$$b_t^e = q_t^k k_t - n_t^e \tag{52}$$

$$S_t^e = \frac{R_t^e}{R_t} \tag{53}$$

k) Banks

$$\phi_t^i = (\nu_t \eta_t^i)^{-1} \tag{54}$$

$$\phi_t^e = (\nu_t \eta_t^e)^{-1} \tag{55}$$

$$b_t = b_t^e + b_t^i \tag{56}$$

l) Auxiliary Equations

Price and wage indexation and wage inflation:

$$\tilde{\pi}_t = \pi^{i_p} \pi_{t-1}^{1-i_p}$$

$$\tilde{\pi}_{w,t} = \pi^{i_w} \pi_{t-1}^{1-i_w}$$

$$\pi_{w,t} = \pi_t \mu_{z^*,t} \frac{w_t}{w_{t-1}}$$

Adjustment cost for the utilization of capital and upstream reserves are:

$$a(u_t) = r^k (exp[\sigma_a (u_t - 1)] - 1)/\sigma_a$$

$$a(u_t^o) = r^o (exp[\sigma_o (u_t^o - 1)] - 1)/\sigma_o$$

Adjustment costs for the capital investment, housing and upstream investments are:

$$S^k(\zeta_{i,t}\mu_{z^*,t}\Upsilon i_t/i_{t-1}) = e^{\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} + e^{-\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} - 2$$

$$S^h(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}) = e^{\sqrt{S^{h\prime\prime}/2}\Upsilon(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}-\mu_{z^*})} + e^{-\sqrt{S^{h\prime\prime}/2}\Upsilon(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}-\mu_{z^*})} - 2$$

$$S^o(\mu_{z^*,t}\Upsilon i_t^o/i_{t-1}^o) = e^{\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} + e^{-\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} - 2$$

Distribution functions for default probability, bank monitoring returns and gross share of profits going to banks are:

$$F^i(\bar{\omega}_t^i, \sigma^i) = \Phi([ln(\bar{\omega}_t^i) + (\sigma^i)^2/2]/\sigma^i)$$

$$G^i(\bar{\omega}_t^i, \sigma^i) = \Phi([ln(\bar{\omega}_t^i) + (\sigma^i)^2/2]/\sigma^i - \sigma^i)$$

$$\Gamma^i(\bar{\omega}_t^i, \sigma^i) = \bar{\omega}_t^i[1 - F^i(\bar{\omega}_t^i, \sigma^i)] + G^i(\bar{\omega}_t^i, \sigma^i)$$

$$F^e(\bar{\omega}_t^e, \sigma^e) = \Phi([ln(\bar{\omega}_t^e) + (\sigma^e)^2/2]/\sigma^e)$$

$$G^e(\bar{\omega}_t^e, \sigma^e) = \Phi([ln(\bar{\omega}_t^e) + (\sigma^e)^2/2]/\sigma^e - \sigma^e)$$

$$\Gamma^e(\bar{\omega}_t^e, \sigma^e) = \bar{\omega}_t^e[1 - F^e(\bar{\omega}_t^e, \sigma^e)] + G^e(\bar{\omega}_t^e, \sigma^e)$$

where $\Phi(.)$ is the cumulative distribution function of the standard normal distribution.
Aggregate bank resources for monitoring impatient households and entrepreneurs are:

$$d_t^b = \frac{1}{\mu_{z^*,t}\pi_t}[\mu^i G^i(\bar{\omega}_t^i)\phi_{t-1}^i R_t^h q_{t-1}^h h_{t-1}^i + \mu^e G^e(\bar{\omega}_t^e)\phi_{t-1}^e R_t^k q_{t-1}^k k_{t-1}]$$

D Equilibrium Equations - Energy Shock Model with Banks

a) Prices

$$F^p_{p,t} = \lambda^p_{z,t} y_{z,t} + \xi_p \beta^p E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{1}{1-\lambda_{p,t+1}}} F^p_{p,t+1} \tag{1}$$

$$K^p_{p,t} = \lambda^p_{z,t} y_{z,t} s_t \lambda_{p,t} + \xi_p \beta^p E_t (\frac{\tilde{\pi}_{t+1}}{\pi_{t+1}})^{\frac{\lambda_{p,t+1}}{1-\lambda_{p,t+1}}} K^p_{p,t+1} \tag{2}$$

$$K^p_{p,t} = \{[1 - \xi_p (\frac{\tilde{\pi}_t}{\pi_t})^{\frac{1}{1-\lambda_{p,t}}}](1-\xi_p)^{-1}\}^{1-\lambda_{p,t}} F^p_{p,t} \tag{3}$$

b) Wages

$$F^p_{w,t} = (1-\tau_l)\lambda_w^{-1} l^p_t \lambda^p_{z,t} + \xi_w \beta^p \mu_{z*}^{\frac{1}{1-\lambda_w}} E_t \mu^{-1}_{z^*,t+1} \pi^{\frac{\lambda_w}{\lambda_w - 1}}_{w,t+1} \tilde{\pi}^{\frac{1}{1-\lambda_w}}_{w,t+1} \pi^{-1}_{t+1} F^p_{w,t+1} \tag{4}$$

$$K^p_{w,t} = l^{p,1+\sigma_l}_t + \xi_w \beta^p E_t (\tilde{\pi}_{w,t+1} \pi^{-1}_{w,t+1} \mu_{z*})^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}} K^p_{w,t+1} \tag{5}$$

$$K^p_{w,t} = \psi_l^{-1} [(1 - \xi_w (\tilde{\pi}_{w,t} \pi^{-1}_{w,t} \mu_{z^*})^{\frac{1}{1-\lambda_w}})(1-\xi_w)^{-1}]^{1-\lambda_w(1+\sigma_l)} w^p_t F^p_{w,t} \tag{6}$$

$$F^i_{w,t} = (1-\tau_l)\lambda_w^{-1} l^i_t \lambda^i_{z,t} + \xi_w \beta^i \mu_{z*}^{\frac{1}{1-\lambda_w}} E_t \mu^{-1}_{z^*,t+1} \pi^{\frac{\lambda_w}{\lambda_w - 1}}_{w,t+1} \tilde{\pi}^{\frac{1}{1-\lambda_w}}_{w,t+1} \pi^{-1}_{t+1} F^i_{w,t+1} \tag{7}$$

$$K^i_{w,t} = l^{i1+\sigma_l}_t + \xi_w \beta^i E_t (\tilde{\pi}_{w,t+1} \pi^{-1}_{w,t+1} \mu_{z*})^{\frac{\lambda_w(1+\sigma_l)}{1-\lambda_w}} K^i_{w,t+1} \tag{8}$$

$$K^i_{w,t} = \psi_l^{-1} [(1 - \xi_w (\tilde{\pi}_{w,t} \pi^{-1}_{w,t} \mu_{z^*})^{\frac{1}{1-\lambda_w}})(1-\xi_w)^{-1}]^{1-\lambda_w(1+\sigma_l)} w^i_t F^i_{w,t} \tag{9}$$

$$w_t = \kappa w^p_t + (1-\kappa) w^i_t \tag{10}$$

c) Production

$$r^k_t = r^k exp(\sigma_a [u_t - 1]) \tag{11}$$

$$r^k_t = s_t \alpha_k \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k - 1} e^{1-\alpha_l - \alpha_k}_t \tag{12}$$

$$w^p_t l^p_t = \alpha_l \kappa s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} e^{1-\alpha_l-\alpha_k}_t \tag{13}$$

$$w^i_t l^i_t = \alpha_l (1-\kappa) s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} e^{1-\alpha_l-\alpha_k}_t \tag{14}$$

$$p^e_t = (1-\alpha_l-\alpha_k) s_t \epsilon_t l^{\alpha_l}_t (u_t \frac{k_{t-1}}{\Upsilon \mu_{z^*,t}})^{\alpha_k} e^{-\alpha_l-\alpha_k}_t \tag{15}$$

$$k_t = (1-\delta) k_{t-1} {\mu_{z^*,t}}^{-1} \Upsilon^{-1} + [1 - S^k(\zeta_{i,t} \frac{i_t}{i_{t-1}} \mu_{z^*,t} \Upsilon)] i_t \tag{16}$$

$$R^k_t = \{(1-\tau^k)[u_t r^k_t - a(u_t)] + (1-\delta) q^k_t\} \pi_t \Upsilon^{-1} q^{k,-1}_{t-1} + \tau^k \delta \tag{17}$$

$$R_t^h = \frac{q_t^h}{q_{t-1}^h}\pi_t \tag{18}$$

$$y_{z,t} = \epsilon_t l_t^{\alpha_l}(\frac{u_t k_{t-1}}{\Upsilon \mu_{z_t^*}})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k} - \theta \tag{19}$$

where θ is:

$$\theta = l_t^{\alpha_l}(\Upsilon^{-1}\mu_{z_t^*}^{-1}u_t k_{t-1})^{\alpha_k} o_t^{1-\alpha_l-\alpha_k}[1 - \frac{1}{\lambda_p}]$$

d) Resource Constraint

$$y_{z,t} = g_t + c_t + \mu_{\Upsilon,t}^{-1} i_t + a(u_t)\Upsilon^{-1}\mu_{z^*,t}{}^{-1} k_{t-1} + d_t^b \tag{20}$$

where

$$d_t^b = \phi_{t-1}^i \mu^i G^i(\bar{\omega}_t^i) R_t^h Q_{t-1}^h \frac{\bar{H}_{t-1}^i}{P_t} + \phi_{t-1}^e \mu^e G^e(\bar{\omega}_t^e) R_t^k Q_{t-1}^k \frac{\bar{K}_{t-1}^i}{P_t}$$

$$c_t = c_t^p + c_t^i \tag{21}$$

$$l_t = l_t^{p,\kappa} l_t^{i,1-\kappa} \tag{22}$$

$$h_t = h_t^p + h_t^i \tag{23}$$

$$y_t = g_t + c_t + \mu_{\Upsilon,t}^{-1} i_t \tag{24}$$

e) Government Monetary Policy and Budget Constraint

$$R_t - R = \rho_p(R_{t-1} - R) + (1-\rho_p)[\alpha_\pi(E_t\pi_{t+1} - \pi) + \alpha_{\Delta Y}(g_{y,t} - \mu_z)] + \epsilon_t^p \tag{25}$$

$$g_t + t_t = ([u_t r_t^k - a(u_t)]\Upsilon^{-1} - \delta q_{t-1}^k \pi_t^{-1}) k_{t-1}\mu_{z^*,t}^{-1}\tau^k + (w_t^i l_t^i + w_t^p l_t^p)\tau^l + c_t\tau^c \tag{26}$$

f) Optimal Capital Investment

$$\lambda_{z,t}^p q_t^k [1 - S^k(.) - \zeta_{i,t}\mu_{z^*,t}\Upsilon i_t i_{t-1}^{-1} S^{k\prime}(.)] - \mu_{\Upsilon,t}^{-1}\lambda_{z,t}^p + \beta^p E_t \lambda_{z,t+1}^p (\Upsilon\mu_{z^*,t})^{-1} q_{t+1}^k \zeta_{i,t+1} (\frac{i_{t+}\mu_{z^*,t+1}\Upsilon}{i_t})^2 S^{k\prime}(.) = 0 \tag{27}$$

g) Coal Producer

$$c_t = \epsilon_t^c u_t^c x_{t-1}^c [\mu_{z^*,t} \Upsilon]^{-1} \tag{28}$$

$$s_t^c = \frac{r_t^c}{\epsilon_t^c} \tag{29}$$

$$p_t^c = \frac{r_t^c}{\epsilon_t^c}\left(\frac{\lambda_{c,t}}{\lambda_{c,t}-1}\right) \tag{30}$$

$$x_t^c = \frac{x_{t-1}^c}{\mu_{z^*,t}\Upsilon}(1-\delta) + [1 - S^c(\frac{i_t^c}{i_{t-1}^c}\mu_{z^*,t}\Upsilon)]i_t^c \tag{31}$$

$$r_t^c = r^c exp(\sigma_a[u_t^c - 1]) \tag{32}$$

$$-\lambda_{z,t}^p + \frac{\beta^p}{\Upsilon} E_t \frac{\lambda_{z,t+1}^p}{\pi_{t+1}\mu_{z_{t+1}^*}} u_{t+1}^c r_{t+1}^c [1 - S^c(.) - \frac{i_t^c}{i_{t-1}^c}\Upsilon\mu_{z_t^*} S^{c\prime}(.)] + \frac{\beta^{p,2}}{\Upsilon^2}\frac{\lambda_{z,t+2}^p}{\pi_{t+1}\pi_{t+2}\mu_{z_{t+1}^*}\mu_{z_{t+2}^*}} u_{t+2}^c r_{t+2}^c (\frac{i_{t+1}^c}{i_t^c}\mu_{z_{t+1}^*}\Upsilon)^2 S^{c\prime}(\frac{i_{t+1}^c}{i_t^c}) = 0 \tag{33}$$

h) Gas Producer

$$g_t = \epsilon_t^g u_t^g x_{t-1}^g [\mu_{z^*,t} \Upsilon]^{-1} \tag{34}$$

$$s_t^g = \frac{r_t^g}{\epsilon_t^g} \tag{35}$$

$$p_t^g = \frac{r_t^g}{\epsilon_t^g}\left(\frac{\lambda_{g,t}}{\lambda_{g,t}-1}\right) \tag{36}$$

$$x_t^g = \frac{x_{t-1}^g}{\mu_{z^*,t}\Upsilon}(1-\delta) + [1 - S^g(\frac{i_t^g}{i_{t-1}^g}\mu_{z^*,t}\Upsilon)]i_t^g \tag{37}$$

$$r_t^g = r^g exp(\sigma_a[u_t^g - 1]) \tag{38}$$

$$-\lambda_{z,t}^p + \frac{\beta^p}{\Upsilon} E_t \frac{\lambda_{z,t+1}^p}{\pi_{t+1}\mu_{z_{t+1}^*}} u_{t+1}^g r_{t+1}^g [1 - S^g(.) - \frac{i_t^g}{i_{t-1}^g}\Upsilon\mu_{z_t^*} S^{g\prime}(.)] + \frac{\beta^{p,2}}{\Upsilon^2}\frac{\lambda_{z,t+2}^p}{\pi_{t+1}\pi_{t+2}\mu_{z_{t+1}^*}\mu_{z_{t+2}^*}} u_{t+2}^g r_{t+2}^g (\frac{i_{t+1}^g}{i_t^c}\mu_{z_{t+1}^*}\Upsilon)^2 S^{g\prime}(\frac{i_{t+1}^g}{i_t^g}) = 0 \tag{39}$$

i) Oil Producer

$$o_t = \epsilon_t^o u_t^o x_{t-1}^o [\mu_{z^*,t} \Upsilon]^{-1} \tag{40}$$

$$s_t^o = \frac{r_t^o}{\epsilon_t^o} \tag{41}$$

$$p_t^o = \frac{r_t^o}{\epsilon_t^o}(\frac{\lambda_{o,t}}{\lambda_{o,t}-1}) \tag{42}$$

$$x_t^o = \frac{x_{t-1}^o}{\mu_{z^*,t}\Upsilon}(1-\delta) + [1 - S^o(\frac{i_t^o}{i_{t-1}^o}\mu_{z^*,t}\Upsilon)]i_t^o \tag{43}$$

$$r_t^o = r^o exp(\sigma_a[u_t^o - 1]) \tag{44}$$

$$-\lambda_{z,t}^p + \frac{\beta^p}{\Upsilon} E_t \frac{\lambda_{z,t+1}^p}{\pi_{t+1}\mu_{z_{t+1}^*}} u_{t+1}^o r_{t+1}^o [1 - S^o(.) - \frac{i_t^o}{i_{t-1}^o}\Upsilon\mu_{z_t^*} S^{o\prime}(.)] + \frac{\beta^{p,2}}{\Upsilon^2} \frac{\lambda_{z,t+2}^p}{\pi_{t+1}\pi_{t+2}\mu_{z_{t+1}^*}\mu_{z_{t+2}^*}} u_{t+2}^o r_{t+2}^o (\frac{i_{t+1}^o}{i_t^o}\mu_{z_{t+1}^*}\Upsilon)^2 \zeta_{o,t+1} S^{o\prime}(\frac{i_{t+1}^o}{i_t^o}) = 0 \tag{45}$$

j) Aggregate Energy Producer

$$e_t = [\omega_c c_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_g g_t^{\frac{\sigma_e-1}{\sigma_e}} + \omega_o o_t^{\frac{\sigma_e-1}{\sigma_e}}]^{\frac{\sigma_e}{\sigma_e-1}} \tag{46}$$

$$p_t^e = [\omega_c p_t^{c,1-\sigma_e} + \omega_g p_t^{g,1-\sigma_e} + \omega_o p_t^{o,1-\sigma_e}]^{\frac{1}{1-\sigma_e}} \tag{47}$$

$$g_t = \frac{e_t}{[\omega_g + \omega_o(\frac{\omega_o p_t^g}{\omega_g p_t^o})^(\sigma_e - 1) + \omega_c(\frac{\omega_c p_t^g}{\omega_g p_t^c})^(\sigma_e - 1)]^{\frac{\sigma_e}{\sigma_e - 1}}} \tag{48}$$

$$o_t = g_t[\frac{\omega_o p_t^g}{\omega_g p_t^o}]^{\sigma_e} \tag{49}$$

$$c_t = g_t[\frac{\omega_c p_t^g}{\omega_g p_t^c}]^{\sigma_e} \tag{50}$$

k) Patient Household

$$\frac{-\mu_{z^*,t}\zeta_{c,t}}{[\mu_{z^*,t}c_t^p - b_c^p c_{t-1}^p]} + \lambda_{z,t}^p(1+\tau^c) + \beta^p \frac{b_c^p E_t \zeta_{c,t+1}}{[\mu_{z^*,t+1}c_{t+1}^p - b_c^p c_t^p]} = 0 \tag{51}$$

$$\frac{1}{h_t^p} - \lambda_{z,t}^p q_t^h + \beta^p E_t \lambda_{z,t+1}^p q_{t+1}^h \mu_{z^*,t+1}^{-1} = 0 \tag{52}$$

$$\lambda_{z,t}^p - \beta^p E_t \lambda_{z,t+1}^p [\mu_{z^*,t+1}\pi_{t+1}]^{-1} R_{t+1} = 0 \tag{53}$$

l) Impatient Household

$$\lambda^i_{z,t}(1+\tau^c) - \frac{\zeta_{c,t}\mu_{z^*,t}}{\mu_{z^*,t}c^i_t - b^i_c c^i_{t-1}} + \beta^i b^i_c \frac{E_t\zeta_{c,t+1}}{\mu_{z^*,t+1}c^i_{t+1} - b^i_c c^i_t} = 0 \tag{54}$$

$$\frac{1}{h^i_t} - \lambda^i_{z,t} r^h_t = 0 \tag{55}$$

$$\lambda^i_{z,t}(r^h_t h^i_t + b^i_t) - \lambda^i_{z,t} q^h_t h^i_t[1 + S^h(.) + \zeta_{h,t}\frac{h^i_t}{h^i_{t-1}}\mu_{z^*,t}S^{h\prime}(.)] + \beta^i\,\mathbb{E}_t\,\lambda^i_{z,t+1}q^h_{t+1}\frac{h^i_t}{\mu_{z^*,t+1}}\zeta_{h,t+1}(\frac{h^i_{t+1}\mu_{z^*,t+1}}{h^i_t})^2 S^{h\prime}(.)$$

$$+\beta^i E_t \frac{\lambda^i_{z,t+1}}{(\pi_{t+1}\mu_{z^*,t+1})}[1 - \phi^i_t\Gamma^i(\bar\omega^i_{t+1})]R^h_{t+1}q^h_t h^i_t = 0 \tag{56}$$

$$\lambda^i_{z,t} - \beta^i\,\mathbb{E}_t\,\frac{1}{\pi_{t+1}\mu_{z^*,t+1}}\lambda^i_{z,t+1}\{R_{t+1} - (1-\mu^i)R^i_{j,t+1}G^{i'}(\bar\omega^i_{j,t+1}) +$$

$$F^{i'}(\bar\omega^i_{j,t+1})\bar\omega^i_{j,t+1}[1 - F^i(\bar\omega_{j,t+1})]^{-1}[R_{t+1} - (1-\mu^i)G^i(\bar\omega^i_{j,t+1})R^h_{t+1}\phi^i_t Q^h_t\frac{\bar H^i_{j,t}}{B^i_{j,t}}]\} = 0 \tag{57}$$

$$w^i_t l^i_t(1-\tau^l) + (\pi_t\mu_{z^*,t})^{-1}[1 - \phi^i_{t-1}\Gamma^i(\bar\omega^i_t)]R^h_t q^h_{t-1}h^i_{t-1} + b^i_t + t^i_t - (1+\tau^c)c^i_t - q^h_t h^i_t = 0 \tag{58}$$

$$R_t b^i_{t-1} - [1 - F^i(\bar\omega^i_t)]R^i_t b^i_{t-1} - (1-\mu^i)G^i(\bar\omega^i_t)R^h_t\phi^i_{t-1}q^h_{t-1}h^i_{t-1} = 0 \tag{59}$$

$$\bar\omega^i_t = \frac{R^i_t b^i_{t-1}}{R^h_t\phi^i_{t-1}q^h_{t-1}h^i_{t-1}} \tag{60}$$

$$n^i_t = (\pi_t\mu_{z^*,t})^{-1}[1 - \phi^i_t\Gamma^i(\bar\omega^i_t)]R^h_{t+1}q^h_{t-1}h^i_{t-1} \tag{61}$$

$$L^i_t = \frac{q^h_t h^i_t}{n^i_t} \tag{62}$$

$$S^i_t = \frac{R^i_t}{R_t} \tag{63}$$

m) Entrepreneur

$$\mathbb{E}_t\{[1 - \phi^e_t\Gamma^e(\bar\omega^e_{t+1})]\frac{R^k_{t+1}}{R_{t+1}} + \frac{\Gamma^{e\prime}(\bar\omega^e_{t+1})}{[\Gamma^{e\prime}(\bar\omega^e_{t+1}) - \mu^e G^{e\prime}(\bar\omega^e_{t+1})]}\{\frac{R^k_{t+1}}{R_{t+1}}\phi^e_t[\Gamma^e(\bar\omega^e_{t+1}) - \mu^e G^e(\bar\omega^e_{t+1})] - 1\}\} = 0 \tag{64}$$

$$[1 - F^e(\bar\omega^e_t)]R^e_t b^e_{t-1} + (1-\mu^e)G^e(\bar\omega^e_t)R^k_t\phi^e_{t-1}q^k_{t-1}k_{t-1} = R_t b^e_{t-1} \tag{65}$$

$$\bar\omega^e_t = \frac{R^e_t b^e_{t-1}}{\phi^e_t R^k_t q^k_{t-1}k_{t-1}} \tag{66}$$

$$n^e_t = \gamma^e_t[\pi_t\mu_{z^*,t}]^{-1}[1 - \phi^e_{t-1}\Gamma^e(\bar\omega^e_t)]R^k_t q^k_{t-1}k_{t-1} - \delta^e n^e_t \tag{67}$$

$$L_t^e = \frac{q_t^k k_t}{n_t^e} \tag{68}$$

$$b_t^e = q_t^k k_t - n_t^e \tag{69}$$

$$S_t^e = \frac{R_t^e}{R_t} \tag{70}$$

n) Banks

$$\phi_t^i = (\nu_t \eta_t^i)^{-1} \tag{71}$$

$$\phi_t^e = (\nu_t \eta_t^e)^{-1} \tag{72}$$

$$b_t = b_t^e + b_t^i \tag{73}$$

o) Auxiliary Equations

Price and wage indexation and wage inflation:

$$\tilde{\pi}_t = \pi^{i_p} \pi_{t-1}^{1-i_p}$$

$$\tilde{\pi}_{w,t} = \pi^{i_w} \pi_{t-1}^{1-i_w}$$

$$\pi_{w,t} = \pi_t \mu_{z^*,t} \frac{w_t}{w_{t-1}}$$

Adjustment cost for the utilization of capital and upstream reserves are:

$$a(u_t) = r^k(exp[\sigma_a(u_t - 1)] - 1)/\sigma_a$$

$$a(u_t^c) = r^c(exp[\sigma_c(u_t^c - 1)] - 1)/\sigma_c$$

$$a(u_t^g) = r^g(exp[\sigma_g(u_t^g - 1)] - 1)/\sigma_g$$

$$a(u_t^o) = r^o(exp[\sigma_o(u_t^o - 1)] - 1)/\sigma_o$$

Adjustment costs for the capital investment, housing and upstream investments are:

$$S^k(\zeta_{i,t}\mu_{z^*,t}\Upsilon i_t/i_{t-1}) = e^{\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} + e^{-\sqrt{S^{k\prime\prime}/2}\Upsilon(\zeta_{i,t}\mu_{z^*,t}i_t/i_{t-1}-\mu_{z^*})} - 2$$

$$S^h(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}) = e^{\sqrt{S^{h\prime\prime}/2}\Upsilon(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}-\mu_{z^*})} + e^{-\sqrt{S^{h\prime\prime}/2}\Upsilon(\zeta_{h,t}\mu_{z^*,t}h_t/h_{t-1}-\mu_{z^*})} - 2$$

$$S^c(\mu_{z^*,t}\Upsilon i_t^c/i_{t-1}^c) = e^{\sqrt{S^{c\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^c/i_{t-1}^c-\mu_{z^*})} + e^{-\sqrt{S^{c\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^c/i_{t-1}^c-\mu_{z^*})} - 2$$

$$S^g(\mu_{z^*,t}\Upsilon i_t^g/i_{t-1}^g) = e^{\sqrt{S^{g\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^g/i_{t-1}^g-\mu_{z^*})} + e^{-\sqrt{S^{g\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^g/i_{t-1}^g-\mu_{z^*})} - 2$$

$$S^o(\mu_{z^*,t}\Upsilon i_t^o/i_{t-1}^o) = e^{\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} + e^{-\sqrt{S^{o\prime\prime}/2}\Upsilon(\mu_{z^*,t}i_t^o/i_{t-1}^o-\mu_{z^*})} - 2$$

Distribution functions for default probability, bank monitoring returns and gross share of profits going to banks are:

$$F^i(\bar{\omega}_t^i, \sigma^i) = \Phi([ln(\bar{\omega}_t^i) + (\sigma^i)^2/2]/\sigma^i)$$

$$G^i(\bar{\omega}_t^i, \sigma^i) = \Phi([ln(\bar{\omega}_t^i) + (\sigma^i)^2/2]/\sigma^i - \sigma^i)$$

$$\Gamma^i(\bar{\omega}_t^i, \sigma^i) = \bar{\omega}_t^i[1 - F^i(\bar{\omega}_t^i, \sigma^i)] + G^i(\bar{\omega}_t^i, \sigma^i)$$

$$F^e(\bar{\omega}_t^e, \sigma^e) = \Phi([ln(\bar{\omega}_t^e) + (\sigma^e)^2/2]/\sigma^e)$$

$$G^e(\bar{\omega}_t^e, \sigma^e) = \Phi([ln(\bar{\omega}_t^e) + (\sigma^e)^2/2]/\sigma^e - \sigma^e)$$

$$\Gamma^e(\bar{\omega}_t^e, \sigma^e) = \bar{\omega}_t^e[1 - F^e(\bar{\omega}_t^e, \sigma^e)] + G^e(\bar{\omega}_t^e, \sigma^e)$$

where $\Phi(.)$ is the cumulative distribution function of the standard normal distribution.
Aggregate bank resources for monitoring impatient households and entrepreneurs are:

$$d_t^b = \frac{1}{\mu_{z^*,t}\pi_t}[\mu^i G^i(\bar{\omega}_t^i)\phi_{t-1}^i R_t^h q_{t-1}^h h_{t-1}^i + \mu^e G^e(\bar{\omega}_t^e)\phi_{t-1}^e R_t^k q_{t-1}^k k_{t-1}]$$

E Data and Observation Equations

Table 7: Data Sources

Mnemonic	Description	Unit	Source
A Macroeconomic Series			
GDP	Gross domestic product	$bn	FRED
GDPDEF	Gross domestic product: implicit price deflator	idx	FRED
PCND	Personal consumption expenditures : nondurables	$bn	FRED
PCESV	Personal consumption expenditures : services	$bn	FRED
PCDG	Personal consumption expenditures : durables	$bn	FRED
GPDI	Gross private domestic investment	$bn	FRED
A006RD3Q086SBEA	Gross private domestic investment : price deflator	idx	FRED
HOANBS	Nonfarm business sector: hours of all persons	idx	FRED
FEDFUNDS	Effective federal funds rate	%	FRED
CNP16OV	Civilian noninstitutional population	ppl	FRED
LABSHPUSA156NR	Share of labor compensation in GDP, annual	%	FRED
B Financial Series			
CMDEBT	Households & nonprofits: debt securities & loans	$ bn	FRED
MORTGAGE30US	30-year fixed rate mortgage average in the US	%	FRED
TBSDODNS	Nonfinancial business: debt securities & loans	$bn	FRED
BAA	Moody's seasoned Baa corporate bond yield	%	FRED
C Energy Series			
WTISPLC	Spot Crude Oil Price: West Texas Intermediate (WTI)	$ per Barrel	FRED
PNGASEUUSDM	Global price of natural gas, EU	$ / MMBTU	FRED
PCOALAUUSDM	Global price of Coal, Australia	$ / MT	FRED

Table 8: Data Treatment

Constructed Series	Formula	Remark
Population	= HPfilter(CNP16OV, $\lambda = 10\,000$)	To remove breaks
Observable Variables		
GDP	= GDP / (GDPDEF x Population)	First diff, demean
Consumption	= (PCND + PCESV) / (GDPDEF x Population)	First diff, demean
Investment	= (PCDG + GPDI) / (GDPDEF x Population)	First diff, demean
Hours	= HOANBS / Population	Demean
Inflation	$= ln(GDPDEF) - ln(GDPDEF)_{-1}$	Demean
Price of investment	$= ln(A006RD3Q086SBEA_t) - ln(GDPDEF)$	Demean
Nominal interest rate	FEDFUNDS / 4	Demean
Household credit	$= CMDEBT/(GDPDEF x Population)$	First diff, demean
Household spread	$= (MORTGAGE30US - FEDFUNDS)/4$	First diff, demean
Business credit	$= TBSDODNS/(GDPDEF x Population)$	First diff, demean
Business spread	$= (BAA - FEDFUNDS)/4$	First diff, demean
Oil price	= WTISPLC / GDPDEF	First diff, demean
Gas price	= PNGASEUUSDM / GDPDEF	First diff, demean
Coal price	= PCOALAUUSDM / GDPDEF	First diff, demean

The model observation equations are as follows:

$$\text{Gross domestic product} : y_t^{obs} = 1 + ln(y_t \mu_{z^*,t}/y_{t-1}) - ln\mu_{z^*} = y_t \mu_{z^*,t}/(y_{t-1}\mu_{z^*})$$

$$\text{Consumption} : c_t^{obs} = c_t \mu_{z^*,t}/(c_{t-1}\mu_{z^*})$$

$$\text{Investment} : i_t^{obs} = i_t \mu_{z^*,t}/(i_{t-1}\mu_{z^*})$$

$$\text{Hours} : l_t^{obs} = 1 + lnl_t - lnl = l_t/l$$

$$\text{Inflation} : \pi_t^{obs} = 1 + ln\pi_t - ln\pi = \pi_t/\pi$$

$$\text{Nominal interest rate} : R_t^{obs} = R_t - R$$

Price of investment : $\mu_{\Upsilon,t}^{obs} = \mu_{\Upsilon,t}/\mu_{\Upsilon,t-1}$

Household credit : $b_t^{i,obs} = b_t^i \mu_{z^*,t}/(b_{t-1}^i \mu_{z^*})$

Household spread : $S_t^{i,obs} = R_t^i - R_t - (R^i - R)$

Business credit : $b_t^{e,obs} = b_t^e \mu_{z^*,t}/(b_{t-1}^e \mu_{z^*})$

Business spread : $S_t^{e,obs} = R_t^e - R_t - (R^e - R)$

Coal price : $p_t^{c,obs} = p_t^c/p_{t-1}^c$

Gas price : $p_t^{g,obs} = p_t^g/p_{t-1}^g$

Oil price : $p_t^{o,obs} = p_t^o/p_{t-1}^o$

F Estimated Parameters of Models with Banking Channels

Table 9: Estimated Structural Parameters of Model with Oil Shocks and Banking Channels

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode	SD
Taylor rate output	α_{Δ_y}	Normal	0.2	0.05	0.2347	0.0121
Taylor rate inflation	α_π	Normal	1.5	0.25	1.6990	0.0601
Impatient consumption habit	b_c^i	Beta	0.6	0.1	0.5792	0.0452
Patient consumption habit	b_c^p	Beta	0.6	0.1	0.5266	0.0374
Entrepreneur default probability	$F^e(\bar{\omega}^e)$	Beta	0.007	0.003	0.0169	0.0011
Impatient default probability	$F^i(\bar{\omega}^i)$	Beta	0.008	0.003	0.0098	0.0010
Price indexation on inflation	ι_p	Beta	0.5	0.2	0.8586	0.0483
Price indexation on wage	ι_w	Beta	0.5	0.2	0.3613	0.0496
Share of patient in labor	κ	Beta	0.5	0.1	0.6023	0.0199
Entrepreneur monitoring cost	μ^e	Beta	0.3	0.1	0.2115	0.0221
Impatient monitoring cost	μ^i	Beta	0.3	0.1	0.5265	0.0322
Taylor rate smoothing	ρ_p	Beta	0.8	0.15	0.7257	0.0265
Capital utilization adjustment cost	σ_a	Normal	1	0.5	1.0620	0.1298
Capital investment adjustment cost	$S^{k\prime\prime}$	Normal	2	1	2.5995	0.2589
Housing adjustment cost	$S^{h\prime\prime}$	Normal	15	20	7.1204	2.7509
Oil investment adjustment cost	$S^{o\prime\prime}$	Normal	10	1	10.0495	0.3653
Calvo price stickiness	ξ_p	Beta	0.6	0.15	0.7128	0.0363
Calvo wage stickiness	ξ_w	Beta	0.6	0.15	0.7470	0.0409

Table 10: Estimated Shock Parameters of Model with Oil Shocks and Banking Channels

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode	SD
Persistence of stationary technology	ρ_ϵ	Beta	0.5	0.2	0.6735	0.0656
Persistence of oil technology	ρ_{ϵ^o}	Beta	0.5	0.2	0.6926	0.0453
Persistence of capital redeployment	ρ_{η^e}	Beta	0.5	0.2	0.3829	0.0813
Persistence of housing redeployment	ρ_{η^i}	Beta	0.5	0.2	0.8809	0.0524
Persistence of gov. spending	ρ_g	Beta	0.5	0.2	0.7125	0.0779
Persistence of entrepreneur equity	ρ_{γ^e}	Beta	0.5	0.2	0.4194	0.0409
Persistence of price markup	ρ_{λ_p}	Beta	0.5	0.2	0.4157	0.0756
Persistence of investment technology	ρ_{μ_Υ}	Beta	0.5	0.2	0.7905	0.0513
Persistence of technology trend	$\rho_{\mu_{z^*}}$	Beta	0.5	0.2	0.9110	0.0345
Persistence of collateral	ρ_v	Beta	0.5	0.2	0.6472	0.0546
Persistence of preference	ρ_{ζ_c}	Beta	0.5	0.2	0.4103	0.0663
Persistence of housing	ρ_{ζ_h}	Beta	0.5	0.2	0.7066	0.0486
Persistence of MEI	$\rho_{\zeta_i^k}$	Beta	0.5	0.2	0.3126	0.0582
SD of stationary technology	σ_ϵ	invg2	0.01	1	0.0199	0.0028
SD of oil technology	σ_{ϵ^o}	invg2	0.01	1	0.2950	0.0369
SD of monetary policy	σ_{ϵ^p}	invg2	0.01	1	0.0033	0.0005
SD of capital redeployment	σ_{η^e}	invg2	0.01	1	0.0034	0.0135
SD of housing redeployment	σ_{η^i}	invg2	0.01	1	0.0603	0.0097
SD of gov. spending	σ_g	invg2	0.01	1	0.0349	0.0059
SD of entrepreneur equity	σ_{γ^e}	invg2	0.01	1	0.0193	0.0023
SD of price markup	σ_{λ_p}	invg2	0.01	1	0.0645	0.0396
SD of investment technology	σ_{μ_Υ}	invg2	0.01	1	0.0099	0.0012
SD of technology trend	$\sigma_{\mu_{z^*}}$	invg2	0.01	1	0.0034	0.0015
SD of collateral	σ_v	invg2	0.01	1	0.0946	0.0121
SD of preference	σ_{ζ_c}	invg2	0.01	1	0.0143	0.0096
SD of housing	σ_{ζ_h}	invg2	0.01	1	0.0072	0.0015
SD of MEI	$\sigma_{\zeta_i^k}$	invg2	0.01	1	0.0732	0.0091

Table 11: Estimated Structural Parameters of Model with Energy Shocks and Banking Channels

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode	SD
Taylor rate output	α_{Δ_y}	Normal	0.2	0.05	0.2510	0.0175
Taylor rate inflation	α_π	Normal	1.5	0.25	1.5346	0.0924
Impatient consumption habit	b_c^i	Beta	0.6	0.1	0.7120	0.0543
Patient consumption habit	b_c^p	Beta	0.6	0.1	0.5958	0.0408
Entrepreneur default probability	$F^e(\bar{\omega}^e)$	Beta	0.007	0.003	0.0155	0.0022
Impatient default probability	$F^i(\bar{\omega}^i)$	Beta	0.008	0.003	0.0065	0.0009
Price indexation on inflation	ι_p	Beta	0.5	0.2	0.9079	0.0635
Price indexation on wage	ι_w	Beta	0.5	0.2	0.6306	0.1340
Share of patient in labor	κ	Beta	0.5	0.1	0.6784	0.0492
Entrepreneur monitoring cost	μ^e	Beta	0.3	0.1	0.1378	0.0177
Impatient monitoring cost	μ^i	Beta	0.3	0.1	0.4227	0.0406
Taylor rate smoothing	ρ_p	Beta	0.8	0.15	0.8213	0.0250
Capital utilization adjustment cost	σ_a	Normal	1	0.5	1.0273	0.3013
Capital investment adjustment cost	$S^{k\prime\prime}$	Normal	2	1	2.2431	0.4880
Housing adjustment cost	$S^{h\prime\prime}$	Normal	15	20	14.1633	5.0208
Coal investment adjustment cost	$S^{c\prime\prime}$	Normal	10	1	9.9379	0.3302
Gas investment adjustment cost	$S^{g\prime\prime}$	Normal	10	1	10.0018	0.2849
Oil investment adjustment cost	$S^{o\prime\prime}$	Normal	10	1	9.9970	0.4852
Calvo price stickiness	ξ_p	Beta	0.6	0.15	0.6853	0.0262
Calvo wage stickiness	ξ_w	Beta	0.6	0.15	0.5453	0.0924

Table 12: Estimated Shock Parameters of Model with Energy Shocks and Banking Channels

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode	SD
Persistence of stationary technology	ρ_{ϵ}	Beta	0.5	0.2	0.5579	0.0552
Persistence of coal technology	ρ_{ϵ^c}	Beta	0.5	0.2	0.7469	0.0500
Persistence of gas technology	ρ_{ϵ^g}	Beta	0.5	0.2	0.7499	0.0533
Persistence of oil technology	ρ_{ϵ^o}	Beta	0.5	0.2	0.6803	0.0525
Persistence of capital redeployment	ρ_{η^e}	Beta	0.5	0.2	0.2692	0.0696
Persistence of housing redeployment	ρ_{η^i}	Beta	0.5	0.2	0.9012	0.0467
Persistence of gov. spending	ρ_g	Beta	0.5	0.2	0.5682	0.0832
Persistence of entrepreneur equity	ρ_{γ^e}	Beta	0.5	0.2	0.4047	0.0592
Persistence of price markup	ρ_{λ_p}	Beta	0.5	0.2	0.7558	0.0533
Persistence of investment technology	ρ_{μ_Υ}	Beta	0.5	0.2	0.8210	0.0762
Persistence of technology trend	$\rho_{\mu_{z^*}}$	Beta	0.5	0.2	0.3949	0.0729
Persistence of collateral	ρ_{ν}	Beta	0.5	0.2	0.8640	0.0466
Persistence of preference	ρ_{ζ_c}	Beta	0.5	0.2	0.6445	0.0689
Persistence of housing	ρ_{ζ_h}	Beta	0.5	0.2	0.6723	0.0551
Persistence of MEI	$\rho_{\zeta_t^k}$	Beta	0.5	0.2	0.1871	0.0536
SD of stationary technology	σ_{ϵ}	invg2	0.01	1	0.0525	0.0068
SD of coal technology	σ_{ϵ^c}	invg2	0.01	1	0.2892	0.0338
SD of gas technology	σ_{ϵ^g}	invg2	0.01	1	0.3634	0.0417
SD of oil technology	σ_{ϵ^o}	invg2	0.01	1	0.2827	0.0394
SD of monetary policy	σ_{ϵ^p}	invg2	0.01	1	0.0035	0.0005
SD of capital redeployment	σ_{η^e}	invg2	0.01	1	0.0432	0.0158
SD of housing redeployment	σ_{η^i}	invg2	0.01	1	0.0423	0.0095
SD of gov. spending	σ_g	invg2	0.01	1	0.0256	0.0038
SD of entrepreneur equity	σ_{γ^e}	invg2	0.01	1	0.0187	0.0023
SD of price markup	σ_{λ_p}	invg2	0.01	1	0.0213	0.0076
SD of investment technology	σ_{μ_Υ}	invg2	0.01	1	0.0098	0.0013
SD of technology trend	$\sigma_{\mu_{z^*}}$	invg2	0.01	1	0.0025	0.0019
SD of collateral	σ_{ν}	invg2	0.01	1	0.1021	0.0140
SD of preference	σ_{ζ_c}	invg2	0.01	1	0.0358	0.0064
SD of housing	σ_{ζ_h}	invg2	0.01	1	0.0112	0.0021
SD of MEI	$\sigma_{\zeta_t^k}$	invg2	0.01	1	0.0592	0.0095

G Shock Decomposition of Per Capita Real GDP Growth for Energy Shock Model

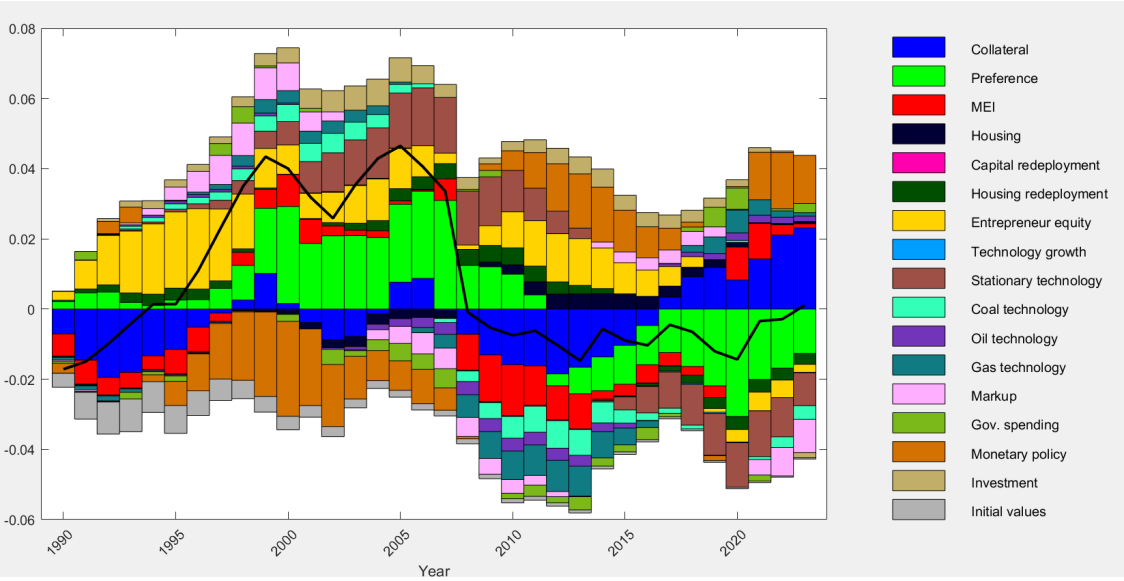


Figure 16: Shock Decomposition of Per Capita Real GDP Growth in Energy Shock Model

H Variance and Shock Decomposition in Oil Shock Model with Banks

Table 13: Calibrated Structural Parameters of Models with Different Periods

Description	Parameter	OS (1990 - 2024)	OS (1973 - 2024)	Based on
Share of capital	α_k	0.3457	0.3034	Sample mean
Share of labor	α_l	0.6081	0.6118	Sample mean
Impatient discount	β^i	0.9750	0.9750	CS
Patient discount	β^p	0.9993	0.9993	CS
Depreciation rate	δ	0.025	0.025	CS
Entrepre. dividend	δ^e	0.0256	0.0199	$L^e = 1.7479$
Gov. spending ratio	η_g	0.1580	0.1713	Sample mean
Firms' price markup	λ_p	1.20	1.20	CS
Wage markup	λ_w	1.025	1.025	CS
Oil markup	λ_o	2.00	2.00	Steady state solution
Growth rate	μ_{z^*}	1.0036	1.0037	Sample mean
Steady-state inflation	π	1.0056	1.0085	Sample mean
Labor disutility weight	ψ_l	0.7595	0.7718	Hours $l = 1$
Inverse elasticity	σ_l	1.00	1.00	CS
Oil utilization adj. cost	σ_a^o	0.2603	0.2603	Estimated σ_a in OSNB
Cons. tax rate	τ^c	0.0476	0.0476	CS
Labor tax rate	τ^l	0.2005	0.2005	CS
Cap. income tax rate	τ^k	0.2290	0.2290	CS
Investment IST change	Υ	1.0023	1.0023	CS

Table 14: Estimated Structural Parameters of Model with Oil Shocks and Banking Channels with Different Periods

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode (90 - 24)	Mode (73 - 24)
Taylor rate output	α_{Δ_y}	Normal	0.2	0.05	0.2347	0.2393
Taylor rate inflation	α_π	Normal	1.5	0.25	1.6990	1.3358
Impatient habit	b_c^i	Beta	0.6	0.1	0.5792	0.6440
Patient habit	b_c^p	Beta	0.6	0.1	0.5266	0.4948
Ent. default prob.	$F^e(\bar{\omega}^e)$	Beta	0.007	0.003	0.0169	0.0160
Impatient def. prob.	$F^i(\bar{\omega}^i)$	Beta	0.008	0.003	0.0098	0.0060
Price indexation	ι_p	Beta	0.5	0.2	0.8586	0.7076
Wage indexation	ι_w	Beta	0.5	0.2	0.3613	0.1471
Patient labor share	κ	Beta	0.5	0.1	0.6023	0.6549
Ent. monitoring cost	μ^e	Beta	0.3	0.1	0.2115	0.1701
Impatient cost	μ^i	Beta	0.3	0.1	0.5265	0.5371
Taylor smoothing	ρ_p	Beta	0.8	0.15	0.7257	0.7274
Cap util. adj.t cost	σ_a	Normal	1	0.5	1.0620	1.09898
Cap inv. adj. cost	$S^{k\prime\prime}$	Normal	2	1	2.5995	2.5828
Housing adj. cost	$S^{h\prime\prime}$	Normal	15	20	7.1204	5.5241
Oil inv. adj. cost	$S^{o\prime\prime}$	Normal	10	1	10.0495	10.4244
Price stickiness	ξ_p	Beta	0.6	0.15	0.7128	0.5912
Wage stickiness	ξ_w	Beta	0.6	0.15	0.7470	0.7729

Table 15: Estimated Shock Parameters of Model with Oil Shocks and Banking Channels with Different Periods

Description	Parameter	Distribution	Prior		Posterior	
			Mean	SD	Mode (90 - 24)	Mode (73 - 24)
Persistence stationary technology	ρ_ϵ	Beta	0.5	0.2	0.6735	0.06316
Persistence oil technology	ρ_{ϵ^o}	Beta	0.5	0.2	0.6926	0.7193
Persistence capital redeployment	ρ_{η^e}	Beta	0.5	0.2	0.3829	0.3307
Persistence housing redeployment	ρ_{η^i}	Beta	0.5	0.2	0.8809	0.8712
Persistence gov. spending	ρ_g	Beta	0.5	0.2	0.7125	0.9102
Persistence entrepreneur equity	ρ_{γ^e}	Beta	0.5	0.2	0.4194	0.4222
Persistence of price markup	ρ_{λ_p}	Beta	0.5	0.2	0.4157	0.2698
Persistence of investment technology	ρ_{μ_Υ}	Beta	0.5	0.2	0.7905	0.9297
Persistence of technology trend	$\rho_{\mu_{z^*}}$	Beta	0.5	0.2	0.9110	0.9183
Persistence of collateral	ρ_ν	Beta	0.5	0.2	0.6472	0.6134
Persistence of preference	ρ_{ζ_c}	Beta	0.5	0.2	0.4103	0.4817
Persistence of housing	ρ_{ζ_h}	Beta	0.5	0.2	0.7066	0.6609
Persistence of MEI	$\rho_{\zeta_i^k}$	Beta	0.5	0.2	0.3126	0.3012
SD of stationary technology	σ_ϵ	invg2	0.01	1	0.0199	0.0272
SD of oil technology	σ_{ϵ^o}	invg2	0.01	1	0.2950	0.3105
SD of monetary policy	σ_{ϵ^p}	invg2	0.01	1	0.0033	0.0038
SD of capital redeployment	σ_{η^e}	invg2	0.01	1	0.0034	0.0034
SD of housing redeployment	σ_{η^i}	invg2	0.01	1	0.0603	0.0578
SD of gov. spending	σ_g	invg2	0.01	1	0.0349	0.0382
SD of entrepreneur equity	σ_{γ^e}	invg2	0.01	1	0.0193	0.0195
SD of price markup	σ_{λ_p}	invg2	0.01	1	0.0645	0.0515
SD of investment technology	σ_{μ_Υ}	invg2	0.01	1	0.0099	0.0123
SD of technology trend	$\sigma_{\mu_{z^*}}$	invg2	0.01	1	0.0034	0.0030
SD of collateral	σ_ν	invg2	0.01	1	0.0946	0.1292
SD of preference	σ_{ζ_c}	invg2	0.01	1	0.0143	0.0035
SD of housing	σ_{ζ_h}	invg2	0.01	1	0.0072	0.0116
SD of MEI	$\sigma_{\zeta_i^k}$	invg2	0.01	1	0.0732	0.0904

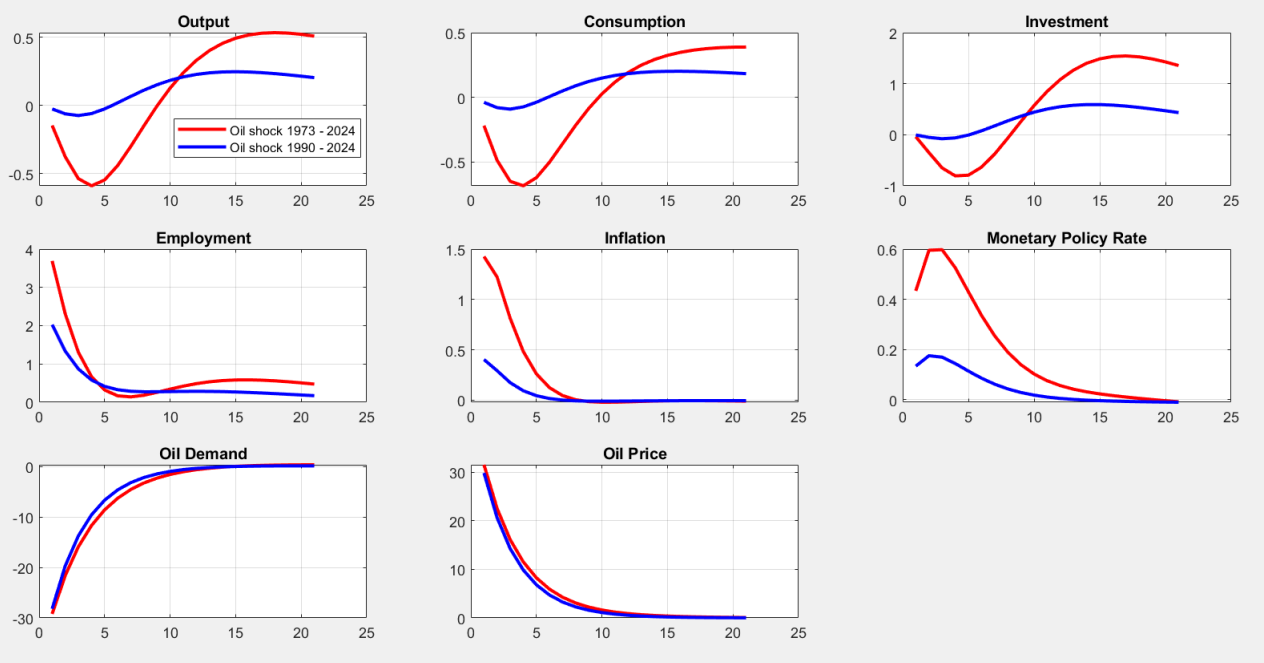


Figure 17: IRFs to negative one standard deviation oil technology shock in models with different time periods

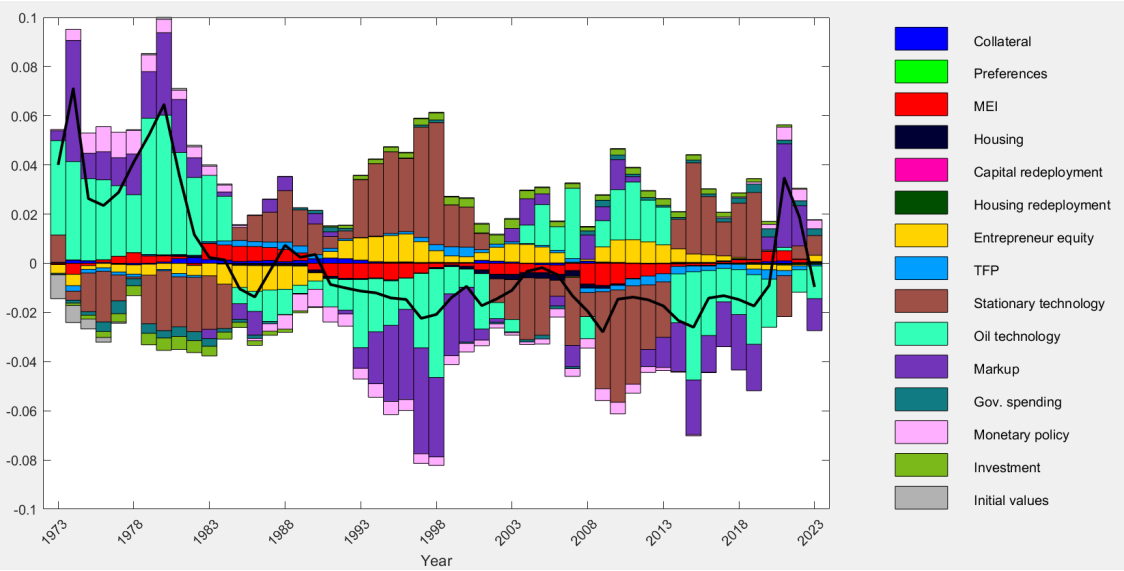


Figure 18: Shock Decomposition of Inflation between 1973 - 2024

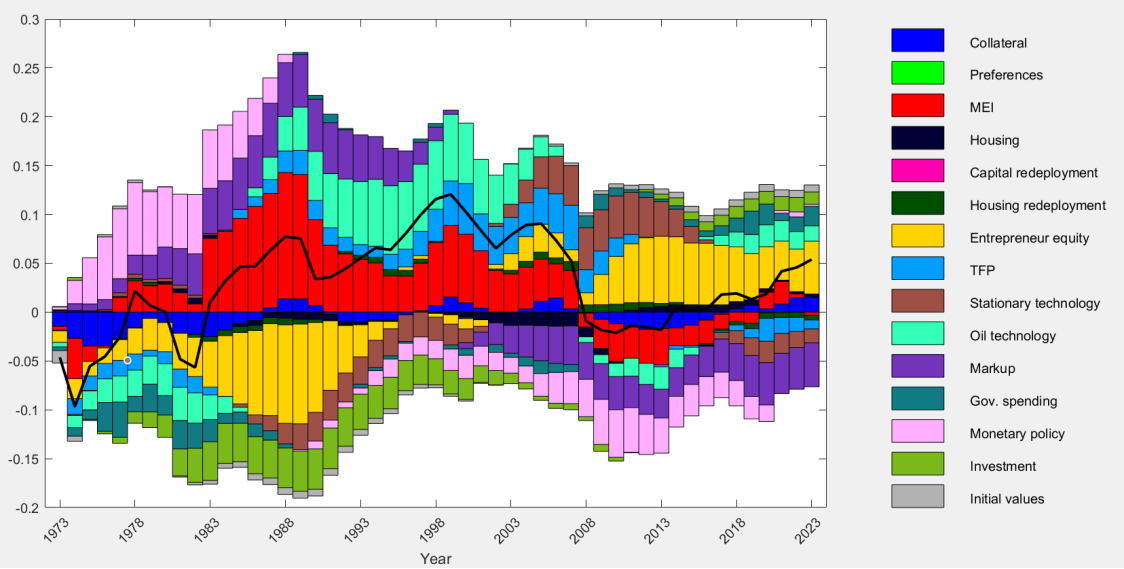


Figure 19: Shock Decomposition of Per Capita Real GDP Growth between 1973 - 2024

Table 16: Oil Shocks Model Variance Decomposition at Business Cycle Frequency from 1973 to 2024

	Collateral ν_t	Technology $\epsilon_t, \mu_{z^*,t}, \lambda_{p,t}$	Investment $\zeta_{i,t}, \mu_{\Upsilon,t}$	Household $\zeta_{c,t}\ \zeta_{h,t}, \eta_t^j$	Firm γ_t^e, η_t^e	Policy g_t, ϵ_t^p	Oil ϵ_t^o
Output	5	15	37	1	19	13	10
Cons.	3	55	7	5	4	8	18
Invest.	5	4	54	0	29	5	3
Hours	2	42	16	0	6	4	30
Inflation	0	56	1	0	2	1	40
MP	0	36	6	0	10	6	42
O Demand	0	1	0		0	0	99
O Price	0	0	0	0	0	0	100

Table 17: Oil Shocks Model Variance Decomposition at Business Cycle Frequency from 1990 to 2024

	Collateral ν_t	Technology $\epsilon_t, \mu_{z^*,t}, \lambda_{p,t}$	Investment $\zeta_{i,t}, \mu_{\Upsilon,t}$	Household $\zeta_{c,t}\ \zeta_{h,t}, \eta_t^j$	Firm γ_t^e, η_t^e	Policy g_t, ϵ_t^p	Oil ϵ_t^o
Output	8	10	36	4	30	11	1
Cons.	4	37	14	22	12	9	2
Invest.	7	5	45	0	38	5	0
Hours	2	43	22	2	11	6	14
Inflation	0	82	1	0	4	1	12
MP	1	38	10	1	24	15	11
O Demand	0	1	0		0	0	99
O Price	0	0	0	0	0	0	100