The Macroeconomics of Energy Shocks

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Abstract

The oil market Vector Autoregressive (VAR) literature has longstanding puzzle of inconsistent relationship between oil price shocks and real output growth. I have used flexible econometric methodology of Bayesian Local Projections (BLP) and incorporated theory of asymmetric market power in the oil supply structure to resolve this inconsistency while clarifying the ambiguous inflation response. The estimated responses show a significant structural shift: while 1970s oil supply shocks were not stagflationary but after structural break of 1986 competitive supply shocks have become stagflationary, primarily because of change in international linkages. Similarly, I show that coal and gas shocks are stagflationary, highlighting the pivotal role of energy price shocks in the recent post-pandemic surge in global inflation. Finally, I demonstrate that the empirical evidence presented in this paper aligns closely with the dynamics of theoretical Dynamic Stochastic General Equilibrium (DSGE) models.

1. Introduction

The recent episode of post-pandemic inflation is global as evident from figure 1 showing the rates of real GDP growth, inflation, and unemployment across G7 countries from 2015 to 2024. 2022 is the year of peak inflation in all these countries except USA which experienced inflation peak of 7.39% in 2021, that dropped to 6.41% in 2022. [1] The subset of countries Germany, Italy, and UK are on the top with inflation rates of 10.81%, 12.34%, and 10.53% respectively. Not surprisingly Japan, which was experiencing deflation in the last decades, is at the bottom with rate of 3.86%. Canada with 6.60% and France with 7.01% are almost in between alongside the USA. Its clear that inflation is coincided with low unemployment rate and not negative but weaker GDP growth in Canada and USA. All other countries have a similar pattern but not so strong unemployment rate which has a downward trend with nearly flat slope. This episode of global inflation has attracted considerable research interest investigating its causes and attributing to different factors of pandemic-induced fiscal stimuli, adverse shock to aggregate supply, large and persistent changes in sectoral-relative prices (Clarida, 2024), and energy shocks (Blanchard and Bernanke, 2023).

Figure 2 shows that energy prices reached their peak around 2022, the year of peak inflation in G7 countries. At the height of the energy crisis, quarterly real prices for coal increased sevenfold, while natural gas prices surged nearly ninefold relative to 2020 levels. The real oil price increase is not of the same magnitude but still significant. Globally, coal, oil, and natural gas remain the primary energy sources; although the share of

[1] According to IMF WEO sources, US inflation reached 7.39% in 2021; however, FRED (CPIAUCSL) data indicates a year-over-year peak of 7.99% in January 2022, following a 4.68% rate in January 2021.

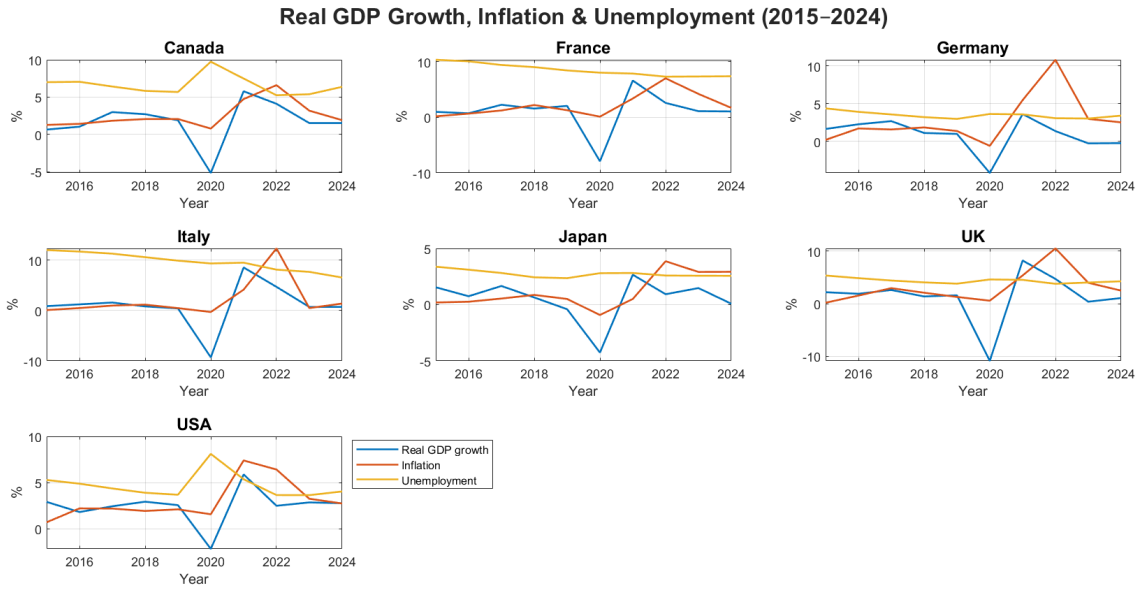


Figure 1: Annual average real GDP growth, inflation, and unemployment rates from 2015 to 2024 in G7 countries. Data source: World Bank

renewables—including nuclear, hydro, wind, and geothermal—is expanding, it has not yet reached a level sufficient to offset fossil fuel volatility. It can be inferred from the data that these commodities prices are correlated with each other [2]. Historically, these prices have moved in staggered successions; for instance, the oil price peak in 2008Q2 was followed by peaks in coal (2008Q3) and gas (2008Q4). Recently, a synchronized upward trend began after the summer of 2020, with initial peaks in late 2021 followed by a secondary, more pronounced peak in 2022Q3 following the onset of the Russia - Ukraine war. Further, oil prices are more volatile than coal and gas. Table 1 shows positive correlation between energy prices and inflation, and a negative correlation between energy prices and real GDP growth over the 1990Q1 – 2025Q1 period. These observations prompt a critical research question: What was the quantitative contribution of the 2021–2022 global energy shocks to U.S. inflation, and through which transmission mechanisms did these shocks propagate throughout the economy? Furthermore, this research paper develops structural empirical models to evaluate whether the observed responses of macro-aggregates align with theory-based responses of Dynamic Stochastic General Equilibrium (DSGE) models.

Table 1: Correlation of Energy Prices with Inflation and Real GDP Growth (1990 Q1 – 2025 Q1)

Energy Source	**CPI Inflation**	**GDP Deflator**	**Real GDP Growth**
Oil Price, West Texas Intermediate	0.17	0.21	−0.06
Global Natural Gas Price	0.25	0.46	−0.06
Global Coal Price	0.32	0.48	−0.06

The remainder of the paper is organised as follows: Section 2 reviews the relevant literature, focusing primarily on the evolution of oil market VAR models. Russia - Ukraine war has attracted research interest into natural gas supply shocks but such studies remain focused on the Euro Area (EA) economy. I couldn't find any paper covering coal supply shocks while these were also experienced in 1960s and 1970s driven

[2]The correlation between oil and gas prices is 0.59, between oil and coal is 0.56, and between coal and gas 0.87

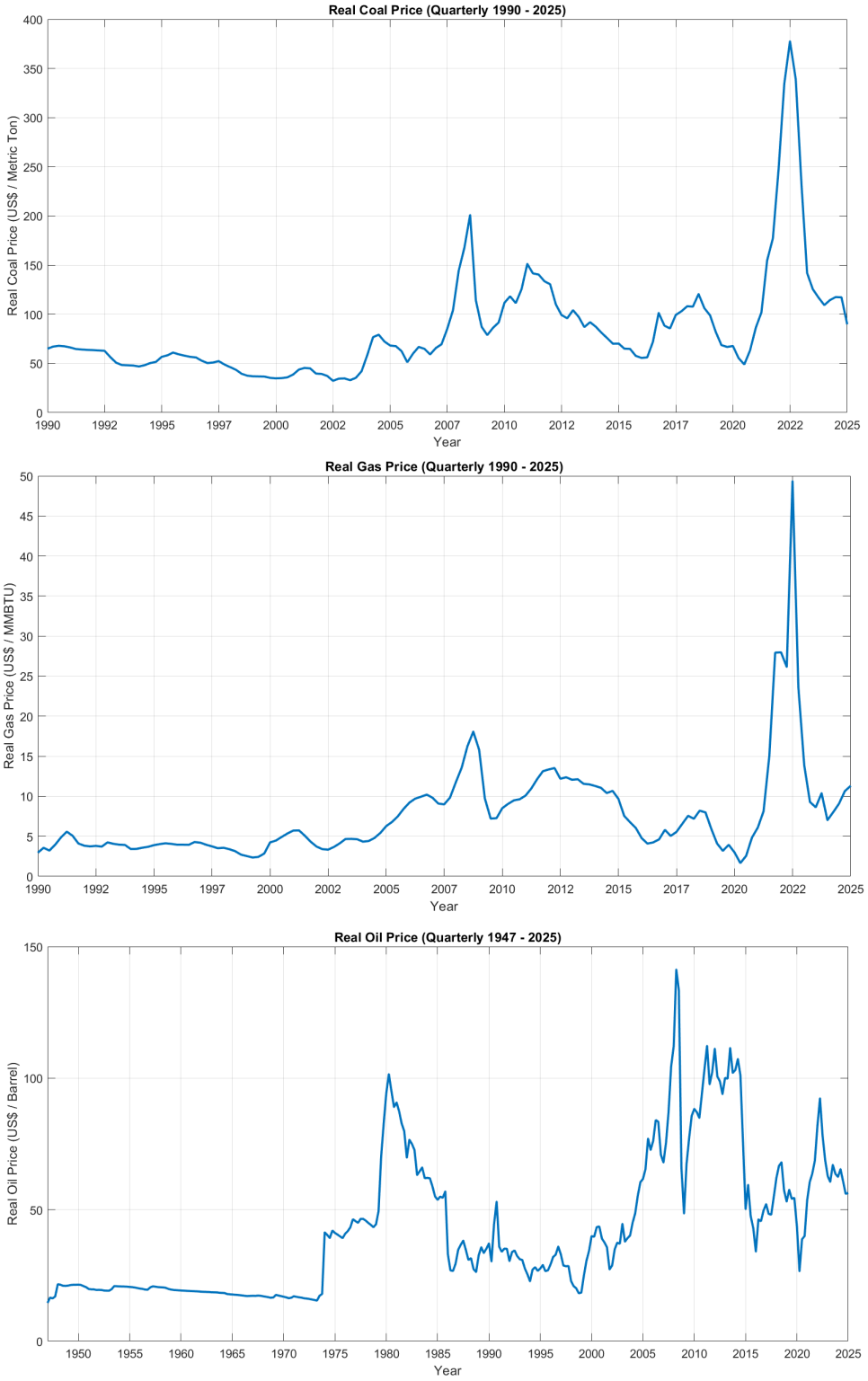


Figure 2: Real Energy Prices (quarterly), data source: https://fred.stlouisfed.org

by labor strikes and surging global demand. Section 3 provides details of the data and a comprehensive overview of the global energy supply and demand structure to explore price dynamics of these commodities. While the U.S. is self-sufficient in coal and natural gas, its relationship with oil is complex. Even being one of the biggest oil producer, the U.S. still imports oil. Section 4 outlines the specifications of different stages of the 'workhorse' models in the literature and describes how these frameworks are adapted to the empirical models developed in this study. Other relevant econometric details that generated unconventional, puzzling or erroneous conclusions are also discussed and addressed as per the relevant literature recommendations. The technical details of BLP methodology are included in the appendix D. Section 5 analyses the Impulse Response Functions (IRFs) derived from structural supply and demand shocks across the coal, natural gas, and oil markets. These responses are utilized to evaluate the transmission channels of energy shocks and to infer the underlying economic relationships between energy prices and macroeconomic aggregates. Finally, Section 6 offers concluding remarks.

2. Relevant Literature

My paper is relevant to three strands of literature. First strand investigates the post pandemic inflation, its causes particularly surges in commodities prices, and its macroeconomic implications. According to Bianchi et al. (2023), a persistent increase in inflation after pandemic can be attributed to unfunded fiscal shocks, including $2.2 trillion fiscal package in March 2020 and $1.9 trillion fiscal stimulus of American Rescue Plan Act 2021.[3] Dao et al. (2024) analyzed inflation dynamics in 21 advanced and emerging market economies since 2020 by decomposing into core and headline inflations. The finding is that three factors of energy prices, food prices, and shipping cost played a dominant role across these countries accounting between 21% and 94% of variation in headline inflation with energy prices as the dominant factor. Further, the relative price shocks (particularly energy prices) and their pass-through into core played the dominant role in the recent inflation drive. Similarly, Afrouzi et al. (2024) showed empirically exogenous positive energy price shocks increased both headline and core inflation while depressed the U.S. real activity. They used panel instrument variable local projections providing theory and evidence that relative price shocks can cause aggregate inflation and act as aggregate supply shocks. Santis (2024) identified both supply chain disruptions and energy supply shocks jointly using narrative restrictions in Bayesian structural VAR (SVAR) model to show how these were key drivers of inflation in the EA economy over the period following 2020 COVID pandemic and smaller role of demand shocks. Real GDP was negatively affected by these shocks, though marginally by adverse retail energy supply shocks.

Chan et al. (2024) developed a small, open-economy two agent New Keynesian (NK) model for the EA economy featuring labor and imported energy as complementary inputs within a constant elasticity of substitution production function. A high price energy shock leads to higher inflation and lower employment due to complementarities between these production inputs. This is validated by empirical IRFs. However, such pattern of lower employment is not so obvious for France, Italy, Germany, and UK in figure 1. They also showed that on the contrary to complementarity a higher degree of substitutability between labor and energy in production function would lead to a greater degree of substitution toward labor, increasing both employment and inflation following positive energy price shock. The later finding appears to be more consistent with the data. Alessandri and Gazzani (2025) focused on gas showing that the impact of negative gas supply shock was stagflationary in general but varied significantly across the EA member countries. The estimated IRFs in my paper also show stagflationary response of the U.S. economy to negative gas supply shocks. They constructed instrument variables for the gas supply shocks through narrative approach and estimated impact of these shocks on different EA economies using a Bayesian VAR model. Gazzani et al. (2024) developed daily SVAR model providing real-time decomposition of the oil price into three structural shocks of supply and future and current global demand. They concluded that oil supply shock

[3] While funded fiscal shocks are backed by future fiscal adjustment and irrelevant for inflation, unfunded fiscal shocks with nominal rigidities have real effects and cause persistent inflation.

has stagflationary impact on the economy that is consistent with impact of competitive supply shocks in my model. However, they also noted peculiarities to the fact that U.S. has become major oil producer and the main oil exporter worldwide. My model specifications analyse implications of this peculiarity in detail. The responses of GDP, investment, and consumption for future and current global demand shocks were positive that are different from negative responses of these variables in my model. While existing literature typically treats energy as an aggregate bundle or focuses on a single commodity, this paper disaggregates energy into its three primary components —coal, natural gas, and oil—to examine their distinct transmission channels independently.

The second strand is the oil market VAR literature. Although the Russia - Ukraine war has increased research interest in natural gas disruptions, the study of oil-related energy shocks has remained a cornerstone of macroeconomic research since the 1970s. The 1970s were marked by U.S. greater dependence on the imported oil, unprecedented disruptions in the global oil markets, and poor U.S. macroeconomic performance. The empirical particularly VAR literature on oil markets has expanded at a rapid pace with puzzling and divergent conclusions. Hamilton (1983a) was the first seminal paper identifying oil shocks as significant contributing factor to the U.S. recessions. It also mentioned coal price increases due to strikes by coal workers but examined the role of only oil by running Granger-causality tests. One of the first paper in the oil market VAR literature was Bernanke et al. (1997) highlighting that many economists considered oil shocks as the leading alternative shocks to monetary policy which caused postwar U.S. recessions. But evaluating the contribution of each factor in the economic fluctuations, oil shocks were ruled out as major factor in economic downturn. The paper served as a benchmark in its time to provide an approximation to the monetary policy behavior during certain historical episodes, but was fundamentally misspecified as it postulated the same response to oil price shocks without investigating the underlying supply and demand factors driving such shocks (Kilian (2009)and Kilian and Lewis (2011)). Barsky and Kilian (2001) were skeptical about the role of oil in 1970s stagflation and noted that absence of a close link between oil prices and stagflation in other times than in 1970s is puzzling for the observers. Barsky and Kilian (2004) without using any econometric methodology but only critical literature review provided key issues and insights gained over the last 30 years regarding link between oil price shocks and the macroeconomic performance. The case against the perception that only oil price shocks were able to explain the U.S. stagflation was presented. The pattern between oil supply disruptions in the Middle East and U.S. recessions is irregular and inconsistent response of real GDP that is positively correlated with real oil prices in the later episodes of 1990s and 2000s is a puzzle in the literature. Its argued that the relationship between oil supply disruption events and CPI inflation is not as apparent as one might would have expected. Kilian (2008a), using single-equation regression approach, showed that exogenous oil supply disruption caused a temporary reduction in real GDP growth in G7 countries that was concentrated in the second year after the shock. The response of inflation varied with median CPI inflation response reached peak after three to four quarters. Using different empirical methodologies, HAMILTON (2009) explored causes of oil price increases in 2007 - 2008 and its effects on the economy. Although, oil price increases of 2007-2008 were demand driven, the consequences were similar to previous oil price increases which were due to physical supply disruptions, with significant effects on consumption spending and automobile purchase. As per Kilian and Zhou (2023) guidance, workhorse models evolved in three stages: in first stage (Kilian, 2009) exploited short-run exclusion restrictions, in second stage Kilian and Murphy (2012) introduced static and dynamic inequality restrictions, and in final stage Kilian and Murphy (2014) incorporated storage demand signifying oil price expectations. These estimated models concluded that while speculative demand shifts played an important role during earlier oil price shock episodes of 1979, 1986, and 1990, oil price surge of 2003 - 08 was driven by fluctuations in the flow demand due to the global business cycle. Baumeister and Peersman (2013) estimated multivariate structural VAR model with time-varying parameters and stochastic volatility. Its showed that oil supply shocks were not crucial for other U.S. recessions but only contributed to the 1991 recession and slowed the economic boom of 1999 - 2000. Importantly oil shocks did not explain the 1970s and early 1980s inflation but other shocks did.

As long as identification is not an issue, first stage of workhorse models with exclusion restrictions can be used. The second stage models are similar to first stage except that they test a number of identifying restrictions but still deficient to identify speculative demand shock. This deficiency is addressed in the third stage model by adding global crude oil inventories allowing expectations to affect the real oil price. I have not considered global crude oil inventories as these are not critical for analysing macroeconomic impact relevant to oil price shocks as confirmed in Kilian and Zhou (2023). I have specified empirical model by following papers Kilian (2009) and Peersman and Van Robays (2012) but followed a novel and flexible econometric methodology of BLP to estimate the IRFs. The empirical models in these papers are in two blocks, the first block captures supply and demand conditions in the oil market and the second block captures macro variables of interest. The real oil price is structurally decomposed into oil supply shock, shock to the global demand for all industrial commodities, and oil-specific demand shock in the first block. The models showed that oil supply disruptions caused a temporary decline in real GDP and had little effect on the price level. Positive aggregate demand shocks initially had a positive impact on the economy that faded as the adverse impact of higher oil price dominated in the later period. The oil specific demand shock lowered real GDP and raised consumer prices. Structural changes in the composition of shocks helped to explain unstable regression of macroeconomic aggregates on oil prices. Still this strand of literature has overlooked the key feature of asymmetric market power as identified first by Salant (1976). The oil markets have intermediate market structure between monopoly, represented by OPEC producers, and perfect competition, represented by U.S. and non-OPEC producers. I have incorporated this asymmetric power by disaggregating oil supply shock into OPEC and non-OPEC supply shocks. Since U.S. is a major oil producer so I have further disaggregated non-OPEC supply by separating U.S. oil production, helpful to analyse peculiarity as mentioned by Gazzani et al. (2024). To the best of my knowledge, no other paper has studied the implications of disruptions to U.S. oil production, a major oil producer but clearly different from OPEC producers. This peculiarity was even important in 1970s when oil industry was under structural transformation with radical shift in power from the major oil companies to the oil producing countries in the Middle East (Kilian (2008b)). Simple exclusion-restrictions, rather than using complex identification restrictions, are sufficient to serve this paper research purpose. The use of BLP methodology and empirical specifications reflecting oil industry asymmetric structure have provided IRFs consistent with theory and without any puzzle. The model developed in guidance with oil market VAR literature is then extended to analyse coal and gas sectors price shocks.

Beside empirical models, theoretical DSGE models are also developed to analyse the macroeconomic impact of energy shocks but mostly focused on oil. This can be third strand of relevant literature. Kim and Loungani (1992) modified Hansen (1985) real business cycle by explicitly including energy as a productive input with both Cobb-Douglas and nested CES production function specifications showing that energy price shocks raised the percentage of output volatility. Rotemberg and Woodford (1996) included energy input along with labor in the production function explaining that the oil price increases alone would have little effect on output and its the monetary contraction following oil price increases that affected output and wages. Fuerst and Carlstrom (2006) incorporated NK frictions showing that output decline following oil shocks could not be attributed to monetary policy. Nakov and Pescatori (2007b), Balke et al. (2010), Nakov and Pescatori (2010), and Balke and Brown (2018) developed DSGE models with endogenous oil sectors showing that these shocks caused volatility to output and inflation.

3. Data and Stylised Facts

The transmission channels of energy shocks have international linkages through which innovations in the energy sector impact macroeconomy. Global energy demand and supply structures are analysed in this section to have basic understanding for setting up empirical framework. Figure 3 shows average of annual energy consumption by primary sources for world and the leading G7 economies from 1980 to 2023. Globally, the approximate share of coal is 30%, gas 20%, oil 40%, and renewable mix of nuclear and other

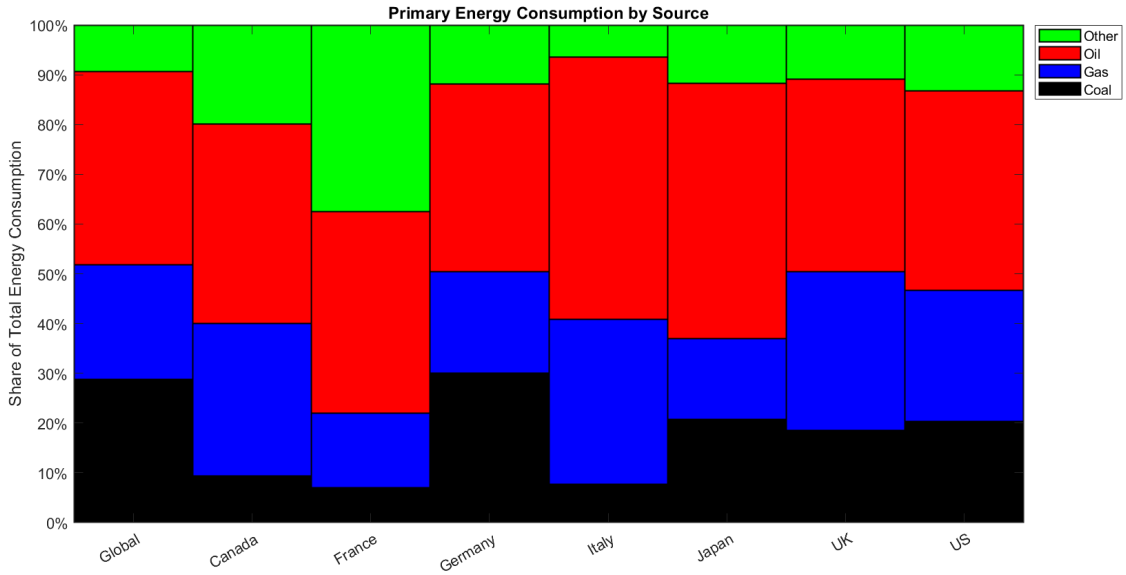


Figure 3: Average of annual energy consumption from 1980 to 2023, source: Energy Information Administration (EIA)

technologies 10%. Germany, Japan, UK, and U.S. have more or less similar energy mix as of the world. Japan has larger share of oil and smaller of gas. Share of coal for Japan, U.S., and UK is lower compare to Germany and global share. Canada, France, and Italy rely even lesser on coal. France has larger share of other low carbon sources in the form of nuclear technology. Canada has also larger share of other mix in the form of hydro technology. Italy is dependent more on oil, almost similar level as of Japan, and also on gas and hence relatively less diversified in its energy sources. It would not be wrong to infer that price of global energy bundle is determined by prices of coal, gas, and oil. Hence, its important to analyse dynamics of these three commodities to satisfy the aim of studying the interaction between energy shocks and macro aggregates. Peersman and Van Robays (2012) analysed these countries based on imports of oil and other energy products. Germany, Italy, France, and Japan are fully dependent on imports of oil and other energy products. US is a net oil and energy importing country but with noticeable domestic oil production, a peculiarity mentioned in the previous section. Canada is net oil and energy exporter whereas UK is an oil-exporting but energy-importing country.

Figure 4 shows intensity of energy by resources. The oil intensity has dropped by approximately 78% and half of this drop was between 1960 and mid 1980s. The gas intensity also dropped from 1970 to mid 2000s by approximately 67% and then plateau and now at the same level as for the oil. Coal experienced the biggest drop by 91% and now its level is less than half of oil and gas and also less than renewable intensity which is almost on a constant trajectory.

In addition to energy demand structure, its also important to analyse energy supply structure and its distribution. Figure 5 top plot shows annual coal production highlighting major coal producing countries. China is the biggest coal producer with significant increase in share since 2002. In 2020, the coal production is in decline for all the producers but then experienced a trend of increased production. Its difficult to infer from the figure the supply side disruptions that I have checked in the data for these countries. A popular approach to identify supply side-shocks uses sign restrictions, imposing condition that an adverse supply shock must lead to a simultaneous increase in the price level and a decrease in aggregate supply. Bottom plot shows declining coal production for Australia in 2021 and 2022 while prices were rising. There were fluctuations

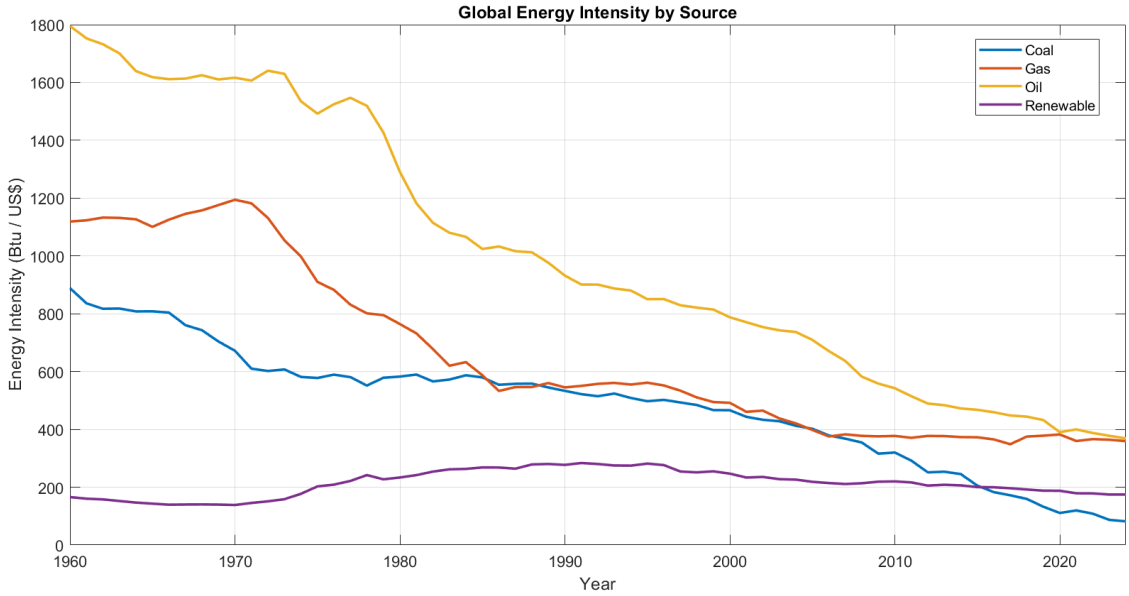


Figure 4: Energy intensity by source type from 1960 to 2024, source: Energy Information Administration (EIA) and World Bank. Energy intensity is measured as British thermal units (Btu) per constant 2015 US$ of Global GDP.

in coal production of South Africa but it does not show recovery to 2020 level. US coal production started declining in 2010 with a steep downward slope till 2020. After 2020 while the production shows increase but not at the same rate as for the decline in the previous years. It can be inferred that after 2020 pandemic coal markets were experiencing supply side disruptions, not in US but presumably in Australia and South Africa or in other global supply chains, that were partially the cause of coal price shocks in addition to post-COVID lock down demand. Similar signs of supply side disruptions can be observed in the gas markets that are more obvious due to 2022 Russia - Ukraine war. Top plot in figure 6 shows that U.S. is the biggest gas producer followed by Russia. The bottom plot shows significant decline in Russian gas production in the years 2022 and 2023, that also happened around 1992. These declines might be difficult to substitute as in short run the supply curve can be vertical due to real rigidities in the supply market, causing gas price shocks.

Due to OPEC block, the oil market supply structure is more simple and more complex at the same time. Simple because it can be grouped into two types of producers, OPEC and non-OPEC, and complex as these are two different types of producers making industry structure neither monopolistic nor competitive but intermediate as explained by Salant (1976). While non-OPEC producers are price takers, OPEC is a monopoly producer which sets price by strategically responding to the oil demand and the non-OPEC oil supply. To study the U.S. peculiarity as its a net oil and energy importing country but with noticeable domestic oil production, U.S. supply is shown separately from the non-OPEC supply. Figure 8 shows U.S. oil production, non-OPEC block (excluding U.S.) oil production, and OPEC block oil production from 1973 Q1 to 2025 Q1. The U.S. oil production experienced a declining trend from the start of sample period to around 2010. Until 1960s U.S. with excess oil capacity played role of the supplier of last resort to Europe and Japan (Barsky and Kilian, 2001). Beginning 1966, rate of increase in U.S. domestic oil production began to decline (Ramey and Vine, 2011) and in March 1971 the U.S. oil production reached 100% capacity for the first time in history and U.S. became dependent on oil imports from the Middle East. The shale boom started in early 2010s and since then U.S. oil production is on upward trajectory with small

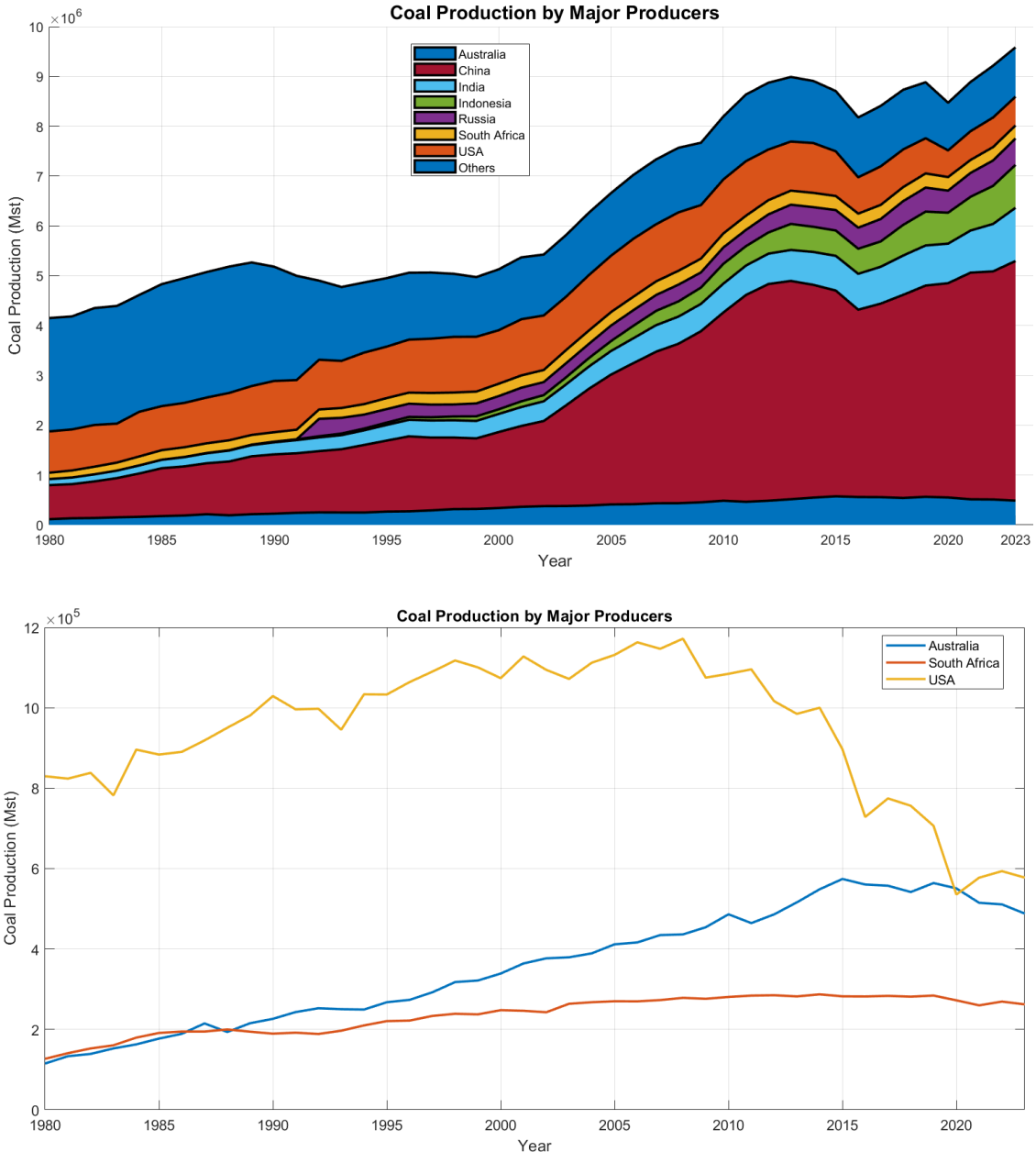


Figure 5: Annual coal production from 1980 to 2023, source: Energy Information Administration (EIA)

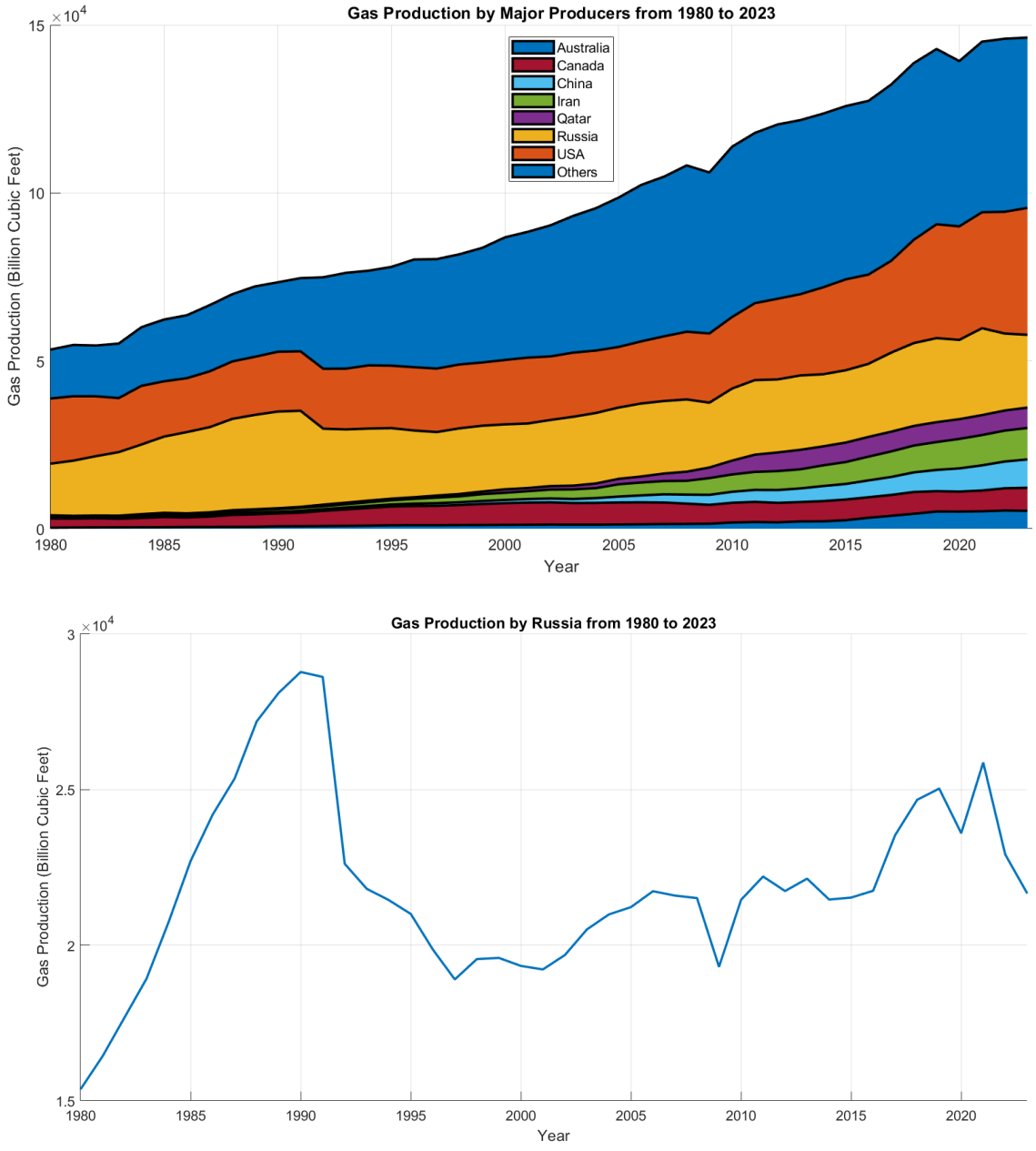


Figure 6: Annual gas production from 1980 to 2023, source: Energy Information Administration (EIA)

Note: Gas production data for Russia before 1991 is based on Former U.S.S.R

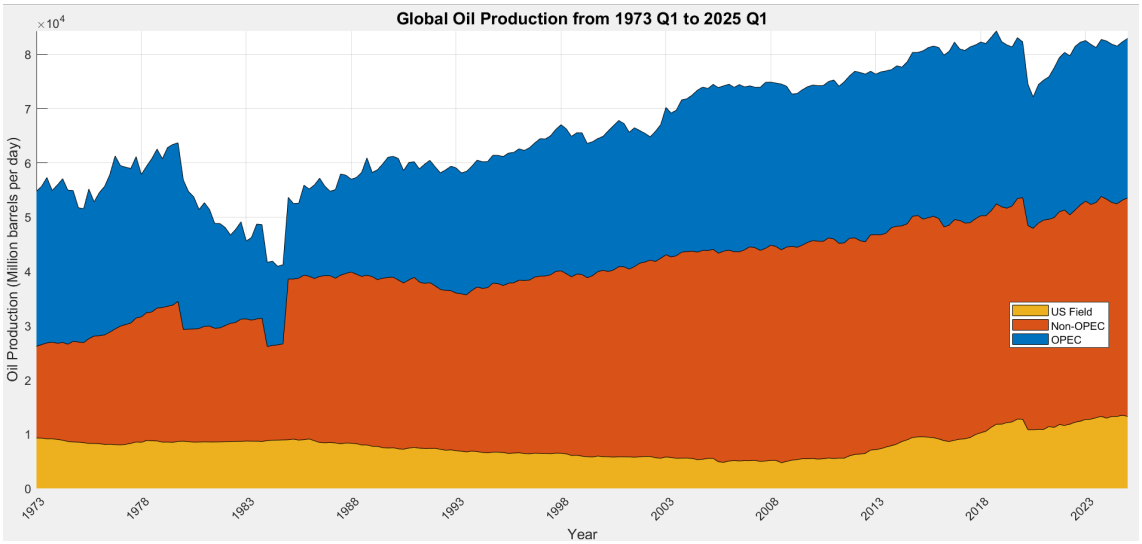


Figure 7: Quarterly oil production from 1973 Q1 to 2025 Q1, source: Energy Information Administration (EIA)

slump around 2016 and then the latest slump of 2020 pandemic. It would not be wrong to interpret that U.S. economy has been dependent on oil imports regardless of its domestic oil production. To evaluate impact of oil price shocks on the U.S. economy, its equally important to consider U.S. oil imports as to consider domestic oil production.

The OPEC oil production declined from October 1973 after Arab oil embargo in response to the Middle East war. After 1979 Iran revolution and 1980 Iran-Iraq war, the production experienced downward trend till mid 1985 when Saudi Arabia decided that it would no longer attempt to prop up the price of oil by reducing its oil production. This also changed the market perception about OPEC's market power (Kilian and Murphy, 2014). In accordance with Peersman and Robays (2009), the oil industry considers structural break in 1986Q1, as its related to the collapse of the OPEC cartel or the start of the Great Moderation. The ending date of July 1987 is more natural for considering structural break, given the transition from Volcker to Greenspan in 1987 (Kilian and Lewis, 2011). OPEC supply experienced volatility again between 1998 and 2002. OPEC member countries phased in several cuts to production quotas at the beginning of 1999 (Ramey and Vine (2011)). The political turmoil in Venezuela disrupted oil production in early 2002 shooting oil prices again. Another disruption in OPEC oil supply was experienced during 2003 Iraq war. It then stabilised until 2020 pandemic slump.

The non-OPEC supply (excluding US supply) responded to the declining OPEC supply in 1973 by substituting it and showing an upward trend. A large number of new oil suppliers such as Egypt, Angola, Malaysia, China, Norway, and the United Kingdom had entered the market by the early 1980s in response to the unusually high oil prices of the 1970s. At the same time, existing producers including the United States (Alaska), Mexico, and the USSR had invested in new capacity and expanded oil production (Barsky and Kilian, 2001). However, after 1979 non-OPEC oil production experienced almost 20% drop and then again in mid-1983. Despite these volatilities, in late 1984 non-OPEC oil supply share reached to almost 67% (as shown in figure 24 in appendix B).

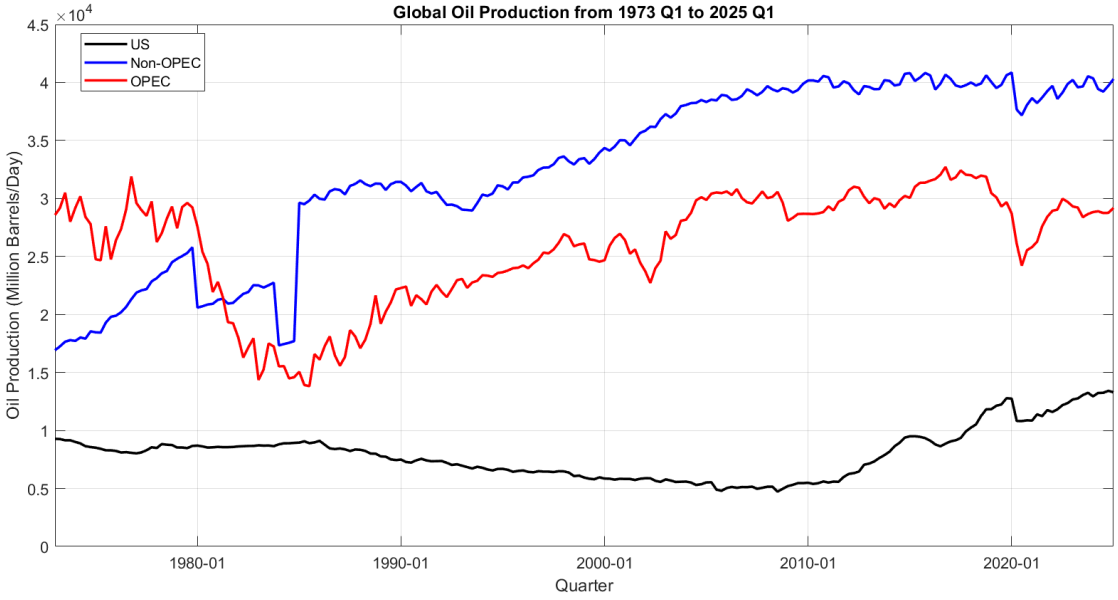


Figure 8: Quarterly oil production from 1973 Q1 to 2025 Q1, source: Energy Information Administration (EIA)

The analysis of international demand and supply structure in the three commodities of coal, natural gas, and oil shows importance of international channels in setting prices of these commodities. Further, its clear that U.S. has always relied on substantial foreign oil imports till date. Figure 9 shows that U.S. oil exports were almost negligible till 2016 and then increased. U.S. oil imports peaked around 2008 before the financial crisis and then decreased gradually. U.S. has been the net oil importer throughout the sample period with peak around 2008. The major source of oil imports till mid 1990s were from OPEC countries as per figure 10. By mid 90s U.S. became more dependent on imports from non-OPEC countries (as clear in figure 23). Hence, its important to account for both U.S. and outside U.S. oil production. But this may not be possible in case of coal and natural gas because quarterly data for coal and gas production outside U.S. is not available. Question is how important it is to account for coal and natural gas production outside U.S. to assess its impact on U.S. macro aggregates. Figure 11 shows that U.S. has always been the net exporter of coal. Similarly, figure 12 shows that U.S. became net exporter of gas in 2017. It would not be wrong to infer that U.S. is almost self sufficient in coal and gas. Hence, in order to evaluate the macroeconomic impact due to supply shocks of these commodities it would be sufficient to consider U.S. production only.

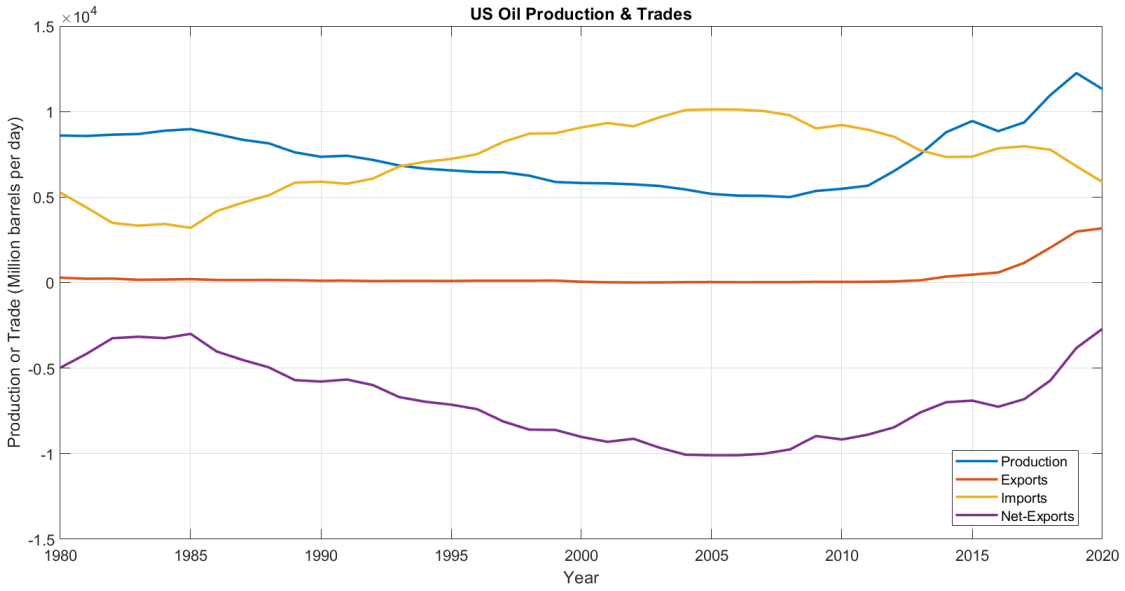


Figure 9: US oil production and trades, source:EIA

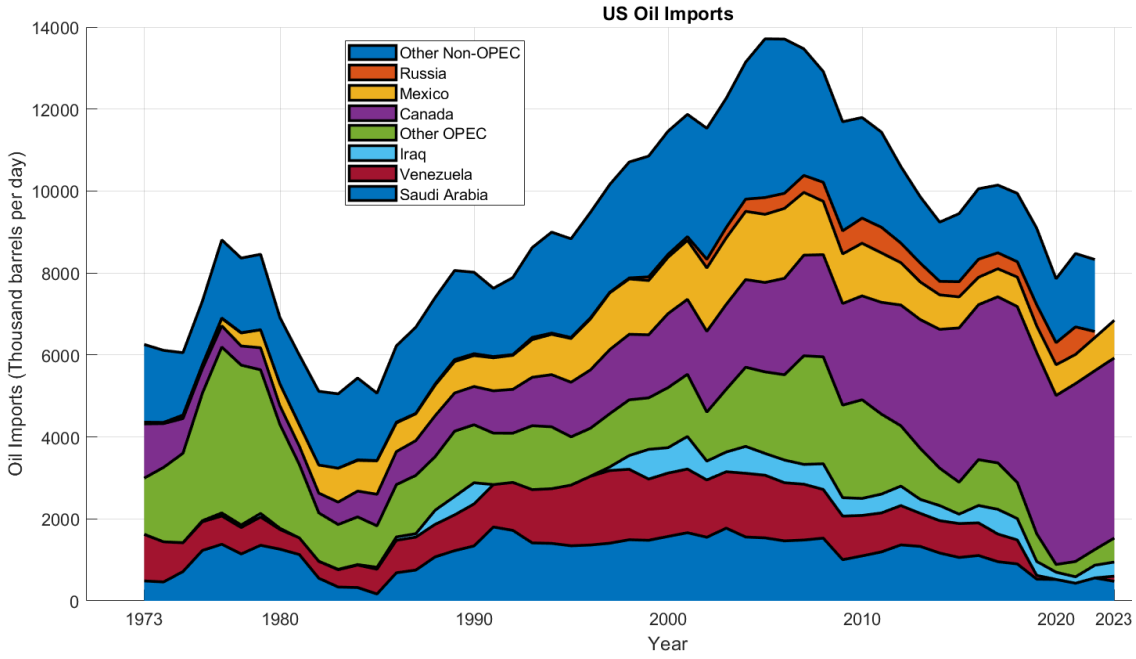


Figure 10: US oil imports by country, source:https://afdc.energy.gov/data

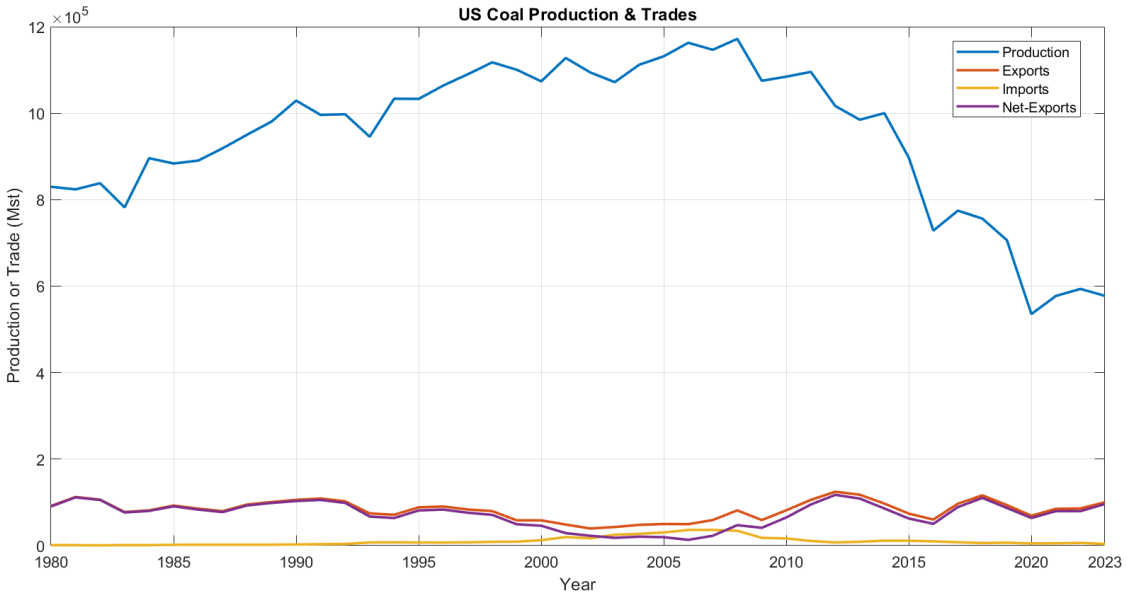


Figure 11: US coal production and trades, source:EIA

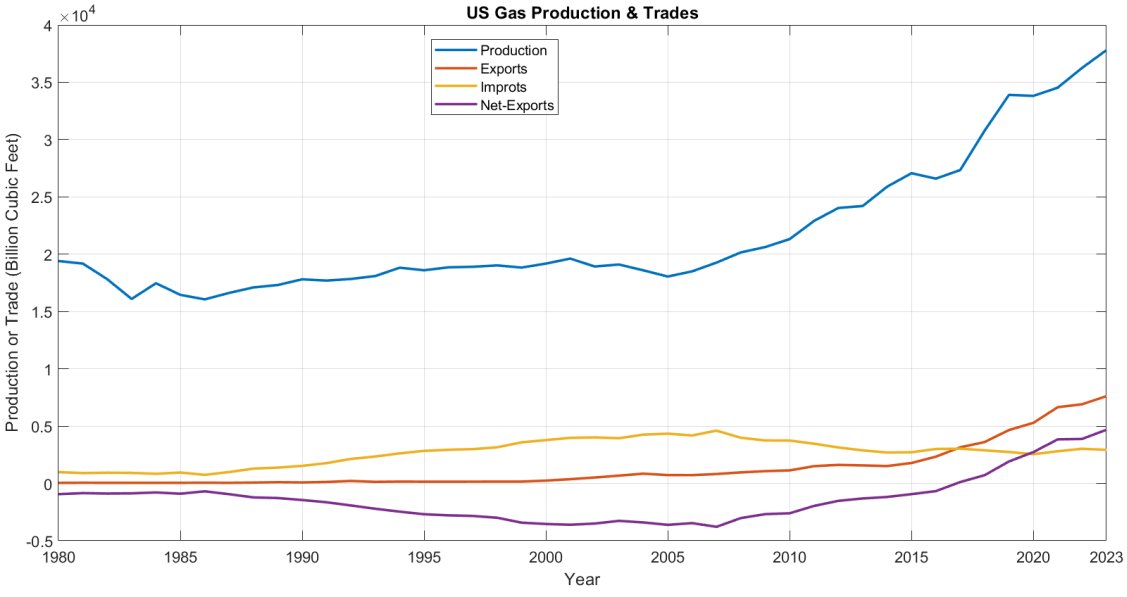


Figure 12: US gas production and trades, source:EIA

4. Empirical Methodology - Bayesian Local Projection

Its clear from the relevant literature review that SVAR models of the global oil market have become the standard tool for understanding the evolution of real oil price and its effect on the macro economy (Kilian and Zhou, 2023). VARs are useful tool for empirical analysis of shock propagation (Carriero et al., 2024). VARs can provide guidance and facilitate to validate micro-founded macroeconomic models and a natural complement to DSGE models for policy makers (Crump et al. (2025)). Standard practice in macroeconomics is to collect stylized facts about dynamic transmission of certain identified shocks using small scale VAR models and then build large scale DSGE models to explain the patterns found (Canova and Ferroni, 2022). But VARs are sensitive to misspecification errors (Zellner and Palm, 1974) for several reasons. Few notable reasons are insufficient information set with omitted variables, underestimation of lag order, unmodelled moving average disturbances, and non-linearities (Miranda-Agrippino and Ricco, 2015). Most importantly VARs are exposed to an aggregated distortion which occurs when the Data Generating Process (DGP) features more structural disturbances than the disturbances employed in the empirical model. Such distortion called deformation is not about omitting variables but omitting disturbances compare to the vector of structural disturbances that makes economic interpretation more difficult or impossible. Deformation may not affect qualitative features of the responses all the times but it affects its magnitude and persistence. Moreover, matching exercise is not useful as linear solution of a DSGE model has VARMA format. Empirical model insensitive to deformation is required for policy advice and hence value of VAR in policy analysis has been questioned. Empirical alternatives can be Bayesian and structural econometric modelling time series (Zellner and Palm, 1974), particularly Factor Augmented VAR (FAVAR), instrumental variable (IV) approaches, and local projections (LP) (based on direct projections of variables onto their lags at the relevant horizon and hence also called non-parametric or direct method). But FAVAR do not necessarily eliminate deformation because of omitting structural disturbances (Canova and Ferroni, 2022). Since LPs do not rely on VAR innovations, they are less prone to deformation because of omitting structural disturbances.

Òscar Jordà (2005) lists advantages of LP including estimation by simple regression techniques and standard regression package, robustness to misspecifications, simplicity of joint or point-wise inference, and easy experimentation with highly non-linear and flexible specifications (that maybe impractical with multivariate). Presenting Monte Carlo evidence, its showed that LP are consistent and efficient under ideal conditions and under several forms of linear and nonlinear mis-specifications. Hence, LP can be inferred as a better choice than fixed parameter VARs and the time varying Bayesian VARs used in Cogley and Sargent (2002). True DGP is unknown in practice and hence preferable to make as few assumptions on its specifications as possible. Experiments demonstrate that LP IRFs are robust to lag length misspecifications, consistent, and mildly inefficient relative to true DGP. Although LP can be used to formalize the estimation of deep parameters in rational expectation models, when primary interest is to calculate IRFs LP are natural and preferable alternative to VARs.

Miranda-Agrippino and Ricco (2015) critically evaluated IRFs estimated from VARs that can be biased due to different misspecifications and LP that can be subject to greater uncertainty. LP are less efficient and expose to bigger uncertainty because of moving average structure of residuals and risk of over parameterisations. The paper introduced flexible econometric methodology of BLP and claimed it to be robust to any misspecifications common in the empirical models. Different approaches to regularise LP have been proposed and BLP is one such approach. BLP is designed to bridge between biased VARs and less-efficient LPs by imposing minimum restrictions on the shape of the estimated IRFs. The responses obtained by this methodology are consistent with the standard macroeconomic theory, stable over time, robust to the vector of endogenous variables, and do not display puzzles. BLP IRFs tend to revert to equilibrium faster than VAR-IRFs and imply richer adjustment dynamics. BLP can sensibly reduce the impact of compounded biases over the horizon effectively dealing with the model misspecifications. Hence, I have chosen empirical methodology of BLP to evaluate relevant theory of shock propagation and to identify inconsistency

between theory and the data. The BLP responses are estimated using conjugate priors centred around an iterated VAR estimated on a pre-sample. The overall informativeness of the priors is treated as an additional parameter for which prior distribution is specified and chosen to maximise the posterior likelihood.

I have followed Kilian (2009) and Peersman and Van Robays (2012) in specifying the empirical model. Kilian and Zhou (2023) stated that natural approach is to specify a block recursive VAR model with the domestic variable ordered last. Hence, following Peersman and Van Robays (2012) the vector of variables is divided into two blocks or groups. The first group of variables model the global crude oil market following Kilian (2009) and has five structural disturbances in total, three supply and two demand shocks. The first group includes variables of US oil production, non-OPEC oil production, OPEC oil production, a measure of world economic activity, and real price of crude oil. The real oil price is structurally decomposed into three components of: crude oil supply shocks ('oil supply shock'); shocks to the global demand for all industrial commodities ('aggregate demand shock') signifying current demand for crude oil driven by fluctuations in the global business cycle; and demand shocks that are specific to the crude oil market ('oil-specific demand shock' or 'precautionary demand shock') signifying demand driven by shifts in the precautionary demand for oil. But this can also capture changes in oil demand due to technology efficiency, urbanisation, and consumption or investment complementarity with oil etc. The supply shock is further disaggregated into three supply shocks of: US oil production, non-OPEC oil production, and OPEC oil production. The proposed recursive structure has theoretical basis that I have further extended to incorporate theory of intermediate oil market supply structure between monopoly and competition. The second group of macroeconomic variables is specified as per Angeletos et al. (2020) which analysed macroeconomic time series data and used its properties to appraise models, both parsimonious and medium scale. The proposed empirical template for business-cycle propagation mechanism best describes the data and uses its properties to appraise DSGE models of any size and complexity for acceptance. Further, it detects flaws in state of the art DSGE models. To match with theoretical models of interest, I have slightly modified the original specifications which is based on 10 macro variables of unemployment rate, per capita levels of GDP, investment (inclusive of consumer durable), consumption (non-durable and services), total hours worked, labor productivity, utilization adjusted total factor productivity, labor share, inflation, and federal fund rates. The modified second group is composed of real GDP, unemployment rate, real consumption (non-durable and services), real investment (inclusive of consumer durable), consumer price index, and federal fund rates. Following Peersman and Van Robays (2012) and Kilian and Lewis (2011) [4], all variables are transformed to quarterly growth rates by taking the first difference of the natural logarithm except the index of real economic activity, unemployment rate, inflation rate, and the federal fund rate. Considering the existence of long cycles in global commodity markets, its essential to include at least two years worth of periodic lags in the VAR model (Kilian and Zhou, 2023) and accordingly lag length of 8 is set. The forecasted horizon is set to standard 20 periods.

Kilian and Zhou (2023) highlighted that to rely on WTI price of crude oil (and similar prices such as the U.S. producer price of crude oil) is a common mistake. Its recommended to use U.S. refiners' acquisition cost of crude oil (RAC) imports as per Kilian (2009). In the baseline model Baumeister and Peersman (2013) used U.S. RAC of imported crude oil highlighting that before 1974 the oil price was regulated (obvious from flat real oil price till 1973 in figure 2), which impairs the use of standard time-series models of the oil market even when time variation is allowed. The proposed time series is only available from January 1974 onward and was backcasted until 1947:I with the quarterly growth rate of the producer price index (PPI) for crude oil retrieved from the Bureau of Labor Statistics (BLS) database (WPU0561). I have used the same time series for oil price in the baseline model. The nominal variables of oil price (RAC), GDP, consumption, and investment are deflated with GDP deflator. Since the intent is to extend the model for coal and gas shocks for which time series are not available before 1990, the baseline model for oil shocks is estimated using quarterly data over the sample period 1990Q1 - 2025Q1 that is after 1986 structural block.

[4]The variables are logged difference considering variables in the VAR model are difference stationary of order one

Oil market VAR models are typically estimated on monthly data as its more credible to use exclusion and inequality restrictions for identification at monthly frequency. However, as stated before identification of shocks is not main focus for this paper and accordingly qaurterly data has been used that can be a limitation of the approach used in this paper. According to Kilian and Zhou (2023) another common mistake is to combine data from the post-1973 era with data from the pre-1973 era. The robustness check model for oil is estimated using quarterly data starting from 1973Q1 (following Kilian (2009)) and ending at 1987Q1 considering structural break around 1987 as discussed in previous sections. First 6 years data is used for estimating prior parameters based on VAR that is then discarded. Any other omitted demand and supply shocks could in principle be captured by commodity-specific demand shock, as assumed in Kilian (2009) . The shocks are identified using exclusion restrictions. Further details on the BLP methodology are provided in the appendix D.

5. Macroeconomic Effects of Energy Shocks

5.1. Oil Shocks

5.1.1. Shock to Competitive (US and Non-OPEC) Oil Supply

Figure 13 shows a negative 1% shock to U.S. oil supply reduces oil supply persistently. Such persistent response in face of high oil price could be because of lack of investment response within the sector facing uncertainty due to shocks specific to U.S. operations. The shock is similar to adverse 'supply shock' reducing productivity of firms to produce less and reducing the oil demand. The result is lower oil price for the first two quarters because of which there is no substitution by OPEC or non-OPEC supply that triggers with lag between 4 and 5 quarters. The global real economic activity increases because of substitution to other sources of productivity to increase labor and capital income resulting in increased consumption and investment at global level. Within the U.S. economy, consumption contracts due to reduced discretionary income and an uptick in precautionary savings. This initially supports investment for the first few quarters. As firms cut production the unemployment rate increases that improves for a quarter but then triggering of the second round effect, reallocation of intrasectoral and intersectoral resources, increases unemployment again. The increased unemployment negatively affects both consumption and investment. The real oil price increases after few quarters due to increased global activity subsequently increasing inflation, implying that supply channels are stronger than demand channels resulting in 'stagflationary' response. The monetary policy rate increases one-for-one with higher inflation and returns to normal level in 4 years, showing sluggishness and persistence of inflation. The fluctuating macro aggregates return to normal level in 5 years.

Macroeconomic response to non-OPEC supply shock, as shown in figure 14, is also stagflationary but with slightly different shapes of IRFs. The real oil price response is instantaneous and stronger than in the case of U.S. oil supply shock. The global real activity response is coinciding with real oil price and increasing instantaneously rather than gradually in the case of negative U.S. supply shock. Again, this can be because of substitution effect increasing labor and capital income and consumption at global level. The oil price recovers with the non-OPEC supply. The dynamic response of real GDP and consumption is negative and similar in shape to the oil price response, showing how strongly increased oil price drives these aggregates. The shape of the investment response is also similar but ambiguous as its positive for first 6 quarters and then negative presumably because of second round reallocation effects of employment. The unemployment fluctuates but stays negative for the whole horizon. The 'aggregate supply' channels are dominant increasing inflation rate gradually for the first 8 quarters increasing the monetary policy rate. As soon as inflation starts declining after 8 quarters, central bank eases the monetary policy rate to improve the unemployment rate.

A number of papers describe the propagation mechanism of global oil supply shocks which are comparable to the competitive supply shocks in my paper, either non-OPEC or U.S. Ramey and Vine (2011) identified four principle channels through which oil or energy shocks impact real growth negatively: (i) importance

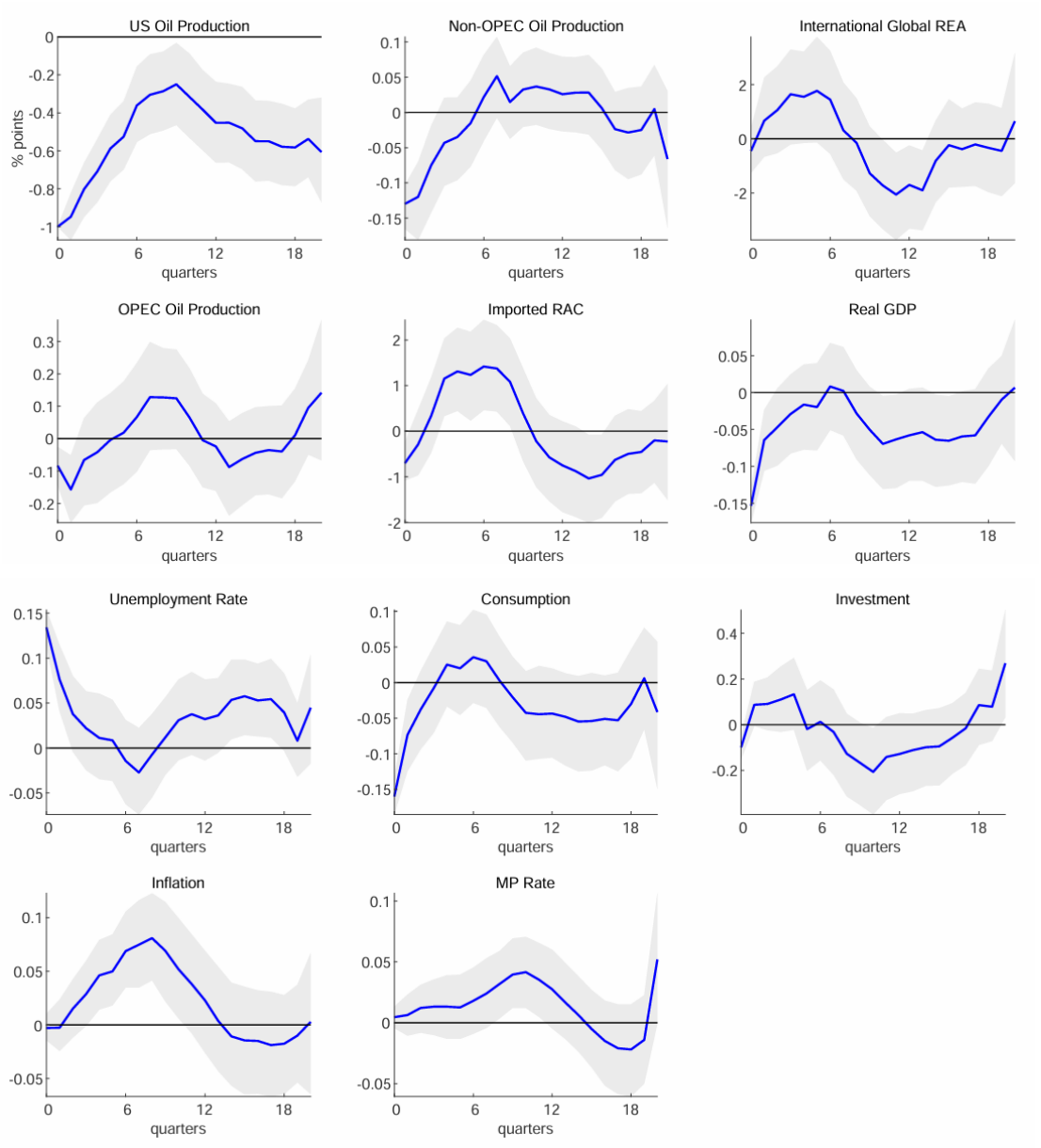


Figure 13: IRFs to negative 1% US oil supply shock based on quarterly data from 1990Q1 to 2025Q1

of energy input in the production function; (ii) importance of energy in the consumption bundle; (iii) structural shift in the demand structure; and (iv) endogenous monetary policy response to energy price shocks. Other candidate factors can be real wage rigidities, imperfect competition, variable utilization rate, and externalities across firms that amplify and propagate the effects of energy price shocks. Seeing the responses of investment (which include durables including motor vehicle) in the two competitive supply shocks, its doubtful that the most important channel through which oil shocks affect the economy is the motor vehicle industry, at least after 1990. It seems to be consumption which is stronger with higher unemployment rate. Edelstein and Kilian (2009) explained how increase in energy prices reduces consumer spending quantifying the direct effect of unanticipated changes in the discretionary income, shifts in precautionary savings, and changes in the operating cost of energy-using durables on real consumption through direct and indirect effects. Higher oil price reduces discretionary household income (less money to spend after paying energy bills), disrupts firms spending on goods and services, postpones irreversible purchase of durables due to greater uncertainty, increases precautionary savings to smooth consumption in face of greater uncertainty, and reduces purchase of durables complementary in use with oil. The indirect effects of higher oil prices are through changing consumption pattern causing intersectoral and intrasectoral reallocations that leads to second round effects of higher unemployment, further consumption cutbacks, and amplifying the effect of purchasing power losses on real economy. The literature debates on which is the primary channel through which higher oil prices affect the economy, direct or indirect effects. The competitive oil supply shocks IRFs show that indirect second round effects are the primary channel which leads to higher unemployment rate in the later stage. Kilian and Lewis (2011) analysing monetary policy response to oil shocks identified two main channels of transmission of oil price shocks: the increased cost of producing domestic output (which is akin to an adverse aggregate supply shock) and the other is the reduced purchasing power of domestic households (akin to an adverse aggregate demand shock). The latter channel of transmission may be amplified by increased precautionary savings and by the increased operating cost of energy-using durables. The empirical evidence based on 1970s and 1980s data suggests that the supply channel of transmission is weak and the demand channel of transmission dominates. However, my analysis based on data sample later than 1990s shows strength of supply channel of transmission resulting in stagflationary response of the economy and its aligned with Bernanke et al. (1997) view that oil price shocks represent adverse aggregate supply shocks, may not be always but necessarily when its because of disturbances within the competitive oil supply for the data after structural break.

The output and inflation IRFs for non-OPEC and U.S. supply shocks are comparable in interpretation to Kilian (2008a), Peersman and Robays (2009), and Peersman and Van Robays (2012) but different in shape. Kilian (2008a) shows 1% world oil supply disruption causes a sharp reduction in U.S. real GDP growth between 5 and 7 quarters after the shock and a sharp increase in CPI inflation in 3 quarters after the shock. While responses of the real GDP growth are roughly similar in figures 13 and 14, the response of inflation is instantaneous in case of U.S. supply shock but for non-OPEC supply it increases gradually to peak after 5 quarters. Peersman and Robays (2009) estimated IRFs almost similar in magnitude and direction for U.S. economy except for the monetary policy rate. In case of U.S. supply shock, the monetary policy response starts increasing gradually from the first quarter to peak in around 10 quarters and then return to normal within 4 years. In case of non-OPEC supply shock, its almost of similar shape but with shorter cycle and stronger magnitude to complete the cycle of monetary tightening in less than 3 years. This highlights the role of monetary policy design in stabilising fluctuations rather than producing fluctuations. IRFs estimated in Peersman and Van Robays (2012) are also similar in sign and magnitude but with different shape.

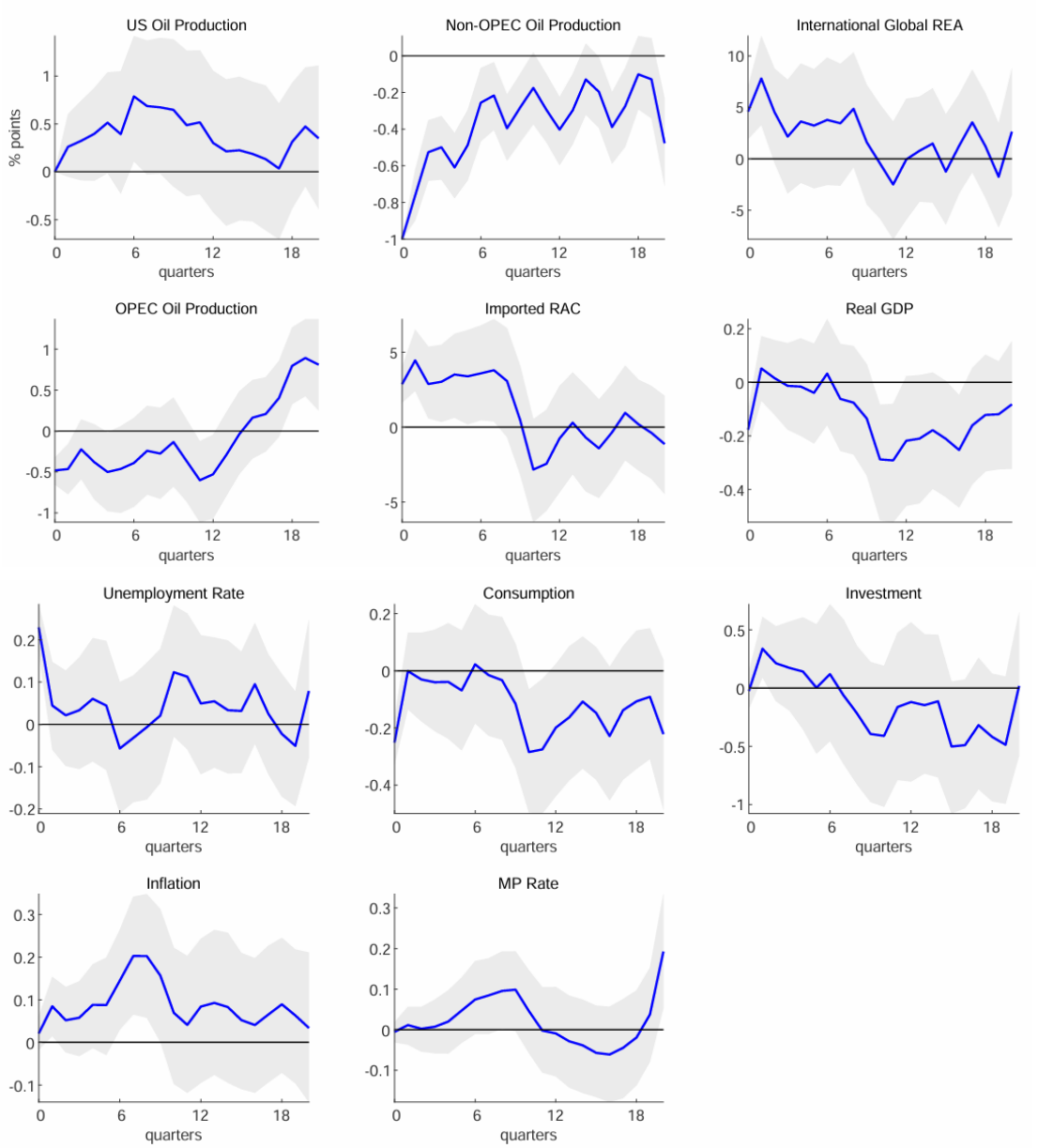


Figure 14: IRFs to negative 1% Non-OPEC oil supply shock based on quarterly data from 1990Q1 to 2025Q1

5.1.2. Shock to Monopolist (OPEC) Oil Supply

Figure 15 shows IRFs of macro aggregates to negative 1% OPEC supply shock that are different from non-OPEC and US supply shocks. The disrupted oil supply is substituted decreasing oil demand to decrease oil price for a quarter or so. Since US oil imports are dependent on OPEC partially and these channels are rigid so the productivity is impacted for a quarter or two increasing unemployment. Reallocation of oil import results in substitution to non-OPEC supply which increases for the remaining horizon. The US real output although fluctuates but stays positive for the remaining horizon showing the overall benefit of reduction in monopoly rent. The dynamic response of the global output is also positive, partially because of reduction in monopoly rent and partially because of substitution effect to increase overall real activity. The non-OPEC oil supply seems to be more cost efficient than US supply and hence substituting not only OPEC supply but also US supply that falls for more than 3 years and then recovers with the U.S. real GDP. The response of consumption is just inverted to the unemployment response, negative in the beginning 4 quarters and then increases with higher labor income. The investment increases from the beginning due to capital substitution effect, similar to substitution effect in previous shocks. In the beginning 4 quarters 'aggregate demand' effect would be dominant creating weaker demand and higher unemployment and hence deflationary. But later than 4 quarters with increased demand due to increased consumption and investment, the inflation starts increasing to reach peak in around 12 quarters. Monetary policy rate that is expansionary in the first 4 to 8 quarters due to deflation and higher unemployment, starts gradually tightening after 2 years in parallel with inflation. The magnitude of monetary policy response is comparable to the response of US supply shock. The OPEC supply shock increases oil and prices with higher inflation but it leads to positive output growth of not only US economy but global economy.

Kilian (2008a), Peersman and Robays (2009), Peersman and Van Robays (2012) or any other paper in literature have not disaggregated oil supply shocks into competitive and monopolist oil supply shocks based on asymmetry of market power. The market power asymmetry is critical to evaluate the response of real output that is inconsistent with real oil prices and depends on the source of shock driving the real oil price increase. Kilian (2008b) introduced a new methodology for quantifying the shortfall of OPEC oil production caused by exogenous political events such as wars or civil disturbances using monthly production data for all OPEC countries and for aggregate non-OPEC oil production. It was showed that the effects of exogenous oil supply shocks (mainly in Middle East and other OPEC countries) on U.S. real GDP growth and CPI inflation were comparatively small on average and of limited importance in explaining oil price changes. This is the closest reference available to assess IRFs of monopolist oil supply shock in this paper.

5.1.3. Aggregate Demand Shock

Figure 16 shows IRFs to positive 1% aggregate demand shock driven by international business cycle. The increase in real oil price is not significant in magnitude compare to supply shocks. The increased oil price results in increased inflation but not at the same level as for the supply shocks. The shape of endogenous monetary policy response is different from the response to supply shocks. The monetary policy rate increases from beginning and stays high for more than 3 years. The unemployment rate decreases in the beginning quarter but then increase due to falling factor productivity which can be due to increased inflation. Similarly, due to increased cost of inputs and uncertainty in the future returns the investment also experiences negative growth. Overall, the macroeconomic impact of aggregate demand shock is not different from U.S. and non-OPEC supply shocks but with weaker magnitude. This inference is aligned with inference of HAMILTON (2009) stating that 2007 - 2008 oil price shocks were primarily caused by strong demand that was different from earlier price shocks caused by supply disruption but the consequences for economy were similar.

Responses of real output, inflation, and the monetary policy rate to aggregate demand shocks in Peersman and Robays (2009) are almost similar in shape but stronger in magnitude for inflation and the monetary

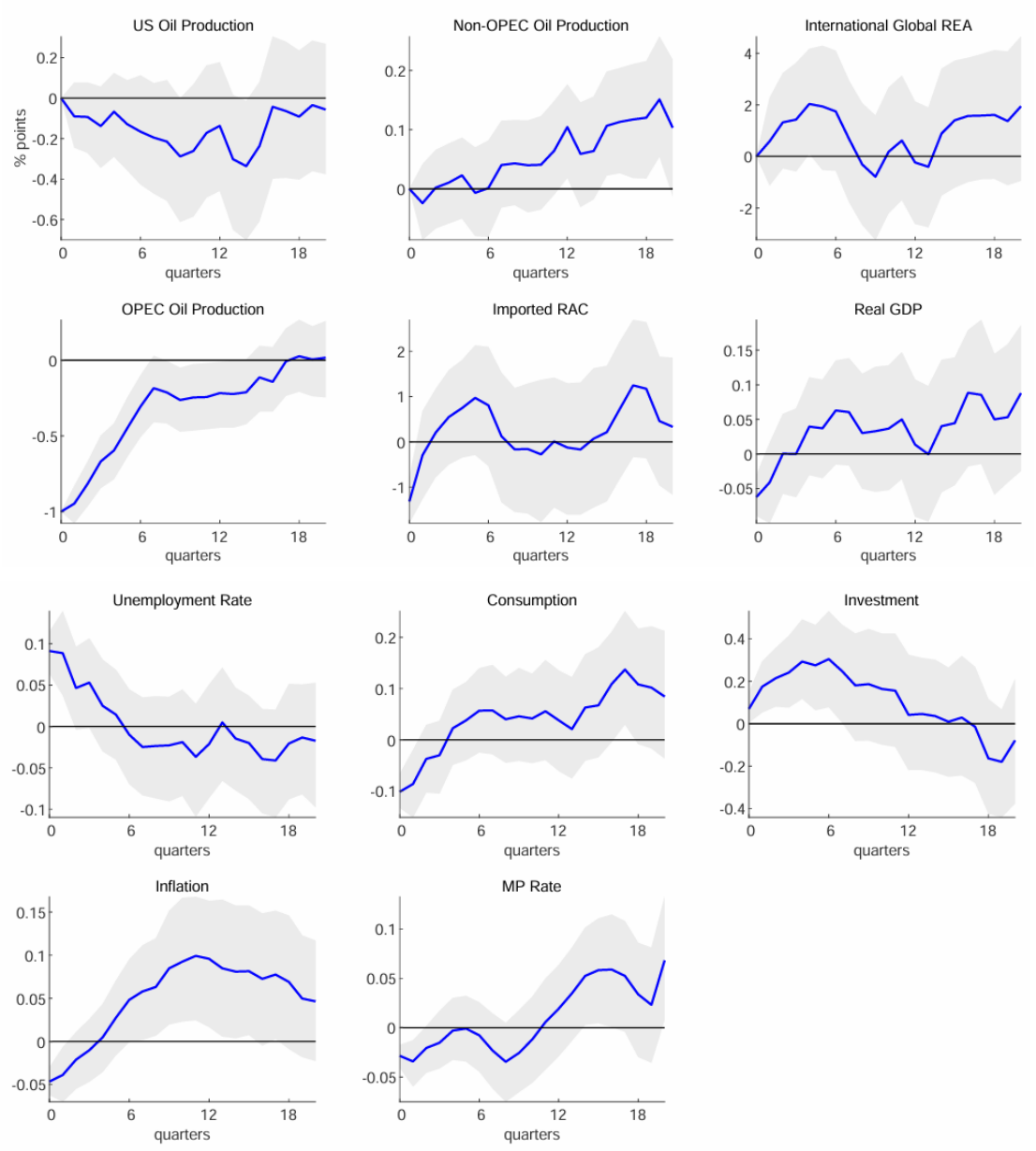


Figure 15: IRFs to negative 1% OPEC oil supply shock based on quarterly data from 1990Q1 to 2025Q1

policy rate. In Peersman and Van Robays (2012), the monetary policy response is significantly strong to control inflation. The shape of the output and inflation responses is comparable to IRFs in my paper. However, the IRFs in my model are more flexible and show quarterly variation due to seasonality whereas in these referred papers responses are more smooth.

5.1.4. Oil-Specific Demand Shock

Figure 17 shows IRFs to positive 1% oil-specific demand shock that is also referred as precautionary demand shock in the literature. All the oil producers increase the oil production driven by high oil price. The increased oil price affects the international global activity negatively and so the US real output. The expensive oil is substituted by labor reducing the unemployment rate. The real consumption follows the income path to stay negative after 4 quarters and fluctuates accordingly. The inflation is high for the first 6 quarters because of higher input prices and higher demand. The monetary policy rate increases for first 5 quarters but then with the negative output growth, the monetary policy rate is expansionary. Due to uncertainty and negative outlook, the investment decreases. The macroeconomic impact of oil-specific demand shock is similar quantitatively and qualitatively to aggregate demand shock.

In Peersman and Robays (2009), oil specific demand shock is stagflationary. The MP response is contractionary for first 3 years and then expansionary. The responses of real output, inflation, and MP rate are similar in Peersman and Van Robays (2012).

5.1.5. How robust are results to 1970s oil shocks?

While Peersman and Robays (2009) estimated benchmark model for the period 1986Q1 - 2008Q1 and Kilian (2008a) performed regression analysis for the period 1971Q1 - 2004Q3, Peersman and Van Robays (2012) estimated models for two different periods of 1971Q1 - 1985Q4 and 1986Q1 - 2010Q4. Following later approach and considering the constraint of data availability for coal and gas prices from 1990, the main model in this paper is for the period 1990Q1-2025Q1. Considering 1987 structural break in the data, the model for period 1973Q1-1987Q1 is also estimated. Motivation is to resolve the puzzle of 1970s stagflation as absence of a close link between oil prices and stagflation in other times than in 1970s is puzzling for the economists (Barsky and Kilian (2001)). Another objective is to assess how robust is the methodology of this paper to different economic times. The estimated IRFs are in the appendix E and main findings are discussed here.

The 1970s aggregate demand shock is perfectly stagflationary (as shown in figure 28) and can be a good explanation to resolve the 1970s stagflation puzzle. The aggregate demand shock was acting as an exogenous supply shock for U.S. economy as interpreted by Blanchard and Gali (2007), not only for oil but also for other commodities. This is aligned with Barsky and Kilian (2001) finding of global economic boom fueled by monetary expansion. The timing of the oil price increase in the 1970s coincided with periods of unusually strong demand for oil, driven in substantial part by global macroeconomic conditions. Such an adverse supply shock reduced productivity to increase unemployment and negatively impacted consumption and investment. Inflation increased due to marginal cost channels and traced closely by the monetary policy rate. OPEC supply was comparatively more responsive than non-OPEC supply due to under utilised oil assets and adjusted its supply reacting to the demand to sustain higher real oil prices. With a lag of 4 quarters, the U.S. oil producers were also more responsive to higher oil prices and produced more. The negative productivity improved as soon as U.S. oil producers started producing more oil. Figure 29 shows that impact of OPEC (monopolist) oil supply shock on real GDP as well as on global real activity was moderately positive. Another difference to note is unemployment response which was rigid to the shock and similarly consumption and investment responses were also rigid. It can be generalised that macroeconomic response was either rigid or positive to the OPEC supply shocks in 1970s. This response is aligned with the literature that rules out the role of exogenous supply disruptions in the Middle East in 1970s and early

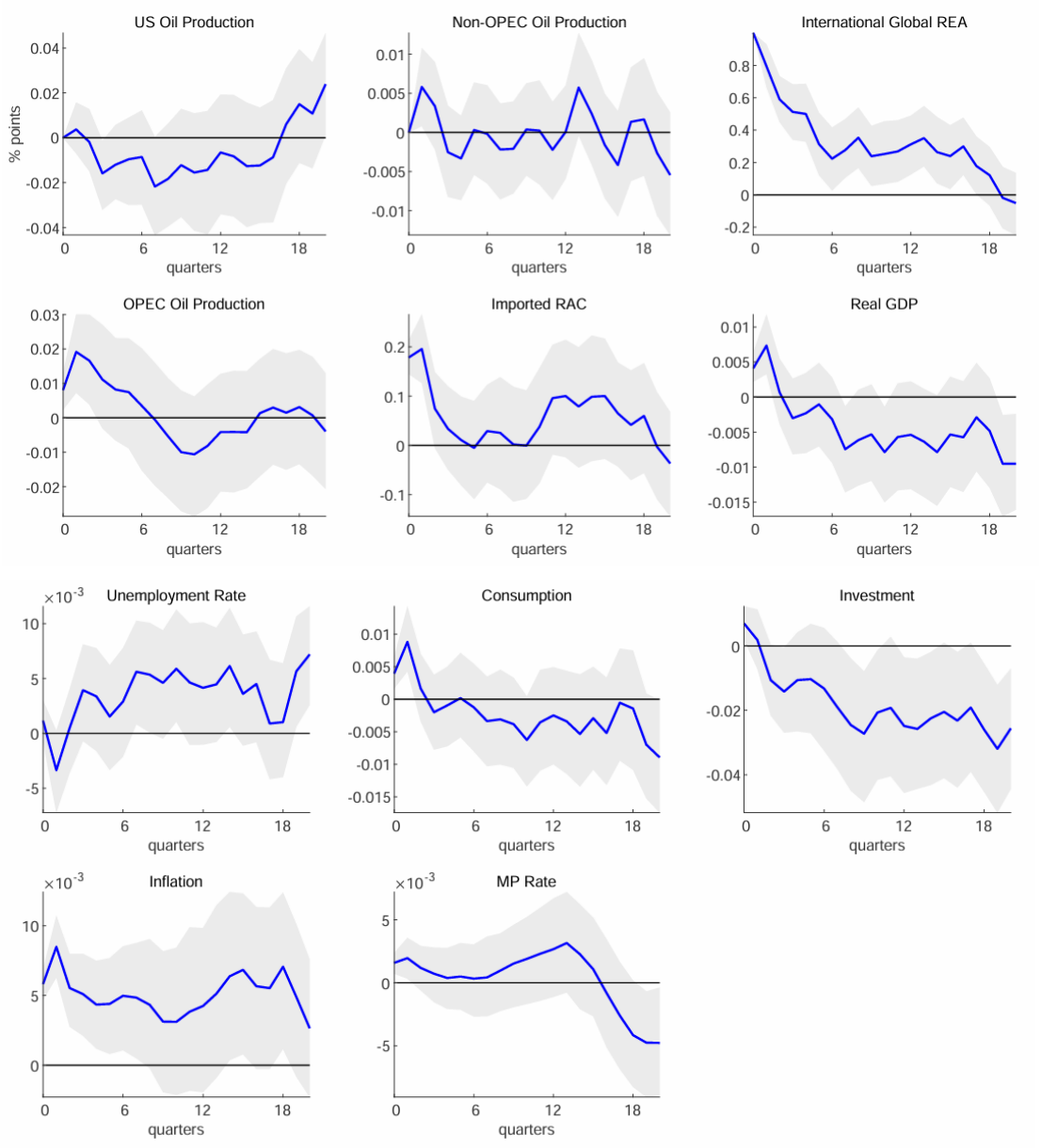


Figure 16: IRFs to postive 1% aggregate demand shock based on quarterly data from 1990Q1 to 2025Q1

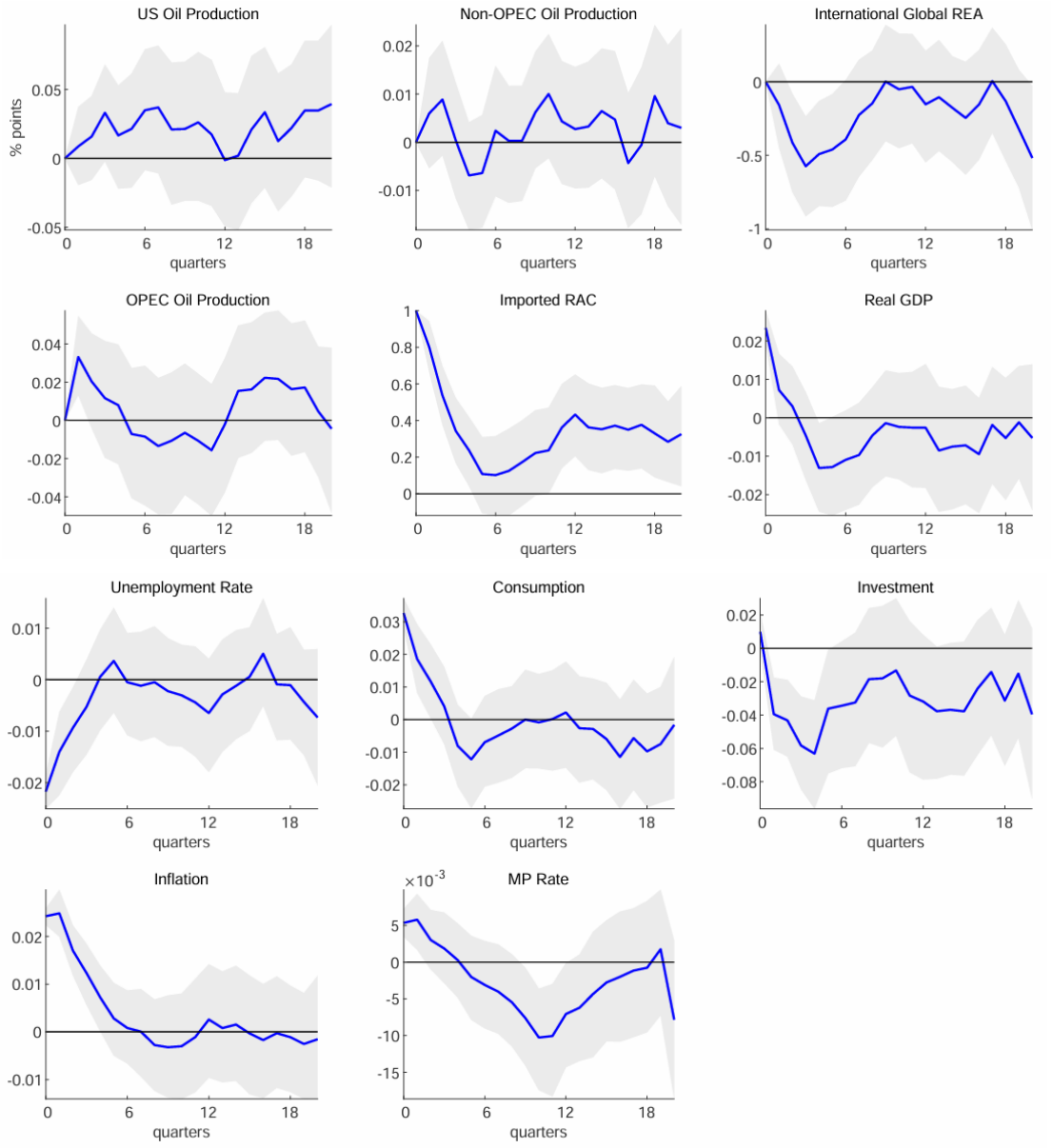


Figure 17: IRFs to postive 1% oil price shock based on quarterly data from 1990Q1 to 2025Q1

1980s in oil price fluctuations and stagflation (Kilian and Zhou (2023), Barsky and Kilian (2001), Kilian (2008a)). In the later period, the macroeconomic responses to negative OPEC supply shocks have become more positive due to increased substitution effect by non-OPEC oil supply.

Figure 30 shows IRFs to U.S. oil supply shock in 1970s, that was less persistent with recovery period of 3 to 4 quarters whereas in the later period its more permanent. The more persistent response in the later period can be due to increased investment frictions because of environmental regulations and climate change policies. Another difference is in the response of non-OPEC and OPEC supplies which were more responsive to such supply losses and substituted it to maintain the real oil price. The most important difference is in the response of aggregate demand that was responding negatively in 1970s contrary to positive response after structural break. The earlier recovery of U.S. oil supply supported earlier recovery of U.S. real growth, within 6 quarters. Both consumption and investment enabled the real GDP recovery but its more because of investment which includes durables i.e. motor vehicle channels as identified by (Ramey and Vine (2011)). Further, the response of real GDP to U.S. oil supply shock has not declined over time, consistent with (Ramey and Vine (2011)). The monetary policy response was muted because of lack of inflation. The intrasectoral and intersectoral reallocations negatively impacted the labor cascading to negative consumption at later stage, the second round indirect effects of oil supply shocks.

Compare to real GDP responses to non-OPEC supply shocks in 1970s –1980s (in figure 31), the response of real GDP has become more negative in 1990s as the U.S. oil import structure has changed. U.S. oil imports were more from OPEC before mid 1990s but after mid 1990s its more from non-OPEC countries as shown in figure 23. While in the period later than the structural break competitive oil supply shocks are stagflationary, in the 1970s none of the oil supply shock was stagflationary but deflationary and recessionary. The global demand was responding negatively (U.S. supply) to mildly positive (non-OPEC supply) to competitive oil supply shocks in 1970s whereas in the later period its responding strongly positive. The earlier period negative response can be explained by higher share of oil in global production as in figure 4. The demand channels were dominant in propagation of oil shocks to economy before the 1986 structural break whereas in the later period supply channels are dominant. Empirical evidence in the literature suggests that the oil shock transmission channel of supply is weak and that of demand is dominant (Kilian and Lewis (2011)), making oil price shock more deflationary that fits with earlier period responses. Baumeister and Peersman (2013) also shows that the bulk of the inflation in the 1970s and early 1980s is explained by other shocks and not the oil shocks. Barsky and Kilian (2001) states that although an oil supply shock may cause recession, its effect on the GDP deflator is ambiguous in theory and appears to be small in practice. Same finding is validated by IRFs in my model showing that competitive (and also monopolist) supply shocks are not inflationary in the period earlier than the structural break. These are the changing international linkages which have changed the relative strength of supply and demand channels explaining the ambiguous response of inflation to oil supply shocks. Regardless of ambiguity of the inflation response, real oil price response to US oil supply shock is equally stronger in both the periods. The lower share of oil in global production, which seems to be at the same level as for natural gas as in figure 4 , has changed the oil demand response because of which response of oil price is getting stronger and leading to inflation. But the same lower share explains reduced impact of these shocks on the real output.

Figure 32 shows IRFs to oil-specific demand shock that was more persistent in 1970s implying imperfect substitutability of oil as explained above. The response of OPEC and non-OPEC oil supply was lower whereas response of US oil supply was higher in 1970s. In none of the periods, oil-specific demand shock is stagflationary. In fact, in 1970s this shock was driving US economic growth positively. On this basis, it can be ruled out that precautionary oil demand was driving higher oil prices in 1970s as real GDP response to the shock was counterfactual. This inference is contradictory to (Kilian and Murphy (2014)) which considered important role of speculative demand shifts during oil price episodes of 1979 and 1986.

Its clear that OPEC oil supply shocks had no role in 1970s stagflation, consistent with the widely accepted literature. However, the role of U.S. oil supply shocks in the negative real growth cannot be ignored as

its traditionally ignored in the literature. The only papers that discussed the role of U.S. supply shocks in negative responses of real variables in 1970s are Ramey and Vine (2011) and Mork (1989). The oil price controls were imposed on the U.S. oil industry in August 1971 that were made more stringent in response to the OPEC embargo of October 1973. These price controls disrupted U.S. oil production. Multiple oil and gas price controls also produced shortages after the Iranian revolution of 1979. It was in January 1981, that President Reagan signed an order completely deregulating oil and gas prices. These complex price controls, old crude oil entitlement and allocation program, and other regulations related to environment discouraged domestic U.S. oil production. The price controls implicitly increased the rate of return of keeping the oil in the ground higher than selling it. Kilian and Murphy (2014) interpreted such speculation as precautionary demand shock but attributed it to OPEC that in anticipation of even higher oil prices held back its production after 2001, using oil below ground effectively as inventories. In my model, U.S. producers holding back oil production in anticipation of rising oil prices would be classified as a negative oil supply shock that was mainly driving fluctuations in oil prices followed by aggregate demand shock. Theoretical explanation in equation 1 is that the oil producers adjust the utilisation rate optimally such that the marginal cost of utilisation rate adjustment is equal to marginal return. Since the marginal returns were controlled by the regulations, not allowing to increase sufficiently to equal the marginal cost but were less, the suppliers were not adjusting the utilisation rate to increase the oil production resulting into supply shock.

$$a\prime(u^{o}_{c,t}) = r^{x}_{t} \tag{1}$$

The aggregate demand driven by international business cycles can best describe 1970s US stagflation. But the negative real impact of US supply shocks and positive real impact of OPEC supply shocks cannot be ignored to resolve the longstanding puzzle of irregular pattern between oil prices and real economic activity. The developed model and methodology are explaining the responses of macro aggregates consistent with the economic theory as shown in appendices G. The oil supply structure has asymmetry of market power which is intermediate between monopolistic (OPEC) and competitive (non-OPEC including U.S.) producers. The monopolistic producer strategically responds to competitive supply curve and demand to sustain high oil prices and revenues. The disruption to monopolistic oil supply has positive real impact on the economy whereas to competitive supply has negative real impact. Theoretically, both disturbances should increase the oil price and inflation that was missing before the structural break due to different international linkages increasing the strength of demand channels that were leading to deflation.

5.2. Gas Shocks

In the last section I developed robust empirical model based on oil market VAR literature providing responses of macro aggregates consistent with the economic theory and helping to resolve long standing puzzle of inconsistent responses of real variables. The same model can be modified to incorporate gas price shocks. The first block of global oil market is modified by replacing U.S. oil supply with U.S. gas supply and oil price with gas price. The time series used for gas price is global price of natural gas EU (PNGASEUUSDM from FED) that is in the unit U.S. Dollars per Million Metric British Thermal Unit and observed in monthly frequency. Same is changed to quarterly frequency by taking average. The time series for U.S. gas production is taken from EIA observed in the units of million cubic feet (mmcf). The U.S. gas supply is ordered first capturing gas supply shocks, followed by international global real economic activity capturing aggregate demand shock, and then the gas price which in principle captures not only gas-specific demand shocks but also shocks due to supply disruptions outside U.S. The second block of macroeconomic variables is not changed. Figure 18 shows IRFs to negative 1% U.S. gas supply shock. Since U.S. is one of the largest gas producer the disruptions to its gas supply impact not only U.S. productivity but also global productivity showing negative response of global real activity for all the forecasted 20 horizons. The U.S. real GDP response is negative throughout with few periods of positive growth that may be because of seasonal variation in employment. The real gas price varies accordingly from positive to negative within beginning 8 quarters and then recovers to normal based on recovery of real economic variables. The inflation

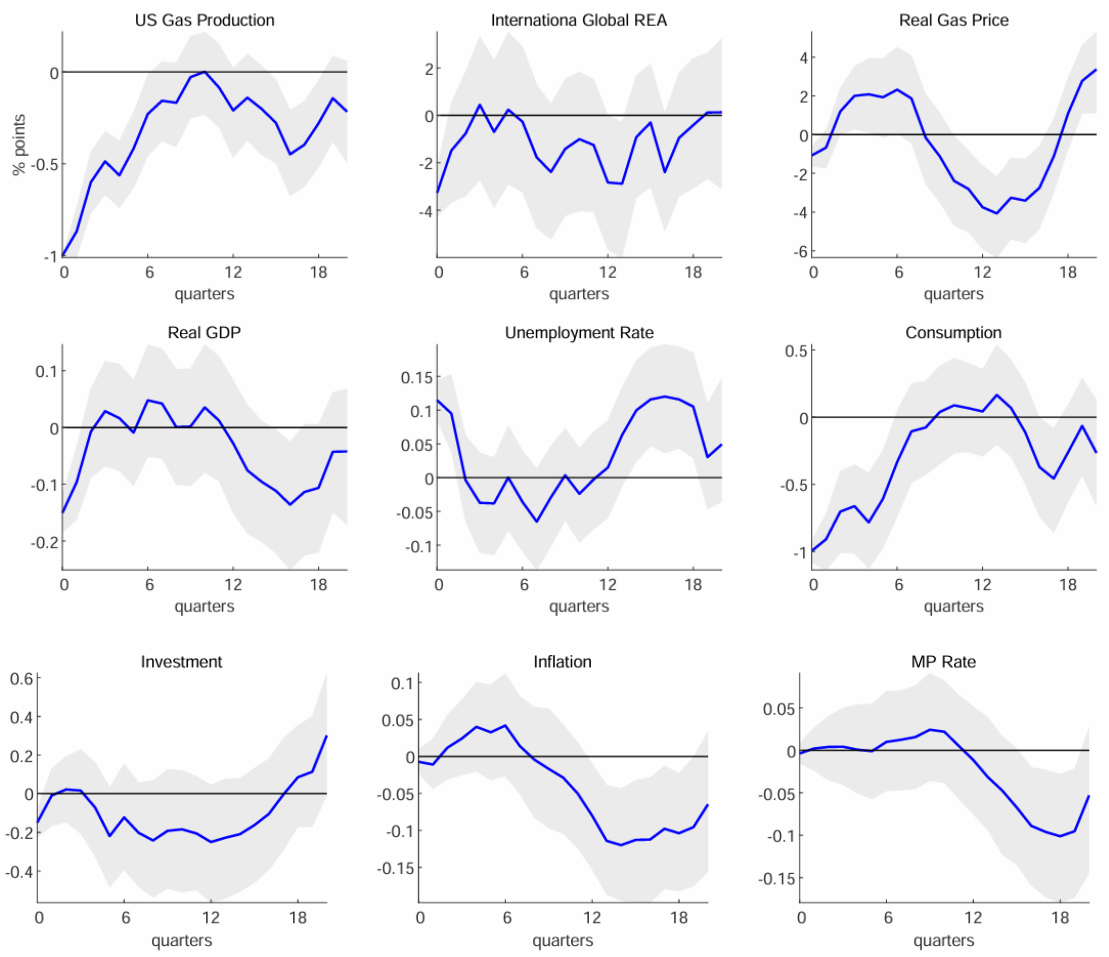


Figure 18: IRFs to negative 1% US gas supply shock based on quarterly data from 1990Q1 to 2025Q1

varies accordingly increasing the monetary policy rate between 6 and 12 quarters. In the following quarters monetary policy is expansionary due to deflation and higher unemployment. The second round indirect effect leading to higher unemployment and negative real growth is evident. The higher unemployment is because of intersectoral and intrasectoral reallocations that in return impacts consumption and investment negatively. The demand channels, mainly because of declined investment, dominates in the later quarters leading to deflation. The initial stagflationary response of negative supply shock is consistent with the results of Alessandri and Gazzani (2025) which used instrument within Bayesian VAR model estimated for European gas market over the period 2010 - 2022.

Figure 19 shows IRFs to positive 1% gas price shock that is more relevant to the recent scenario of post-pandemic inflation when gas prices increased earlier because of post-COVID lock down demand and later because of Russia - Ukraine war. Similar to U.S. gas supply shock, the increase in gas price impacts international real activity negatively throughout the horizon. The U.S. gas supply increases responding to higher gas prices increasing GDP for a quarter or two but then it turns negative. The firms substitute more expensive gas inputs in production with labor. The consumption is high because of increased labor income. Because of higher marginal cost the inflation is high for 6 quarters, increasing the monetary policy rate. However, the increase in inflation is less in magnitude compare to U.S. gas supply shock. After 8 quarters

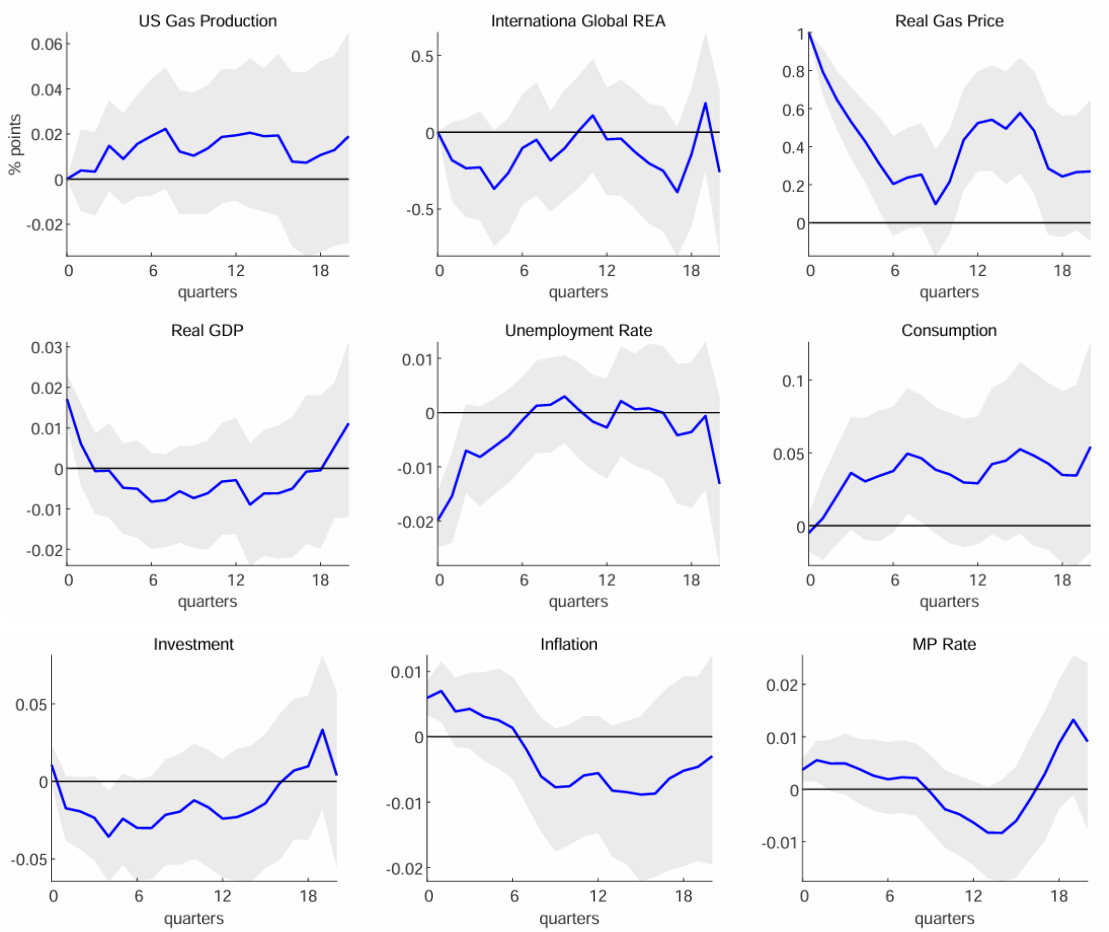


Figure 19: IRFs to positive 1% gas price shock based on quarterly data from 1990Q1 to 2025Q1

monetary policy is expansionary because of deflation and negative real GDP. The investment declines and then starts increasing after 8 quarters and returns to its normal level in around 4 years. In the last quarters, the real growth is positive because of increased investment. Both the shocks show stagflationary response at least for 2 to 4 quarters, although magnitude and shape of IRFs are different.

5.3. Coal Shocks

Similar to the last sections the model of coal price shocks is in tow blocks. The first block of global coal market composed of U.S. coal supply, international economic activity, and coal price. The time series used for coal price is global price of coal, Australia (PCOALAUUSDM from FED) in unit U.S. Dollars per Metric Ton and observed in monthly frequency. Same is changed to quarterly frequency by taking average. The time series for US coal production is taken from EIA observed in the unit of thousand short tons. The U.S. coal supply is ordered first capturing coal supply shocks, followed by international global real economic activity capturing aggregate demand shock, and then the coal price which in principle captures coal-specific demand shocks and shocks due to supply disruptions outside U.S. The second block of macroeconomic variables is not changed. Figure 20 shows IRFs to negative 1% U.S. supply shock which impacts the international demand positively for first 6 quarters after which it becomes negative. The U.S. real GDP is

negatively impacted throughout the horizon due to reduced productivity. Reduced productivity impacts unemployment that becomes volatile with not so much substitution effect. The employment volatility affects consumption for first 6 to 8 quarters that recovers with lower coal prices. The increase in real coal price peaks in 6 quarters after which it returns to normal level in 12 quarters and then becomes negative. The inflation increases and follows the coal price response. Due to higher unemployment and fallen consumption, monetary policy does not respond to inflation for first 6 quarters and as soon as consumption recovers to its normal level, monetary policy rate increases to control inflation within 3 to 4 years from the shock occurrence.

Figure 21 shows IRFs to positive 1% coal price shock increasing inflation instantaneously that follows the coal price curve closely. Similar to U.S. coal supply shock, the international real economic activity responds negatively but throughout the horizon. Real economic activity is positive for first three quarters after which it experiences negative trend for the remaining quarters. Because of positive real growth in the first few quarters employment is high but then decreases as the recession starts. The monetary policy rate increases and stays high for a year but then expansionary due to higher unemployment and lower growth. Because of loss in discretionary income, the consumption falls for a year and then increases by expansionary monetary policy. The response of investment is negative for first 3 years which then recovers to positive because of expansionary monetary policy.

The macroeconomic responses to U.S. coal supply and coal price shocks are stagflationary for the sample period. The quarterly data is not available before 1990s otherwise its useful to verify if 1970s coal price shocks contributed to inflation within the U.S. economy. The narrative evidence on coal price shocks and its strong correlation with oil prices is available from previous papers (Hamilton (1983a),Hamilton (1983b)). Larger increases in coal prices were observed in late 1969 and 1970 at the time of Japanese steel industry boom increasing U.S. coal exports to 40%. Despite increased coal demand, the coal production was not increased due to health and safety legislations and labor strikes.

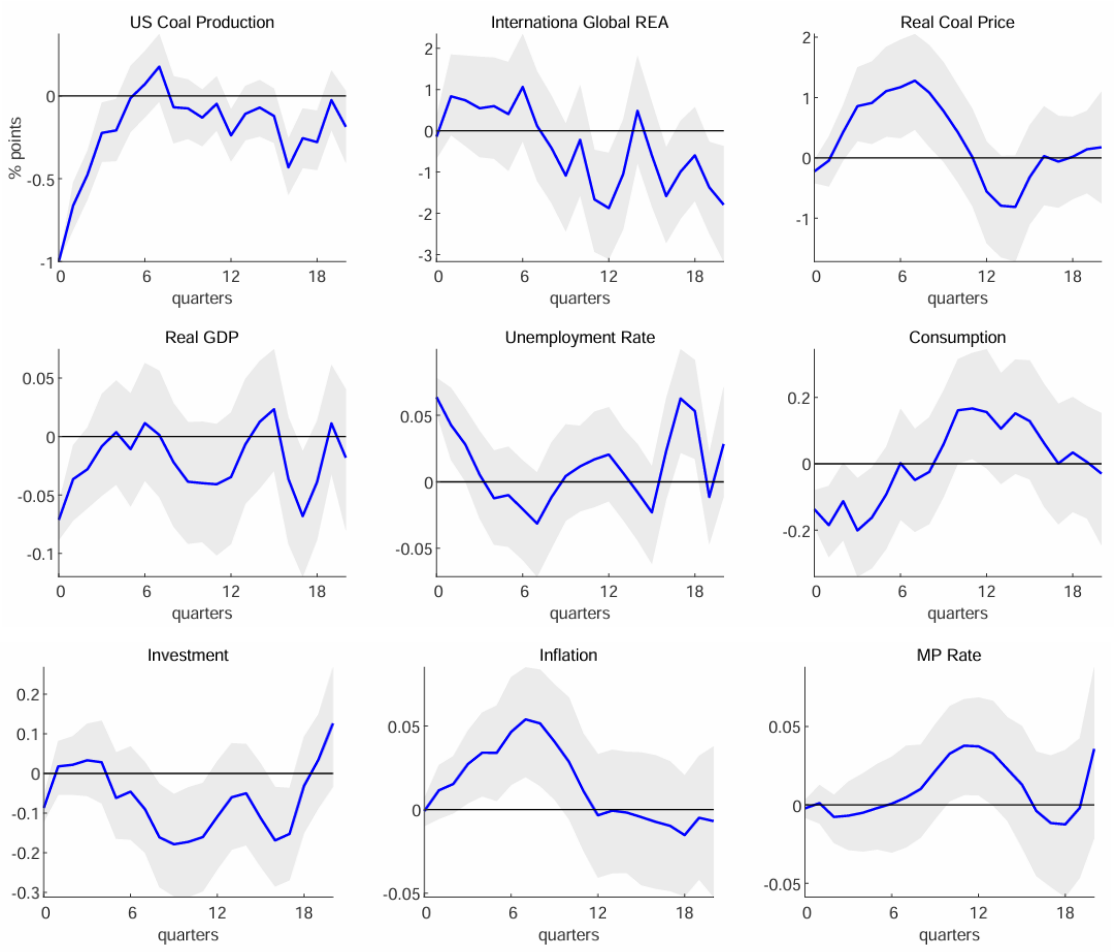


Figure 20: IRFs to negative 1% coal supply shock based on quarterly data from 1990Q1 to 2025Q1

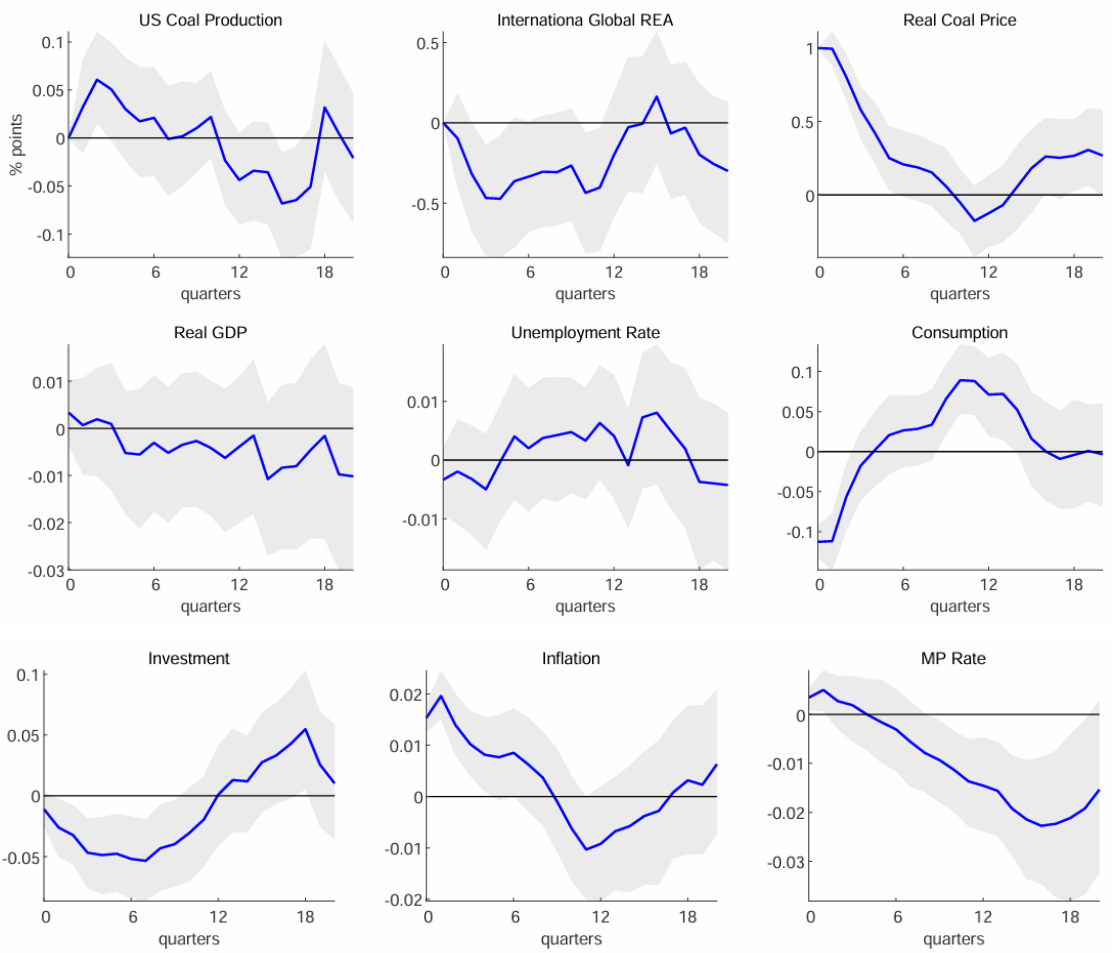


Figure 21: IRFs to positive 1% coal price shock based on quarterly data from 1990Q1 to 2025Q1

6. Conclusion

The oil market VAR literature has evolved rapidly. There are divergent views on the macroeconomic impact of oil price shocks with a long-standing puzzle of inconsistent relationship between oil prices and economic growth. In addition, the relationship between oil price shocks and inflation is also ambiguous. Generally, the macroeconomics literature has been exposed to problem of mismatch between (larger scale) DSGE models and (small-scale) VAR models because of deformation. I have addressed these challenges by using econometric methodology of BLP which is robust to misspecifications, non-linearity, and moving average structure of residuals. Except few theoretical DSGE models (Nakov and Pescatori (2007a),Nakov and Nuño (2013)), oil market VAR literature has not taken into account asymmetric market power between competitive (non-OPEC) and monopolist (OPEC) producers in the oil industry. The disturbances to competitive oil supply are too critical to ignore to resolve the issue of *deformation*. I have addressed this issue by diaggregating the oil supply into US, non-OPEC excluding US, and OPEC supplies. Even without using any complex shock identification restrictions but only exclusion restrictions, I have developed models validating the relevant economic theory of DSGE models and showing stability with time.

The modelling results show that 1970s stagflation was not due to 1973 oil embargoes, 1979 Iran revolution, or the later Iran-Iraq war. Similarly, the negative OPEC supply shocks were not driving the increases in real oil prices. Although, there was an institutional change with OPEC setting the oil prices by strategically responding to oil demand and competitive oil supply, but more than OPEC it was the disturbances in the U.S. oil supply increasing oil prices and impacting real output growth negatively. The oil production in U.S. was disrupted by regulations of price control and health and safety resulting in oil storage below the ground. Such negative supply shock is interpreted as 'speculative demand' shock in the literature and identified using the inventories or oil price variables. But such identification scheme cannot capture negative competitive oil supply shocks unless variables of competitive oil production are taken into account. It was negative U.S. and non-OPEC oil supply shocks that were mainly driving increase in the real oil price and not the oil-specific demand shock as such a shock was leading to counterfactual response of positive real growth. Most importantly the responses of real output growth to supply shocks are not homogeneous but heterogenous that explains the inconsistency in the relationship between oil prices and the output.

The ambiguity of inflation to the oil supply shocks can be explained by international linkages, relative strength of supply and demand channels, and the OPEC response. The international linkages are reflected in the share of oil in global production that has fallen considerably. These linkages has increased the substitution effect of oil supply disruptions within the oil sector, within energy sector, and within productivity factors. The differences between responses of macro aggregates to negative OPEC supply shocks in the two periods can explain this substitution. In the later period, diversified non-OPEC supply can substitute more effectively the lost OPEC supply. Similarly, the closing gap between oil intensity and other commodities have made oil more substitutable by other commodities. Its highly likely that oil can be substituted by labor and capital due to expanding services sector globally. The oil supply shocks trigger these substitution effects increasing the global real economic activity leading to higher oil prices and inflation. Another factor explaining this ambiguity is the relative strength of supply and demand channels. The relative strength of supply channels has increased increasing real oil prices and inflation whereas in the earlier period demand channels were stronger resulting in recession and deflation. The estimated IRFs also show that in the earlier period OPEC response was not so effective to the supply shocks whereas in the later periods OPEC has become more effective in implementing its strategy to maximize its utility by increasing oil prices.

The shock which can explain 1970s stagflation in U.S. is of aggregate demand. There is evidence in the literature of positive aggregate demand shocks in 1970s, driven by expansionary monetary policy globally. Similarly, there is evidence in literature of coal and gas negative supply shocks but contribution of these shocks to stagflation cannot be evaluated and verified because of non-availability of data before 1990s, regardless there was no structural break in these sectors as in the oil sector in 1986. The estimated IRFs

predict stagflation due to coal and gas price shocks, an inference aligned with theory-based responses of DSGE models, shown in appendix F. The competitive oil supply shocks were not stagflationary before structural break of 1986 but have become stagflationary after the break. Similarly, this inference of oil shocks is aligned with theory-based responses of DSGE models, shown in appendix G[5]. The negative impact of energy shocks on real growth is not doubtful but impact of these shocks on inflation can be ambiguous because of international linkages. This merits further research into these linkages to evaluate and design monetary policy to stabilise fluctuations induced by energy shocks.

[5]These are estimated in other two papers in progress

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A US Crude Oil Imports Share

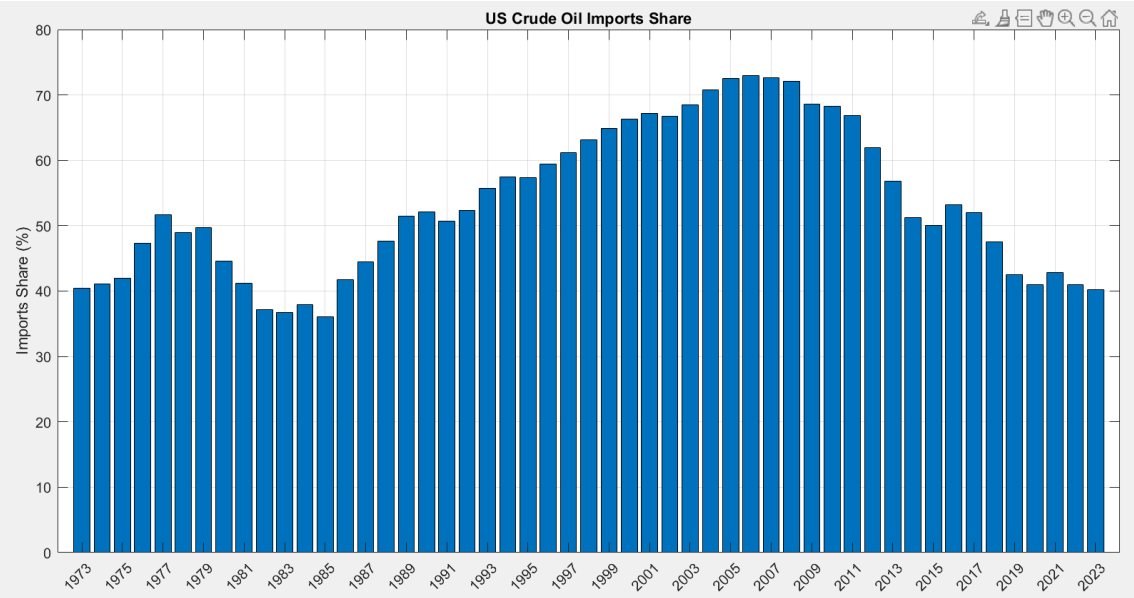


Figure 22: US Crude Oil Import Share (Source: EIA and https://afdc.energy.gov/data)

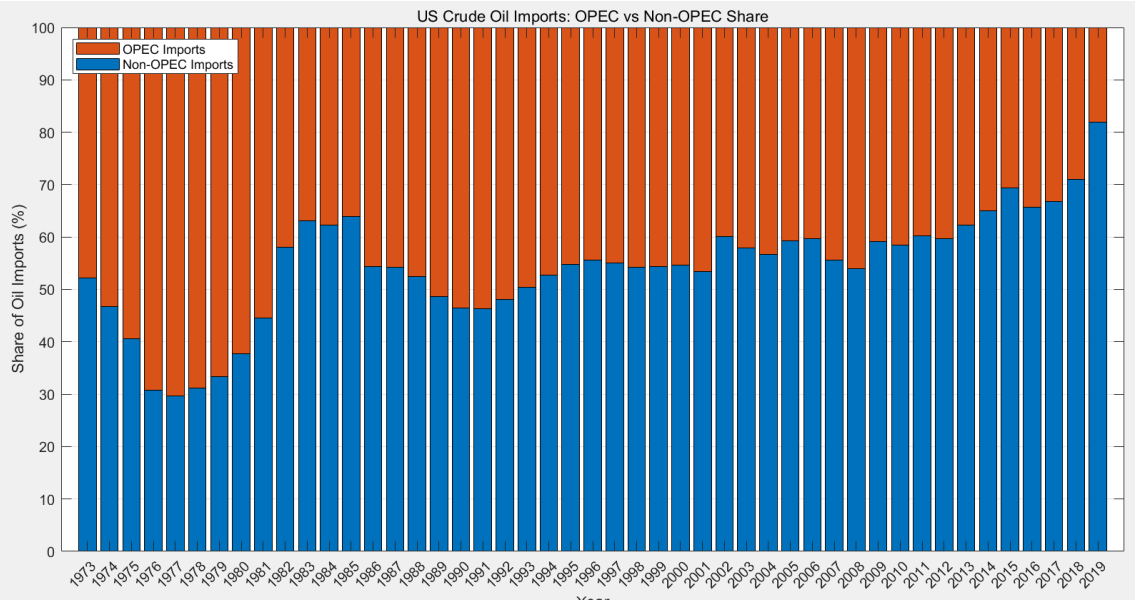


Figure 23: OPEC and Non-OPEC Share Allocation in US Crude Oil Imports (Source: https://afdc.energy.gov/data)

B Global OPEC Production Share

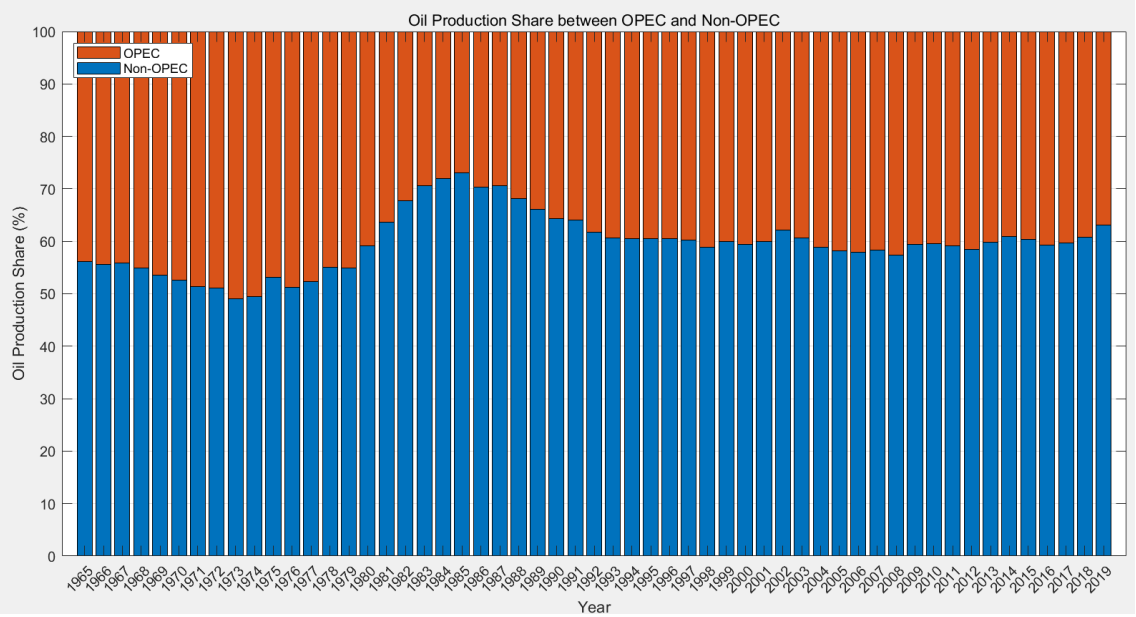


Figure 24: Oil production share of OPEC and non-OPEC producers.
Source: `https://ourworldindata.org/grapher/oil-production-by-country`

C US Energy Consumption

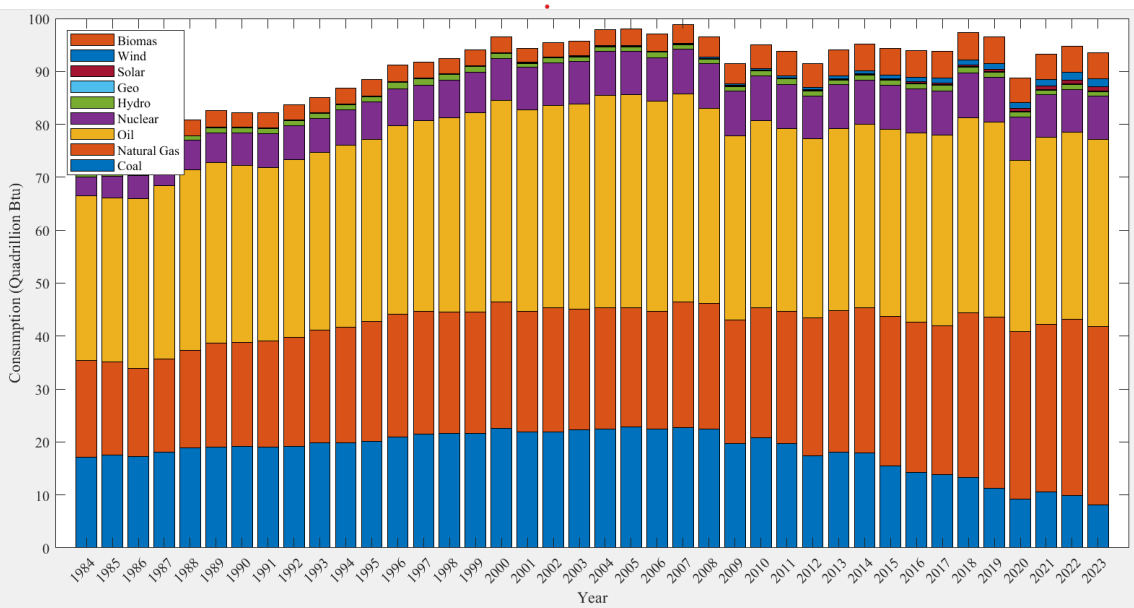


Figure 25: US Primary Energy Consumption by Source (Source: EIA)

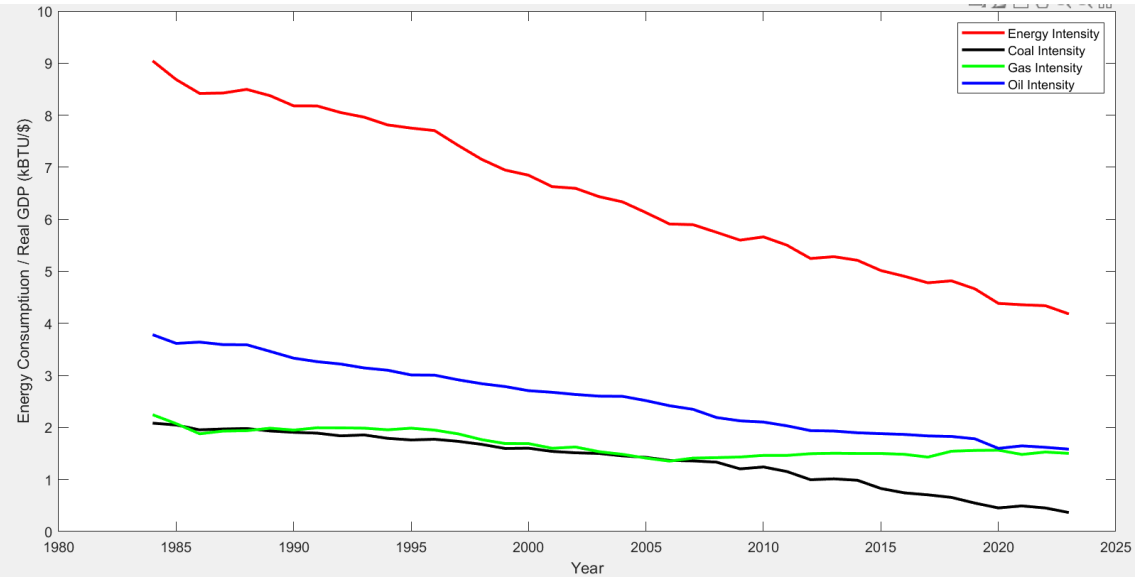


Figure 26: US Energy Intensity Trend (Source: EIA)

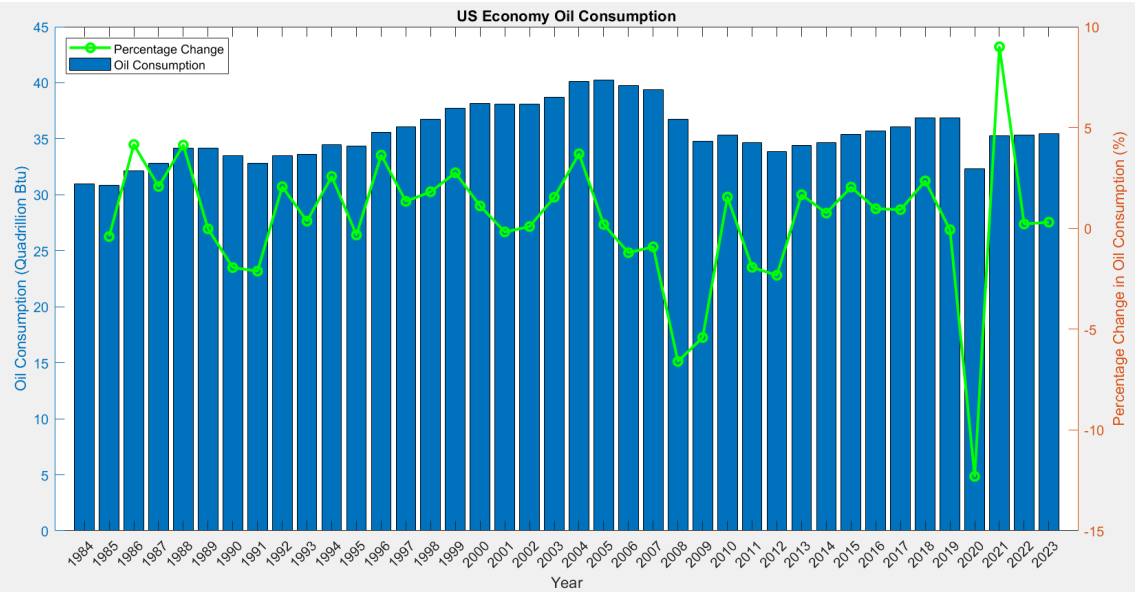


Figure 27: US Economy Oil Consumption (Source: EIA)

D Econometric Methodology of Bayesian Local Projections

The IRFs in VARs are produced by iterating the co-efficient of a one-step-ahead model up to the relevant horizon. In case of any mis-specifications, the resulting errors are compounded at each horizon in the estimated IRFs. On the other hand, the LP method estimates impulse response functions from the coefficients of direct projections of variables onto their lags at the relevant horizon, making them more robust to any mis-specification and thus theoretically a preferred choice but needs to be balanced against large uncertainty. Consider a (n x1) random vector $y_t = (y_t^1, ..., y_t^n)'$ of macroeconomic variables and (n x 1) reduced form innovations ϵ_t, then impulse response is estimated by iterating co-efficient of n-dimensional matrix B. The equation of the system is:

$$y_{t+1} = By_t + \epsilon_{t+1}, \qquad \epsilon \sim (o, \Sigma_\epsilon) \tag{2}$$

LPs estimate the IRFs directly from a set of linear regressions of the following form where $\epsilon_{t+h}^{(h)}$ is a combination of one-step-ahead forecast errors and so serially correlated and heteroskedastic.

$$y_{t+h} = B^{(h)}y_t + \epsilon_{t+h}^{(h)}, \qquad \epsilon_{t+h}^{(h)} \sim (o, \Sigma_\epsilon^{(h)}) \quad \forall h = 1, ..., H \tag{3}$$

The impulse response functions from the two methods are given by:

$$IRF_h^{VAR} = A_0^{-1}B^h \tag{4}$$

$$IRF_h^{LP} = A_0^{-1}B^{(h)} \tag{5}$$

If VAR is the true description of the data generating process then the coefficients and residuals of an iterated VAR can be mapped to those of LP as follows:

$$B^{(h)} \leftrightarrow B^{VAR,h} = B^h \tag{6}$$

$$\epsilon_{t+h}^{(h)} \leftrightarrow \epsilon_{t+h}^{(VAR,h)} = \sum_{j=1}^{h} B^{h-j}\epsilon_{t+h} \tag{7}$$

Above equations provides a natural bridge between the two empirical specifications that can be exploited to inform priors for BLP methodology. If VAR(p) is supposed to be with correct specifications then LP would have to be specified as ARMA(p,h-1) regressions. Their coefficients can then be estimated by combining informative priors with a fully specified likelihood as in Chan et al. (2016). In addition following observations can be made from above:

- Assuming that the underlying data generating process in equation 2 is linear and the estimation uncertainty can be abstracted, the computed IRFs from the two methods should coincide.
- Assuming that the linear model is correctly specified, LPs are bound to have higher estimation variance due to autocorrelated residuals as in equation 7.
- Considering that for $h = 1$ VARs and LPs should coincide, the identification problem is identical for the two methods. In other words, in both the cases matrix A_0 derived from external instruments or theory-based assumptions coincide.

Without taking into account the structure of the projection residuals, for the co-efficient in equation 3 the standard conjugate Normal-inverse Wishart informative priors can be specified in the following form:

$$\Sigma_{\epsilon}^{(h)} \mid \lambda^{(h)} \sim IW\Big(\Psi_0^{(h)}, d_0^{(h)}\Big),$$

$$\beta^{(h)} \mid \Sigma_{\epsilon}^{(h)}, \lambda^{(h)} \sim N\Big(\beta_0^{(h)}, \Sigma_{\epsilon}^{(h)} \otimes \Omega_0^{(h)}(\lambda^{(h)})\Big) \tag{8}$$

where $\beta^{(h)} \equiv vec(B^{(h)})$ is the vector of all the local projection coefficients at horizon h, $\lambda^{(h)}$ is the hyperparameter regulating variance of the coefficients $\beta^{(h)}$ and determining the overall tightness of the priors. The prior mean $\beta_0^{(h)}$ is estimated by iterated coefficients of similarly specified VAR estimated over pre-sample of length T_0.

$$\beta_0^{(h)} = vec(B_{T_0}^h) \tag{9}$$

where $(B_{T_0}^h)$ is the h-th power of the autoregressive coefficients estimated over a pre-sample T_0 that is discarded later. Following standard Bayesian econometrics modelling, $d_0^{(h)}$ is fixed to number of variables minus 2 such that prior mean of $\Sigma_{\epsilon}^{(h)}$ exists, and the remaining hyperparameters of $\Psi_0^{(h)}$ and $\Omega_0^{(h)}$ using sample information as per Kadiyala and Karlsson (1997) and Banbura et al. (2010). The posterior distribution for the BLP coefficients can be obtained by combining priors in equation 8 with the likelihood of the data conditional on the parameters without taking into account autocorrelations of the projection residuals. Such modelling choice has the following three implications:

- Since the priors are conjugate, hence the posterior distribution is of the same Normal inverse-Wishart family as the prior distribution.
- The Kronecker structure of the standard macroeconomic priors is preserved.
- The shape of the true likelihood is asymptotically Gaussian and centred at the Maximum Likelihood Estimator (MLE), but has a different larger variance than the misspecified posterior distribution.

Müller (2013) shows that posterior beliefs constructed from misspecified likelihood lead to inadmissible decisions about the pseudo-true values and recommended a superior mode of inference based on artificial 'sandwich' posteriors. Hence, inference about $\beta^{(h)}$ is conducted by replacing the original posterior with an artificial Gaussian posterior centred at the MLE but with a HAC-corrected covariance matrix allowing to remain agnostic about the source of model misspecification as in Òscar Jordà (2005).

$$\Sigma_{\epsilon,HAC}^{(h)} \mid \lambda^{(h)}, y \sim IW\Big(\Psi_{HAC}^{(h)}, d\Big),$$

$$\beta^{(h)} \mid \Sigma_{\epsilon,HAC}^{(h)}, \lambda^{(h)} \sim N\Big(\tilde{\beta}^{(h)}, \Sigma_{\epsilon,HAC}^{(h)} \otimes \Omega^{(h)}\Big) \tag{10}$$

Following above methodology, BLP IRFs have been engineered between VAR and LP space. Considering prior in equation 8, the posterior mean of BLP responses takes the form:

$$B_{BLP}^{(h)} \propto \left(X'X + \left(\Omega_0^{(h)}(\lambda^{(h)})\right)^{-1}\right)^{(-1)} \left(X'XB_{LP}^{(h)} + \left(\Omega_0^{(h)}(\lambda^{(h)})\right)^{-1} B_{VAR}^h\right) \tag{11}$$

where $X \equiv (x_{h+2}, ..., x_T)'$ and $x_t = (1, y'_{t-1}, ..., y'_{t-(h+1)})'$, while posterior variance of BLP coefficients is equal to

$$Var\Big(B_{BLP}^{(h)}\Big) = \Sigma_{\epsilon,HAC}^{(h)} \otimes \left(X'X + \left(\Omega_0^{(h)}(\lambda^{(h)})\right)^{-1}\right)^{(-1)} \tag{12}$$

The relative weight of VAR and LP responses is set by $\Omega_0^{(h)}(\lambda^{(h)})$ at each horizon and is a function of the overall level of informativeness of the prior $\lambda^{(h)}$, when $\lambda^{(h)} \to 0$ BLP IRFs collapse into VAR IRFs (estimated over T_0) and conversely when $\lambda^{(h)} \to \infty$ BLP IRFs coincide with LP IRFs.

Its important to note that BLP IRFs may not lie between VAR and LP IRFs for two reasons. Firstly, the VAR prior for BLP coefficients is drawn over a pre-sample whose properties may differ from the estimation sample. Secondly, equation 11 can be rewritten as:

$$B_{BLP}^{(h)} \propto [I_k + M^{-1}]^{-1} B_{LP}^{(h)} + [I_k + M]^{-1} B_{VAR}^{h}, \tag{13}$$

$$= Q B_{LP}^{(h)} + [I_k - Q]^{-1} B_{VAR}^{h},$$

where $M \equiv X'X\Omega_0^{(h)}$ is a k-dimensional matrix with k = n(p+1). Each column of $B_{BLP}^{(h)}$ refers to a different equation in the system. Because Q is a full rank matrix, BLP IRFs for variable j at horizon h are not a simple weighted sum of the LP and VAR IRFs for variable j at horizon h with scalar weights at each horizon and may not be in between. Argument of Giannone et al. (2015) is extended by treating $\lambda^{(h)}$ as an additional model parameter for which a Gamma prior probability distribution is specified and its estimated at each horizon as the maximiser of the posterior likelihood. This hierarchical modelling approach effectively balance bias and estimation variance at all horizons, solving the trade-off in a fully data-driven way.

E IRFs of 1970s Oil Shocks

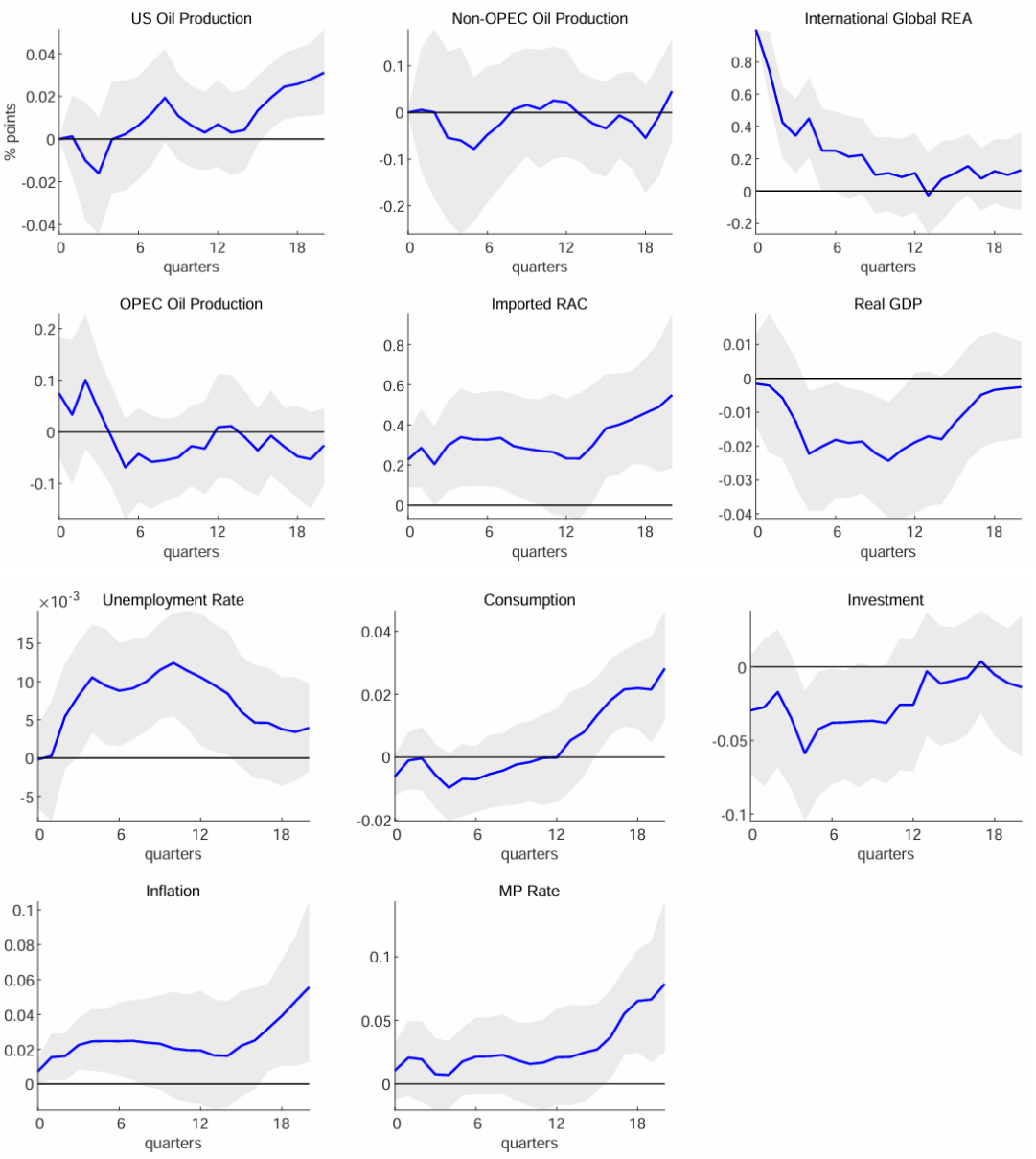


Figure 28: IRFs to positive 1% global real economic activity shock based on quarterly data from 1973 Q1 to 1987 Q1

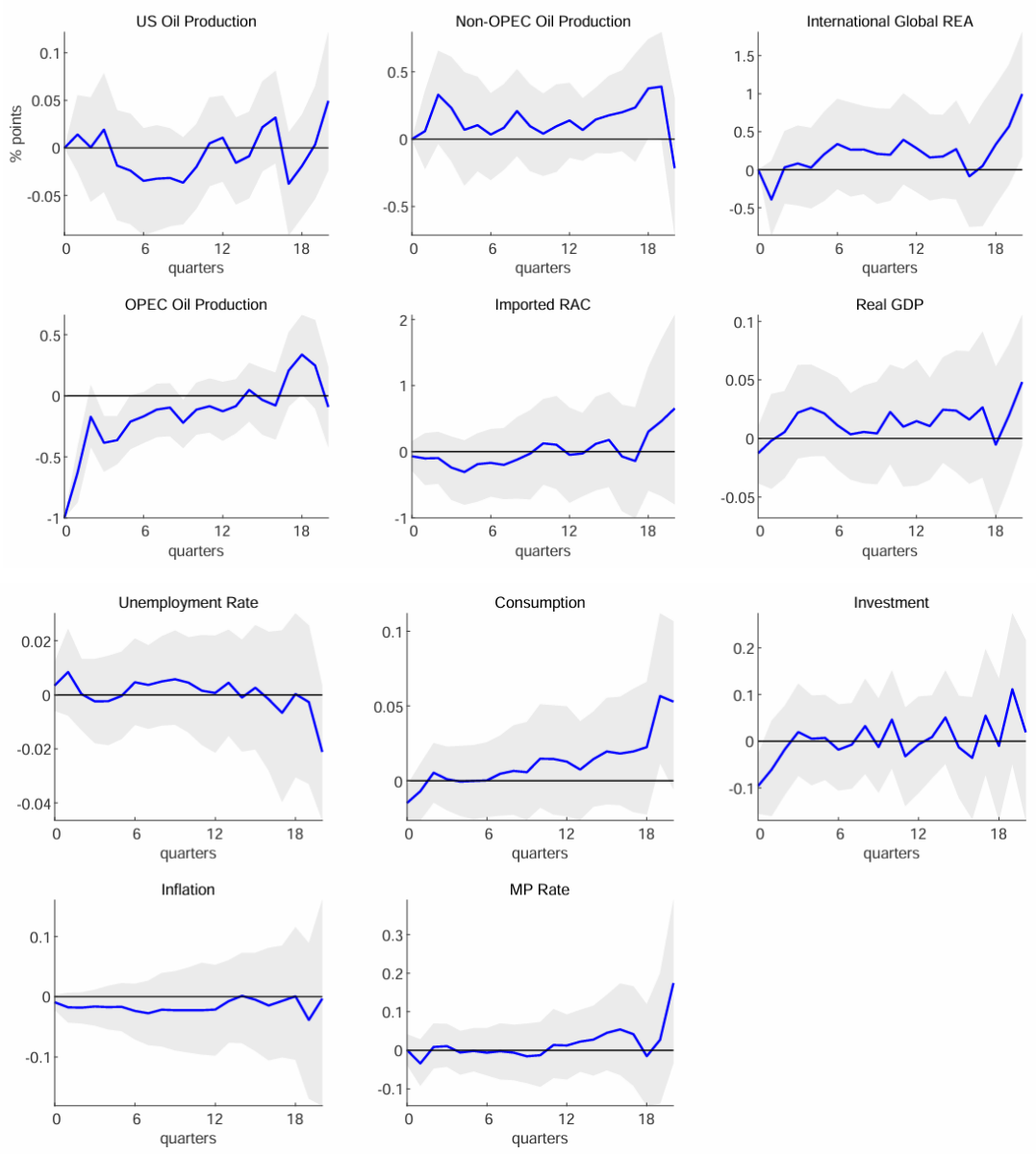


Figure 29: IRFs to negative 1% OPEC oil supply shock based on quarterly data from 1973 Q1 to 1987 Q1

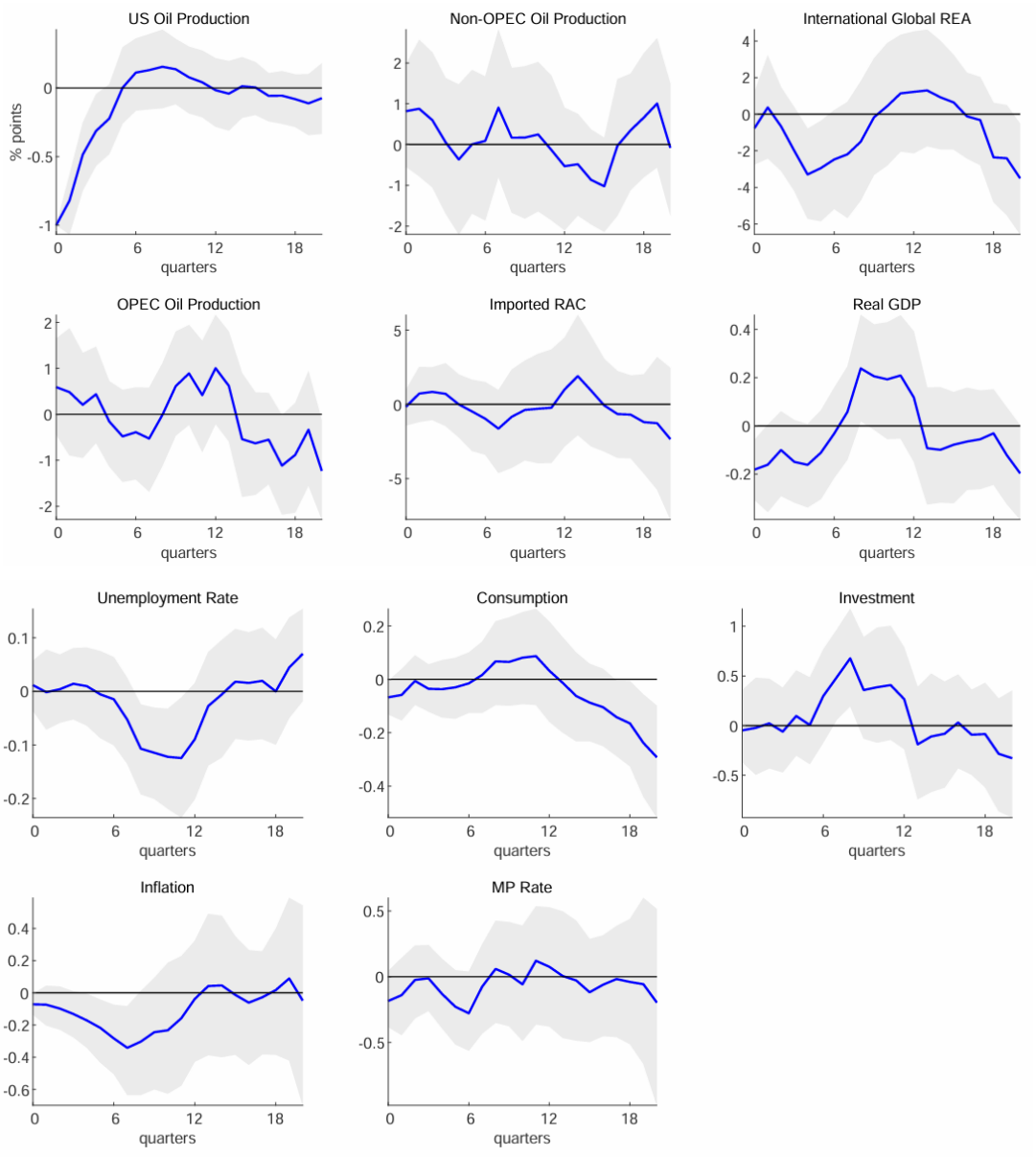


Figure 30: IRFs to negative 1% US oil supply shock based on quarterly data from 1973 Q1 to 1987 Q1

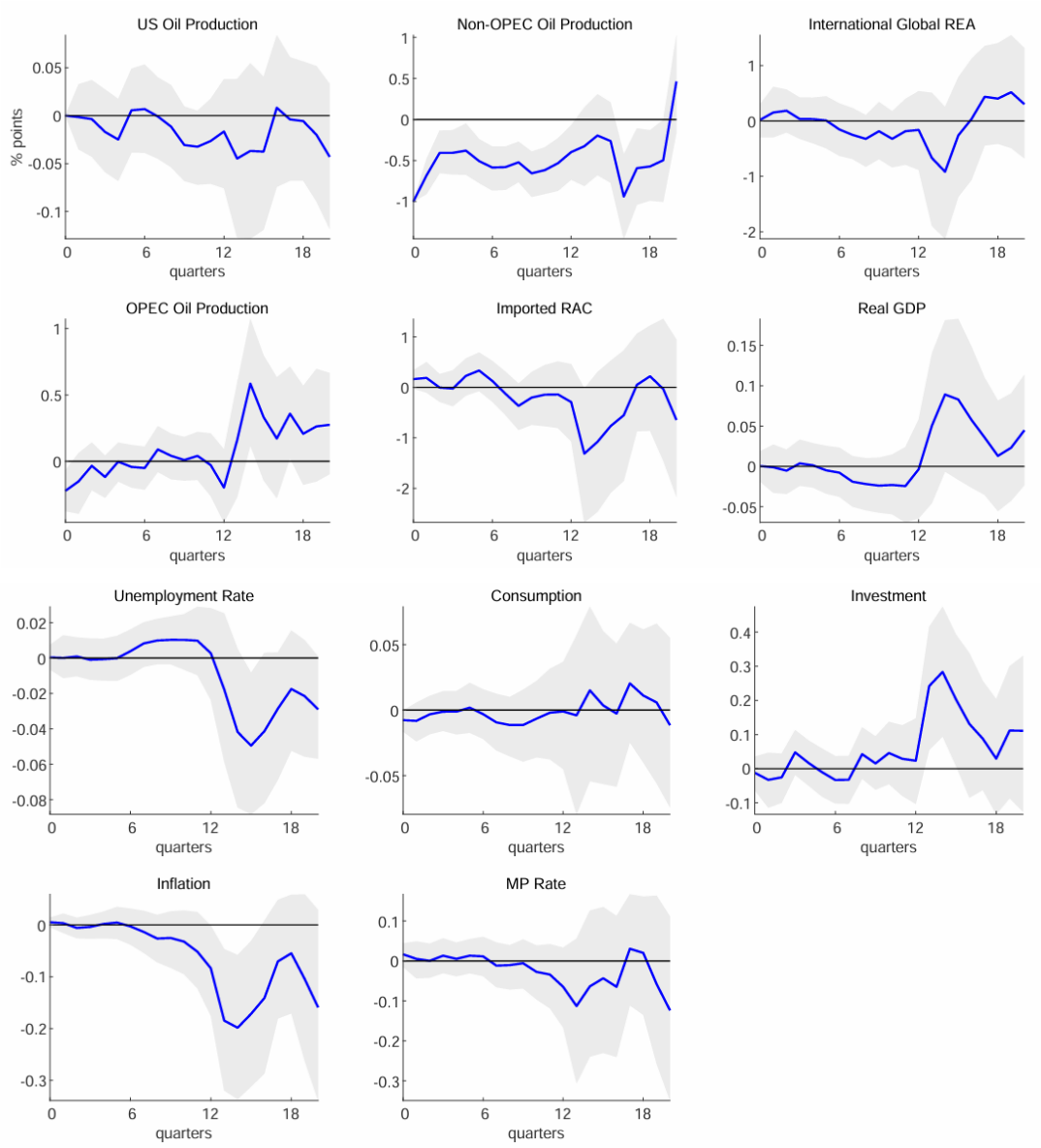


Figure 31: IRFs to negative 1% Non-OPEC oil supply shock based on quarterly data from 1973 Q1 to 1987 Q1

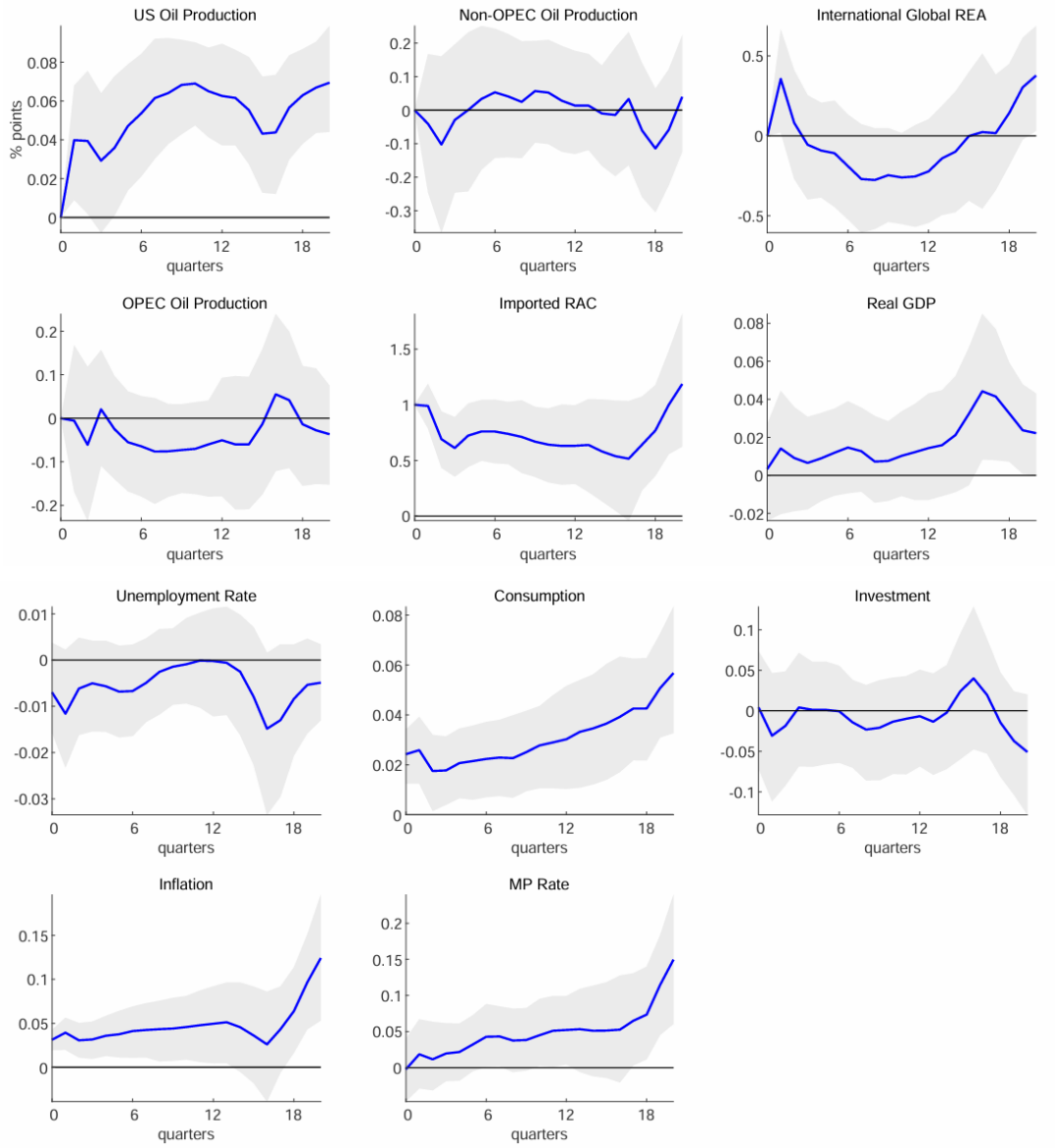


Figure 32: IRFs to positive 1% real oil price shock based on quarterly data from 1973 Q1 to 1987 Q1

F IRFs of Energy Shocks in Closed Economy DSGE Model

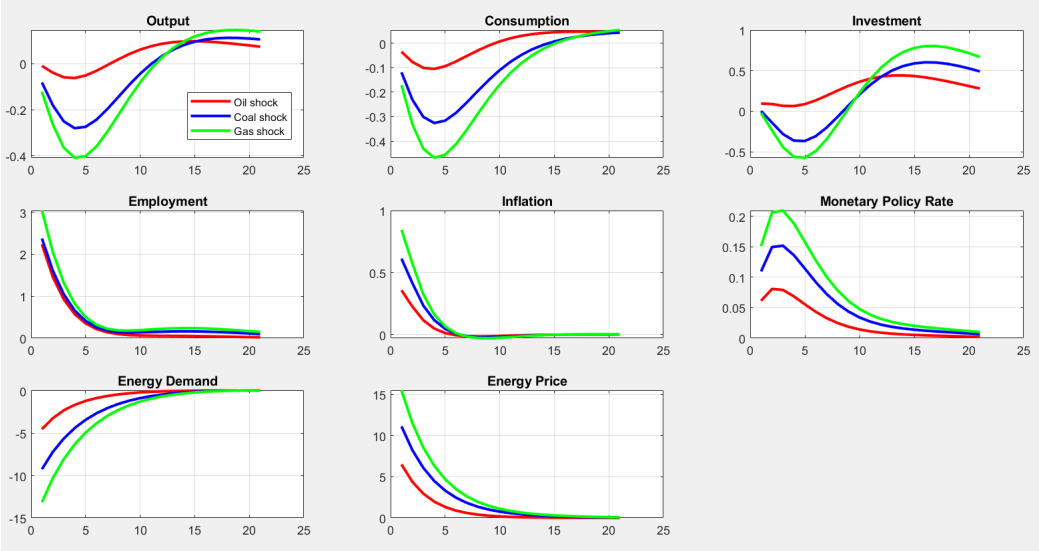


Figure 33: IRFs to negative one standard deviation energy technology shocks in closed economy model

G IRFs of Oil Shocks in Open Economy DSGE Model

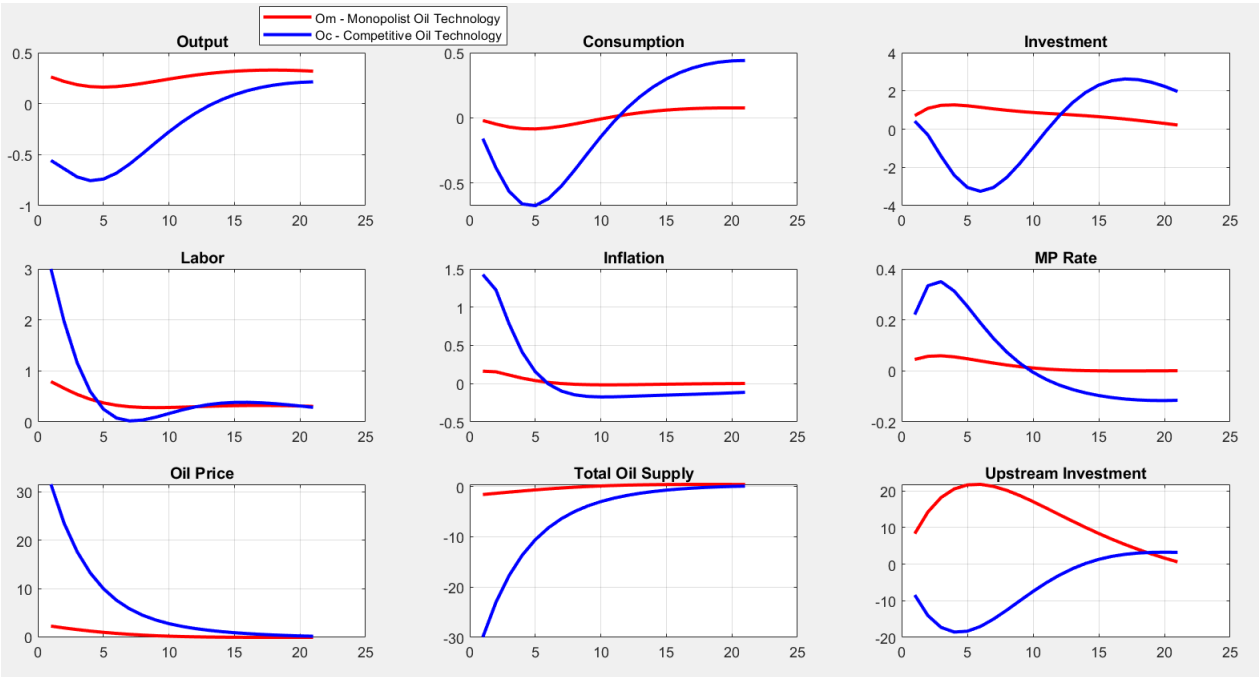


Figure 34: Response to negative 1 SD of competitive and monopolist producers oil technology shocks in NK model