ESSAYS ON BUSINESS CYCLES AND MACROECONOMIC POLICIES

by

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To my parents and family

for their endless love, support and encouragement

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Abstract

It is critical to investigate the behaviour and the impact of shocks during crises to comprehend their persistence and how they affect the economy. Furthermore, studying macroeconomic policies is critical as it helps answer the issues of whether the economy and society are better off with the implemented policies, and how the application of these policies may truly mitigate the effects of unfavourable shocks.

Consequently, this thesis focuses on using the Dynamic Stochastic General Equilibrium (DSGE) models to examine the effects of exogenous shocks on the business cycles as well as the effectiveness of government-implemented macroeconomic policies.

The framework of this thesis is outlined in chapter one, as well as a brief summary of each chapter's primary concepts, results, and contributions.

In chapter 2, we use a DSGE model with heterogeneous agents and other common features of medium-scale DSGE models, such as consumption habit formation, adjustment costs, and variable capacity utilisation, to answer the question of whether active or passive fiscal policies are more effective in a closed economy.

Chapter 3 uses Bayesian approaches together with the DSGE model for a small open economy to estimate the impact of pandemic shocks on the UK economy. We also discover how these shocks are transmitted to other economic variables. To simulate the UK government's reaction during the epidemic, we integrate the extensive margins of labour supply and the lockdown policy shock.

The fourth chapter estimates the spillover effects of US shocks on the Vietnamese economy using a DSGE model with two-country blocs. In addition, we modify the model to include a commodity sector to analyse the impact of the oil price shock.

Finally, the last chapter summarises the main findings and explores their implications for macroeconomic policy planning. Furthermore, this chapter offers some directions for future research from this thesis.

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Chapter 1

Introduction

The twenty-first century has witnessed major economic challenges and uncertainty due to several events that affect the global economy. Firstly, it is worth noting the global financial crisis of 2008 that was caused by the burst of the housing bubble in the US. This crisis costs people's jobs, savings, and homes; as a result, the US Government steps in to bail out big financial institutions with the aim of relieving the impact of the crisis and hope to avoid the destruction of the global financial system. Another noticeable economic event was the Sovereign Debt Crisis in Greece in 2015, which threatens the stability of other heavily indebted European Union (EU) members. Therefore, the EU agrees to loan to Greece, but with restrictions on this country's public spending, so that it can continue to pay its debt in the future. Additionally, the spread of COVID-19 in 2020 causes a disruption in the global supply chain that leads to a hike in price levels around the world. Many governments intervene in the market by increasing public spending or proposing tax-cut bills to support local businesses; by doing this, they try to lessen the impact of the pandemic on these economies. Finally, it is worth mentioning the impact of the war in Ukraine. Although this war starts as early as 2014, the tension rises over time until it reaches a tipping point in early 2022 when Russia employs a ”special military operation” in Ukraine with a massive military presence surrounding this country. As a result, this incident together with international sanctions against Russia leads to great economic turmoil due to the global energy and supply chain crisis.

In general, these crises are expected to create unexpected shocks to the economy that lead to instability and affect the business cycle. For example, they may affect the unemployment rate, inflation rate, or consumption levels in one economy. Therefore, it is important to study the behaviour as well as the effect of these shocks to understand the persistence of them and how they transmit to the economy. Besides, it is customary for governments to implement policies in order to deal with these crises and tackle the results. However, the impacts and effectiveness of these policies may be ambiguous until they are finished. As a consequence, the study of the macroeconomic policy is essential for estimating its influence; furthermore, it helps answer the questions if the economy and society are better off with the implemented policies, and how the use of these policies can actually alleviate the outcome of unfavourable shocks.

However, analysing macroeconomic policies is not an easy task because the economy is a complex system that includes interconnected components; hence, model-based policy analysis is crucial for implementing forward-looking and counter-cyclical macroeconomic policies successfully. Therefore, any macroeconomic model which integrates such structural linkages can be a powerful instrument for this type of work. Particularly, one of the macroeconomic models that satisfy this requirement is the Dynamics Stochastic General Equilibrium (DSGE) model, which is an important improvement in macroeconomic modelling. Fundamentally, the New Keynesian DSGE model refers to the quantitative models of economic growth or business cycles; it features the micro-founded structure that describes how the whole economy develops over time to achieve equilibrium after being affected by random shocks. Besides, it also explains aggregate economic phenomena, including growth, business cycles, and the effects of monetary and fiscal policies.

Consequently, this thesis focuses on implementing various DSGE models to analyse the business cycles impacted by exogenous shocks as well as the effectiveness of macroeconomic policies. By doing this, we attempt to shed light on the sources and transmission of economic shocks. The main research questions that we aim to answer are: (i) are active or passive fiscal policies more effective in a closed economy? (ii) what are the estimates of shocks caused by the pandemic, and how are they transmitted to the economy? (iii) how do lockdown policy and furlough scheme affect the economy? (iv) how do the spillover effects emerge in an emerging market?

The contributions of this thesis to the existing literature are as follows. Firstly, it helps distinguish the different effects between tax shocks and spending shocks on the economy as well as introducing separate monetary-fiscal policy mixed regimes in estimating the effect of fiscal measures. Secondly, this thesis estimates the impact of shocks in the pandemic on the economy, which makes us understand how they are transmitted to other economic variables. Furthermore, it analyses the intervention of the government in tackling the pandemic and easing the economic impact on our society. Finally, this study also contributes to the growing number of literature working on estimating and analysing the spillover effects for emerging countries by explaining the sources of variations in the business cycle in emerging markets.

This thesis consists of three articles working on various topics of New Keynesian DSGE models to analyse the business cycles and public policies. Each of them is shown in a separate chapter that gives a deeper discussion of the topic. In this introductory chapter, we outline the structure of this thesis as well as briefly summarise the main ideas, findings, and contributions of each chapter.

In chapter 2, we answer the question of whether active or passive fiscal policies are more effective in a closed economy. In order to do this, we include consumption tax, labour income tax, and capital tax in the conventional dynamic stochastic general equilibrium (DSGE) models of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007). In addition, we allow for the existence of heterogeneous agents and other common features of medium-scale DSGE models, including consumption habit formation, adjustment costs, and variable capacity utilisation.

In this chapter, the impacts of fiscal policies and the impulse response functions for relevant structural shocks are analysed in two separate regimes. Furthermore, this chapter demonstrates that selecting a regime for optimal fiscal policy based just on the magnitude of multipliers (Leeper, Traum and Walker, 2017) is insufficient; accordingly, the welfare loss of the policy is an essential aspect that we need to examine in each regime. Overall, our findings suggest that in regime M, where monetary policy is active and fiscal policy is passive, fiscal policy is more advantageous in terms of welfare loss. This result supports the view of Leeper (2018) that central banks can attain their inflation target and price stability, provided that the policymakers can accommodate public spending passively to strengthen the monetary policy rule. Regarding the behaviour of households in regime M, non-Ricardian households are proved to work more, although they get lower wages given positive fiscal shocks. Concerning the effect of fiscal shocks in regime F, which is presented by passive monetary policy and active fiscal rule, we realise that public consumption is the only tool triggering short-run output growth, while other fiscal measures have a negative effect. Furthermore, shocks in public spending lead to a fall in investment and capital, together with a high level of public debt. Consequently, our results support the view of implementing fiscal policy under regime M rather than regime F.

Next, we go beyond the theoretical DSGE models in chapter 2 to estimate the impact of the shocks in the pandemic on the UK's economy in chapter 3. The model in this chapter is developed based on the framework of the previous chapter which provides key agents and blocs in an economy. However, in this case, we expand the model to include a foreign market to make it a DSGE model for a small open economy and be more relevant to a real economy. Furthermore, we also learn how these shocks caused by the pandemic are transmitted to economic variables. Besides, we evaluate the policies used to tackle the pandemic, given the fact that the UK government implements the Coronavirus Job Retention Scheme (CJRS) or the furlough scheme in order to ease the economic impact on households and businesses by helping furloughed workers, those who remain employed by the firms but are not actually working, maintain their income and sharing costs with employers. Particularly, workers who are on furlough will receive 80% of their wage from the government. The main purpose of this programme is to encourage firms not to expel their employees during the lockdown in order to keep a connection with them. As a result, when the lockdown policy is relaxed, it is simpler for people to return to work, allowing for a stronger recovery in the future. Therefore, in this model, instead of disaggregating the labour market according to different types of households as in chapter 2, we focus on analysing the impact of the shocks given the various statuses of workers during the pandemic. Consequently, in order to include this feature of the policy in the model, we extend the model of Christiano, Eichenbaum and Trabandt (2015) to incorporate the extensive margins of labour supply. Besides, we include several exogenous processes to represent pandemic shocks and the lockdown policy. Finally, we exploit macroeconomic data collected from 1992 to 2020 together with the Bayesian method in order to get estimates of stochastic shocks in the UK.

The result of this chapter suggests that autoregressive parameters are rather stable over time, except for technology shock and price mark-up shock, which appear to be very varied. More crucially, we show that technology shock and price mark-up shock are the primary drivers of high volatility in production when the pandemic first begins, while preferences shock contributes very little. These shocks reduce the growth rate of output, consumption, and investment; moreover, it is demonstrated that the corresponding working hours decrease dramatically in the quarter after the shock. In terms of government responses in combating COVID-19, the lockdown strategy is seen to have a negative impact on the UK economy; however, the introduction of the furlough scheme reduces the economic impact on consumption and the unemployment rate. This finding contributes to the growing literature by estimating the supply shock and demand shock affected by the pandemic in the United Kingdom (UK). Furthermore, it also sheds light on the mechanism of the pandemic shock as well as the public policies implemented to fight the pandemic.

Chapter 4 investigates the spillover effects of US shocks on the Vietnamese economy, which is a typical South East Asian rising country with a thriving economic reform. One significant element of the Vietnamese economy is its substantial exposure to the international market, which has made foreign trade a vital industry in this country. According to the World Bank (2022b), Vietnam turns into one of the most open economies in the world as its degree of openness keeps rising to reach the level of approximately 210% of GDP in 2019. Therefore, in this study, we use a DSGE model with two-country blocs to estimate shocks in both markets and analyse their influence on the Vietnamese economy. Particularly, the model in this chapter still employs key features of the theoretical framework in chapter 2 which includes different types of households to answer the corresponding research question. Besides, we also incorporate foreign market in this model in order to build a DSGE model with two-country blocs; however, we do not take the foreign market as exogenous as in chapter 3. In this case, we rather model a separate system for the foreign bloc so that the net export sector in home countries will be affected by the dynamic of the foreign economy. Additionally, we realise that the production and trading of commodities are significant activities in Vietnam; therefore, we modify the model to include a commodity sector to estimate the shock in the oil price. Consequently, data collected from the FRED database, the World Bank, GSO, and SBV for both the US and Vietnam from 1999 to 2019 on real GDP, consumption level, inflation rate, interest rate, and the exchange rate will be used for the estimation. This research explains the causes of fluctuations in Vietnam's business cycle as a developing market. Furthermore, it assists individuals in comprehending the characteristics of the Vietnam market in an open economy context.

In this chapter, we show that technology, price mark-up, and investment shocks are more enduring in Vietnam than policy shocks. In the instance of the US economy, we see that monetary policy and investment demand shocks are highly consistent, but other shocks are less so. Furthermore, with the exception of the price mark-up shock, shocks in Vietnam are typically smaller than those in the US market. The estimate of oil price shock implies substantial volatility in the price of this commodity; nevertheless, this shock is not enduring because the majority of its influence would fade within one period. In terms of spillover effects, we believe that technology shock, price mark-up shock, and investment shock that occur in the United States are the key sources of foreign shocks impacting output growth and price level in Vietnam. Furthermore, an examination of impulse response functions demonstrates that foreign shocks in technology and monetary policy diminish Vietnam's production growth and inflation rate. On the contrary, if price mark-ups and investment demand rise in the United States, Vietnamese income will rise as well, albeit at the expense of a greater inflation rate. Lastly, a positive shock in oil prices is likely to restrain production growth, consumption, and investment in Vietnam.

Finally, the last chapter summarises major findings and discusses implications for planning macroeconomic policies. In addition, this chapter also states several limitations and suggests some future research for any improvement and development of this thesis.

Chapter 2

Active and Passive Fiscal Policies in a Closed Economy DSGE Model

Abstract

The world economy changed dramatically in the year 2020 due to the spread of COVID-19. This event leads to a shortfall in global demand and interruption in the supply chain; hence, an economic crisis is projected to occur in the following years. Many governments have stepped in to lessen the impact of the pandemic on the economy, either by increasing public spending or proposing tax-cut bills to support businesses. Although the effect of fiscal policies has been studied for years, these papers are empirically oriented and they mainly focus on estimating fiscal multipliers. As a result, this chapter builds a comprehensive theoretical Dynamic Stochastic General Equilibrium (DSGE) model with the government sector to investigate the effect of individual fiscal shocks in various regimes. In this respect, we look at active and passive fiscal policies in a closed economy and show that welfare loss is an

important criterion in selecting an optimal regime besides the fiscal multiplier. The result indicates that pursuing the regime of active monetary and passive fiscal policies will create less welfare loss to society because this regime causes less variation in the output gap and inflation rate.

Keywords: Fiscal policy, Monetary transmission, DSGE model, welfare loss.

2.1 Introduction

There has been much progress in recent years in the study of fiscal policy for the purpose of stabilising debt and stimulating the downturn economy. However, the answer to an optimal policy is still vague. Much discourse about the effectiveness of these policies focuses on the magnitude of fiscal multipliers. For instance, Ramey and Zubairy (2018) suggest that the government spending multiplier is small with a figure of less than one. This result implies that the outcome of this policy comes from the excessive amount of public spending rather than its major impact. This finding is consistent with the study by Christiano, Eichenbaum and Rebelo (2011); however, there is a contrast between their conclusions about the value of government spending in Zero Lower Bound (ZLB) of interest rate. Christiano, Eichenbaum and Rebelo (2011) argue that the impact multiplier can be as high as 2.3 in ZLB while this figure is modest in the case of Ramey and Zubairy (2018).

As far as the revenue side is concerned, it is believed that the implementation of tax changes itself has a greater impact on output compared to the news of changes; this means that the unexpected tax changes are more effective than the expected ones (Romer and Romer, 2010; Mertens and Ravn, 2011). In addition, Mertens and Ravn (2013) show that cuts in average personal income tax rates would stimulate employment, consumption and investment at the cost of the government budget. On the other hand, a growth in investment is attributed to cuts in the average corporate income tax; however, these tax cuts in corporate income do not lead to a higher employment rate and sometimes they even squeeze the consumption of the private sector.

These studies provide insightful knowledge about the impact of each fiscal component on the state of the economy individually; however, they fail to distinguish the relative effect of those components. In this case, Alesina, Favero and Giavazzi (2019) claim that increases in taxes to combat a deficit have a greater negative effect on output compared with cutting government spending. Accordingly, austerity caused by increasing taxes would inflict national debt and initiate a recession while cutting public spending is associated with only a minimal negative impact on output. In certain cases, the latter measure could lead to expansionary austerity through raising private consumption, investment, and net exports. This finding suggests that the cost associated with spending cuts is relatively modest compared to raising taxes; therefore, austerity plans based on the expenditure side would be plausible. On the other hand, Kuang and Mitra (2018) construct a business cycle model based on learning of policymakers regarding the potential output to examine the consequences of mis-measuring cyclically-adjusted budget balance (CAB) for fiscal policy and the macroeconomics in the recession of European countries following the global financial crisis. The study shows that an initial recession results in over-pessimism of potential output and structural balance, resulting in an austerity policy. This outcome exacerbates the crisis, which restrains the potential output and CAB pessimism, leading to a further austerity measure, and a prolonged recession.

The existing literature contributes greatly to the knowledge gap in fiscal policy; however, there are still questions that need to be answered. Therefore, this chapter is motivated by these studies to investigate the role of government intervention in terms of fiscal policy in closed economy settings. In this case, we attempt to extend the conventional dynamic stochastic general equilibrium (DSGE) models by Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007) to include consumption tax, labour income tax and capital tax. In addition, we allow for both optimizing and non-Ricardian households besides other common features of medium-scale DSGE models, including consumption habit formation, adjustment costs and variable capacity utilisation. In this case, non-Ricardian consumers are assumed to consume their entire labour income net of taxes every period (Campbell and Mankiw, 1989). Another piece of evidence supporting the inclusion of different types of households is that the existence of non-Ricardians helps explain structural VAR evidence which shows that private consumption rises in response to higher state expenditure (Galí, López-Salido and Vallés, 2007). Finally, Leeper (2018) claims that in order to gain the optimal effect of monetary and fiscal policies, governments should consistently pursue one out of two types of monetary-fiscal policy regimes to determine the price and stabilise the debt. Accordingly, the conventional regime is a mix of active monetary policy and passive fiscal policy. Additionally, the alternative regime is a combination between passive monetary rule and active fiscal policy. As a result, we will consider the impact of fiscal policies and structural shocks in these two separate regimes.

Our main findings show that in regime M, where monetary policy is active and fiscal policy is passive, the use of fiscal policy is more beneficial in terms of welfare loss. We agree with the view of Leeper (2018) stating that central banks can achieve their inflation target and price stability if the fiscal authorities passively adjust their state budget to support the monetary policy rule. Besides, this result shows that choosing a regime for the optimal fiscal policy that is merely based on the magnitude of multipliers (Leeper, Traum and Walker, 2017) is not sufficient; we also need to look at the welfare loss of policy in each regime. Regarding the effect of fiscal shock in regime F (passive monetary policy and active fiscal rule), we acknowledge that public consumption in this regime is the only factor that can initiate growth in output in the short run, while other fiscal components have an inverse effect. Besides, the costs of spending shocks in terms of investment, and capital are enormous. Moreover, these measures also raise the level of public debt to a high level above steady-state value. As a consequence, our results support the view of undertaking fiscal policy under regime M, which contradicts the study of Leeper, Traum and Walker (2017).

This study contributes to the existing literature on fiscal policy as follows. Firstly, we build a DSGE model that includes all fiscal instruments applied by the government to influence the economy. This model is different from other standard models which mainly focus on monetary policy; in this model, we also allow habit formation and the existence of different kinds of households. Therefore, we are able to see how these households are impacted individually by these shocks. Above all, we apply the approach of Leeper, Traum and Walker (2017) to separate two monetary-fiscal policy mixed regimes. This methodology is interesting in the way that we can estimate the effectiveness of fiscal policy and the interaction between revenue and expenditure measures in each regime. However, in this chapter, we employ the loss function to evaluate an optimal regime based on deviations from the output gap and inflation. As a result, policymakers can make a decision on which regime is suitable for their choice of fiscal plans. Secondly, this study is able to distinguish the different effects between tax shocks and spending shocks on the economy.

The remainder of this chapter is organized as follows. Firstly, we will set up a New Keynesian DSGE model with government expenditure and tax distortion systems on consumption, investment, labour income, and capital; this is done in section 2 of the chapter. In addition, section 3 introduces the solution to the model as well as the calibrated parameters based on existing literature. In section 4, we discuss the results and analyse the impulse response functions for fiscal stimulus and other structural shocks to see how they interact with each other; this section will comprise two separate subsections for different regimes of policies. Then, we analyse the loss function in both regimes to determine which regime is more efficient in section 5. Finally, we come up with a conclusion in the last section.

2.2 The Model

The model consists of various types of agents and blocs including households, producers, a fiscal authority, and a monetary authority. Accordingly, the household sector consists of Ricardian and non-Ricardian households that supply their labour to earn income. In those, only Ricardian households can generate their savings by purchasing private and public bonds. This assumption is consistent with Mankiw (2000) who argues that economic models should allow for the coexistence of Ricardian and non-Ricardian households because these models capture the empirical estimate of excessive dependence of consumption on current income and the existence of households that have no net worth. All households are required to pay consumption and income taxes to the government in each period. In fact, the use of these two types of households in DSGE modelling is common across literature (Coenen and Straub, 2004; Galí, López-Salido and Vallés, 2007) due to several reasons. Firstly, it overcomes the equivalence model with only the representative household and solves the consumption problem with a high enough share of non-Ricardian households. Secondly, by including two types of households, it improves the fit of the Euler equation that determines the consumption level.

Besides, there are two types of producers including final goods producers (retail firms) and intermediate goods producers (wholesale firms) in the goods market. Wholesale firms produce intermediate goods by employing labour and capital acquired from households and selling their products to retail firms in a competitive market. Retail firms then differentiate these intermediate goods and sell them to households and the government. This model only allows for one type of nominal rigidity, which is price stickiness following Calvo's price-setting (Calvo, 1983) caused by the optimal price-setting behaviour of intermediate goods producers.

Moreover, the public sector represented by the government is responsible for collecting taxes and stimulating funding to the public in various approaches including consumption, investment, and transfer payment. In certain cases, if the government's revenue is below its expenditure, this gap will be closed by the issuance of government bonds which allow the government to borrow money from households. As far as the monetary policy is concerned, the central bank sets the nominal interest rates of government bonds to achieve its mandate following the Taylor rule (Taylor, 1993). Further, this model also allows for habit formation, adjustment costs for investment, and variable capital utilisation. In this section, we will describe the behaviour of the agents and their linkages, and explain the potential channels of fiscal policy.

2.2.1 Households

There are two types of private households taking part in the economy. A share of $(1 - \omega)$ of consumers is assumed to have full access to financial markets and smooth their consumption; thus, they are able to buy and sell financial assets to optimize consumption intertemporally. This type of agent is regarded as Ricardian or Optimising households.

The second type of household is regarded as non-Ricardian or rule-of-thumb households. These consumers, who are accounted for a fraction of ω, are assumed to be excluded from saving and borrowing. As a consequence, they consume their entire disposable income net of taxes from supplying labour in each period.

Ricardian households

Each Ricardian household seeks to maximise their lifetime utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t^o, N_t^o) \tag{2.1}$$

where E_0 is the expectation formed in period 0, $\beta \in (0,1)$ represents the discount factor; the superscript 'o' denotes "Optimising household" and the utility level is a function of consumption by Ricardian household C_t^o with the persistence of external habit formation h and hours worked N_t^o at time t, which is

$$U(C_t^o, N_t^o) = \varepsilon_t^c \left(\frac{(C_t^o - hC_{t-1}^o)^{1-\sigma}}{1-\sigma} - \varepsilon_t^n \frac{N_t^{o1+\varphi}}{1+\varphi} \right) \tag{2.2}$$

In this function, σ denotes the elasticity of substitution intertemporally while φ shows the elasticity of hours worked. Furthermore, this utility function includes shocks such as ε_t^c and ε_t^n; they represent a shock to consumption preference and labour supply, respectively. For instance, the preference shock takes into account disparities in consumption that are not captured by other economic features of the model, while the latter impacts the trade-off between consumption and leisure. As a result, these shocks affect overall utility in period t. These shocks are assumed to follow the AR(1) process in log values with i.i.d. normal shocks υ^c and υ^n.

It is assumed that all Ricardian households have identical initial wealth, fully access the financial market, and generate profits from firms, so that each Ricardian household faces the same budget and makes identical consumption and portfolio decisions. Assuming the only available assets are one-period bonds, the flow budget constraint for all $t > 0$ is given by

$$(1+\tau_t^c)P_t(C_t^o + I_t^o) + B_t^o = R_{t-1}^b B_{t-1}^o + (1-\tau_t^n)W_t N_t^o + (1-\tau_t^k)(R_t u_t - a(u_t)P_t)K_t^o + \tau_t^k \delta_0 P_t K_t^o + P_t TR_t^o + J_t \tag{2.3}$$

where P_t is the price level in period t, I_t^o denotes private investment, and B_t^o represents the nominal value of one-period bonds purchased by a Ricardian consumer. These households receive income from purchasing one-period government bonds in the previous period B_{t-1}^o with the nominal rate of return R_{t-1}^b, the nominal value of wage W_t from providing labour N_t^o, the income from renting capital stock K_t^o at the nominal rate of return R_t with the capital utilisation of u_t, which is associated with the cost function $a(u_t)$. Given that the depreciated capital $\delta_0 P_t K_t^o$ is exempt from capital tax, knowing that δ_0 is the rate of depreciation. Finally, they also receive transfer payments from the government spending TR_t^o and a lump-sum component of income J_t from firms' profits. In those, τ_t^c, τ_t^l and τ_t^k denote taxes on consumption, labour and capital, respectively.

The cost function of the variation in capital utilisation can be shown as below

$$a(u_t) = \delta_1(u_t - 1) + \frac{\delta_2}{2}(u_t - 1)^2 \tag{2.4}$$

where δ_1, δ_2 are parameters of the function. In a steady state, it is assumed that capital utilisation has the value of $\bar{u} = 1$; hence, $a(\bar{u}) = 0$.

The capital is accumulated with the following law of motion

$$K_{t+1}^o = (1-\delta_0)K_t^o + I_t^o \left[1 - \frac{\eta}{2}\left(\frac{I_t^o}{I_{t-1}^o} - 1\right)^2\right] \tag{2.5}$$

where the term $\frac{\eta}{2}\left(\frac{I_t^o}{I_{t-1}^o}-1\right)^2$ represents the investment adjustment cost function, in which η reflects the investment cost.

Ricardian households maximise their utility (2.1) subject to their budget constraint (2.3) and the physical capital accumulation function (2.5) with respect to consumption (C_t^o), government bond holdings (B_t^o), investment (I_t^o), the size of capital stock in next period (K_{t+1}^o), and utilisation rate (u_t). Therefore, the first-order conditions (F.O.C) are as follows:

$$C_t^o : \varepsilon_t^c (C_t^o - hC_{t-1}^o)^{-\sigma} = (1+\tau_t^c)\lambda_t^o P_t \tag{2.6}$$

$$B_t^o : R_t^b = \frac{\lambda_t^o}{\beta E_t \lambda_{t+1}^o} \tag{2.7}$$

$$\begin{aligned} I_t^o : Q_t &\left[1 - \frac{\eta}{2}\left(\frac{I_t^o}{I_{t-1}^o}-1\right)^2 - \eta\frac{I_t^o}{I_{t-1}^o}\left(\frac{I_t^o}{I_{t-1}^o}-1\right)\right] \\ &+ \eta\beta E_t\left[Q_{t+1}\left(\frac{I_{t+1}^o}{I_t^o}\right)^2\left(\frac{I_{t+1}^o}{I_t^o}-1\right)\right] = (1+\tau_t^c)\lambda_t^o P_t \end{aligned} \tag{2.8}$$

$$\begin{aligned} K_{t+1}^o : \frac{Q_t}{\beta} &= E_t[\lambda_{t+1}^o(1-\tau_{t+1}^k)(R_{t+1}u_{t+1} - a(u_{t+1})P_{t+1}] \\ &+ \delta_0 E_t \lambda_{t+1}^o \tau_{t+1}^k P_{t+1} + (1-\delta_0)E_t Q_{t+1} \end{aligned} \tag{2.9}$$

$$u_t : R_t = P_t[\delta_1 + \delta_2(u_t - 1)] \tag{2.10}$$

where λ_t^o is the Lagrangian multiplier for budget constraint (2.3) and Q_t is the

Lagrangian multiplier for capital accumulation function (2.5).

Non-Ricardian households

The utility function of non-Ricardian households is identical to that of Ricardian ones; however, these households have no access to the financial market; thus, they do not invest or accumulate assets. Hence, they do not behave to optimise the changes in the interest rate. Instead, these households choose their labour supply in this case; since they consume all their income, this determines their consumption. In other words, their entire current income net of taxes in each period generated from labour supply and government transfer is spent for consumption purposes. The budget constraint of non-Ricardian households is

$$(1+\tau_t^c)P_tC_t^{nr} = (1-\tau_t^n)W_tN_t^{nr} + P_tTR_t^{nr} \tag{2.11}$$

Therefore, the consumption and labour supply of non-Ricardian households can be determined as

$$(C_t^{nr} - hC_{t-1}^{nr})^{-\sigma} = (1+\tau_t^c)\lambda_t^{nr}P_t \tag{2.12}$$

where superscript nr indicates non-Ricardian households, and λ_t^{nr} is the Lagrangian multiplier for budget constraint.

Household Aggregation

The aggregate level of any household-specific variable X_t^j can be presented by $X_t = \int_0^1 X_t^j dj$. Given that rule-of-thumb households are accounted for a share of ω and households in each of the two groups are identical, we have $X_t = (1-\omega)X_t^o + \omega X_t^{nr}$.

Therefore, aggregate consumption, hours worked, and government transfers are given by

$$C_t = (1-\omega)C_t^o + \omega C_t^{nr},$$

$$N_t = (1-\omega)N_t^o + \omega N_t^{nr},$$

$$TR_t = (1-\omega)TR_t^o + \omega TR_t^{nr}.$$

Noticing that in a steady state, the labour market equilibrium is characterised by $N_t = N_t^o = N_t^{nr}$.

Because only Ricardian households have full access to the financial market, we obtain the following conditions for aggregate holdings of bonds, capital and investment:

$$B_t = (1-\omega)B_t^o,$$

$$K_t = (1-\omega)K_t^o,$$

$$I_t = (1-\omega)I_t^o.$$

2.2.2 Labour Market

The labour market can be estimated as a weighted sum of labour supply among two types of households, given the share of Ricardian households is $1-\omega$. Hence,

$$N_t = (1-\omega)N_t^o + \omega N_t^{nr} \tag{2.13}$$

Aggregate Labour Supply

Households are assumed to supply differentiated labour in a monopolistically competitive market. Then, this service is sold to a representative firm which aggregates these different types of labour into a single labour input N.

$$N_t = \left(\int_0^1 N_t(i)^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{2.14}$$

where ϵ_w is the elasticity of substitution between differentiated jobs, $N(i)$ is the differentiated labour supply by household (i) with $i \in [0, 1]$ and N_t is the homogeneous labour. This labour aggregating firm will maximise its profit by

$$\max_{N_t(i)} W_t N_t - \int_0^1 W_t(i) N_t(i) di \tag{2.15}$$

By substituting equation (2.14) in (2.15), we have

$$\max_{N_t(i)} W_t \left(\int_0^1 N_t(i)^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} - \int_0^1 W_t(i) N_t(i) di \tag{2.16}$$

The F.O.C for this problem is

$$\begin{aligned}
& W_t \left(\int_0^1 N_t(i)^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right)^{\frac{1}{\epsilon_w - 1}} N_t(i)^{\frac{-1}{\epsilon_w}} - W_t(i) = 0 \\
& W_t \left[\left(\int_0^1 N_t(i)^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \right]^{\frac{1}{\epsilon_w}} N_t(i)^{\frac{-1}{\epsilon_w}} - W_t(i) = 0 \\
\Rightarrow & W_t N_t^{\frac{1}{\epsilon_w}} N_t(i)^{\frac{-1}{\epsilon_w}} - W_t(i) = 0
\end{aligned} \tag{2.17}$$

As a result, the demand function for differentiated labour (i) is indicated as below

$$N_t(i) = N_t \left(\frac{W_t(i)}{W_t} \right)^{-\epsilon_w} \tag{2.18}$$

Aggregate Wage Level

By substituting equation (2.18) in (2.14), we have

$$\begin{aligned} N_t &= \left\{ \int_0^1 \left[N_t \left(\frac{W_t(i)}{W_t} \right)^{-\epsilon_w} \right]^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right\}^{\frac{\epsilon_w}{\epsilon_w - 1}} \\ &= N_t W_t^{\epsilon_w} \left\{ \int_0^1 \left[W_t(i)^{-\epsilon_w} \right]^{\frac{\epsilon_w - 1}{\epsilon_w}} di \right\}^{\frac{\epsilon_w}{\epsilon_w - 1}} \end{aligned} \tag{2.19}$$

Therefore, the aggregate wage level has the form

$$W_t = \left(\int_0^1 W_t(i)^{1-\epsilon_w} di \right)^{\frac{1}{1-\epsilon_w}} \tag{2.20}$$

As far as the optimal wage setting is concerned, both two types of households face the same problem for which they are supposed to determine the wage level according to the Calvo rule. Consequently, wages and hour labour hours will remain the same for both Ricardian and non-Ricardian households. In each period, a fraction of $1-\theta_w$ of households decides to adjust the wage and a probability of θ_w keeping the wage fixed. Let W_t^* denote the newly set wage in period t. Hence, the aggregate level of wage is illustrated as follows.

$$W_t = \left(\int_0^{\theta_w} W_{t-1}(i)^{1-\epsilon_w} di + \int_{\theta_w}^1 W_t^*(i)^{1-\epsilon_w} di \right)^{\frac{1}{1-\epsilon_w}}$$
$$\Rightarrow W_t = \left[\theta_w W_{t-1}^{1-\epsilon_w} + (1-\theta_w) W_t^{*1-\epsilon_w} \right]^{\frac{1}{1-\epsilon_w}} \tag{2.21}$$

Dividing both sides of equation (2.21) by $W_{t-1}^{1-\epsilon_w}$, we have

$$\Pi_t^{w\,1-\epsilon_w} = \theta_w + (1-\theta_w) \left(\frac{W_t^*}{W_{t-1}} \right)^{1-\epsilon_w} \tag{2.22}$$

where $\Pi_t^w = \frac{W_t}{W_{t-1}}$. In a steady state with zero wage inflation, $W_t^* = W_t = W_{t-1}$ for all t. Taking log-linearisation of equation (2.22); hence,

$$\pi_t^w = (1-\theta_w)(w_t^* - w_{t-1}) \tag{2.23}$$

Optimal Wage Setting

The household will choose the optimal price W_t^* considering that the probability of the newly set price being fixed for k periods in the future is θ_w^k. Therefore, the problem is to maximise

$$\max W_t^* E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k U(C_{t+k|t}^o, N_{t+k|t}^o) \tag{2.24}$$

where $C_{t+k|t}$ and $N_{t+k|t}$ denote the consumption and labor supply in period $t+k$ of a household that last reset its wage in period t, respectively. Maximization of (2.24) is subject to the sequence of labor demand schedules and flow budget constraints while W_t^* remains effective.

$$N^o_{t+k|t} = N^o_{t+k}\left(\frac{W_t}{W_{t+k}}\right)^{-\epsilon_w} \tag{2.25}$$

Therefore, we have

$$\max W_t^* E_t \sum_{k=0}^{\infty}(\beta\theta_w)^k U\left[\frac{(1-\tau^n_{t+k})}{(1+\tau^c_{t+k})P_{t+k}} W_t^* N^o_{t+k}\left(\frac{W_t^*}{W_{t+k}}\right)^{-\epsilon_w}, N^o_{t+k}\left(\frac{W_t^*}{W_{t+k}}\right)^{-\epsilon_w}\right]$$

Taking F.O.C with respect to W_t^*, we have

$$E_t \sum_{k=0}^{\infty}(\beta\theta_w)^k \Bigg[U_C(C^o_{t+k|t}, N^o_{t+k|t})\frac{(1-\tau^n_{t+k})}{(1+\tau^c_{t+k})P_{t+k}} N^o_{t+k}(1-\epsilon_w)\left(\frac{W_t^*}{W_{t+k}}\right)^{-\epsilon_w} - \epsilon_w U_N(C^o_{t+k|t}, N^o_{t+k|t})\frac{N^o_{t+k}}{W_{t+k}}\left(\frac{W_t^*}{W_{t+k}}\right)^{-\epsilon_w-1}\Bigg] = 0 \tag{2.26}$$

We multiply both side of this equation with $\frac{W_t^*}{1-\epsilon_w}$

$$E_t \sum_{k=0}^{\infty}(\beta\theta_w)^k \left[U_C(C^o_{t+k|t}, N^o_{t+k|t})\frac{(1-\tau^n_{t+k})}{(1+\tau^c_{t+k})P_{t+k}} N^o_{t+k|t} W_t^* - \frac{\epsilon_w}{1-\epsilon_w} U_N(C^o_{t+k|t}, N^o_{t+k|t}) N^o_{t+k|t}\right] = 0 \tag{2.27}$$

If we define $MRS^o_{t+k|t} = -\frac{U_N(C^o_{t+k|t}, N^o_{t+k|t})}{U_C(C^o_{t+k|t}, N^o_{t+k|t})}$ as the marginal rate of substitution between consumption and hours in period $t+k$ for the household resetting the wage in period t , the condition above can be rewritten as

$$\mathrm{E}_t \sum_{k=0}^{\infty}(\beta\theta_w)^k \left\{U_C(C^o_{t+k|t}, N^o_{t+k|t}) N^o_{t+k|t}\left[\frac{(1-\tau^n_{t+k})W_t^*}{(1+\tau^c_{t+k})P_{t+k}} - \frac{\epsilon_w}{\epsilon_w - 1} MRS_{t+k|t}\right]\right\} = 0$$

Taking log around steady state, we have

$$w_t^* = (1-\beta\theta_w)\sum_{k=0}^{\infty}(\beta\theta_w)^k E_t\left[mrs^o_{t+k|t} + \ln\left(\frac{\epsilon_w}{\epsilon_{w-1}}\right) + p_{t+k} + \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}^c_{t+k} + \left(\frac{\tau^n}{1-\tau^n}\right)\tilde{\tau}^n_{t+k}\right] \tag{2.28}$$

where τ^n is the steady state value of labour supply tax.

The utility function is assumed to be separable between consumption and hours, combined with the assumption of complete asset markets. This implies that consumption is independent of the wage history of a household. Therefore, $C^o_{t+k|t} = C^o_{t+k}$. We have

$$\begin{aligned} mrs^o_{t+k|t} &= \varphi n^o_{t+k|t} + \tilde{\epsilon}^n_{t+k} \\ &\quad - \left[\frac{\tilde{\epsilon}^c_{t+k} - \beta h\tilde{\epsilon}^c_{t+k+1}}{1-\beta h} - \frac{\sigma}{(1-\beta h)(1-h)}[(c^o_{t+k} - hc^o_{t+k-1}) - \beta h(c^o_{t+k+1} - hc^o_{t+k})]\right] \\ &= \varphi n^o_{t+k|t} + \tilde{\epsilon}^n_{t+k} - \tilde{\lambda}^o_{t+k} - p_{t+k} - \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}^c_{t+k} \end{aligned} \tag{2.29}$$

$\mathrm{mrs}^o_{t+k} = \varphi n^o_{t+k} + \tilde{\epsilon}^n_{t+k} - \tilde{\lambda}^o_{t+k} - p_{t+k} - \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}^c_{t+k}$ where $\tilde{\epsilon}^n_t = \rho_{\tilde{\epsilon}^n}\tilde{\epsilon}^n_{t-1} + \upsilon^{\tilde{\epsilon}^n}_t$

As a result,

$$\begin{aligned} mrs^o_{t+k|t} &= mrs^o_{t+k} + \varphi(n^o_{t+k|t} - n^o_{t+k}) \\ &= mrs^o_{t+k} - \epsilon_w\varphi(w^*_t - w_{t+k}) \end{aligned} \tag{2.30}$$

Therefore, equation (2.28) can be rewritten as

$$\begin{aligned} w_t^* &= (1-\beta\theta_w)\sum_{k=0}^{\infty}(\beta\theta_w)^k E_t\left[mrs_{t+k}^o - \epsilon_w\varphi(w_t^* - w_{t+k}) + \ln\left(\frac{\epsilon_w}{\epsilon_{w-1}}\right) + p_{t+k}\right. \\ &\qquad \left. + \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}_{t+k}^c + \left(\frac{\tau^n}{1-\tau^n}\right)\tilde{\tau}_{t+k}^n\right] \\ &= \frac{(1-\beta\theta_w)}{1+\epsilon_w\varphi}\sum_{k=0}^{\infty}(\beta\theta_w)^k E_t\left[\varphi n_{t+k}^o + \tilde{\epsilon}_{t+k}^n - \tilde{\lambda}_{t+k}^o + (1+\epsilon_w\varphi)w_{t+k} - w_{t+k} + \ln\left(\frac{\epsilon_w}{\epsilon_{w-1}}\right)\right. \\ &\qquad \left. + \left(\frac{\tau^n}{1-\tau^n}\right)\tilde{\tau}_{t+k}^n\right] \end{aligned} \tag{2.31}$$

Substituting $\pi_t^w = (1-\theta_w)(w_t^* - w_{t-1})$ in this equation

$$\Rightarrow \pi_t^w = \beta E_t \pi_{t+1}^w + \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w(1+\epsilon_w\varphi)}\left[\varphi n_t^o + \tilde{\epsilon}_t^n - \tilde{\lambda}_t^o - w_t + \ln\left(\frac{\epsilon_w}{\epsilon_{w-1}}\right) + \left(\frac{\tau^n}{1-\tau^n}\right)\tilde{\tau}_t^n\right] \tag{2.32}$$

2.2.3 Firms

The production sector is separated into two types: final goods production and firms producing intermediate goods. The former aggregates differentiated intermediate goods to produce a homogeneous product using constant elasticity of substitution (CES) technology, while the latter employs labour and capital to generate different types of output. As a result, intermediate goods-producing firms have the pricing power due to the imperfect substitutes of the intermediates in the production process.

Final Goods

There is a continuum of differentiated intermediate goods i with $i \in [0;1]$. The production function of final goods follows the CES form:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \tag{2.33}$$

where $Y_t(i)$ denotes the quantity of the differentiated intermediate good i, and ϵ denotes the elasticity of substitution between products. These firms confront profit maximisation by optimising the amount of each intermediate good produced.

The profit maximisation of the final goods firms takes the form

$$\begin{aligned} &\max_{Y_t(i)} P_t Y_t - \int_0^1 P_t(i) Y_t(i) di \\ \Rightarrow &\max_{Y_t(i)} P_t \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} - \int_0^1 P_t(i) Y_t(i) di \end{aligned} \tag{2.34}$$

Taking F.O.C with respect to $Y_t(i)$, we have

$$P_t \left(\frac{Y_t}{Y_t(i)} \right)^{\frac{1}{\epsilon}} - P_t(i) = 0 \tag{2.35}$$

Thus, the demand for intermediate goods is

$$Y_t(i) = Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} \tag{2.36}$$

Intermediate Goods

The economy consists of a continuum of firms indexed by $i \in [0; 1]$ which exploits capitals, labour, and technology to produce a differentiated good according to a Cobb-Douglas function:

$$Y_t(i) = A_t \hat{K}_t(i)^\alpha N_t^{1-\alpha}(i)(K_t^g)^\kappa \tag{2.37}$$

where $\hat{K}_t = K_t u_t$ is the amount of private capital utilised in time t, A_t represents a level of total factor productivity (TFP) which follows AR(1) process in log values with normal i.i.d shock. $Y_t(i)$ is the differentiated output i produced by firm i at time t, α and κ represent the share of input including private capital $\hat{K}_t(i)$, labour hours $N_t(i)$, and government capital K_t^g, respectively. Households supply differentiated labour to the intermediate goods producing firms. Each differentiated labour service is supplied by both Ricardian and non-Ricardian households, and demand is uniformly allocated among these two households. This assumption is consistent with other papers such as in Galí, López-Salido and Vallés (2007); Leeper, Traum and Walker (2017).

Firms will minimise their cost of production subject to the output constraint. Therefore, the Langrangian takes the form

$$\mathcal{L} = W_t N_t + R_t \hat{K}_t + \mu_t (Y_t - A_t {\hat{K}_t}^{\alpha} N_t^{1-\alpha} K_t^{g\kappa}) \tag{2.38}$$

Taking F.O.C with respect to labour hours and private capital, we can determine the demands for inputs as follows

$$N_t = (1-\alpha)\mu_t \frac{Y_t}{W_t} \tag{2.39}$$

$$\hat{K}_t = \alpha \mu_t \frac{Y_t}{R_t} \tag{2.40}$$

with μ_t is the nominal marginal cost at time t.

From (2.39) and (2.40), the optimal demand of labour hours with respect to capital is given by

$$N_t = \left(\frac{1-\alpha}{\alpha}\right) \frac{\hat{K}_t R_t}{W_t} \tag{2.41}$$

Hence, the amount of labour hours increases with a fall in nominal wage or a rise in private capital and a nominal rate of return on private investment.

From (2.39), the function of nominal marginal cost can be achieved as

$$\mu_t = \frac{W_t}{(1-\alpha) A_t \hat{K}_t^{\alpha} N_t^{-\alpha} K_t^{g\kappa}} \tag{2.42}$$

As a result, by substituting $\hat{K}_t = \frac{\alpha}{1-\alpha} \frac{W_t N_t}{R_t}$ from equation (2.41) in the previous equation and dividing by the price level P_t, we have the real marginal cost

$$MC_t = \frac{\mu_t}{P_t} = \frac{1}{A_t K_t^{g\kappa} P_t} \left(\frac{R_t}{\alpha}\right)^{\alpha} \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha} \tag{2.43}$$

Aggregate Price Level

Firms producing intermediary goods can maximise profit by determining the optimal price following the Calvo rule. In each period, a fraction $(1-\theta)$ of producers resets their prices P_t^* while the rest of the firms keep their prices unchanged. In this context, θ can be regarded as a natural index of price stickiness. As a result, the aggregate price can be indicated as follows

$$P_t = \left[\theta(P_{t-1})^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{2.44}$$

If we manipulate this equation, we can get

$$\Pi_t^{1-\epsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\epsilon} \tag{2.45}$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is gross inflation. In a steady state with zero inflation, $P_t^* = P_{t-1} = P_t$, for all t. Hence, by taking log-linearisation around the steady state, we have

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}) \tag{2.46}$$

with $\pi_t = p_t - p_{t-1}$.

Optimal Price Setting

As far as the optimal price-setting behaviour is concerned, a re-optimising firm will choose the price P_t^* that maximises the current market value of the profits generated while that price remains effective. Thus, the representative firm's profit maximisation problem is thus given by

$$\max_{P_t^*} E_t \sum_{k=0}^{\infty} (\beta\theta)^k [P_t^* Y_{t+k|t} - TC_{t+k}(Y_{t+k|t})] \tag{2.47}$$

subject to demand constraint

$$Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon} Y_{t+k} \tag{2.48}$$

where $TC_t(\cdot)$ is the function of firm's total cost and $Y_{t+k|t}$ denotes output in period $t+k$ for a firm that last resets its price in period t. This term can be linearised as $y_{t+k|t} = -\epsilon(p_{t+k|t} - p_{t+k}) + y_{t+k}$ with $p_{t+k|t} = p_t^*$. Taking F.O.C with respect to P_t^*, we have

$$E_t \sum_{k=0}^{\infty} (\beta\theta)^k Y_{t+k|t} \left(P_t^* - \frac{\epsilon}{\epsilon - 1} MC_{t+k|t} P_{t+k} \right) = 0 \tag{2.49}$$

Thus, the optimisation yields the following price-setting rule

$$P_t^* = \frac{\epsilon}{\epsilon - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\theta)^k Y_{t+k|t} MC_{t+k|t} P_{t+k}}{E_t \sum_{k=0}^{\infty} (\beta\theta)^k Y_{t+k|t}} \tag{2.50}$$

The term $\frac{\epsilon}{\epsilon-1}$ is the gross-up desired by the firm. Taking log-linearisation around the steady-state, we have

$$p_t^* = (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t(\widehat{mc}_{t+k|t} + p_{t+k}) \tag{2.51}$$

where $\widehat{mc}_{t+k|t} = mc_{t+k|t} - mc = mc_{t+k|t} + \ln \frac{\epsilon}{\epsilon-1}$. Combining aggregate price dynamics in equation (2.46) with the optimal price setting rule in this equation; thus, we derive the New Keynesian Phillips curve (NKPC)

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \widehat{mc}_t \tag{2.52}$$

where $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\epsilon}$. This equation for the NKPC shows a relationship between the inflation rate and its future expectation as well as the marginal cost of producing intermediate goods. Particularly, inflation π_t rises with the inflation expectation $E_t \pi_{t+1}$ and the marginal cost $\widehat{mc}_t$.

2.2.4 Government

Fiscal Policy

The government will generate income from taxes collected from households and issuance of new public debt to fund its expenditures and finance existing debt; it is worth noting that all government debt consists of one-period bonds. As a result, the nominal flow of budget constraint is given by:

$$B_t + T_t = P_t G_t + P_t I_t^g + P_t TR_t + R_{t-1}^b B_{t-1} \tag{2.53}$$

where B_t is the issuance of new government bonds in time t, T is the tax revenue collected from households to finance its government spending (G_t), public investment (I_t^g), government transfer (TR_t), and existing debt in previous period B_{t-1}. The law of motion of public capital has the form

$$K_{t+1}^g = (1 - \delta_g) K_t^g + I_t^g \tag{2.54}$$

The total government revenue collected is as follows

$$T_t = \tau_t^c P_t (C_t + I_t) + \tau_t^n W_t N_t + \tau_t^k [R_t - (a(u_t) + \delta_0) P_t] K_t \tag{2.55}$$

In steady-state, it is assumed that the debt over GDP ratio is $B = \psi_B Y$, the public investment/GDP is $I^g = \psi_{I^g} Y$ and the level of transfer of income to households/GDP is $TR = \psi_{TR} Y$. Taking log-linearisation of government budget constraint in equation (2.53), we have

$$Bb_t - R^b B(b_{t-1} + r_{t-1}^b) + Tt_t = PG(g_t + p_t) + PI^g(i_t^g + p_t) + PTR(tr_t + p_t) \tag{2.56}$$

We follow Leeper, Walker and Yang (2010) in determining spending and revenue rules for this sector. Public spending follows the same fiscal policy rule in a log-linearised process

$$x_t = \gamma_x x_{t-1} - (1-\gamma_x)\phi_x(b_{t-1} - y_{t-1} - p_{t-1}) + e_t^x \tag{2.57}$$

where $x \in \{g, i^g, tr\}$and e_t^x are fiscal shocks that follow AR(1) processes

$$e_t^x = \rho_x e_{t-1}^x + \epsilon_t^x \tag{2.58}$$

with ϵ_t^x are i.i.d and normally distributed $N(0, \sigma^2)$.

The revenue side is given as below

$$z_t = \gamma_z z_{t-1} + (1-\gamma_z)\phi_z(b_{t-1} - y_{t-1} - p_{t-1}) + e_t^z \tag{2.59}$$

where $z \in \{\tilde{\tau}^c, \tilde{\tau}^n, \tilde{\tau}^k\}$and e_t^z are fiscal shocks that follow AR(1) processes

$$e_t^z = \rho_z e_{t-1}^z + \epsilon_t^z \tag{2.60}$$

with ϵ_t^z are i.i.d and normally distributed $N(0, \sigma^2)$.

Monetary Policy

In this section, we focus on analysing unexpected shocks in a normal time; therefore, the central bank does not need to employ an unconventional monetary policy. Instead, they will set the nominal interest rate following a simple Taylor rule (Taylor, 1993). Accordingly, in a normal time, where the ZLB is not binding, it positively adjusts the nominal interest rate r_t^b in response to inflation of the consumer price index (CPI), and output gap y_t to stabilise the business cycle. The log-linearised monetary rule is as follows

$$r_t^b = \gamma_{r^b} r_{t-1}^b + (1 - \gamma_{r^b})(\gamma_\pi \pi_t + \gamma_y y_t) - e_t^m \tag{2.61}$$

where e_t^m is a monetary shock that follows AR(1) process $e_t^m = \rho_{e^m} e_{t-1}^m + \epsilon_t^{e^m}$ with $\epsilon_t^{e^m}$ is a Gaussian white noise process with mean zero and standard deviation; hence, $\epsilon_t^{e^m}$ is i.i.d and normally distributed $N(0, \sigma^2)$.

2.2.5 Market Clearing

In equilibrium, goods market-clearing expects the output produced net of utilisation costs to equal the demand for private as well as public consumption and investment. In other words, aggregate demand is equal to aggregate supply

$$Y_t = C_t + I_t + I_t^g + G_t \tag{2.62}$$

2.3 Model Solution and Parameters Calibration

In this section, we first discuss how a DSGE model can be solved for a closed economy, and then calibrate the necessary parameters for simulating the impacts of any policy changes.

2.3.1 Model Solution

This model comprises 45 endogenous variables which are estimated by determining 45 equilibrium conditions. In general, because this DSGE model has the nature of non-linear equations, this chapter follows the general procedure suggested by Uhlig (2001) to solve and analyse the model. For instance, this methodology can combine the following steps: (i) establish constraints and first-order conditions to identify the equilibrium; (ii) apply the Taylor approximation around the steady-state approach to log-linearise key equations in the first step; (iii) calibrate the parameters in the model and find the steady-state values of variables; (iv) solve the recursive equilibrium law of motion by exploiting standard methods (Blanchard and Kahn, 1980; Klein, 2000; Sims, 2002); (v) simulate the impulse response functions of the economy to stochastic shocks and analyse the solution.

The first step has been accomplished in the previous section. For the second step, a full log-linearisation model is shown in Appendix A. Overall, we can express the model in a general form of the multivariate linear rational expectations (RE) model:

$$AE_t x_{t+1} = Bx_t + Cz_t \tag{2.63}$$

where x_t is a 45×1 vector of endogenous variables and z_t is a 10×1 vector of the stochastic process; it is worth noticing that these matrices are denoted in log-deviated values. Furthermore, A and B are two coefficient matrices of dimension 45×45 while coefficient matrix C is a 45×10 matrix.

In the following stage, we exploit Dynare to solve the model based on calibrated parameters (Adjemian et al., 2011). Particularly, this is a software platform developed based on Matlab by Michel Juillard for solving a wide class of economic models including DSGE and overlapping generations (OLG) models which rely on the rational expectations hypothesis. However, it is important to make sure this DSGE model has a unique solution to the equilibrium; one way to achieve this is to satisfy Blanchard-Kahn conditions which state that there exists a unique solution iff the number of unstable eigenvalues is equal to the number of non-predetermined variables at the steady state of the model (Blanchard and Kahn, 1980).

After calibrating parameters and solving our DSGE model, we analyse the impulse response functions for structural shocks under each policy mixed regime. In order to understand the effect of each fiscal component, we investigate impulse responses to positive spending shocks and tax shocks in regime M. These shocks are assumed to change by one percent of their steady-state value. Consequently, these effects are compared with impulse responses to the same shocks in regime F. By doing this, we are able to see how fiscal components interact in different regimes to stimulate the economy. Besides, we also consider impulse responses to other structural shocks including monetary policy shock, preference shock, and technology shock. This analysis gives us a better understanding of how these shocks affect the economy given the existence of government intervention. Finally, we exploit a simple loss function to measure the efficiency of each regime in terms of welfare loss due to variations in the output gap and inflation. This approach is also applied to individual fiscal shocks to distinguish which instrument performs better in pushing economic growth.

2.3.2 Parameters Calibration

In this section, we calibrate the parameters $\{\omega, \beta, \sigma, \varphi, \alpha, \kappa, \delta_0, \delta_2, \delta_g, \theta, \epsilon, h, \eta\}$, and the steady state values for some variables so that the model is consistent with long-run growth facts and microeconomic observations. In this model, we adopt quarterly frequency values that are standard in literature for this model (Smets and Wouters, 2003; Leeper, Walker and Yang, 2010; Leeper, Traum and Walker, 2017). The calibrated parameters are summarised in Table 2.1.

Firstly, we discuss the parameters of the utility function. Accordingly, the discount factor β is set to 0.99, which implies a 4 percent annual rate of return. This in turn determines the nominal risk-free rate in the steady state, $R^b = \frac{1}{\beta}$. Besides, we assume that 70 percent of households can fully access the financial market; as a result, ω is set to be 0.3. Moreover, we set the inverse of the intertemporal elasticity of consumption σ and the inverse Frisch labour elasticity φ at 1.5 and 2, respectively. In addition, it is assumed that consumers have a habit formation h of 0.7 (Smets and Wouters, 2007).

As far as the production is concerned, the share of capital in production α is set to be 0.3; this suggests labour income accounts for 70 percent of total output at the steady-state. In line with Baxter and King (1993), we set the productivity of public capital κ to 0.05. The elasticity of substitution among intermediate goods has the value of $\epsilon = 6$; hence, the mark-up in the steady-state is given as $\frac{\epsilon}{\epsilon - 1} = 1.2$ (Blanchard and Galí, 2010). Besides, nominal price rigidity θ is set to be 0.75; hence, $\frac{1}{1-\theta} = 4$ which means that price of intermediate goods is stable for four quarters. Additionally, the adjustment cost of investment η has the value of 2.48, being consistent with Stähler and Thomas (2012). The quarterly depreciation rates are the same for both private and public capital; hence, $\delta_0 = \delta_g = 0.025$ so that the annual depreciation rates are estimated at 10 percent. Finally, firms are assumed to utilise full capital intensity in the steady-state with $u = 1$ and the capital utilisation δ_2 is set at 0.7 (Leeper, Walker and Yang, 2010).

According to Leeper, Traum and Walker (2017), government policies give the optimal outcome when they jointly interact to support each other in order to determine the price level and stabilise debt. As a result, there are two regimes of monetary-fiscal policy mixes that the government should consider. In particular, the conventional regime (regime M) occurs when the central bank aggressively adjusts the interest rate in response to inflation while fiscal authorities accommodate their primary budget surpluses to stabilise the long-run debt-to-GDP ratio. The alternative regime (regime F) happens when the central bank weakly adjusts its policy rate following a change in the general price level while the government actively pursues other objectives instead of focusing merely on debt stabilisation. As a result, we follow this approach to allow for two distinctive regimes when estimating the effect of changes in tax and public spending on the economy.

In this regard, in regime M, monetary policy is assumed to follow the Taylor rule in setting parameters; as a result, the authority responds aggressively to inflation and weakly to the output gap quarterly; hence, $\gamma_\pi = 1.5$ and $\gamma_y = 0.125$. The persistence of the policy rule is determined by the coefficient on the lagged interest rate, which has the value of $\gamma_{r^b} = 0.5$. On the other hand, all parameters of fiscal policy are set to capture the effect of conventional monetary-fiscal policy mix; hence, $\gamma_x = \gamma_z = 0.5$ and $\phi_x = \phi_z = 0.15$ where $x \in \{g, i^g, tr\}$ and $z \in \{\tau^c, \tau^n, \tau^k\}$.

In regime F, the central bank responds weakly to changes in inflation; thus, $\gamma_\pi = 0.5$ while fiscal authority does not act based on public debt, output, and price level in the previous period; in this case, $\phi_x = \phi_z = 0$. By doing this, the increase in government debt raises the price level; this outcome together with a lower bond price in turn makes the real market value of public debt fall, leading to a stable debt-to-GDP ratio (Leeper, 2018).

Finally, the steady-state tax rates and the ratios of government spending and transfers to output remain the same in both regimes and are set as follows: $\tau^c = 0.095$, $\tau^n = 0.214$, $\tau^k = 0.384$, $\psi_G = 0.144$, $\psi_{I^g} = 0.038$, $\psi_{TR} = 0.1783$, $\psi_B = 1$.

Table 2.1: Structural model parameter values

	Parameter	Calibrated value
	Preferences and Households	
1	ω share of non-Ricardians households	0.3
2	β discount factor	0.99
3	σ elasticity of consumption	1.5
4	φ inverse Frisch labour elasticity	2
5	h habit persistence	0.7
	Frictions and Production	
6	α share of private capital in production	0.3
7	κ share of public capital in production	0.05
8	δ_0 depreciation rate of private capital	0.025
9	δ_g depreciation rate of public capital	0.025
10	θ price stickiness parameter	0.75
11	ϵ elasticity of substitution	6
12	θ_w wage stickiness parameter	0.75
13	ϵ_w elasticity of substitution between differentiated jobs	6
14	η sensitivity of adjustment cost	2.48
15	δ_2 capital utilisation	0.7
	Fiscal policy	
16	τ^c tax rate on consumption	0.095
17	τ^n tax rate on labour	0.214
18	τ^k tax rate on capital	0.384
19	ψ_G share of public consumption to GDP	0.144
20	ψ_{I^g} share of public investment to GDP	0.038
21	ψ_{TR} share of transfer payment to GDP	0.1783
22	ψ_B share of public debt to GDP	1

Table 2.1: Structural model parameter values

	Parameter	Calibrated value
23	γ_g response to lagged public consumption	0.5
24	ϕ_g debt response for public consumption	0.15 (M) - 0 (F)
25	γ_{i^g} response to lagged public investment	0.5
26	ϕ_{i^g} debt response for public investment	0.15 (M) - 0 (F)
27	γ_{tr} response to lagged transfer payment	0.5
28	ϕ_{tr} debt response for transfer payment	0.15 (M) - 0 (F)
29	γ_{τ^c} response to lagged consumption tax	0.5
30	ϕ_{τ^c} debt response for consumption tax	0.15 (M) - 0 (F)
31	γ_{τ^n} response to lagged labour tax	0.5
32	ϕ_{τ^n} debt response for labour tax	0.15 (M) - 0 (F)
33	γ_{τ^k} response to lagged capital tax	0.5
34	ϕ_{τ^k} debt response for capital tax	0.15 (M) - 0 (F)
	Monetary policy	
35	γ_{r^b} response to lagged interest rate	0.5
36	γ_π interest rate response to inflation	1.5 (M) - 0.5 (F)
37	γ_y interest rate response to output	0.125 (M) - 0.75 (F)
	Shocks	
38	$\rho_{\tilde{\epsilon}^c}$ preference shock	0.5
39	$\rho_{\tilde{\epsilon}^n}$ labour shock	0.5
40	ρ_a technology shock	0.5
41	ρ_g public consumption shock	0.5
42	ρ_{i^g} public investment shock	0.5
43	ρ_{tr} transfer payment shock	0.5
44	$\rho_{\tilde{\tau}^c}$ consumption tax shock	0.5
45	$\rho_{\tilde{\tau}^n}$ labour tax shock	0.5
46	$\rho_{\tilde{\tau}^k}$ capital tax shock	0.5

Table 2.1: Structural model parameter values

	Parameter	**Calibrated value**
47	ρ_{e^m} monetary policy shock	0.5

2.4 Model Dynamics

In this section, we investigate the dynamic effect of fiscal policies on the economy using impulse response functions. Particularly, the analysis includes the evaluation of tax components and spending behaviour in two separate regimes with the aim of understanding how expansionary fiscal rules influence the economy. Moreover, given the fact that other structural shocks, including technology shock and preference shock, also enter the model, we study the fluctuation caused by these shocks and discuss their transmission mechanisms in Appendix B.

2.4.1 Regime M - Active Monetary and Passive Fiscal Policies

Expansionary Fiscal Policy Shocks

In this part, we investigate the transmission mechanism of expansionary fiscal policies via expenditure and tax channels in regime M. It is worth noting that in this chapter, we assume a closed economy; hence, there are neither cross-country trading activities nor foreign sectors. Besides, we do not allow for ZLB to exist in this chapter; thus, the policy rule can be adjusted following the Taylor rule. In the context of regime M, it is assumed that monetary policy aggressively adjusts the interest rate to control inflation, while fiscal authority passively controls primary budget surpluses, which are revenues minus expenditures and do not include interest expenses on government debt, to stabilize the long-run debt-to-GDP ratio.

The Effect of Tax Cuts

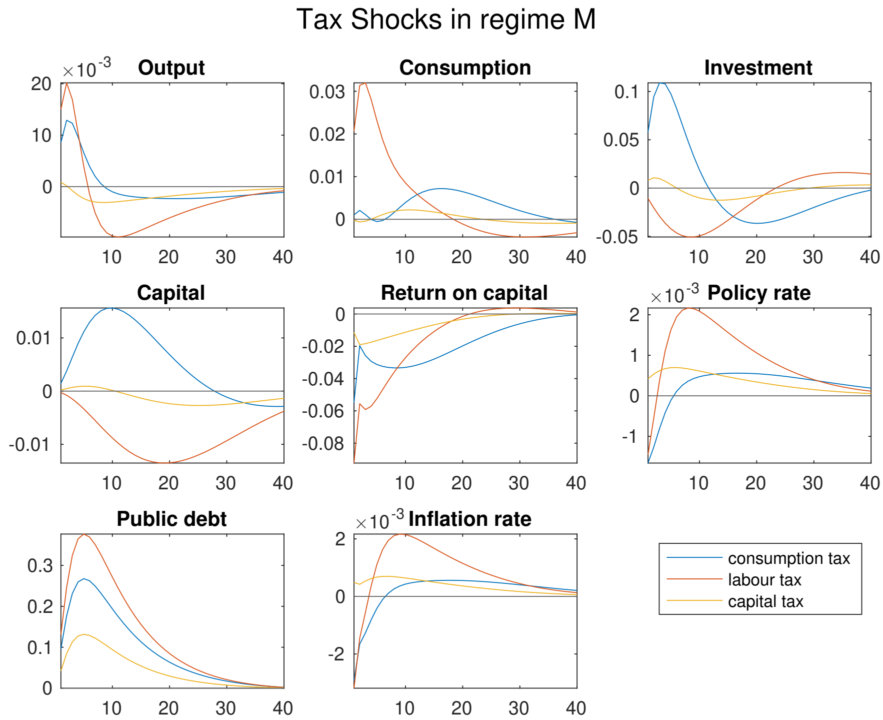

Figure 2.1: The impulse response functions for tax shocks in regime M

Regarding the goods market, only expansionary shocks in consumption and labour tax have an initial impact on output in the short-run while generating potential cost-to-GDP growth after 5 quarters. As a result, the general price level accelerates significantly for nearly ten quarters following the shocks. According to the monetary policy rule in equation (2.61) when the ZLB does not bind, an increase in inflation π can boost the policy rate r^b, especially when the economy is pursuing an active monetary policy regime. Even though the trends in the shocks caused by cutting these two taxes are similar, the influence of labour tax is much more intense. Besides, it is worth noticing the differences in the behaviour of households' consumption and investment following a fall in tax rates. In this case, while a fall in labour income tax raises the growth rate of aggregate consumption, it appears to restrain the growth rate of investment. In contrast, a reduction in consumption tax can boost the level of investment significantly but its effect on the consumption growth rate is modest. To emphasise, only Ricardian households have full access to the financial markets; consequently, any changes to the investment are caused by the behaviour of these households. Thus, it can be argued that in the financial market, a fall in consumption tax tends to cause a substitution effect so that Ricardian households are willing to postpone a part of their consumption to the future via investment. As a result, we witness a greater change in investment growth compared to the growth rate in consumption level in terms of magnitude. If these Ricardian households choose not to postpone their consumption, then we should expect a much greater value of consumption growth after the shock. This outcome is opposite to the effect of labour tax which has an income effect in this case. For impulse responses to consumption, we need to decompose aggregate consumption into the consumption of two separate households for a better understanding of their behaviour. In terms of capital tax, a decrease in this kind of tax shares some common characteristics with the other two measures, even though it does not initiate an increase in the output growth rate, and its effect on other variables is moderate. Finally, it is distinct that a fall in any type of tax puts pressure on government debt because this shock exacerbates the government budget. In those, a cut in labour tax creates the greatest rise in public debt.

In the case of the labour market, a decrease in tax rates has opposite impacts across households. In particular, we first consider the effect of tax cuts on Ricardian households. These households are influenced the most by shocks in consumption and labour tax. However, while Ricardian households' labour supply increases with a fall in labour tax (substitution effect), it decreases with a reduction in consumption tax

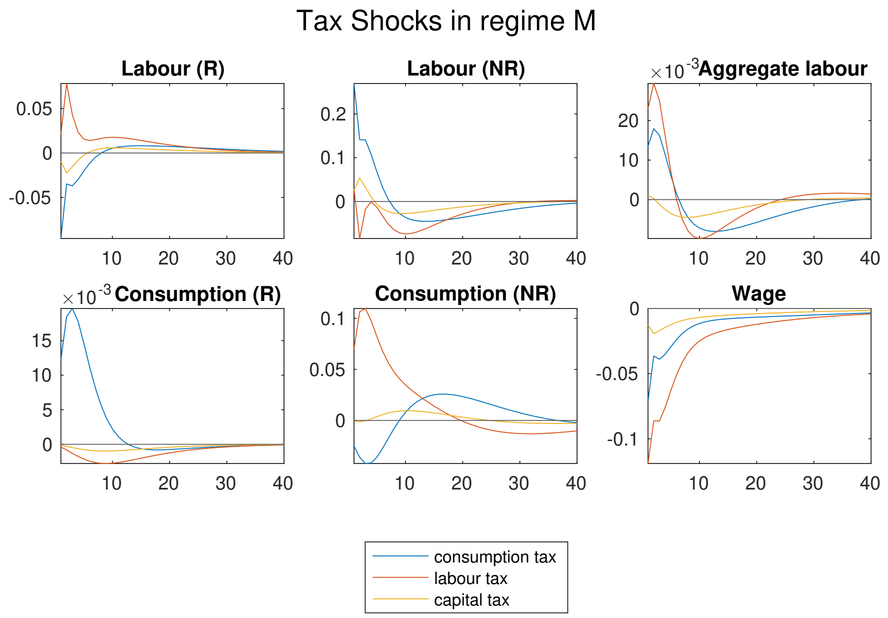

Figure 2.2: The effect of tax shocks on household components in regime M

(income effect). In contrast, regarding the behaviour of non-Ricardian households, a reduction in consumption tax raises their labour supply and inflicts consumption, while the same impact applied to income tax stimulates their consumption growth rate and restrains labour supply. Despite those differences, the influence of reducing consumption and labour taxes on aggregate labour supply is positive; for instance, these shocks encourage aggregate labour supply to increase by more than 1.3%. Besides, it is worth noting that the impact of these fiscal shocks is greater on non-Ricardian households. This is because this type of household only has one source of income, which makes them vulnerable to any policy changes, making their responses fluctuate strongly. Thus, policymakers should pay more attention to the behaviour of this group of people in decision-making. Finally, the relaxation in terms of capital tax does not significantly affect both households' behaviour.

In fact, the negative correlation between tax shocks and output is not a new story in macroeconomics research. For years, much empirical research has exploited various methods such as SVAR, the narrative approach, and sign restriction to identify shocks and estimate their effect on the economy. In those, most papers focus on the impact of fiscal consolidation and conclude that a rise in tax will hinder economic growth by inflicting output and raising the unemployment rate (Romer and Romer, 2010; Leigh et al., 2010; Favero and Giavazzi, 2012). Some others are interested in investigating the effect of tax cuts on the economy; for instance, Mertens and Ravn (2013) state that unexpected tax cuts would stimulate output and reduce the unemployment rate. Particularly, it is shown that one percentage point decrease in the average personal income tax rate raises output by 1.4% in the first quarter and results in a peak increase of 1.8% after three quarters. Likewise, cutting the average corporate tax rate leads to a similar consequence when it increases real GDP by 0.6% within a year. However, they decompose unexpected tax shocks into Personal income tax and Corporate income tax rather than those variables in our theoretical model. Overall, our model is consistent with these empirical results when expansionary tax shocks bring about output stimulus, an increase in investment, and a rise in the aggregate employment rate.

The Effect of Expenditure Stimulus

Regarding expansionary spending shocks, the result of an increase in public consumption is very similar to the impact of labour income tax cuts. As can be shown in figure 2.3, a raise in this variable causes a higher demand for output, which puts pressure on the price levels. As a result, the central bank increases the interest rate using the Taylor rule; thus, this action results in a lower price for the government bond, making it an attractive asset. Consequently, it is shown that demands for aggregate consumption and investment fall sharply; this phenomenon is known as the crowding-out effect, which limits the effect of growth in economic activity. Accord-

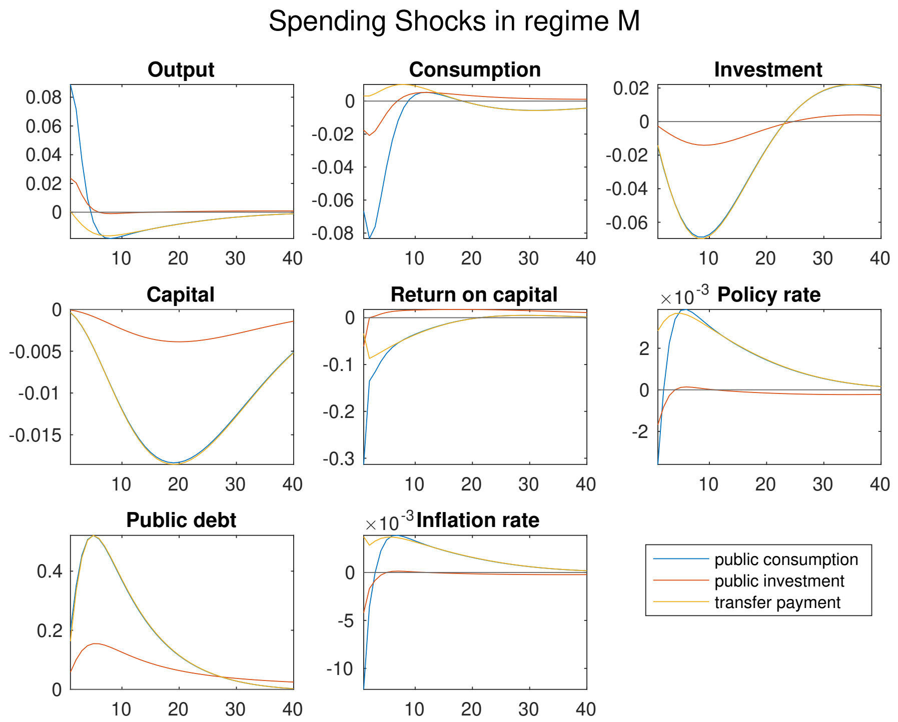

Figure 2.3: The impulse response functions for spending shocks in regime M

ing to Ramey (2016), the positive impact of growth in government spending on GDP and labour supply is predicted by various versions of standard new Keynesian theories; besides, a positive expenditure shock is expected to decrease consumption and real wages. Consequently, our model is no exception because it captures this trend of movement. Additionally, these theories have been confirmed in several empirical studies. Particularly, Smets and Wouters (2007) show that government spending is one of the main factors that drive output; a shock to this factor is believed to raise GDP, hours worked and inflation immediately while reducing consumption.

By accelerating government spending, the government budget significantly deteriorates; thus, the solution for financing government consumption is to issue more debt. In terms of production, the supply of capital is witnessed to fall together with a decrease in investment demand; the rate of investment only starts to recover after nearly ten quarters, and it takes twenty quarters for the same effect to take place in the case of capital accumulation. This may explain a long-lasting deterioration in the growth rate of aggregate demand. As discussed before, a positive shock in public investment does not cause significant harm in terms of output; notably, this still holds for other variables including the capital, investment, and consumption. Especially, an increase in public investment leads to a rise in return on capital. Finally, an increase in transfer payments, on the other hand, leads to a rise in consumption with a cost of inflated public debt. In such cases, the negative effect of this impact is similar to the one caused by a rise in public consumption; for instance, it causes a fall in investment and the supply of capital, an increase in inflation rate and policy rate, despite the fact that it cannot initiate a significant growth in output as the expansionary shock in public consumption does.

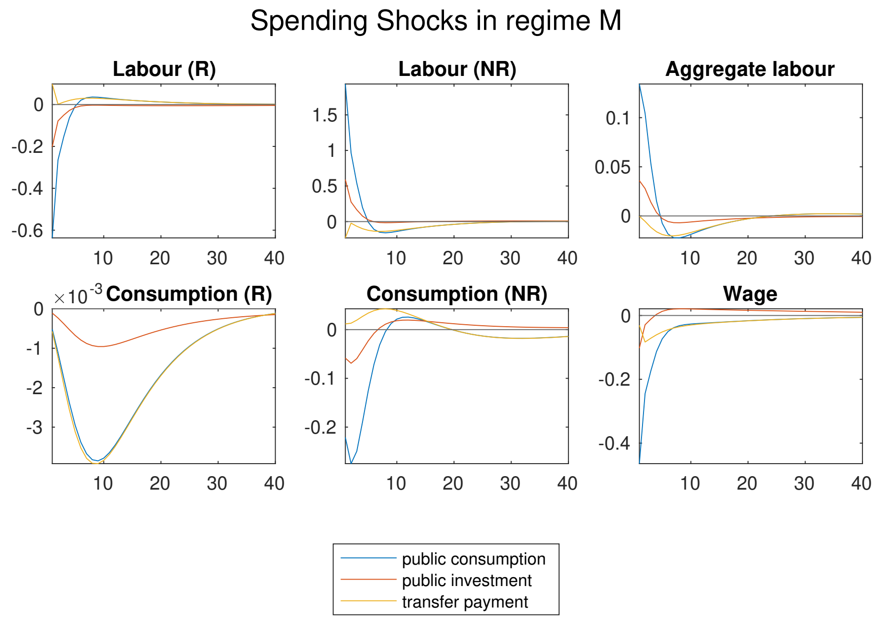

Figure 2.4: The effect of spending shocks on household components in regime M

The Ricardian households and non-Ricardian households still behave in the opposite direction when we consider the labour market. In general, while an expansionary shock in public consumption or investment reduces the growth rate of the Ricardian labour supply, it has a positive effect on the non-Ricardian labour market. On the other hand, in terms of consumption, they behave in line with each other; in this case, the consumption growth rate of both types of households is negatively affected by these shocks.

Expansionary Monetary Policy Shock

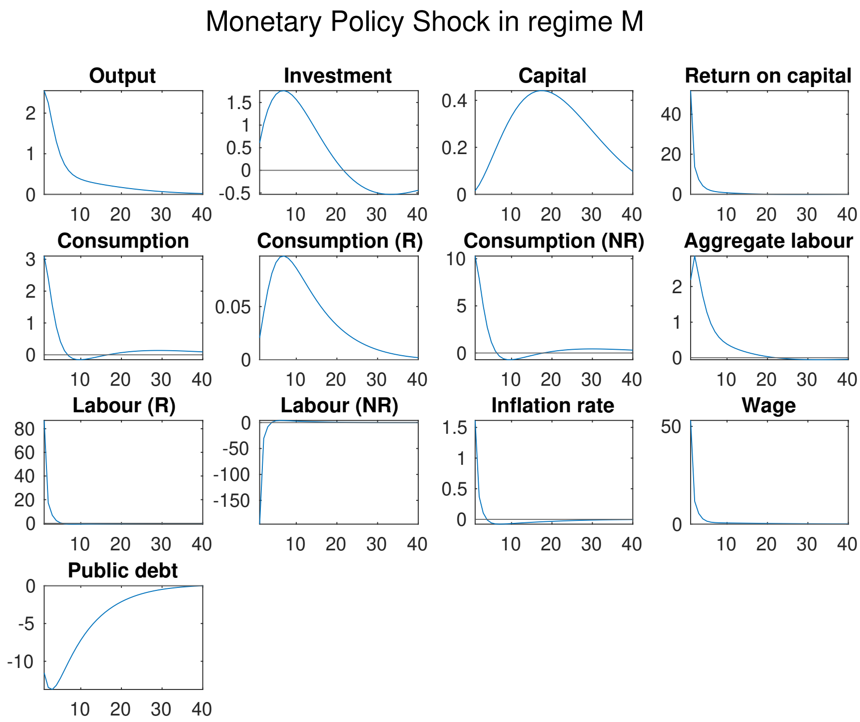

Figure 2.5: The impulse response functions for monetary policy shock in regime M

Figure 2.5 shows impulse responses for a one percent expansionary monetary shock by decreasing the interest rate. As expected, it is consistent with existing literature on the effect of monetary policy; in general, an expansionary monetary policy accelerates output growth rate by more than two percent; this effect drops greatly for the first 8 quarters and diminishes slowly for the remaining ten years. As a result, inflation is expected to rise with the output when the shock initiates. Besides, a fall in interest rate, in turn, raises the price of government bonds, making

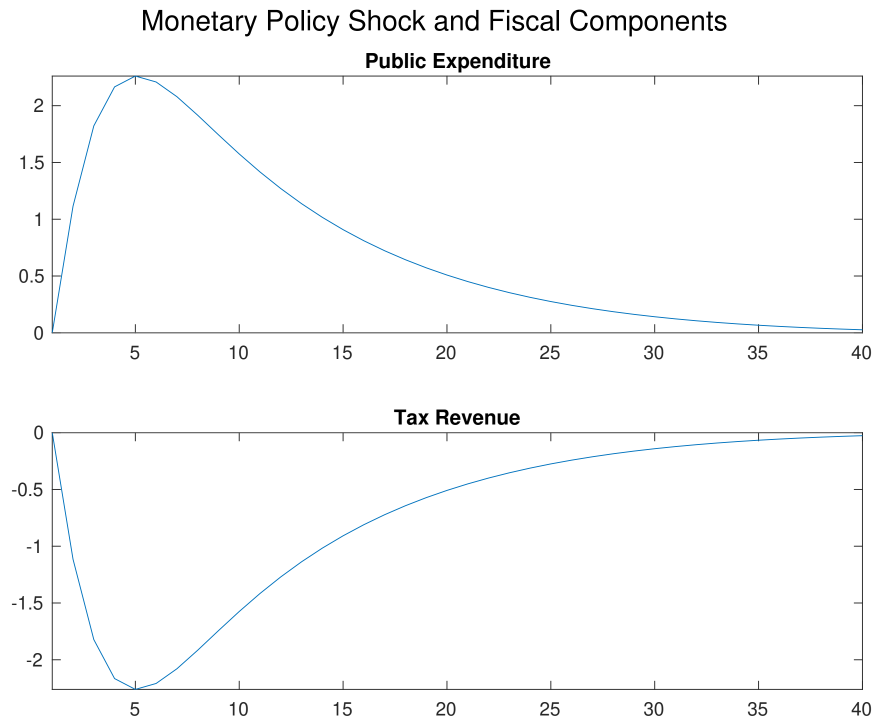

Figure 2.6: The impact of monetary policy shock on fiscal components in regime M

this asset less attractive; thus, bringing down demand for bonds. In contrast, this is the reason for private capital to increase because investing in the private sector can be more attractive due to a higher return. Together with a rise in GDP and household consumption, we see a reduction in public debt at the beginning of the shock. As far as investment and consumption are concerned, a rise in money supply boosts investment and aggregate consumption by 1.5 and 3 percent, respectively; however, the reactions are hump-shaped due to the cost of investment adjustment and habit formation of consumers. Regarding the labour market, an expansionary money supply causes an increase in labour supply and wage rate; however, these effects are short-lived and disappear after approximately five quarters.

Regarding the effect of expansionary monetary policy shock on the growth rate of fiscal components, we analyse the impulse response functions as shown in figure 2.6. In this case, we see that government expenditure and tax revenue behave in the opposite direction. For instance, a decrease in the policy rate tends to raise the growth rate of government spending while reducing the level of tax. This is because in regime M, the fiscal authorities take into account the value of the debt-to-GDP ratio when they set the policy rule (in equations 2.57, 2.59). Accordingly, when the expansionary monetary policy is implemented, the public debt falls while the growth rate of output increases, leading to a lower debt-to-GDP ratio. As a result, the government steps in to raise public expenditure and lower the tax rates. This finding is consistent with Leeper (2018) who states that looser monetary policy needs to be supported by a fiscal stimulus in this regime in order for the central bank to achieve the inflation target and manage debt stability.

2.4.2 Regime F - Passive Monetary and Active Fiscal Policies

Expansionary Fiscal Policy Shocks

In this section, we analyse the effect of expansionary shocks in fiscal components on aggregate demand in the context of regime F. In this regime, fiscal authority actively pursues other objectives rather than stabilising debt. In this case, the government will not change their policies in accordance with the lagged value of public debt, output and price level; thus, $\phi_x = \phi_z = 0$. On the other hand, the central bank adjusts the interest rate weakly in response to the change in inflation and strongly in response to the change in output; hence, γ_π has the value of 0.5 while γ_y has the value of 0.75.

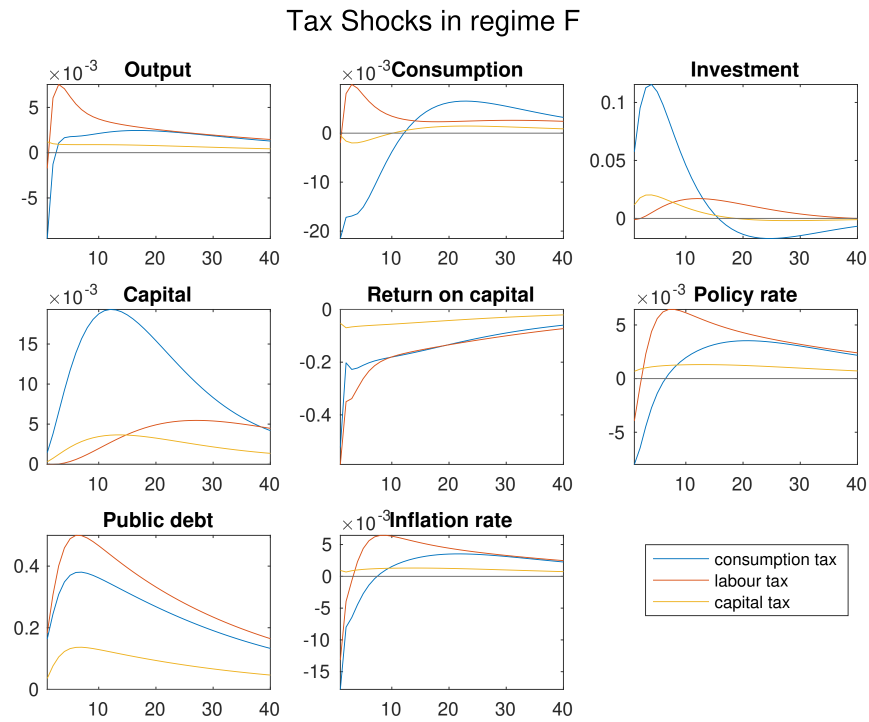

Figure 2.7: The impulse response functions for tax shocks in regime F

The Effect of Tax Cuts

Firstly, we consider the effect of expansionary fiscal shocks in terms of tax components on the performance of the economy. Figure 2.7 displays the impulse responses for one percent decrease in tax rates. For instance, a favourable shock in capital tax causes an immediate increase in output; then, it takes more than forty quarters for aggregate demand to grow before returning to its steady state. Taking into account the labour tax, a cut in this tax rate does have the greatest influence on the GDP growth rate compared to the other measures. Finally, a reduction in consumption tax increases the growth rate of GDP after the third quarter. Although the growth rate of output is still low, it lasts for a long period (up to more than eight years) before returning to its steady-state value.

Besides, we acknowledge that the level of public debt rises significantly with a reduction in taxes. In this case, a decrease in labour tax has the greatest influence on this variable. The increase in public debt can be explained by a fall in the state budget and inflation that makes the value of debt exacerbate. Furthermore, due to tax cuts, growth rates of both consumption and output fall significantly initially. As a result, the inflation rate is negatively affected by this event. In the money market, as the central bank adjusts the policy rate weakly in accordance with the price level and strongly to the output gap, the interest rate is pulled down as a consequence. Regarding the private sector, the investment grows with a reduction in consumption tax; consequently, this leads to a dynamic surge in the capital after several quarters. On the other hand, capital tax and labour tax do not appear to greatly affect this sector. Besides, it can be noticed that an expansionary shock in any kind of tax can drive down the return on capital.

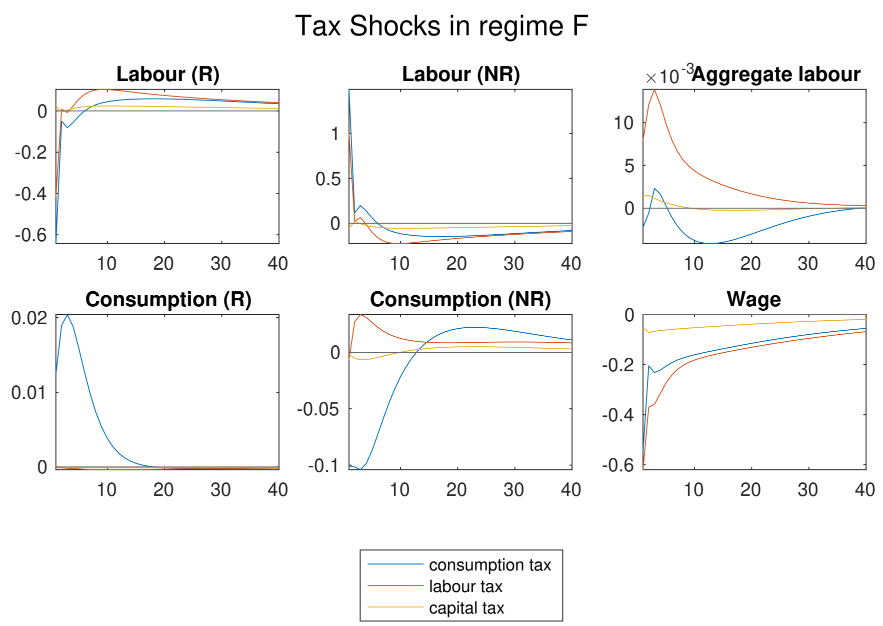

Figure 2.8: The effect of tax shocks on household components in regime F

In the case of the labour market, tax cuts tend to cause a reduction in the wage rate and aggregate labour supply. Regarding the behaviour of households in consumption, it is worth noticing that the consumption rate of Ricardian households is greatly impacted by a decrease in consumption tax; in other cases, their consumption stays very low near the steady-state level. On the other hand, although non-Ricardian households spend more hours working, this could not compensate for the fall in their wage rate; as a result, their disposable income appears to decrease, which makes the consumption of the non-Ricardians to reduce in the first quarter after the shock.

The Effect of Expenditure Stimulus

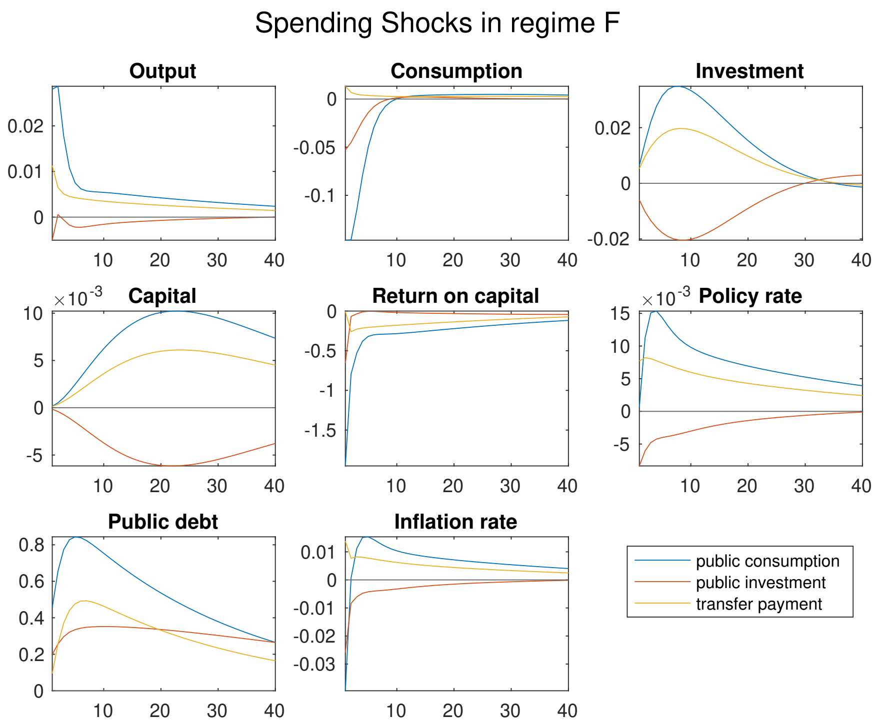

Figure 2.9: The impulse response functions for spending shocks in regime F

As far as public expenditure is concerned, the effect on GDP growth can be various based on the type of government spending. Figure 2.9 indicates impulse response functions for various expansionary shocks in different types of public spending. Particularly, an increase in transfer payments leads to a growth in output. This can be explained by an increase in investment although there is a reduction in consumption rate. Compared to the impulse response for transfer payment in regime M, the outcome is more significant in this case. In addition, an increase in public investment is shown to inflict on the output growth rate in the first ten quarters before generating a positive result in the long run. Finally, when we consider the measure of public consumption, its expansionary shock significantly boosts the growth rate of output immediately in the first quarter; in fact, this instrument gives the highest stimulus to the economy.

In general, these shocks have a similar pattern of impact on most structural variables except for the GDP growth rate. In particular, an expansionary shock in public expenditure raises the sovereign debt growth rate while causing inflation, capital return, and aggregate consumption to fall. In most cases, growth in public consumption has the greatest impact on these variables. Regarding the mechanism of spending shocks, it is in contrast to the case of tax relief. For instance, an increase in the output drives up the interest rate via monetary policy rule as the central bank adjusts its policy rate strongly to the change in output and weakly to the change in inflation. Furthermore, the return on capital changes sharply after the shock. However, in this case, capital and investment respond significantly to the change in government spending. They have hump-shaped response functions, and in the long run, they can grow well above the steady-state level for certain types of spending shocks; they are those in public consumption and transfer payment.

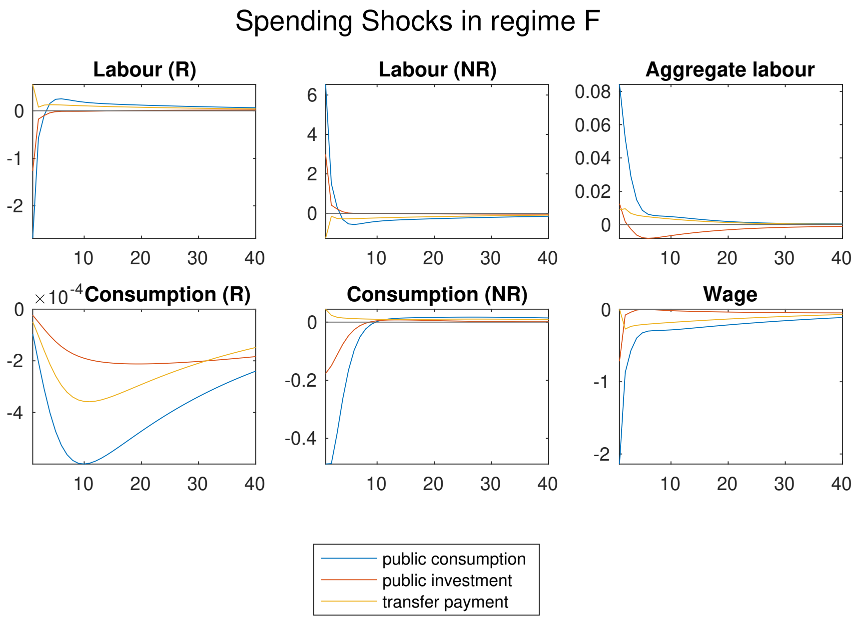

Figure 2.10: The effect of spending shocks on household components in regime F

If we decompose the components of aggregate consumption to investigate the effect of expansionary spending shocks on the behaviour of different households, we acknowledge that Ricardians' consumption is most vulnerable to an increase in public consumption. Moreover, this result appears to diminish over time to reach its steady-state level after a long period. This outcome also applies to the case of raising transfer payments. In case of a surge in public investment, the cost is less severe with regard to Ricardians' consumption compared to the other shocks, although the amount of time needed for recovering to its steady state can be enormous in this case. The fall in their consumption can be explained by a reduction in their wage growth rate and labour supply which reduces their disposable income. On the other hand, soaring spending also brings consumption well below its steady-state level for non-Ricardians; however, this effect is modest and it diminishes much sooner compared to the case of Ricardian households.

Expansionary Monetary Policy Shock

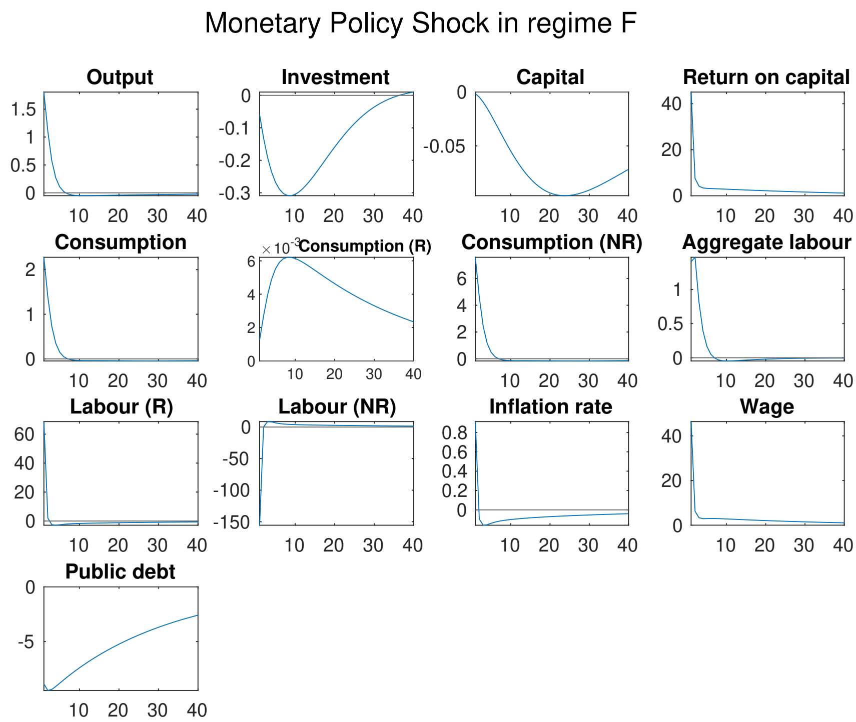

Figure 2.11: The impulse response functions for monetary policy shock in regime F

Regarding the monetary policy shock, figure 2.11 shows impulse responses for a one percent shock in the policy rate in regime F where monetary movement is passive. Particularly, the growth rate of output jumps by 1.5 percentage points after the shock. This growth in GDP can be attributed to a rise in aggregate consumption. In this regime, the impact of monetary policy causes a great influence on output; however, the effect is short-lived. Moreover, due to this result, the price level also rises accordingly. Taking into account the financial market, an expansionary monetary shock results in a deep fall in capital accumulation after nearly twenty quarters. As far as the labour market is concerned, a shock in interest rate does not cause a long-term effect on the labour supply and wage rate of both types of households; in fact, the impact only lasts two quarters before these variables return to their steady-state value.

2.5 Loss function analysis

In this section, we wish to evaluate the performance of policy rules in two regimes by comparing the value of welfare loss. To be clear, we will consider a simple quadratic loss function developed by Galí (2015) to identify an optimal policy rule in a NKPC model with nominal rigidities. In fact, this approach has adopted a utility-based welfare criterion which was introduced by Rotemberg and Woodford (1999); the idea is to take the second-order approximation to the utility loss of the representative consumer due to the deviations from natural output and volatility in the inflation rate. According to Kuang, Mitra and Tang (2022), diverse output gap estimations interact differently with monetary policy decisions and macro results, which has important welfare implications. In this case, we employ an identical output gap estimation for both regimes; the mentioned estimation is derived as the deviations from the steady-state value of output. As a result, the average welfare losses in one period can be given as a function of the output gap and inflation variances.

$$\mathcal{L} = \tilde{y}_t^2 + \lambda \pi_t^2 \tag{2.64}$$

where $\tilde{y}_t^2$ is the variance of output gap which measures the difference between actual and natural output and π_t^2 is the volatility of inflation rate as a result of policy changes. In those, λ is the weight of variation in inflation.

At this stage, given the policy rules in each regime, we exploit the calibrated parameters and the dynamics of variables in the previous section to determine the variance of the output gap, and inflation so as to compute the corresponding loss relative to the optimal solution. Firstly, we consider the general case where $\lambda = 0.5$; by doing this, we can evaluate which regime is more efficient in terms of welfare loss. Then, we will estimate the loss for different values of λ in each regime in order to investigate the robustness of this result. It is worth mentioning that we only analyse the welfare loss of two extreme cases where only either regime M or regime F exists in the economy because it is stated by Leeper (2018) that only these two policy mixes can determine inflation and stabilise the public debt.

	Regime M	**Regime F**
γ_π	1.5	0.5
γ_y	0.125	0.125
$\tilde{y}_t^2$	0.0018	0.0066
π_t^2	0.0003	0.0014
Welfare Loss	0.0020	0.0073

Table 2.2: Evaluation of policy regimes

As can be seen from table 2.2, the variance of each time series and losses of each regime are reported for two disparate values of γ_π. For instance, regime M will put more weight on inflation deviation when it estimates the policy rule; in this case, γ_π will have a value of 1.5. On the other hand, this parameter has a value of 0.5 when we consider regime F. Furthermore, we assume a weak response to output and keep the value of γ_y fixed for both regimes. Overall, the result shows that variances of the output gap and inflation tend to be smaller in regime M; hence, given the same weights on the output gap's variance and inflation's volatility in the loss function, we get a lower value for the implied welfare loss.

	λ	**Regime M**	**Regime F**
1	0.05	0.0018	0.0067
2	0.25	0.0019	0.0070
3	0.50	0.0020	0.0073
4	0.75	0.0020	0.0077
5	1.00	0.0021	0.0080

Table 2.3: Welfare loss for different values of weights on inflation

Table 2.3 shows different values of welfare loss for various weights on the volatility of inflation. In this case, we have 5 sample values in total for each regime and they are plotted to see how these values change if we put different weights on inflation.

These changes can be illustrated in figure 2.12 with three noticeable patterns. Firstly, welfare loss appears to be greater in regime F for every value of weight. Secondly, welfare losses in both regimes tend to increase with the rise in the weight of variation in inflation λ. Finally, the loss gap between these regimes gets bigger if we set a higher weight on the variance of inflation.

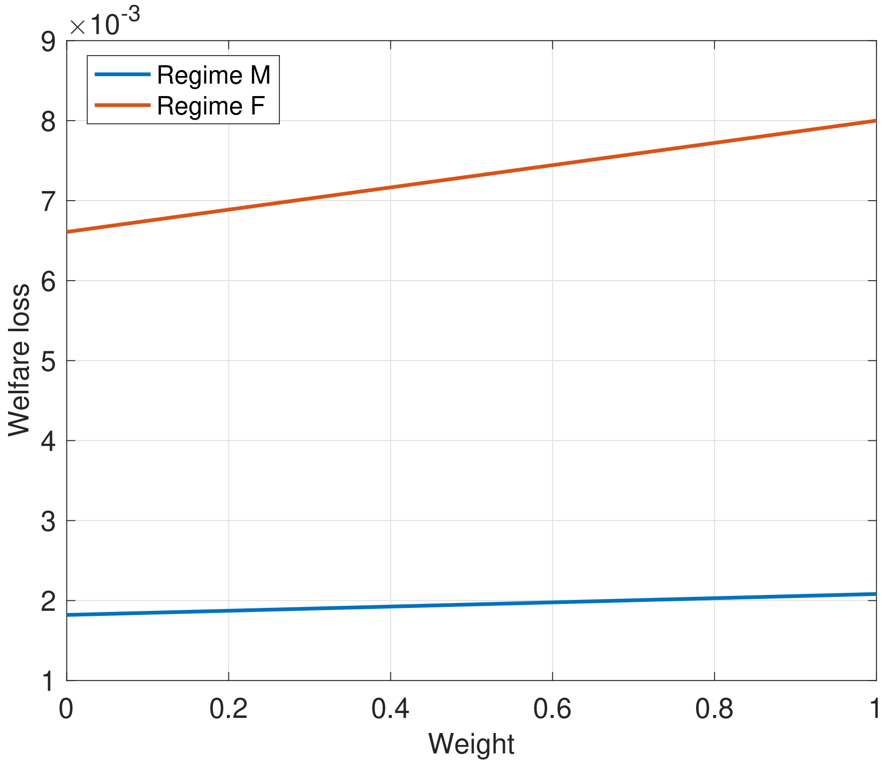

Figure 2.12: Welfare loss for different values of λ

The difference in welfare loss between the two regimes can be explained as follows. In regime M, when unexpected shocks impact the economy, output and inflation rate are directly affected by this event. In response, the central bank aggressively adjusts the interest rate to keep inflation stable at their target rate; hence, we will not see large volatility in the inflation rate in this case. However, this is not the case for regime F. In this alternative regime, fiscal rule follows the AR(1) process, which is independent of debt and price level. In addition, the central bank allows inflation to be volatile together with output in order to leave room for effective fiscal policy. As a result, this action leads to a greater variance in the inflation rate, which in turn creates a much higher welfare loss in regime F.

2.6 Conclusion

Overall, the purpose of this chapter is to use a theoretical framework to analyse the impact of unexpected shocks in each fiscal measure and to investigate how these fiscal components have diverse effects on the economy in all sectors; therefore, we do not use data in this chapter for estimation. However, it does provide the reliability and validity of the conclusions. Firstly, we build a New Keynesian DSGE model with a government intervention bloc in terms of tax and government spending to shed light on how the impacts of fiscal components are transferred to other sectors of the economy. Additionally, we allow for the role of non-Ricardian households in the model to see how they behave differently from the optimising households. Besides, we also discover how effective the fiscal stimulus is in certain policy regimes and analyse the effect of each component on the economy as well as how the monetary policy interacts with fiscal measures in various contexts. Finally, we examine impulse response functions for relevant structural shocks on the behaviour of households and other aspects of the economy, including investment, policy rate, employment and consumption.

Our study reveals that fiscal policy works more effectively in regime M, where the fiscal authority reacts passively to support the central bank's mandate in targeting prices. This is because expansionary fiscal shocks in regime F cause a higher welfare loss to society as shown in section 2.5. These results contradict the finding of Leeper, Traum and Walker (2017) which supports the use of fiscal policy in regime F. However, this is because their paper merely estimates the fiscal multipliers and does not take into account the value of welfare loss caused by the policy shocks in both regimes. Regarding the behaviour of households in regime M, positive fiscal shocks appear to encourage non-Ricardian households to contribute a higher labour supply although the wage rates are reduced accordingly.

This chapter contributes to the existing literature on fiscal policy by introducing separate monetary-fiscal policy mixed regimes in estimating the effect of fiscal measures. Compared to the baseline New Keynesian DSGE models and the remainder of the literature which mostly focus on the effect of monetary policy shocks, our model takes into account various fiscal measures including expansionary expenditure shocks (public consumption, investment and, transfer payment) and tax-cut policies (consumption tax, labour income tax, and capital tax). As a result, the research outcome does not simply estimate the fiscal multiplier and compare it with the effect of monetary policy; alternatively, this chapter decomposes the fiscal policy to investigate which measure provides an optimal solution in the context of a specific monetary-fiscal policy mixed regimes using a loss function. Besides, the result also presents the behaviour of different households' characteristics as a result of an expansionary fiscal plan which is not considered in other papers. For instance, non-Ricardian households are those that do not have access to the financial market; therefore, their only income is from supplying labour and they consume all they have in the same period. As a result, this kind of household is likely to suffer the most when there is an unexpected shock. Consequently, the implemented policies should be carefully considered taking into account the existence of non-Ricardian households and understanding how they behave under the new policies. Particularly, an expansionary shock in most fiscal measures will be worse for these households in regime F as their consumption growth is restricted accordingly.

In general, this research is able to estimate the effectiveness of fiscal policy and the interaction among policies in each regime. By doing this, policymakers can pursue the right regime if they want to have an optimal fiscal plan. Secondly, this study distinguishes the different effects of tax shocks, and spending shocks on the economy. Hence, we have a better understanding of the mechanisms of each type of instrument across sectors. Nevertheless, there are limitations to this study. For instance, this is a closed economy model so we cannot see how changes in fiscal plans affect the foreign sector. Additionally, our research relies on a DSGE approach that assumes constant coefficients which are not affected by shocks. Besides, the parameters are calibrated based on existing literature without utilising Bayesian estimation to perform posterior estimates. Therefore, the research could be improved further in this way to give a better model for explaining the fluctuation of the economy. Finally, we suspect that there might exist an optimal combination of the two regimes to achieve the highest social welfare. Therefore, we will continue the research to solve this problem in the future as a major extension for this chapter.

2.7 Appendix

A. Log-linearisation

The log-linearisation process in this paper will follow a first-order Taylor expansion approximation around the steady-state. Hence, any variable can be interpreted as log deviation from its steady-state value

$$X_t = X(1 + x_t) \tag{2.65}$$

where X is the steady-state value of X_t and x_t is a log-deviation from its steady-state with $x_t = \log X_t - \log X$

Ricardian households' budget constraint

$$\begin{aligned} &PC^o[(1+\tau^c)(p_t + c_t^o) + \tau^c \tilde{\tau}_t^c] + PI[(1+\tau^c)(p_t + i_t) + \tau^c \tilde{\tau}_t^c] + Bb_t \\ =&R^b B(r_{t-1}^b + b_{t-1}) + WN^o[(1-\tau^n)(w_t + n_t^o) - \tau^n \tilde{\tau}_t^n] + RKu[(1-\tau^k)(r_t + k_t + \tilde{u}_t) - \tau^k \tilde{\tau}_t^k] \\ -&(1-\tau^k)PK\delta_1 \tilde{u}_t + \tau^k \delta_0 PK(p_t + k_t + \tilde{\tau}_t^k) + PTr^o(p_t + tr_t^o) \end{aligned} \tag{2.66}$$

The physical capital accumulated

$$k_{t+1} = (1-\delta_0)k_t + \delta_0 i_t \tag{2.67}$$

Ricardian households' consumption

$$c_t^o = hc_{t-1}^o + \frac{1}{\sigma}\left[\tilde{\epsilon}_t^c - p_t - \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}_t^c - \tilde{\lambda}_t^o\right] \tag{2.68}$$

where $\tilde{\lambda}_t^o$ is the Lagrange multiplier for Ricardian households, and $\tilde{\epsilon}_t^c = \rho_{\tilde{\epsilon}^c}\tilde{\epsilon}_{t-1}^c + \upsilon_t^{\tilde{\epsilon}^c}$

Demand for investments

$$\eta\beta(i_{t+1} - i_t) = \tilde{\lambda}_t^o + p_t + \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}_t^c - q_t + \eta(i_t - i_{t-1}) \tag{2.69}$$

Tobin's Q

$$\begin{aligned}\frac{Qq_t}{\beta} &= \lambda^o(1-\tau^k)R\left[\tilde{\lambda}_{t+1}^o + r_{t+1} + u_{t+1} - \left(\frac{\tau^k}{1-\tau^k}\right)\tilde{\tau}_{t+1}^k\right] \\ &- \lambda^o(1-\tau^k)P\delta_1\tilde{u}_{t+1} + \lambda^o P\tau^k\delta_0(\tilde{\lambda}_{t+1}^o + p_{t+1} + \tilde{\tau}_{t+1}^k) + (1-\delta_0)Qq_{t+1}\end{aligned} \tag{2.70}$$

Demand for installed capacity

$$r_t = p_t + \frac{\delta_2\tilde{u}_t}{\delta_1} \tag{2.71}$$

Euler equation (Public bond)

$$r_t^b = \tilde{\lambda}_t^o - \tilde{\lambda}_{t+1}^o \tag{2.72}$$

Budget constraint of Non-Ricardian households

$$\begin{aligned}PC^{nr}[(1+\tau^c)(p_t + c_t^{nr}) + \tau^c\tilde{\tau}_t^c] &= WN^{nr}[(1-\tau^n)(w_t + n_t^{nr}) - \tau^n\tilde{\tau}_t^n] \\ &+ PTr^{nr}(p_t + tr_t^{nr})\end{aligned} \tag{2.73}$$

Demand for consumption of Non-Ricardian households

$$c_t^{nr} = hc_{t-1}^{nr} + \frac{1}{\sigma}\left[w_t - p_t - \varphi n_t^{nr} + \tilde{\epsilon}_t^c - \tilde{\epsilon}_t^n - \left(\frac{\tau^c}{1+\tau^c}\right)\tilde{\tau}_t^c - \left(\frac{\tau^n}{1-\tau^n}\right)\tilde{\tau}_t^n\right] \tag{2.74}$$

where $\tilde{\lambda}_t^{nr}$ is the Lagrange multiplier for Non-Ricardian households

Production function

$$y_t = a_t + \alpha k_t + \alpha u_t + (1-\alpha)n_t + \kappa k_t^g \tag{2.75}$$

$$w_t - r_t = k_t + \tilde{u}_t - n_t \tag{2.76}$$

with $\hat{k}_t = k_t + \tilde{u}_t$.

Log-linearised function of the marginal cost function has the form

$$mc_t = \alpha r_t + (1-\alpha)w_t - a_t - \kappa k_t^g - p_t \tag{2.77}$$

where $a_t = \rho_a a_{t-1} + \epsilon_t^a$.

Taking log-linearisation of government budget constraints, we have

$$Bb_t - R^b B(b_{t-1} + r_{t-1}^b) + Tt_t = PG(g_t + p_t) + PI^g(i_t^g + p_t) + PTR(tr_t + p_t) \tag{2.78}$$

where $T\tilde{t}_t$ is log-linearisation around steady-state for tax revenue

$$\begin{aligned} Tt_t =& \tau^c P[C(p_t + c_t + \tilde{\tau}_t^c) + I(p_t + i_t + \tilde{\tau}_t^c)] + \tau^n WN(w_t + n_t + \tilde{\tau}_t^n) \\ &+ \tau^k RK(r_t + k_t + \tilde{\tau}_t^k) - \tau^k PK\left[\delta_0(p_t + k_t + \tilde{\tau}_t^k) + \delta_1 \tilde{u}_t\right] \end{aligned} \tag{2.79}$$

The law of motion of public capital has the form

$$k_{t+1}^g = (1-\delta_g)k_t^g + \delta_g i_t^g \tag{2.80}$$

In equilibrium, the aggregate demand is equal to the aggregate supply; hence

$$y_t = \psi_C c_t + \psi_I i_t + \psi_{i^g} i_t^g + \psi_G g_t \tag{2.81}$$

where $\psi_C = \frac{C}{Y}, \psi_I = \frac{I}{Y}, \psi_G = \frac{G}{Y}$

B. Other Impulse Response Functions

Regime M

Technology Shock

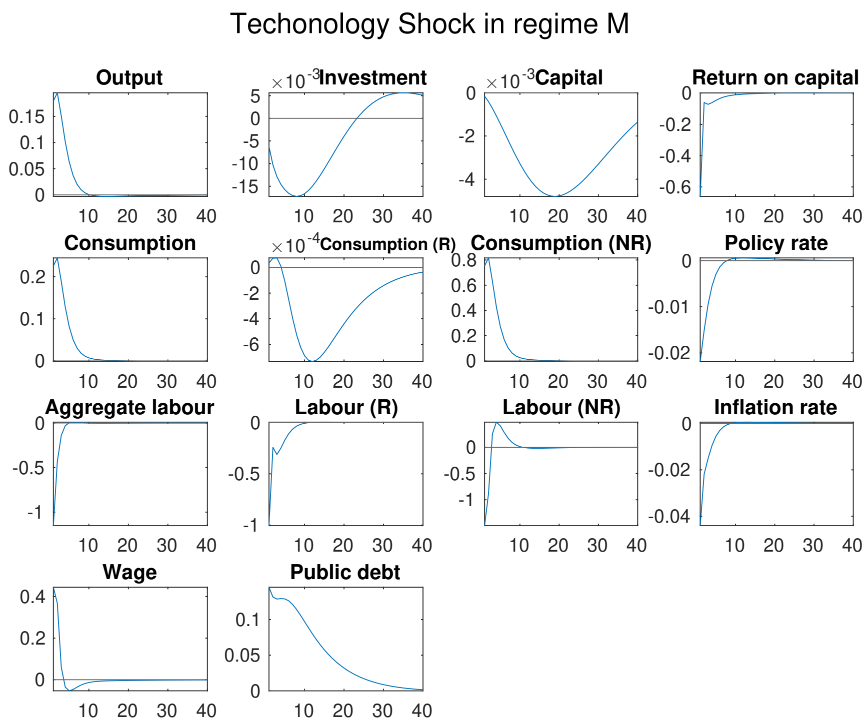

Figure 2.13: The impulse response functions for technology shock in regime M

Figure 2.13 shows the results for the total factor productivity shock via impulse response functions. The temporary shock is represented by a one percent growth in total factor productivity. The impact of this shock on the labour market is straightforward as it raises the marginal productivity of labour and capital; as a result, an increase in productivity leads to an immediate drop in the employment rate because firms require a lower labour force to produce the same amount of goods. As a result, both Ricardian and non-Ricardian households experience a shortfall in labour supply. However, it is shown that non-Ricardians consume more goods and services while Ricardians have a negative shock in their consumption following a slight increase at the beginning of the technology shock. Overall, aggregate consumption is positive as a result of an increase in non-Ricardian consumption. In effect, this is one of the reasons that push GDP growth in this model. Regarding the financial market, technology shocks cause the policy rate to fall following a decrease in inflation. Besides, a reduction in return on capital due to the shock can be responsible for the fluctuation in capital and investment demand. Compared to the basic New Keynesian model in Galí (2015), the transmission mechanism of this shock is quite the same; however, in our case, the effects of technology shock on output, inflation and policy rate are short-lived. Furthermore, being consistent with Galí and Rabanal (2004), we find that a positive shock in technology results in an immediate drop in labour as a consequence of habit formation, nominal price rigidities, and investment adjustment costs.

Preference Shock

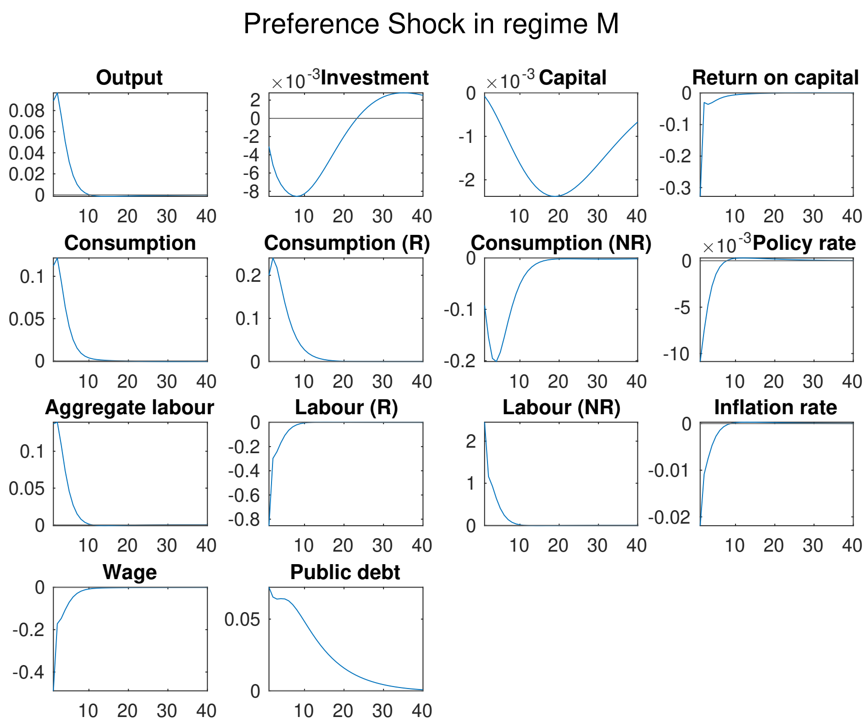

Figure 2.14: The impulse response functions for preference shock in regime M

The effect of preference shock in this model is quite the same as the impact of technology shock (figure 2.14). For instance, there is a growth in aggregate demand after one quarter; additionally, investment and capital are hump-shaped and diminish gradually over time. Furthermore, return on capital, inflation, and policy rate are negatively affected by the shock. These variables are influenced in the same way they are affected by technology shocks, but the magnitude caused by this shock is much smaller. As far as households' behaviour is concerned, we acknowledge that with preference shock, Ricardians tend to consume more goods and services while spending fewer hours working; accordingly, this shortfall in their labour supply can be explained by a decrease in their wage rate. In other words, this creates a substitution effect as Ricardians prefer to consume more when they have less income. On the other hand, a shock in preference makes non-Ricardian households prefer to consume below their steady-state level and supply more hours worked. Overall, it can be seen that aggregate consumption and labour are positively generated by this event.

Regime F

Technology Shock

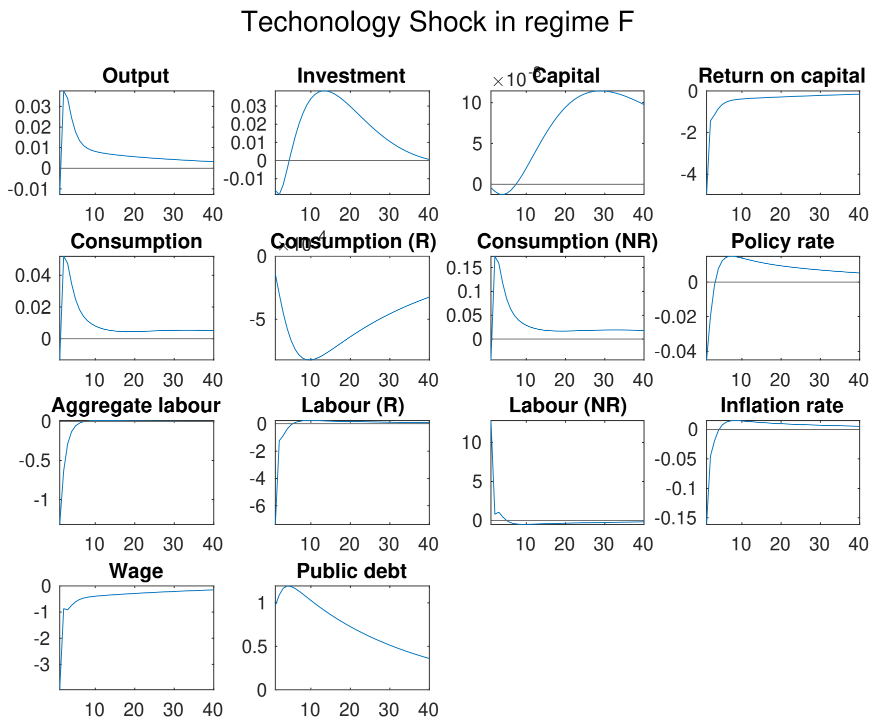

Figure 2.15: The impulse response functions for technology shock in regime F

In this case, we analyse the shock in total factor productivity in figure 2.15. Accordingly, the effect of this shock on the goods market is consistent with the one in regime M in the way that it raises the growth rate of output and consumption above the steady-state level; moreover, it also brings about a deterioration in inflation and interest rate. However, what makes it different is that in this regime, technology shock accelerates private investment and stimulates capital accumulation, although the return on capital still stays negative in this case. In addition, the public debt caused by productivity shock in this regime rises significantly and takes more time to diminish to its steady state compared to regime M. In light of the labour market, the aggregate labour supply and nominal wage rate are negatively impacted by this shock. If we take into account the behaviour of separated households, it is noticed that only non-Ricardian households witness an increase in their consumption, which can be explained by an increase in labour supply. In contrast, this is not the case for Ricardian households whose consumption growth rate and labour supply are both negative after the shock.

Preference Shock

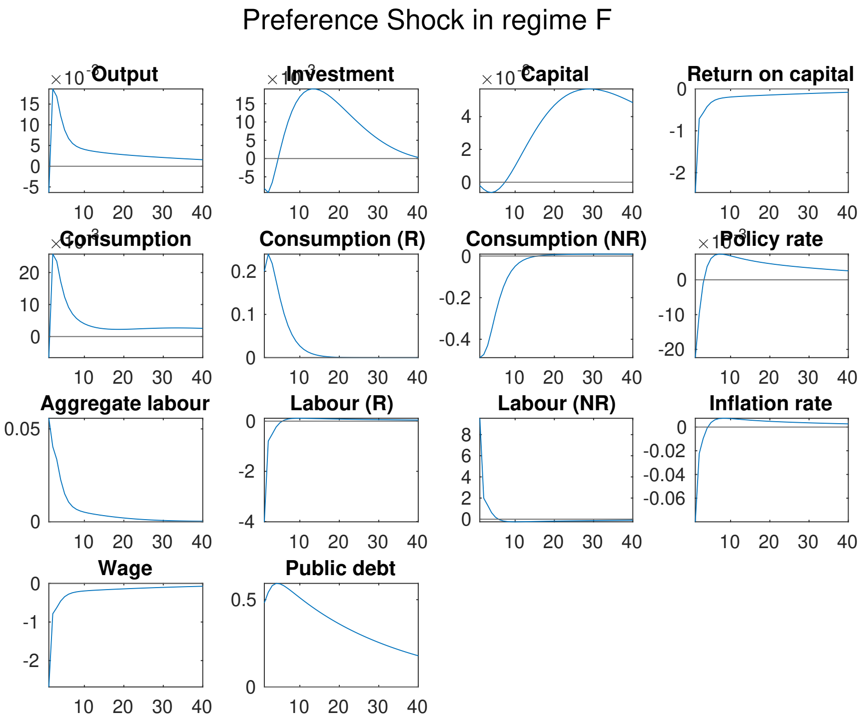

Figure 2.16: The impulse response functions for preference shock in regime F

Figure 2.16 shows the results of preference shock having effects on the economy. Firstly, the shock stimulates the growth rate of private investment and aggregate consumption, which in turn raises the growth rate of GDP. Besides, private capital accumulation grows over time with a hump-shaped pattern. In addition, it is noticed that the impulse response functions for preference shock in regime M and regime F are quite similar. For instance, Ricardians reduce their hours worked while increasing the rate of consumption together with a fall in wage level due to a substitution effect. Similarly, a shock in preference causes the consumption rate of non-Ricardians drops below the steady-state level, knowing that their labour supply accelerates after the shock. Despite the similarity, we should emphasise that in most cases, the effect of preference shock in regime F is more extreme compared to the one in regime M.

Chapter 3

The Economy of the United Kingdom in Pandemic

Abstract

The COVID-19 pandemic has been challenging the global public health system and the world economy since its first outbreak in 2019. As a result, many governments are forced to make a trade-off between health and recessionary effects. For instance, there are policies that are implemented by the government in the hope of alleviating the pressure on the public health system and easing the economic impact caused by the pandemic on households and businesses. This chapter investigates the impact of these policies in the United Kingdom from a macro-dynamic perspective. In this case, we build a Dynamic Stochastic General Equilibrium Model for a Small Open Economy to estimate the shocks at the beginning of the pandemic and analyse their contagion within the economy. Our study reveals that supply shock constituted by technology shock and price mark-up shock is the main factor causing the output to

drop during the pandemic while the impact of demand shock is not trivial in this case. Additionally, a combination of these shocks leads to a significant decrease in the growth rate of output, consumption, investment, and working hours. Besides, it is shown that the lockdown policy is carried out at the cost of a fall in the growth rate of output, consumption, and a rise in the unemployment rate; on the other hand, with the help of the Coronavirus Job Retention Scheme (CJRS), the economic impact in terms of consumption, and the unemployment rate is alleviated.

Keywords: Bayesian estimation, DSGE model, the lockdown policy, the Coronavirus Job Retention Scheme (CJRS).

3.1 Introduction

The COVID-19 pandemic first appeared in late 2019 and it has caused a significant impact globally in many ways. On the one hand, the epidemic causes considerable human losses and overloads the Public Health systems. On the other hand, it leads to disruption to the economy as production productivity and efficiency are negatively affected. According to Boone et al. (2020), the virus is affecting economies via several direct channels such as quarantines, travel restrictions, closures of factories, and a fall in service sector activities. As a result, policymakers face a trade-off between preventing deaths from the virus and an economic downturn. In general, it is obvious that the impact of COVID-19 on the economy is significant; however, we need to estimate the shock empirically in this pandemic and understand how it is transmitted within our economy.

There is a rapidly growing number of papers working on the topics of epidemiology and economics. One approach is to extend the susceptible-infected-recovered (SIR) model (Atkeson, 2020) or Susceptible-Exposed-Infectious-Recovered (SEIR) model (Berger, Herkenhoff and Mongey, 2020) to include features of the macroeconomics. For instance, Eichenbaum, Rebelo and Trabandt (2020) combine the SIR model and New-Keynesian model to analyse the effects of an epidemic from a macroeconomics perspective. They show that the monopolistic competition feature in a model rationalises the positive co-movement of consumption and investment caused by recessions associated with an epidemic. Furthermore, it is illustrated that nominal price rigidity exacerbates the impact of this recession. Additionally, Krueger, Uhlig and Xie (2022) apply the same approach as Eichenbaum, Rebelo and Trabandt (2020); however, in their study, they assume heterogeneous sectors in the economy and follow the Swedish solution by allowing no Government intervention in the model.

From another perspective, Fornaro and Wolf (2020) use a New-Keynesian framework to show that the outbreak of the virus generates stagnation traps caused by pessimistic productivity growth. Another approach is to estimate economic responses after the shocks caused by the pandemic. Particularly, different forms of fiscal policy are studied by Faria-e Castro (2021) using a calibrated DSGE New Keynesian model; this model is developed based on Faria-e Castro (2018) and represents the pandemic as a large negative shock to the propensity to consume. The authors include incomplete market features with financial friction among savers and borrowers and conclude that unemployment benefits are the most effective tool to stabilize income for borrowers while savers prefer liquidity assistance programs. Additionally, Guerrieri et al. (2022) show that supply shocks from the pandemic can generate aggregate effects that are similar to aggregate demand shocks in an economy with multiple-sector, incomplete markets under certain conditions.

Based on the existing literature, we acknowledge the necessity to estimate the impact of shocks in the pandemic on the economy as well as to understand how they are transmitted to economic variables. Furthermore, it is vital to take into account the intervention of the government in tackling pandemics and easing the economic impact on our society. One policy to consider is the Coronavirus Job Retention Scheme (CJRS) which was introduced by the UK government at the end of March 2020. Under this scheme, furloughed workers, those who remain employed by the firms but are not actually working, will receive 80% of their salaries from the government. The main purpose of this programme is to encourage firms to retain their staff during the lockdown in order to retain a connection between employers and their staff. As a result, it is easier for people to get back to work when restrictions are lifted, allowing for a stronger recovery in the future.

Therefore, we contribute to the growing literature by estimating the supply shock and demand shock at the beginning of the pandemic in the United Kingdom (UK).

There are several reasons for choosing the UK. Firstly, the UK's economy has been hit really hard by the pandemic since the first appearance of COVID-19 in January 2020. Especially, the service sector, including travel and hospitality, is put in severe difficulties. This is because the UK government implements policies to impede the spread of the virus in the country, such as social distancing, quarantines, and restrictions on travel. According to Sumit Dey-Chowdhury and Walton (2021), the UK economy has suffered the greatest decline in volume GDP amongst the G7 countries. Therefore, studying the impact of pandemic shock in this country is very crucial for understanding as well as tackling the negative economic outcome caused by COVID-19. Besides, the UK government also implements policies to ease the economic impact on households and businesses, such as the furlough scheme that is implemented to help affected workers and share costs with employers. It is believed to be the most radical economic policy implemented by the UK government in response to the coronavirus. Furthermore, the UK's scheme is among the most generous in value which pays 80% of an employee's wage for hours not worked compared to France (70%), Germany (60%), and Canada (55%), and its support is among the last to phase out (Pope and Shearer, 2021). Therefore, our research questions in this chapter are: What are the estimates of shocks in the pandemic in the UK? How are these shocks transmitted to endogenous variables? And do government interventions worse off or better off economically? In order to answer these questions, we estimate a Dynamic Stochastic General Equilibrium (DSGE) model for a small open economy country (SOE) using the Bayesian method. In this model, we assume the pandemic impacts our economy via several exogenous processes and extend the model of Christiano, Eichenbaum and Trabandt (2015) to include the extensive margins of labour supply. Besides, this study proposes a model that also incorporates UK policies to estimate the effect of the shocks at the beginning of the pandemic on the UK economy, as well as investigate the impact of government policies including the lockdown policy and the furlough scheme programme.

Our estimates show that autoregressive parameters are relatively persistent over time and that the volatility of technology shock, and price mark-up shock appear to be highly volatile. More importantly, we illustrate that technology shock and price mark-up shock are the main sources that cause high volatility in the level of output when the pandemic first starts, while the contribution of preferences shock is relatively small accordingly. These shocks lead to a downfall in the growth rate of output, consumption, and investment; furthermore, it is shown that the corresponding working hours also drop significantly in the quarter following the shock. Regarding the government intervention in tackling COVID-19, the lockdown policy is implemented at the cost of a fall in the growth rate of output, consumption, and a rise in the unemployment rate; on the other hand, with the introduction of the furlough scheme, the economic impact on consumption, and the unemployment rate is alleviated.

The remainder of this chapter is organised as follows. Firstly, we build a DSGE model with extensive margins of labour supply together with exogenous shocks including supply shock, demand shock, and other shocks that are triggered by government policies in section 3.2. Next, we set some fixed parameters and estimate structural parameters together with exogenous shocks in section 3.3; in this part, we also analyse variance decomposition and impulse response functions of the related shocks. Finally, we come up with a conclusion in the last section.

3.2 The Model

The model features both goods and the labour market as they are greatly affected by the pandemic. This is because when the pandemic starts, both supply shocks and demand shocks hit the economy. In the goods market, we estimate the preferences shock, which is also known as demand shock, given that there are two kinds of consumption which are domestic consumption and consumption of imported goods. For the labour market, we take into account the fact that in the UK, many employees are made idle as some services and sectors are forced to close during the pandemic; the implementation of the furlough scheme means that these idle employees are kept employed while receiving 80% of their wage from government. In this case, this model exploits an extensive margin of labour supply as in Blanchard and Galí (2010) to examine this policy of the government. As a result, instead of separating the labour market into two different types of households as in the previous chapter, we try to focus on the separation of the labour market based on the working status (working or being idle) of each individual labour.

3.2.1 The labour market

At period t, we assume that a fraction of the labour force is unemployed which is available to hire, denoted by U_t. This can be given by the rate of people that are unemployed in the previous period $t-1$, plus those who just lost their job at the end of this period. Therefore, it evolves as a function of the employment rate in the previous period N_{t-1}. Accordingly,

$$U_t = 1 - N_{t-1} + sN_{t-1} = 1 - (1-s)N_{t-1} \tag{3.1}$$

where $s \in (0, 1)$ is an exogenous separation rate.

The employment can be described as below:

$$N_t = (1-s)N_{t-1} + L_t \tag{3.2}$$

In this case, L_t represents the estimate of newly hired labour in period t. According to this equation, workers who lose a job at time $t-1$ can look for a job at the beginning of time t. Besides, during the pandemic, only a fraction of employed people work while the others are made idle and do not involve in production.

$$N_t = \omega_t^n N_t + (1-\omega_t^n)N_t = N_t^w + N_t^f \tag{3.3}$$

where N_t^w is the working labour during the pandemic, and N_t^f is the employed workers that stay at home. Additionally, ω_t^n is the proportion of working labour at time t that follows a stochastic shock; it has the value $\omega_t^n = 1$ in normal time.

The number of newly hired labour follows the standard matching function

$$L_t = mU_t^{\mu}V_t^{1-\mu} \tag{3.4}$$

In this equation, V_t denotes aggregate vacancies, $m > 0$ captures matching efficiency, and $0 < \mu < 1$ shows the elasticity of the matching function with respect to unemployment.

Hiring an additional employee in a differentiated sector is given by $\Gamma_t L_t$, where Γ_t denotes the cost per labour hired. It is an increasing function of labour market tightness

$$\Gamma_t = \chi A_t x_t^{\iota} \tag{3.5}$$

where x_t is an index of labour market tightness, which is derived as the ratio of hiring rate to unemployment, $x_t = \frac{L_t}{U_t}$, $\chi > 0$ is a scaling factor and $\iota \geq 0$ is the elasticity of hiring costs with respect to vacancies.

3.2.2 The goods market

Households

In this section, we study the optimisation problem of households in the economy. It is worth mentioning that we only have one type of household in this chapter which is different from the previous chapter's approach that separates the households into Ricardian and non-Ricardian. This is because we simplify this model to understand the behaviour of the individuals given the implementation of the furlough scheme. Accordingly, the representative households maximise their lifetime utility:

$$U = \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\xi_t^p (C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \frac{H_t^{1+\varphi}}{1+\varphi} \right\} \tag{3.6}$$

where C_t is the utility from consumption, and h is the parameter measuring habit formation of consumption. The second term shows the disutility of supplying labours H_t in terms of hours worked. In this function, σ denotes the elasticity of substitution intertemporally while φ shows the elasticity of hours worked, and β is the parameter that represents the discount factor. Finally, ξ_t^p is the preferences shock that affects the demand for consumption of agents. The problem of this household is to maximise its utility subject to budget constraint

$$\begin{aligned} \upsilon_t C_t P_t + P_t^B B_t + P_t^{B^*} S_t B_t^* + I_t P_t^i + T_t = B_{t-1} + S_t B_{t-1}^* + W_t N_t^w H_t + W_t^g N_t^f H_t \\ + (1 - N_t) b + \widehat{R}_t^k K_t + J_t \end{aligned} \tag{3.7}$$

In each period, households buy an amount of domestic B_t and foreign bonds B_t^* at nominal price P_t^B and $P_t^{B^*}$, respectively, given the nominal exchange rate S_t. Furthermore, υ is the exogenous shock when the government enforces a lockdown policy which aims to stop the spread of the virus by reducing the consumption activity of agents. Additionally, P_t is the CPI index that includes an imported component. Besides, these households invest an amount of I_t at price P_t^i and receive a return $\widehat{R}_t^k$ on their capital K_t. In addition, W_t is the wage from providing labour supply for working employees N_t^w as they receive the full payment due to their working status. It is worth noting that during the pandemic, the government agrees to implement the job retention scheme that pays up to 80% of the wage rate to idle employees; therefore, W_t^g can be understood as a proportion of the full wage rate of W_t, which can be described as $W_t^g = \omega^w W_t$, where ω^w is the wage rate paid by the UK government. If there is no furlough scheme, agents face a standard constraint that gives income $W_t N_t H_t$ to all employees regardless of their working status; in this case, this cost is totally borne by their employers.

Unemployed people will receive a constant value of benefit b from the Government. Finally, households receive a profit of J_t from the firm and pay a lump-sum tax of T_t to the government.

The first-order conditions with respect to consumption, and bonds holding are:

$$\xi_t^p (C_t - hC_{t-1})^{-\sigma} = \lambda_t^b P_t \upsilon_t \tag{3.8}$$

$$P_t^B = \beta E_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}} \right] \tag{3.9}$$

$$P_t^{B^*} = \beta E_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}} \frac{S_{t+1}}{S_t} \right] \tag{3.10}$$

where $\Lambda_{t+1} \equiv \frac{\lambda_{t+1}^b}{\lambda_t^b}$.

Nominal return on domestic bond holdings is given by $R_t^b = \frac{1}{P_t^B}$. In the case of foreign bonds, they are assumed to depend on a risk premium that takes into account the exposure to foreign debt

$$R_t^{b^*} = \frac{1}{P_t^* \psi\left(\frac{S_t B_t^*}{P_t^H Y_t}\right)} \tag{3.11}$$

where $\psi(x)$ is a functional form which can be shown as follow

$$\psi(x) = \exp(-\psi_B x); \psi_B > 0 \tag{3.12}$$

Accordingly, we can re-write and combine equations (3.9), and (3.10) to give an uncovered interest parity condition (UIP)

$$R_t^b = R_t^{b^*} \psi\left(\frac{S_t B_t^*}{P_t^H Y_t}\right) \pi_{t+1}^s \tag{3.13}$$

where $\pi_{t+1}^s \equiv \frac{S_{t+1}}{S_t}$ is the depreciation rate of home currency.

Consumption Demand

Consumption C_t is a Dixit-Stiglitz aggregator of a bundle of differentiated goods which includes domestic consumption C_t^h and consumption of imported goods C_t^f. Therefore, households demand consumption goods to maximise:

$$C_t = \left[(\omega_c^h)^{\frac{1}{\nu_c}} {C_t^h}^{\frac{\nu_c - 1}{\nu_c}} + (1-\omega_c^h)^{\frac{1}{\nu_c}} {C_t^f}^{\frac{\nu_c - 1}{\nu_c}}\right]^{\frac{\nu_c}{\nu_c - 1}} \tag{3.14}$$

The price index P_t is given by the equation

$$P_t = \left[\omega_c^h {P_t^h}^{1-\nu_c} + (1-\omega_c^h) {P_t^f}^{1-\nu_c}\right]^{\frac{1}{1-\nu_c}} \tag{3.15}$$

where ω_c^h represents the weight of domestic produced goods' consumption. Maximising total consumption in (3.14) subject to the aggregate expenditure $P_tC_t = P_t^hC_t^h + P_t^fC_t^f$ yields

$$C_t^h = \omega_c^h \left(\frac{P_t^h}{P_t}\right)^{-\nu_c} C_t \tag{3.16}$$

$$C_t^f = (1-\omega_c^h) \left(\frac{P_t^f}{P_t}\right)^{-\nu_c} C_t \tag{3.17}$$

In this case, agents need to choose between two kinds of consumption with $\nu_c > 1$ determining the elasticity of substitution. (Kaplan, Moll and Violante, 2020).

Investment Demand

Let P_t^i denote the aggregate price for the investment. Households choose to invest in the domestic market and abroad to maximise

$$I_t = \left[(\omega_i^h)^{\frac{1}{\nu_i}} I_t^{h\frac{\nu_i-1}{\nu_i}} + (1-\omega_i^h)^{\frac{1}{\nu_i}} I_t^{f\frac{\nu_i-1}{\nu_i}}\right]^{\frac{\nu_i}{\nu_i-1}} \tag{3.18}$$

The price index P_t^i is given by the equation

$$P_t^i = \left[\omega_i^h P_t^{h1-\nu_i} + (1-\omega_i^h) P_t^{f1-\nu_i}\right]^{\frac{1}{1-\nu_i}} \tag{3.19}$$

Maximising total investment in (3.18) subject to the aggregate expenditure $P_t^iI_t = P_t^hI_t^h + P_t^fI_t^f$ yields

$$I_t^h = \omega_i^h \left(\frac{P_t^h}{P_t^i}\right)^{-\nu_i} I_t \tag{3.20}$$

$$I_t^f = (1 - \omega_i^h)\left(\frac{P_t^f}{P_t^i}\right)^{-\nu_i} I_t \tag{3.21}$$

Firms

Wholesaler

The economy consists of a continuum of firms indexed by $i \in [0;1]$ which exploits labour and technology to produce a differentiated good. Each intermediate good i is produced by a monopolistically competitive producer following the Cobb-Douglas production function:

$$Y_t(i) = A_t K_t^{1-\alpha}(N_t^w(i)H_t(i))^{\alpha} \tag{3.22}$$

where A_t represents a level of total factor productivity (TFP) which follows $AR(1)$ process in log values with normal i.i.d shock, K_t denotes capital stock, α is the share of labour participating in the production, and $Y_t(i)$ is the differentiated output i produced by firm i at time t. Besides, as only active workers actually contribute to the production activity, the variable N_t^w instead of N_t enters the production function.

Given these constraints, firms will maximise their profit knowing that they only have to pay active workers.

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k} \left\{ Y_{t+k}(i) P_{t+k}(i) - R_t^k K_t - W_t N_t^w(i) H_t(i) - \Gamma_{t+k} L_{t+k} \right\} \tag{3.23}$$

The first order conditions with respect to K_t, and N_t^w are

$$R_t^k = (1-\alpha) MC_t \frac{Y_t(i)}{K_t} \tag{3.24}$$

$$W_t H_t(i) + \Gamma_t = \alpha MC_t \frac{Y_t(i)}{N_t^w(i)} + \beta(1-s) E_t \Lambda_{t+k} \Gamma_{t+1} \tag{3.25}$$

where MC_t is the nominal marginal cost. In the last equation, the left-hand side gives the cost of hiring one additional worker which includes the hourly wage payment and hiring cost per worker. On the other hand, the right-hand side is the productivity gain from additional workers plus the expected hiring cost in the future.

On the other hand, in case there is no support from the government, firms will maximise their profit knowing that they have to pay all of their existing employees, even if they are idle. Therefore,

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k} \left\{ Y_{t+k}(i) P_{t+k}(i) - R_t^k K_t - W_t N_t(i) H_t(i) - \Gamma_{t+k} L_{t+k} \right\} \tag{3.26}$$

The first order conditions with respect to N_t^w now becomes

$$\frac{W_t H_t(i)}{\omega_t^n} + \Gamma_t = \alpha MC_t \frac{Y_t(i)}{N_t^w(i)} + \beta(1-s) E_t \Lambda_{t+k} \Gamma_{t+1} \tag{3.27}$$

Capital Producers

In order to produce capital, firms purchase investment goods domestically as well as import them from foreign retail firms at real price $\frac{P_t^i}{P_t}$, and then they sell these produced capitals at real price Q_t to maximise profits

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k} \left[Q_{t+k} \left(1 - \mathcal{S}(I_{t+k})\right) I_{t+k} - \frac{P_t^i}{P_t} I_{t+k} \right] \tag{3.28}$$

where $\mathcal{S}(I_t)$ is a function of investment adjustment cost, which can be shown as

$$\mathcal{S}(I_t) \equiv \frac{\eta}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \tag{3.29}$$

where η measures the intensity of investment adjustment cost.

The capital is accumulated with the following law of motion

$$K_{t+1} = (1-\delta)K_t + (1 - \mathcal{S}(I_t))I_t \tag{3.30}$$

where δ is the depreciation rate of capital.

Given the capital's law of motion and demand for investment in equation (3.18), the first-order condition can be derived as follow

$$\frac{P_t^i}{P_t} = Q_t(1 - \mathcal{S}(I_t) - \frac{I_t}{I_{t-1}} \mathcal{S}'(I_t)) + E_t \left[\Lambda_{t+1} Q_{t+1} \mathcal{S}'(I_{t+1}) \frac{I_{t+1}^2}{I_t^2} \right] \tag{3.31}$$

We then define gross real return on capital as $\widehat{R}_t^k$, which is given by

$$\widehat{R}_t^k = \frac{(1-\alpha)\frac{Y_t(i)P_t(i)}{K_t P_t} + (1-\delta)Q_t}{Q_{t-1}} \tag{3.32}$$

Finally, we assume efficient financial intermediation within the home country that implies zero arbitrage condition in the market, giving Q_t the steady-state value of 1.

$$E_t\left[\Lambda_{t+1}\widehat{R}^k_{t+1}\right] = E_t\left[\frac{\Lambda_{t+1}}{\pi_{t+1}}\right]R^b_t = 1 \tag{3.33}$$

Wage Bargaining

Before deriving the wage rate for employees, we first define the marginal value of being employed and unemployed. Hence, the value of employment at firm i is given by

$$\begin{aligned} W^e_t(i) = W_t(i)H_t(i) - \frac{H_t^{1+\varphi}(i)}{1+\varphi} &+ \beta_t E_t\left\{\Lambda_{t+1}\left[s\left(x_{t+1}W^e_{t+1} + (1-x_{t+1})W^u_{t+1}\right)\right]\right\} \\ &+ \beta_t E_t\left\{\Lambda_{t+1}\left[(1-s)W^e_{t+1}(i)\right]\right\} \end{aligned} \tag{3.34}$$

where $W^e_t = \int_0^1 W^e_t(i)di$ is the expected value of a match. This equation includes main terms which state that the marginal value of a job for a worker is given by the real wage bill $W_t(i)$ from providing $H_t(i)$ hours of the working net of the disutility of labour supply plus the expected discount value from being either employed or unemployed in the following period.

The value of being unemployed after hiring has taken place is given by

$$W^u_t = b + \beta_t E_t\left\{\Lambda_{t+1}\left[\left(x_{t+1}W^e_{t+1} + (1-x_{t+1})W^u_{t+1}\right)\right]\right\} \tag{3.35}$$

which shows that the marginal value of unemployment equals the unemployment benefit and the expected discounted value of being either employed or unemployed in the next period.

The wage is chosen in a way that maximises the Nash bargain where the cost per labour hired equals the difference in the value of employment and the value of being unemployed, given the bargaining power of the worker; therefore, this sharing rule is derived as follow:

$$\zeta \Gamma_t = (1 - \zeta)(W_t^e(i) - W_t^u) \tag{3.36}$$

where ζ denotes the bargaining power of the worker. By substituting the value of $W_t^e(i)$ in 3.34 and W_t^u in 3.35 into equation 3.36, the wage set by firm i is given as

$$W_t(i) = \frac{b + \frac{H_t^{1+\varphi}(i)}{1+\varphi} + \frac{\zeta}{1-\zeta}\Gamma_t - \frac{\zeta}{1-\zeta}\beta E_t \left\{\Lambda_{t+1}(1-s)(1-x_{t+1})\Gamma_{t+1}\right\}}{H_t(i)} \tag{3.37}$$

Hours Bargaining

We assume that workers bargain their working hours and wages at the same time and that bargaining on hours is efficient. Hence, hours satisfy the Nash bargaining criterion:

$$H_t(i) = \arg\max \left(W_t(i)\right)^{\zeta} {\Gamma_t}^{1-\zeta} \tag{3.38}$$

Using the sharing rule in equation (3.36), we have the first-order condition as follows

$$H_t^{\varphi}(i) = MC_t A_t \alpha^2 N_t^{\alpha-1}(i) H_t^{\alpha-1}(i) K_t^{1-\alpha} \tag{3.39}$$

Final Goods

In each sector, there is a continuum of differentiated intermediate goods i with $i \in [0;1]$. The production function of this type of firm follows the CES form:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \tag{3.40}$$

where $Y_t(i)$ denotes the quantity of the differentiated intermediate good i across sectors, and $\epsilon > 0$ denotes the elasticity of substitution between products. These firms confront profit maximisation by optimising the amount of each intermediate goods produced.

The profit maximisation of the final goods firms takes the form

$$\max_{Y_t(i)} P_t^h Y_t - \int_0^1 P_t^h(i) Y_t(i) di \tag{3.41}$$

Taking F.O.C with respect to $Y_t(i)$, we have

$$P_t^h \left(\frac{Y_t}{Y_t(i)} \right)^{\frac{1}{\epsilon}} - P_t^h(i) = 0 \tag{3.42}$$

Thus, the demand for intermediate goods is

$$Y_t(i) = Y_t \left(\frac{P_t^h(i)}{P_t^h} \right)^{-\epsilon} \tag{3.43}$$

where $P_t^h = \left[\int_0^1 P_t^h(i)^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$ is price index.

Aggregate Price Level

Firms producing intermediary goods can maximise profit by determining the optimal price following the Calvo rule. In each period, a fraction $(1-\theta)$ of producers resets their prices $P_t^{h^o}$ while the rest of the firms keep their prices unchanged. In this context, θ can be regarded as a natural index of price stickiness. As a result, the aggregate price can be indicated as follows

$$P_t^h = \left[\theta(P_{t-1}^h)^{1-\epsilon} + (1-\theta)(P_t^{h^o})^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{3.44}$$

Optimal Price Setting

As far as the optimal price-setting behaviour is concerned, a re-optimising firm will choose the price $P_t^{h^o}$ that maximises the current market value of the profits generated while that price remains effective. Thus, the representative firm's profit maximisation problem is given by

$$\max_{P_t^{h^o}} E_t \sum_{k=0}^{\infty}(\beta\theta)^k \Lambda_{t+k}[P_t^{h^o} Y_{t+k}(i) - TC_{t+k}(Y_{t+k}(i))\xi_{t+k}^m] \tag{3.45}$$

subject to demand constraint

$$Y_{t+k}(i) = \left(\frac{P_t^{h^o}}{P_{t+k}^h}\right)^{-\epsilon} Y_{t+k} \tag{3.46}$$

where $TC_t(\cdot)$ is the function of firm's total cost and $Y_{t+k|t}$ denotes output in period $t+k$ for a firm that last resets its price in period t, and price mark-up shock ξ_t^m. Taking F.O.C with respect to $P_t^{h^o}$, we have

$$E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} Y_{t+k}(i) \left(P_t^{h^o} {P_{t+k}^h}^{\epsilon-1} - \frac{\epsilon}{\epsilon-1} mc_{t+k} \xi_{t+k}^m {P_{t+k}^h}^{\epsilon} \right) = 0 \tag{3.47}$$

where mc_t is the real marginal cost.

Thus, the optimisation yields the following price-setting rule

$$P_t^{h^o} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {P_{t+k}^h}^{\epsilon} Y_{t+k} mc_{t+k} \xi_{t+k}^m}{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {P_{t+k}^h}^{\epsilon-1} Y_{t+k}} \tag{3.48}$$

By defining $\pi_{t+k}^h \equiv \frac{P_{t+k}^h}{P_t^h}$ as home inflation, we can re-write previous equation as

$$\frac{P_t^{h^o}}{P_t} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {\pi_{t+k}^h}^{\epsilon} Y_{t+k} mc_{t+k} \xi_{t+k}^m}{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {\pi_{t+k}^h}^{\epsilon-1} Y_{t+k}} \tag{3.49}$$

By including the price mark-up shock in the Phillips curve, we capture any changes in inflation that are caused by any disturbance other than productivity, real wages, and the cost of capital. For example, the rise in the cost of wages and raw materials increases the cost of production; hence, they could be factors leading to inflation. Previously, inflation is set based on future expectations and the output gap with no error term. This is the case that Blanchard and Galí (2007) called the "divine coincidence" where stabilising inflation will also lead to the stabilisation of output at its natural level. As a result, the mark-up shock is included to get rid of this problem. Particularly, inflation would be derived as a function of expected inflation, the output gap, and the mark-up shock (Steinsson, 2003). Consequently, the central bank faces a trade-off between stabilising inflation and output in this situation. A good example of the price mark-up shock could be linked to The Organisation of the Petroleum Exporting Countries (OPEC); this organisation is an oil cartel that can exercise monopoly power over controlling oil production level which leads to shocks in oil prices and cost of production.

3.2.3 Foreign market

We assume that the UK has the features of a small open economy. In this case, it takes foreign consumption C_t^* and investment I_t^* as given; accordingly, these variables follow exogenous processes. Let RER_t denote the real exchange rate of the Pound against the foreign currency; it is defined as $RER_t \equiv \frac{P_t^* S_t}{P_t}$. As a result, the foreign country faces the same problem as the home country in demanding exported goods. The demand for the export of home goods is therefore defined by this equation

$$C_t^{h^*} = (1 - \omega_c^{h^*}) \left(\frac{P_t^{h^*}}{P_t^*} \right)^{-\nu_c^*} C_t^* \tag{3.50}$$

By substituting S_t and P_t^* into this equation, we have

$$C_t^{h^*} = (1 - \omega_c^{h^*}) \left(\frac{P_t^h}{P_t RER_t} \right)^{-\nu_c^*} C_t^* \tag{3.51}$$

Besides, as the home country is small, and the law of one price implies $P_t^* = P_t^{f^*}$, we have $S_t P_t^* = P_t^f$; therefore, the real exchange rate can be derived as $RER_t = \frac{P_t^f}{P_t}$. Defining terms of trade as a ratio of the price of imported goods in the home country to that of domestic goods, $\mathcal{T}_t \equiv \frac{P_t^f}{P_t^h}$; consequently, equation (3.51) becomes

$$C_t^{h^*} = (1 - \omega_c^{h^*}) \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_c^*} C_t^* \tag{3.52}$$

This condition also holds for foreign investment demand; therefore, we have

$$I_t^{h^*} = (1 - \omega_i^{h^*}) \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_i^*} I_t^* \tag{3.53}$$

The aggregate export of the UK is determined by foreign demand for consumption and investment in the home country's export

$$X_t = C_t^{h^*} + I_t^{h^*} \tag{3.54}$$

Given the small size of the home country's economy relative to the rest of the world, the export demand for consumption and investment are directly proportional to the aggregate consumption and investment of foreign countries; hence, we have

$$C_t^{h^*} \propto \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_c^*} C_t^* \tag{3.55}$$

$$I_t^{h^*} \propto \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_i^*} I_t^* \tag{3.56}$$

As a result, we can derive the deviation of export demand from its steady-state as below

$$\frac{X_t}{X} = x_c \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_c^*} \frac{C_t^*}{C^*} + x_i \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_i^*} \frac{I_t^*}{I^*} \tag{3.57}$$

where x_c and x_i are export shares of consumption, and investment, respectively.

3.2.4 Government

Fiscal Policy

The government will generate income from taxes collected from households and issue new public debt through government bonds to fund its expenditures and finance the existing debt. As a result, the nominal flow of budget constraint is given by:

$$P_t^B B_t + T_t = B_{t-1} + G_t + W_t^g N_t^f H_t \tag{3.58}$$

where $P_t^B B_t$ is the issuance of new government bonds at price P_t^B in time t, T_t is the tax revenue collected from households to finance its government spending (G_t), and existing debt in previous period B_{t-1}. Additionally, the government promises to share costs with employers by paying idle workers an amount of W_t^g. If there is no furlough scheme, the term $W_t^g N_t^f H_t$ will be eliminated.

The government spending is assumed to follow the following AR(1) process

$$\log(G_t) = \gamma_g \log(G_{t-1}) + \epsilon_t^g; \tag{3.59}$$

Monetary Policy

In this case, we put more effort into estimating and analysing the pandemic shock together with the implementation of government policies. Therefore, it would be initially done with the standard conventional monetary policy so that we could have a preliminary understanding of how the pandemic shocks are transferred to the economy. The unconventional monetary policy would be considered a major extension for this chapter and will be performed in a separate section besides this thesis. Consequently, the central bank will set the nominal interest rate following a simple Taylor rule (Taylor, 1993) with Zero Lower bound (ZLB). The central bank positively adjusts the interest rate R_t^b in response to inflation of the consumer price index (CPI), and the output gap to stabilise the business cycle. The monetary rule is as follows

$$\log\left(\frac{R_t^b}{R^b}\right) = max\left(0, \gamma_\pi \log\frac{\pi_t}{\pi} + \gamma_y \log\frac{Y_t}{Y} + \epsilon_t^r\right) \tag{3.60}$$

where γ_π, γ_y are the feedback from inflation, and output, respectively, and ϵ_t^r is the error term.

3.2.5 Market Clearing

In equilibrium, goods market clearing expects the output produced net of utilisation costs to equal the demand for private as well as public consumption and investment. In other words, the aggregate demand is equal to the aggregate supply

$$Y_t = C_t + I_t + G_t + X_t + \Gamma_t L_t \tag{3.61}$$

Foreign bond holdings evolve in accordance with the law of motion

$$P_t^{B^*} S_t B_t^* = S_t B_{t-1}^* + P_t \tau_t \tag{3.62}$$

where $P_t \tau_t$ is the nominal trade balance that is equivalent to the difference between domestic output, private and public consumption, investment, and hiring cost.

$$P_t\tau_t = P_t^h Y_t - P_t C_t - P_t^i I_t - P_t^h G_t - P_t^h \Gamma_t L_t \tag{3.63}$$

3.2.6 Shock Processes

For home countries, we have technology shock A_t, price mark-up shock ξ_t^m, and preferences shock ξ_t^p. The structural shock processes in the log-linearised form are assumed to follow AR(1) processes are

$$\log(A_t) = \gamma_a \log(A_{t-1}) - \epsilon_t^a; \tag{3.64}$$

$$\log(\xi_t^m) = \gamma_{\xi^m} \log(\xi_{t-1}^m) + \epsilon_t^{\xi^m}; \tag{3.65}$$

$$\log(\xi_t^p) = \gamma_{\xi^p} \log(\xi_{t-1}^p) - \epsilon_t^{\xi^p}; \tag{3.66}$$

Besides, we also have exogenous processes arising from the public policy implemented by the government including lockdown policy υ_t, and the fraction of employees that are made idle due to pandemic ω_t^n

$$\log(\upsilon_t) = \gamma_\upsilon \log(\upsilon_{t-1}) + \epsilon_t^\upsilon; \tag{3.67}$$

$$\log(\omega_t^n) = \gamma_{\omega^n} \log(\omega_{t-1}^n) + \epsilon_t^{\omega^n}; \tag{3.68}$$

Similarly, the exogenous variables in foreign countries are also assumed to follow AR1 processes

$$\log(C_t^*) = \gamma_{c^*} \log(C_{t-1}^*) + \epsilon_t^{c^*}; \tag{3.69}$$

$$\log(R_t^{b^*}) = \gamma_{R^{b^*}} \log(R_{t-1}^{b^*}) + \epsilon_t^{R^{b^*}}; \tag{3.70}$$

$$\log(\pi_t^*) = \gamma_{\pi^*} \log(\pi_{t-1}^*) + \epsilon_t^{\pi^*}; \tag{3.71}$$

3.3 Calibration and Estimation

3.3.1 Calibration

In this section, we first calibrate some common parameters based on the existing macroeconomic literature and related studies. Table 3.1 shows all calibrated parameters being used in this model. We divide these parameters into three groups, including preferences and households, labour market parameters, and frictions and production. For the first group, we set the discount factor at $\beta = 0.99$, which is in line with the large literature on New Keynesian models. Besides, we set $\varphi = 0.0063$

so that H has the value of 0.3; this is the steady-state value of hours worked per employee. Additionally, we set habit formation $h = 0.7$ as we assume that households would be persistent in their consumption behaviour over time.

In this model, we fix risk premium elasticity $\psi_B = 0.001$. According to Schmitt-Grohé and Uribe (2003), for a positive value of risk premium elasticity that is close to 0, our access to foreign financial assets is open and the external debt would tend to reverse to its mean value. The preferences for domestic consumption and imported goods are assumed to have no significant difference; hence, ν_c and ν_{c^*} are set relatively low at 1.5. This is also the case for parameters of the elasticity of substitution between home demand for investment ν_i and foreign demand for investment ν_{i^*}.

For the parameter set in the labour market, the unemployment benefits coefficient, b, is calibrated at 0.34. This measure gives the proportion of household income earned when being employed maintained after specific months of unemployment. Following Blanchard and Galí (2010), we set parameters so that in steady-state, the unemployment rate is 4% in the UK, while the job-finding rate x is fixed at 0.25. The choices of U and x then help determine our job destruction rate through the term $s = \frac{Ux}{(1-U)+Ux}$; therefore, s has the value of 0.03. Regarding the values of matching efficiency and matching function elasticity, we set $m = 0.5$ and $\mu = 0.7$, respectively.

On the production side, we fix labour share at 70% as input of the production function and the rest relies on capital share; therefore, $\alpha = 0.7$. Regarding the capital assets, we assume that they depreciate at the rate $\delta = 0.025$ to match an average annual rate of capital destruction of 10%. For export demand, we assume that the share of foreign consumption demand outweighs that of foreign investment in aggregate export; hence, $x_c = 0.9$ and $x_c = 0.1$. Finally, the steady-state value of

	Parameter	**Calibrated value**
	Preferences and Households	
β	Discount factor	0.99
φ	Inverse Frisch labour elasticity	0.0063
h	Habit formation	0.7
ψ_B	Risk premium elasticity	0.001
ν_c	Elasticity of substitution for domestic consumption	1.5
ν_i	Elasticity of substitution for domestic investment	1.5
ν_{c*}	Elasticity of substitution for foreign consumption	1.5
ν_{i*}	Elasticity of substitution for foreign investment	1.5
	Labour market	
b	Unemployment benefits	0.34
s	Job separation rate	0.03
m	Matching function constant	0.5
μ	Matching function elasticity	0.7
	Frictions and Production	
α	Labour share	0.7
δ	Depreciation rate of capital	0.025
x_c	Share of consumption in exports	0.9
x_i	Share of investment in exports	0.1
g_y	Share of government spending	0.35

Table 3.1: Calibrated parameter values

government spending g_y is assumed to account for 35% of the home country's GDP.

3.3.2 Estimation

At this stage, we estimate stochastic shocks and parameters using Bayesian methods. There are several reasons for using this approach; firstly, Bayesian estimation allows us to employ prior information to determine key structural parameters. Additionally, the estimations made by these methods are efficient because they fully utilise the cross-equation restriction in the general equilibrium setup. Furthermore, according to Fernández-Villaverde (2010), this approach enables users to analyse the source of fluctuations while providing a method of evaluating the model's ability to capture the cyclical features of the data. In this estimation process, we also utilise the Kalman filter in order to find the likelihood function of the observable variables. Then, we combine this function and the prior distribution to get the posteriors. Finally, by using the Metropolis-Hasting algorithm (MH), we compute the posterior kernel, choose a transition, and use a rejection rule to draw posterior sequences. We start our estimation with the baseline model to estimate shocks and parameters; in this case, υ_t, and ω_t^n are kept at the steady-states that give them the value of 1, and $\omega^w = 0$. In other words, this is the market before the intervention of the UK government.

Priors and Data

	Description	**Prior Distribution**			**Posterior Distribution**		
		Distribution	*Mean*	*Prior SD*	*Mean*	*5%*	*95%*
	Structural parameters						
σ	Elasticity of intertemporal substitution	*Gamma*	2.0	0.5	2.3703	1.7117	2.9821
χ	Cost function multiplier	*Gamma*	0.1	0.05	0.2069	0.1043	0.3062
ι	Elasticity of the vacancy cost function	*Gamma*	1.1	0.1	1.1289	0.9639	1.3055
ξ	Employee's bargaining power	*Beta*	0.5	0.05	0.5204	0.4537	0.5979
ϵ	Elasticity of demand	*Gamma*	7.0	0.5	7.1958	6.2273	8.2712
η	Investment adjustment cost intensity	*Gamma*	3.0	0.5	1.9131	1.5814	2.2725
ω_c^h	Share of local consumption	*Beta*	0.5	0.01	0.4992	0.4828	0.5152
ω_i^h	Share of local investment	*Beta*	0.5	0.01	0.5078	0.4916	0.5252
θ	Calvo price stickiness	*Beta*	0.5	0.01	0.5267	0.5103	0.5433
γ_π	Feedback from inflation	*Gamma*	2.0	0.01	2.0012	1.9844	2.0171
γ_y	Feedback from output	*Gamma*	0.1	0.01	0.0913	0.0761	0.1055
	Autoregressive parameters						
γ_a	Technology	*Beta*	0.5	0.01	0.5124	0.4954	0.5286
γ_{ξ^p}	Preferences	*Beta*	0.5	0.01	0.5014	0.4843	0.5173
γ_{ξ^m}	Mark-up	*Beta*	0.5	0.01	0.5215	0.5053	0.5382
γ_g	Government spending	*Beta*	0.5	0.01	0.5174	0.5010	0.5337
γ_{c^*}	Foreign consumption demand	*Beta*	0.5	0.01	0.5001	0.4840	0.5159
	Standard errors						
ϵ^a	Technology	*InvGamma*	0.01	0.01	0.1137	0.0984	0.1266
ϵ^{ξ^p}	Preferences	*InvGamma*	0.01	0.01	0.0953	0.0676	0.1215
ϵ^{ξ^m}	Mark-up	*InvGamma*	0.01	0.01	0.1649	0.1394	0.1904
ϵ^g	Government spending	*InvGamma*	0.01	0.01	0.0493	0.0432	0.0553
ϵ^{c^*}	Foreign consumption demand	*InvGamma*	0.01	0.01	0.0593	0.0380	0.0805
ϵ^r	Monetary policy	*InvGamma*	0.01	0.01	0.0156	0.0130	0.0183

Table 3.2: Prior and posterior distribution of parameters

Our model is estimated using quarterly data extracted from the Office for National Statistics and Bank of England over the period 1992:Q1 - 2020:Q1. This data set includes gross domestic product (GDP), consumption, fixed capital formation, government spending, inflation rate, and hours worked. These series are seasonally adjusted and have been detrended using the first difference filters technique for estimation. To match the data with the observable variable Y, we use quarterly data for the latest GDP estimates in chained volume measures and at current market prices. The consumption series are collected using data on individual consumption expenditure (P.31) by households and Non-profit institutions serving households.

In this case, we estimate six stochastic shocks including technology shock, preferences shock, mark-up shock, government spending shock, foreign consumption demand shock, and monetary policy shock. Besides, except for the fixed parameters, we estimate the remaining parameters and other autoregressive parameters of the AR1 processes. We use three types of distribution depending on the specific kind of parameters. Accordingly, the beta distribution will be used to estimate parameters that take sensible values in the range of zero to one; the gamma distribution is used for parameters that are restricted to be positive. Finally, the shock variances will be estimated using the inverse gamma distribution.

Firstly, we need to choose the prior mean of estimated parameters. To begin with, we start with the parameter set in the household sector. Accordingly, the elasticity of intertemporal substitution is assigned the value of $\sigma = 2$. The next step is to determine the prior means of parameters in the labour market. Firstly, we consider the parameter that gives the level of hiring costs, χ. We set the prior mean of this parameter to 0.1 to keep hiring cost low for the economy. The elasticity of the hiring cost function, ι, is given the value of 1.1, a value which satisfies the assumption of convexity and is close to the standard assumption of linear adjustment costs. Additionally, we assume that the workers and employers equally share the surplus from working; therefore, making the prior mean of the worker bargaining power ξ equal to 0.5.

Then, we consider the prior means for the production sector. For the value of Calvo price stickiness, we set $\theta = 0.5$. Regarding the monetary policy and Taylor rule, we set the prior means of the response to inflation, γ_π, equal to 2 while the response to output is kept low at 0.1. For capital goods, we set the prior mean of investment adjustment cost intensity η at the value of 3. For elasticity of demand ϵ, the prior mean is set to 7, which implies an average markup of 15% at the steady-state. Additionally, for the openness of the UK to the rest of the world, we assign the prior means of $\omega_c^h = \omega_i^h = 0.5$ to the share of domestic consumption and investment so that the imported shares of consumption and investment account for 50% of the local market.

Finally, we consider the autoregressive parameters and the stochastic shocks of the AR1 processes. Their prior means are assigned the value of 0.5 while that of the standard errors is set to 0.001 for all the shocks. The result for the prior and posterior distribution of parameters and shocks can be shown in Table 3.2

Parameter estimates

The last three columns of Table 3.2 summarise the posterior means of the structural parameters as well as their 90% confidence intervals. Based on these figures, it is worth noting a number of characteristics of the posterior distribution of the estimated parameters in our model.

Firstly, the elasticity of intertemporal substitution σ is equal to 2.3703, which suggests an insensitivity to the interest rate of consumption growth. For instance, consumption growth changes by only 0.03% when there is a one percentage point increase in the interest rate. Clearly, this data set has provided much information for this parameter to change greatly compared to its prior distribution. Regarding the labour market, we find that the posterior distribution of the hiring cost function multiplier χ is greater than expected, which shows that the model prefers a higher cost of posting a vacancy. In the case of employees' bargaining power ξ, and elasticity of the vacancy cost function ι, their posterior means are close to their prior means with the value of 0.5204, and 1.1289, respectively.

Additionally, the elasticity of demand ϵ is estimated to be about 7.2, this figure implies a high price mark-up of approximately 16%. Furthermore, the posterior mean of investment adjustment cost intensity is close to its prior mean with $\eta = 1.9131$, implying that investment is sensitive to the price of capital. Also, the estimation of parameters ω_c^h, and ω_i^h show that the openness of the UK's international trade is high. In fact, it is estimated that the UK imports approximately 50% of foreign goods for their aggregate consumption and investment. Furthermore, the estimates of the Taylor rule parameters indicate that the monetary policy rule responds strongly to inflation, this value is close to the prior mean, $\gamma_\pi = 2.0012$. In contrast, this is not the case for the posterior mean of the response to output γ_y; it is estimated to be 0.0913, meaning that the policy rule responds weakly to the change in output.

Finally, the estimations of autoregressive parameters reveal that they are relatively persistent over time; their posterior means are close to 0.5 accordingly. On top of that, technology shock ϵ^a, and price mark-up shock ϵ^{ξ^m} appear to be highly volatile as their estimated variance is greater than 10%. Especially, price mark-up shock has the greatest volatility whose posterior mean of the variance has the value of 16%. By contrast, the shock to policy rule rate is the least volatile shock in this model with a posterior mean of 0.0156.

3.4 Variance Decomposition and Impulse Response Functions

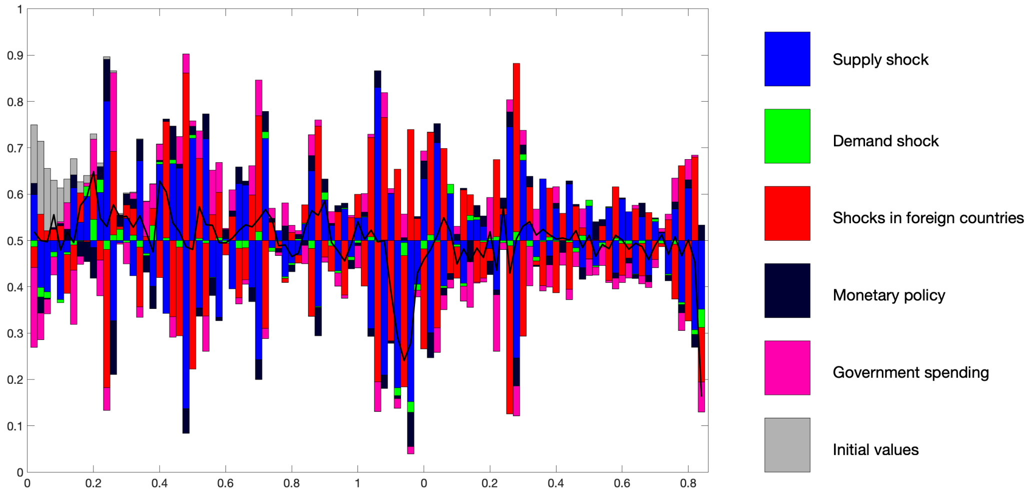

Figure 3.1: Variance decomposition of Output

In this section, we look at variance decomposition to understand which cyclical variation of each variable is explained by the shock; in other words, we know which shocks are the main sources that cause these variables to fluctuate. As both technology shock and price mark-up shock affect the supply side of the economy, they can be classified as supply shock; additionally, we label preferences shock as demand shock as it impacts the demand side of the economy. Shocks in foreign countries refer to shocks that originate abroad. Regarding figure 3.1, it can be seen that supply shock is one of the main factors explaining the cyclical movements of output. Additionally, if we look closely at the recent spike in output's variance in the last period, it can be seen that the demand shock also contributes significantly to a decrease in output; however, though the impact of a demand shock on output is much greater than that in previous periods, its effect is still modest compared to the impact of a supply shock. Therefore, it can be argued that during the pandemic, output in the UK is affected mainly by the supply side rather than the demand side.

At this stage, impulse response functions will be analysed to understand how shocks are transmitted to endogenous variables during the pandemic. As both supply shock and demand shock hit the economy during the pandemic, we simulate the aggregate effect of them simultaneously on the economy instead of getting separate impulse response functions for each type of shock. By doing this, we create a new exogenous shock that can cause an impact on technology shock, price mark-up shock and preferences shock at the same time using the estimated value of their standard errors.

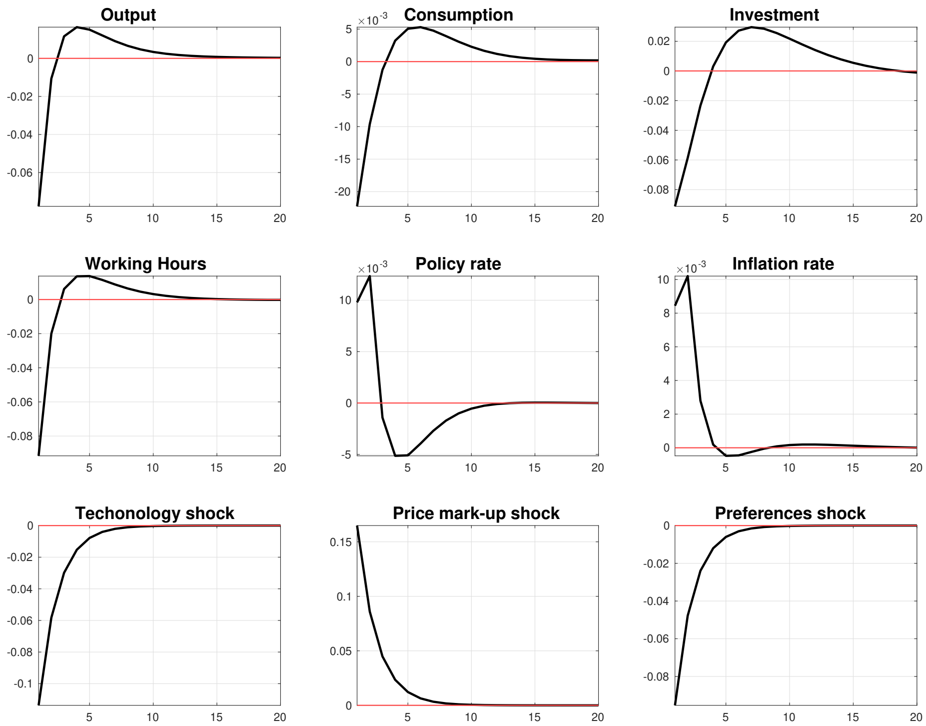

Figure 3.2: The impact of supply shock and demand shock in pandemic

As can be seen from figure 3.2, technology shock is estimated to decrease by 11% and price mark-up shock increases by more than 16%. On the other hand, on the demand side, the preferences shock is measured to fall by 9% from its steady-state; this means that each unit of consumption is now less valuable in utility terms. Therefore, we expect a fall in the level of consumption as people are willing to give up more units of consumption. Overall, the aggregate impact of these shocks leads to a significant reduction in the growth rate of output, consumption, and investment; however, these effects are witnessed to move in the opposite direction, which raises the growth rate of output, consumption and investment after approximately four quarters. This could be explained by an increase in demand for consumption and investment after being impeded in previous periods during the pandemic. Furthermore, as production activities are hindered as a consequence of shocks, the inflation rate rises accordingly. As a result, the central bank raises the interest rate corresponding to the change in inflation because they put more weight on the volatility in this term compared to the output gap; by doing this, policymakers can pursue their primary goal, which is stabilising the price level. Finally, it is shown that the value of working hours decreases dramatically after 2 quarters following the shocks.

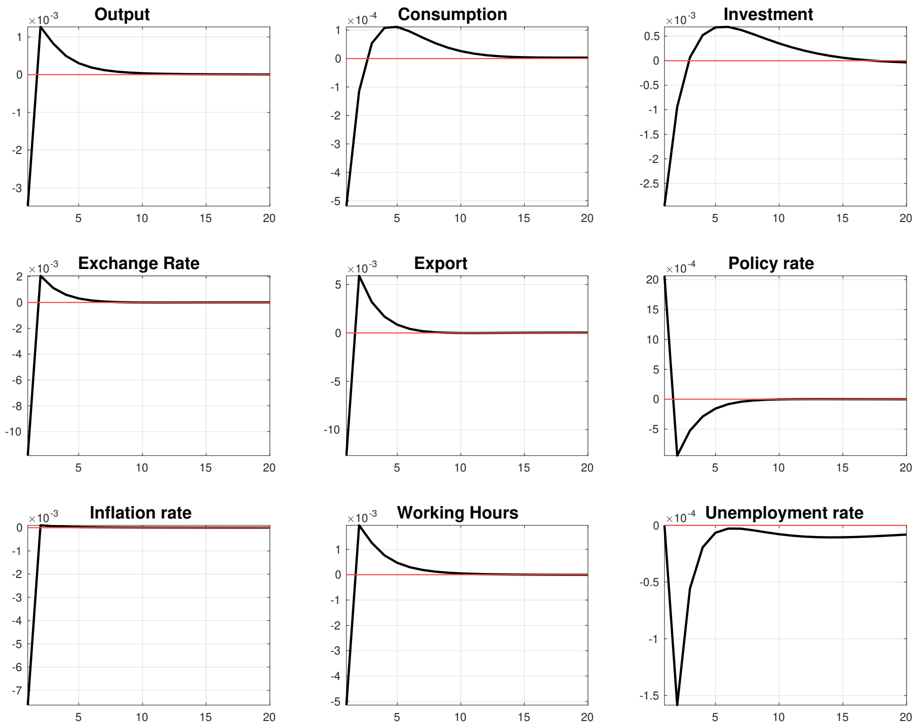

Figure 3.3: Monetary policy

One possible solution to a high inflation rate caused by the pandemic is to raise the interest rate. According to the Taylor rule (Taylor, 1993), when the central bank increases the policy rate, it makes borrowing become more expensive and saving more attractive; therefore, the aggregate demand should decrease due to lower growth in investment and consumer spending, leading to a fall in the inflation rate. In figure 3.3, the movement of the inflation rate, output growth, consumption, investment, and export follow this rule. Particularly, an increase in the interest rate helps combat inflation by restraining the price level; however, it comes at the cost of output growth, consumption, investment, and net export, though these effects are short-lived. Additionally, it is worth noting that the ZLB does not exist because the central bank raises the interest rate in this case so it does not reach the boundary. Finally, the other effects of this policy are an appreciation in the exchange rate and an immediate decrease in working hours and the unemployment rate.

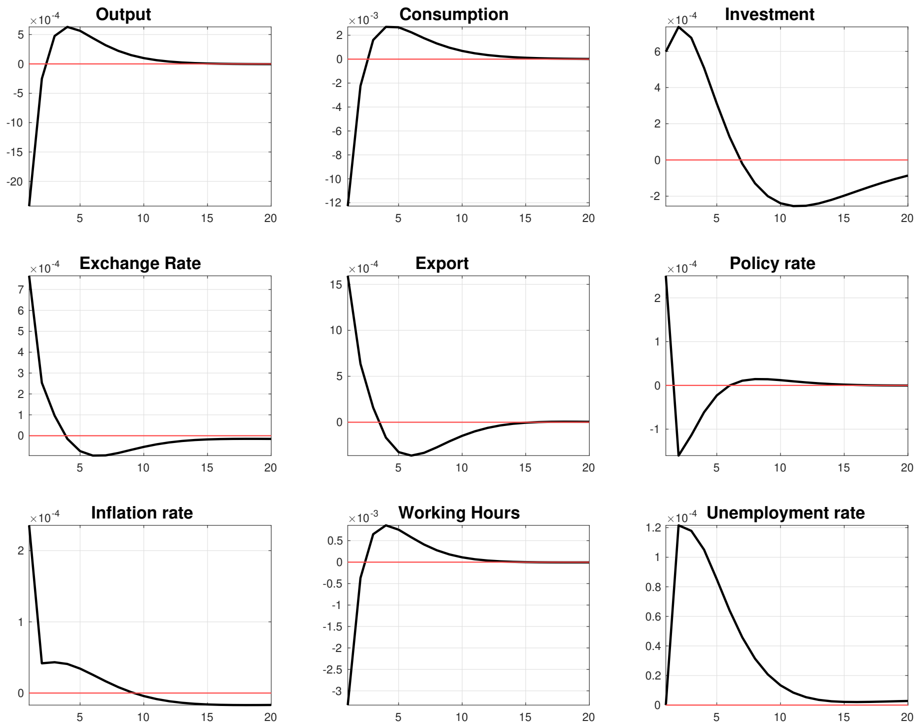

Figure 3.4: The impact of lockdown policy

Given that the UK government introduces a lockdown policy and furlough scheme to stop the spread of the virus and ease the adverse impact of the pandemic on the economy, we study how these measures affect the economy as a whole in our model. In figure 3.4, we get the impulse response functions for endogenous variables from the shock υ which is caused by the lockdown policy. It can be seen that this policy causes a negative impact on both output and consumption; however, as the lockdown restriction is relaxed over time, the demand for goods and services starts to rise again, pushing the growth rate of consumption and output above its steady-state value. Alternatively, investment is the sector that benefits most from the shock. This is because people tend to shift their current level of consumption, which is hampered by the lockdown, to the future; hence, investment is a possible channel for them to achieve this goal. Furthermore, another drawback of implementing a lockdown is that it causes the price level to rise. Finally, it is expected that the unemployment rate will increase after one period following the enforcement of this policy. This is because when there is a lockdown, demand for goods and services falls significantly; besides, non-essential services are required to stop. As a result, employees in these sectors are being made redundant.

Moreover, we discuss the impact of the furlough scheme programme that the UK government introduces to tackle the negative impact of the pandemic. In figure 3.5, we compare the economy in two different states given an adverse shock to the number of working employees when the government orders non-essential services and sectors to close so as to stop the spread of COVID-19. For instance, the solid black line shows the impulse response of the economy to the furlough scheme; in this case, the government agrees to share costs with employers by paying idle workers 80% of their wages. On the other hand, the dashed red line indicates the economy with no furlough scheme; this means that employers now bear all the cost of paying their idle employees without the help of the government.

In general, the introduction of the furlough scheme helps reduce the unfavourable

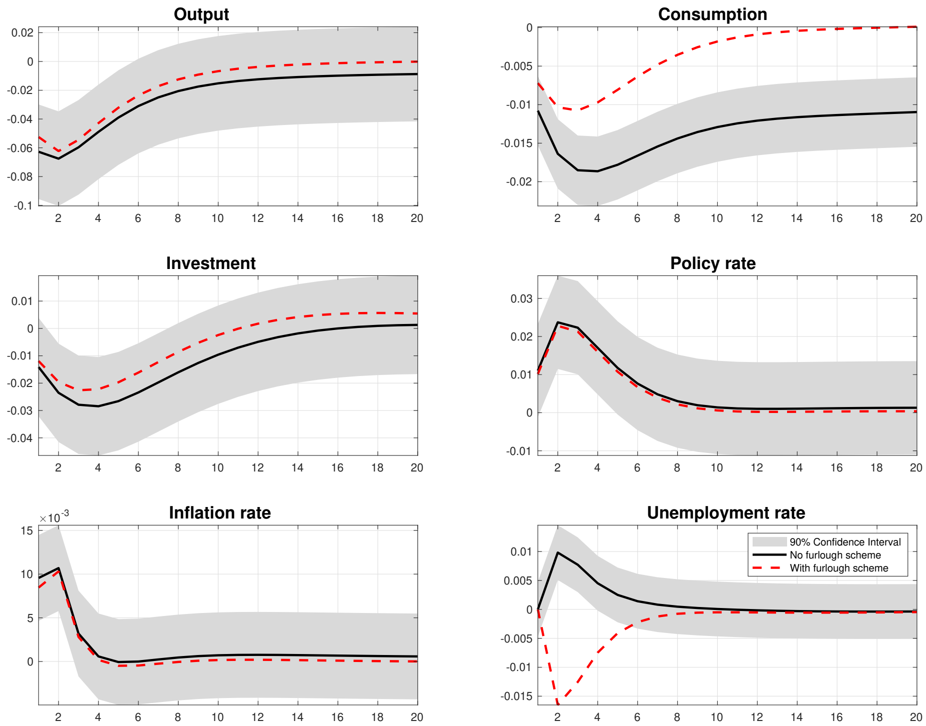

Figure 3.5: The impact of furlough scheme

impact of the shock on consumption. Additionally, it can be seen that the greatest achievement of the furlough scheme is to reduce the unemployment rate; if the government does not intervene in this market, the number of people losing their job may rise massively after the shock. On the other hand, we do not see any discrepancy in the level of output growth, investment, inflation rate, and policy rate between the circumstances with and without the furlough scheme.

3.5 Welfare Measure

In this part, we evaluate the welfare measure of implementing the furlough scheme policy. We exploit the commonly used measure by estimating the percentage change in the consumption rate that makes individuals indifferent between two settings, with a furlough scheme and with no furlough scheme, leaving the number of hours worked unchanged. We denote C_t^o, H_t^o as the equilibrium allocations of consumption and hours worked with no furlough scheme programme while C_t^f, H_t^f are the allocations when the policy is implemented, the welfare gain for agents is therefore, given by the percentage of κ that satisfies

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t & \left[\frac{\xi_t^p [(C_t^o - hC_{t-1}^o) \left(1 + \frac{\kappa}{100}\right)]^{1-\sigma}}{1-\sigma} - \frac{{H_t^o}^{1+\varphi}}{1+\varphi} \right] \\ = & E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\xi_t^p [(C_t^f - hC_{t-1}^f)]^{1-\sigma}}{1-\sigma} - \frac{{H_t^f}^{1+\varphi}}{1+\varphi} \right] \end{aligned} \tag{3.72}$$

Accordingly, welfare increases by 2.82% when the government implements the furlough scheme policy. In general, it can be concluded that households are generally better off with the introduction of the furlough scheme. This result is expected because the purpose of this programme is to protect the income of those who are heavily disturbed by the pandemic; therefore, when the income is secured, it enables people to consume and invest more, making these variables have a higher value compared to the case with no furlough scheme in place.

For instance, with the furlough scheme, households receive two sources of income. On the one hand, active workers contribute to production activities and get paid by their employers, while idle workers still get income from the government. Consequently, the programme preserves the incomes of millions of people across the working sectors in the UK that are put on hold. In other words, the living standards of these households are secure and their incomes are not impacted much during the pandemic. On the other hand, households receive only one source of income had there been no furlough scheme; in this case, only working employees get payments from their employers. Therefore, the incomes of these households are reduced significantly during the pandemic, which eventually impedes their demand for consumption.

3.6 Conclusion

This chapter studies the impact of the pandemic on the economy of the United Kingdom using a DSGE model, which has been modified to fit the policies implemented by the UK government. The shock in a pandemic is represented by a combination of three exogenous processes including a negative preferences shock on the demand side as well as an adverse technology shock and a positive price mark-up shock on the supply side. In addition, other common shocks such as monetary policy shock, government spending shock, and foreign consumption demand are also estimated. Our estimation indicates that autoregressive parameters are relatively persistent over time and that the volatility of technology shock, and price mark-up shock appear to be highly volatile.

Furthermore, as we investigate the variance decomposition of the change in output, we find that supply shock constituted by technology shock and price mark-up shock is the main factor causing the output to drop during the pandemic while the effect of preferences shock (or demand shock) on this variable is relatively modest in the latest period. In general, the aggregate impact of these shocks leads to a significant decrease in the growth rate of output, consumption, and investment; furthermore, as production activities are impeded during the pandemic, the inflation rate rises accordingly. As a result, the central bank sets to increase the interest rate to stabilise the price level. Besides, we expect a reduction in the working hours of employees; it can be explained by the shortage of labour supply due to health-related problems.

Finally, we determine the impact of the lockdown policy and the Coronavirus Job Retention Scheme (CJRS) implemented by the UK government. For instance, the purpose of the lockdown policy is to stop the spread of COVID-19; however, it is carried out at the cost of a fall in the growth rate of output, consumption, and a rise in the unemployment rate. On the other hand, the only sector that benefits from a lockdown is investment as people use it as a way to defer their consumption to the future. Another solution that has been provided by the government to ease the economic impact of the pandemic is to operate a furlough scheme programme. We notice that the use of the furlough scheme alleviates the impact on consumption. More importantly, this programme also helps reduce the unemployment rate; had no furlough scheme been put in place, we would have witnessed a large increase in the number of people being made redundant.

Chapter 4

The Spillover Effects in Emerging Market: Perspective of Vietnam

Abstract

This chapter studies the spillover effects of US shocks on Vietnam's economy, which is a typical emerging market in the South East Asia region that has a successful economic reform. In this research, we employ a DSGE model with two-country blocs in order to estimate the shocks in both markets and analyse the impact of these shocks on Vietnam's economy. This study gives explanations for the sources of variations in the business cycle in Vietnam and it helps people understand the attributes of Vietnam's market in an open economy setting. Overall, this study shows that besides domestic shocks in technology, and price mark-up, shocks in technology, price mark-up, and investment arising in the US are the major sources that influence the output growth, and price level in Vietnam. Accordingly, positive shocks in technology and monetary policy in the US would cause output growth

and inflation rate to fall in Vietnam. On the other hand, an increase in US price mark-up and investment demand would boost income in Vietnam but at the cost of a higher inflation rate. Finally, it is expected that a rise in oil prices will reduce output growth, consumption, and investment in this country.

Keywords: Bayesian estimation, DSGE model, emerging market, open economy.

4.1 Introduction

In the modern economy, we are getting familiar with the term globalisation thanks to the advancement in international trade. Additionally, the enhancement in trading activities and cooperation among countries helps their connection get more robust and the world becomes "flatter". For instance, many trade agreements and unions have been established with the aim to create free-trade areas and boost the exchange of capital, goods, and services to a higher level. To name a few, we have the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), Economic Partnership Agreements, The European Union (EU), the Regional Comprehensive Economic Partnership (RCEP), and The Association of Southeast Asian Nations (ASEAN). Above all, we also have The World Trade Organization (WTO) founded to regulate and facilitate international trade between nations.

The benefits of an open economy are undoubtedly significant; however, it does not exist without any cost. Due to a close connection among countries, the spillover effect arises and makes the impact of any shock in one country spread to the economies of other nations. A great example of that is the Financial Crisis of 2008 which first occurs in the US and expands worldwide afterwards. For instance, this incident triggers the sovereign debt crisis in Greece in early 2009. Besides, it is worth mentioning the China–United States trade war in 2018. The trade war brings about higher costs and prices in the US while hampering the output growth rate in China. However, other countries in Asia experience a shock in foreign direct investment as many American firms seek to shift their supply chains to these countries.

In this regard, there have been many papers working on this topic to shed light on the spillover effect of one country on others from different perspectives. For instance, some papers focus on the effect of knowledge and information spillovers

(Poole, 2013; Cole, Neuhann and Ordoñez, 2016; Keller, 2021), inflation spillovers (Auer, Levchenko and Sauré, 2019), productivity and terms of trade (Corsetti, Martin and Pesenti, 2007), the international policy cooperation (Korinek, 2017). Another aspect of it is the financial market; for instance, Ha et al. (2020) create a new dynamic factor model to jointly characterise global macroeconomic, financial cycles and spillovers. They show that there are spillovers from equity and house price shocks conducted mainly through global rather than local macroeconomic factors. Besides, these effects get greater in the stages leading up to and following the financial crisis.

Additionally, Rey (2015) shows that a global financial cycle in prices of assets, capital flows, and credit growth co-moves with the level of market uncertainty; besides, the countries that are more exposed to the credit inflows are more sensitive to the cycle, which is not associated with macroeconomic conditions of these countries. As a result, the author states that exchange rate regimes do not protect countries from global financial cycles; hence, reducing the monetary trilemma to a dilemma that consists of only monetary independence and capital mobility. However, the view of the trilemma is proved to be valid in the extent of financial linkage between the centre economies and the peripheral economies (Aizenman, Chinn and Ito, 2016, 2017). Besides, it is evidently supported by Obstfeld (2021), Obstfeld, Shambaugh and Taylor (2005), Shambaugh (2004).

Furthermore, there are many studies estimating the impact of fiscal stimulus in one country on another through the channels of capital flows and international trade. Accordingly, it has been established that the spillover effects of fiscal stimulus can be distinct relying on how shocks are determined Auerbach and Gorodnichenko (2012); Amendola et al. (2020). Moreover, regarding trade and the global business cycles, Di Giovanni and Levchenko (2010, 2012) show that countries having higher exposure to an open economy could have higher business cycle correlation. As a result, Devereux, Gente and Yu (2020) combine the findings on production networks and international fiscal spillovers to determine that international production network linkages are significant for a fiscal stimulus in one country to spread internationally.

Realising the importance of spillover effects in explaining the business cycles, and given the fact that emerging countries are greatly impacted by the volatility in developed countries (Li and Giles, 2015; Su, 2015; Bhattarai, Chatterjee and Park, 2020), we develop a DSGE model with two-country blocs to estimate and analyse the impact of shocks in the US on Vietnam, a typical developing economy. Regarding the choice of the foreign bloc, we choose the US because this country is a major trading partner of Vietnam, accounting for up to 23.21% of total share (World Bank, 2022b). Additionally, it is common to implement the US as the foreign economy in models with two-country blocs (Buncic and Melecky, 2008; Choi and Hur, 2015).

For the home country bloc, there are several reasons that we are interested in investigating the business cycle of Vietnam. According to the World Bank (2022a), Vietnam is one of the emerging countries that are most dynamic in the East Asia region; besides, this country has successfully reformed to become a lower-middle-income country from one of the poorest in the world.

As stated by Tuan (2012), the reform, titled "Doi Moi" in Vietnamese, which means "the restoration", started in 1986 when the country was on the verge of economic collapse. Previously, the major reason leading to the crisis of the Vietnamese economy is that this country imitates the outdated economic model of the Soviet Union, a model of centralised planning which allows the state to have all control over the allocation of economic inputs, materials, and investment decisions; as a result, only state-owned enterprises existed and there was no private sector. Realising this shortcoming, Doi Moi has been implemented by the Vietnamese government to remove the barriers against the advancement and application of market-oriented mechanisms. This reform includes the liberalization of the domestic market, encourages foreign direct investment (FDI), enhances the private sector, and reduces the share of state-owned enterprises in the economy.

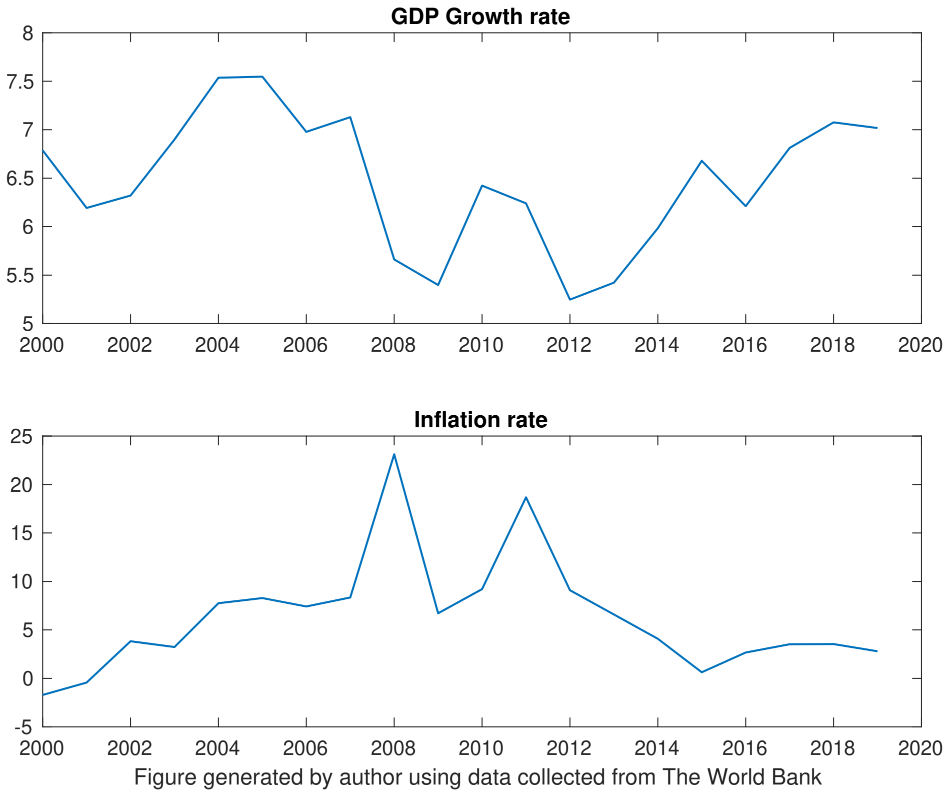

Figure 4.1: Overview of Vietnamese economy

After the reform, Vietnam witnesses positive changes in the economy; it has resurrected itself and is reaching for economic prosperity. For example, this country has been a rice exporter since 1989 despite a history of experiencing food shortages. In 2008, Vietnam shipped approximately 4.7 million tons of rice abroad, making it the world's second-largest rice exporter just after Thailand. Regarding productivity, the data shows that the GDP per capita in Vietnam rises more than 8 times to reach the level of approximately 3,400 USD from just 390 USD over the last 20 years, and the poverty rates reduce significantly from more than 32% in 2011 to below 2% in 2020. In addition, as can be seen in figure 4.1, Vietnam has an average GDP growth rate of approximately 6.5% per annum from 2000 to 2019. Particularly, the highest GDP growth rate in this country is 7.55% in 2005, which is noticeably greater than the world's average rate of 4%. After this, Vietnam's economy experiences an unstable stage from 2008 to 2015 when its growth rate falls below 6.5%; this can be explained by the event of the global financial crisis stemming from the US. However, it quickly recovers and even reaches China's growth rate after 2014. On the other hand, Vietnam encounters high inflation with an average rate of 6.37% from 2000 to 2019, reaching an all-time high of 23.12% in 2008 (figure 4.1).

Another important feature of the Vietnamese economy is that it is highly exposed to the foreign market, which makes international trade an essential sector in this country. According to the World Bank (2022b), Vietnam turns into one of the most open economies in the world as its degree of openness, defined as the ratio of exports plus imports over GDP, keeps rising to reach the level of approximately 210% of GDP in 2019. In this case, Vietnam depends greatly on foreign direct investment and exports, especially to China and the US. Furthermore, trade liberalisation is actively committed by the Vietnamese government by joining the WTO in 2007, signing Free Trade Agreements (FTAs) with the ASEAN countries and the US, the EU, and having a Regional Comprehensive Economic Partnership (RCEP) with 16 countries. Finally, Vietnam is one of the markets that is greatly impacted by the China–United States trade war in 2018. As can be seen in figure 4.2, Vietnam has experienced a significant increase in export to the US market since the trade war in 2018; on the other hand, imports from China started to rise in the same period. This phenomenon is caused by the shift in the supply chain system from China to Vietnam due to the trade war. Particularly, Vietnamese firms purchase more inputs from China and produce more goods and services in order to meet increasing demand from the US. Therefore, Vietnam's trade relation with the US is getting stronger in this way, which makes the study of the spillover effects of US shocks on Vietnam's economy essential and relevant.

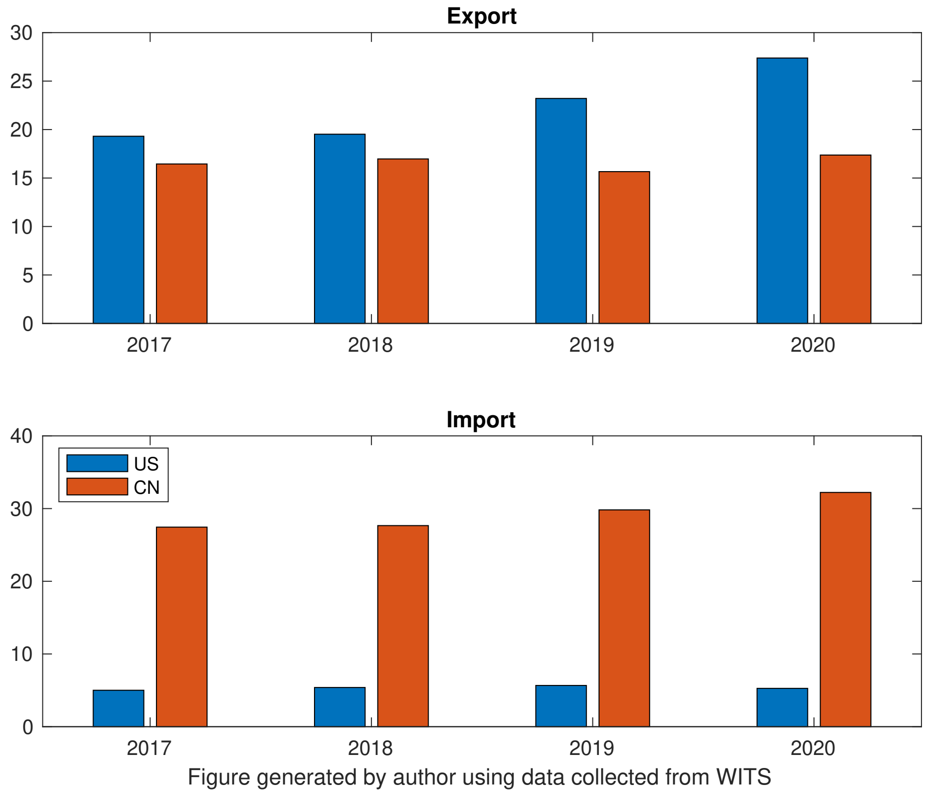

Figure 4.2: Partner share of Vietnam

There has been an increasing number of papers working on the Vietnamese economy. For instance, Le (2014) exploits a structural VAR model to study the dynamics of the business cycle in Vietnam and compare it with that of the Philippines and Indonesia. Using another approach, Khieu (2015) extracts data in Vietnam from January 1995 to December 2012 to estimate the model of three main equations including the expectational IS curve, the Phillips curve, and a monetary policy rule. Additionally, Pham, Sala and Silva (2020) analyse Vietnamese cyclical behaviour and compare it with other five trading partners in ASEAN using the standard small open economy RBC model with habit persistence and government consumption. Although these papers focus on examining the business cycle of Vietnam as well as determining the factors influencing its economy, they fail to take into account the spillover effects on this country. Besides, the models in these papers are either compact (Le, 2014) or unrealistic with no price rigidity feature (Pham, Sala and Silva, 2020), or it is put in a closed economy context (Khieu, 2015). Therefore, given these shortcomings and limited literature on estimating a DSGE model for the Vietnamese economy, this chapter tries to estimate and analyse the influences of US shocks on the Vietnamese economy using a DSGE model with two-country blocs.

Overall, this study contributes to the growing number of literature working on estimating and analysing spillover effects for emerging countries. By doing this, it explains the sources of variations in the business cycles in emerging markets. Furthermore, as there is limited literature on estimating a DSGE model for Vietnam, this chapter will give an insight into Vietnam's economy by estimating the model that includes many critical features for this country using real data collected over the past 20 years. As a result, we learn the characteristics of Vietnam in an open economy setting.

In this study, we show that shocks in technology, price mark-up and investment are more persistent than policy shocks in Vietnam. In the case of the US economy, we realise that shocks in monetary policy and investment demand are relatively steady, while the other shocks are less persistent. Besides, it is worth noting that generally, shocks in Vietnam are smaller than those in the US market, except for price mark-up shocks. The estimate of oil price shock suggests high volatility in the price of this commodity; however, this shock is not persistent because most of its effect would diminish after one period. Regarding the spillover effects, it is clear to us that technology shock, price mark-up shock, and investment shock that occur in the US are the major sources of foreign shocks influencing the output growth, and price level in Vietnam. Moreover, the analysis of impulse response functions reveals that foreign shocks in technology and monetary policy reduce output growth and the inflation rate in Vietnam. On the contrary, if there is an increase in price mark-up and investment demand in the US, the GDP growth rate in Vietnam would rise accordingly, but at the cost of a higher inflation rate. Finally, it is expected that a positive shock in oil prices hampers output growth, consumption, and investment in Vietnam.

The rest of this chapter is organised as follows. Firstly, we develop a DSGE model with two-country blocs, whose foreign bloc is built and estimated separately using the New Keynesian model; additionally, this model features characteristics of emerging countries by including a shock in commodity price. In section 3, we present the data and estimation process for both Vietnam and US markets. Next, we provide an analysis of the sources of the variance in the Vietnamese economy as well as give a discussion about the impulse response functions. The final part is a conclusion section.

4.2 The Model

In this part, we generalise an open economy New Keynesian model which includes some main features of an emerging country. For instance, we will introduce heterogeneous agents such as Ricardian and credit-constrained consumers, as well as a commodity-exporting sector. Furthermore, rather than modelling the open market as an exogenous independent AR1 process, we now extend this model to endogenise the impact of the foreign market.

4.2.1 Households

In this section, we study the optimisation problem of two different types of households in the economy. There are $(1 - \omega)$ of them being Ricardian consumers who have full access to financial markets. The remaining ω of households are rule-of-thumb consumers and they are expected to consume their entire disposable income net of taxes from supplying labour in each period. The reason we reintroduce different types of households in this chapter is due to the fact that a significant share of Vietnamese people has no access to financial services in Vietnam. According to Demirguc-Kunt et al. (2018), there are only 39% of adults in Vietnam open a bank account, which is much lower compared to the regional average of 69%. This can be explained partially by the lack of banking infrastructure in rural and isolated areas, the lack of formal identification documents, and low incomes. Therefore, it is worth applying the heterogeneous households feature integrated into the theoretical framework in chapter 2 to the model that simulates the Vietnamese market.

Ricardian households

Each Ricardian household seeks to maximise their lifetime utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t^o - hC_{t-1}^o)^{1-\sigma}}{1-\sigma} - \frac{H_t^{o\,1+\varphi}}{1+\varphi} \right) \tag{4.1}$$

where superscript 'o' denotes "Optimising household". The utility level is a function of consumption by Ricardian household C_t^o with the persistence of external habit formation h combined with the disutility from supplying labours in terms of hours worked H_t^o at time t. Furthermore, in this function, σ denotes the elasticity of substitution intertemporally while φ shows the elasticity of hours worked. The problem of these households is to maximise their utility subject to the budget constraint

$$\begin{aligned} C_t^o P_t + P_t^B B_t^h + P_t^{B^*} S_t B_t^{f^*} + I_t P_t^i = B_{t-1}^h + S_t B_{t-1}^{f^*} + (1-\tau_t^w) W_t H_t^o \\ + (1-\tau_t^k) \widehat{R}_t^k K_t + J_t \end{aligned} \tag{4.2}$$

In each period, households buy a number of domestic bonds B_t^h and foreign bonds $B_t^{f^*}$ at nominal price P_t^B and $P_t^{B^*}$, respectively, given the nominal exchange rate S_t. Additionally, P_t is the CPI index that includes an imported component. In addition, W_t is the wage from providing labour supply H_t^o, which is then charged a proportional labour tax τ_t^w. Besides, these households invest an amount of I_t at price P_t^i, and receive a return $\widehat{R}_t^k$ on their capital K_t, net of the capital gain tax τ_t^k. Finally, households get a profit of J_t from the firm.

The first-order conditions with respect to consumption, labour, and bond holding are:

$$(C_t - hC_{t-1})^{-\sigma} = \lambda_t^b P_t \tag{4.3}$$

$$H_t^{o\varphi} = \lambda_t^b (1 - \tau_t^w) W_t \tag{4.4}$$

$$P_t^B = \beta E_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}} \right] \tag{4.5}$$

$$P_t^{Bf^*} = \beta E_t \left[\frac{\Lambda_{t+1}}{\pi_{t+1}} \frac{S_{t+1}}{S_t} \right] \tag{4.6}$$

where $\Lambda_{t+1} \equiv \frac{\lambda_{t+1}^b}{\lambda_t^b}$.

The nominal return on domestic bond holdings is given by $R_t^b = \frac{1}{P_t^B}$. In the case of foreign bonds, they are assumed to depend on a risk premium that takes into account the exposure to foreign debt

$$R_t^{b^*} = \frac{1}{P_t^* \psi \left(\frac{S_t B_t^{f^*}}{P_t^h Y_t} \right)} \tag{4.7}$$

where $\psi(x)$ is a functional form which can be shown as follow

$$\psi(x) = \exp(-\psi_B x); \psi_B > 0 \tag{4.8}$$

Accordingly, we can re-write and combine equations (4.5), and (4.6) to give an uncovered interest parity condition (UIP)

$$R_t^b = R_t^{b^*} \psi \left(\frac{S_t B_t^{f^*}}{P_t^h Y_t} \right) \pi_{t+1}^s \tag{4.9}$$

where $\pi_{t+1}^s \equiv \frac{S_{t+1}}{S_t}$ is the depreciation rate of the nominal exchange rate in the home country.

Non-Ricardian households

Credit-constrained consumers face the same problem as Ricardian households; however, their budget constraint function is more simplified. Each of these households seeks to maximise its lifetime utility function knowing that

$$P_t C_t^{nr} = (1 - \tau_t^w) W_t H_t^{nr} \tag{4.10}$$

where superscript nr denotes non-Ricardian households. The first order condition is therefore:

$$(C_t^{nr} - hC_{t-1}^{nr})^v H_t^{nr\zeta} = (1 - \tau_t^w) \frac{W_t}{P_t} \tag{4.11}$$

where υ, and ζ are the elasticity of substitution inter-temporally and the elasticity of hours worked for non-Ricardian households, respectively.

Aggregate Consumption and Labour

Aggregate consumption level and labour supply are given by

$$C_t = (1-\omega)C_t^o + \omega C_t^{nr},$$

$$H_t = (1-\omega)H_t^o + \omega H_t^{nr},$$

4.2.2 Consumption Demand

Consumption C_t is a Dixit-Stiglitz aggregator of a bundle of differentiated goods which includes consumption in the home country C_t^h and consumption of imported goods from foreign countries C_t^f. Therefore, households demand consumption goods to maximise:

$$C_t = \left[(\omega_c^h)^{\frac{1}{\nu_c}} {C_t^h}^{\frac{\nu_c-1}{\nu_c}} + (1-\omega_c^h)^{\frac{1}{\nu_c}} {C_t^f}^{\frac{\nu_c-1}{\nu_c}} \right]^{\frac{\nu_c}{\nu_c-1}} \tag{4.12}$$

The price index P_t is given by the equation

$$P_t = \left[\omega_c^h {P_t^h}^{1-\nu_c} + (1-\omega_c^h) {P_t^f}^{1-\nu_c} \right]^{\frac{1}{1-\nu_c}} \tag{4.13}$$

where ω_c^h represents the weight of domestic produced goods' consumption. Maximising total consumption in (4.12) subject to the aggregate expenditure $P_t C_t =$

$P_t^h C_t^h + P_t^f C_t^f$ yields

$$C_t^h = \omega_c^h \left(\frac{P_t^h}{P_t}\right)^{-\nu_c} C_t \tag{4.14}$$

$$C_t^f = (1-\omega_c^h) \left(\frac{P_t^f}{P_t}\right)^{-\nu_c} C_t \tag{4.15}$$

In this case, agents need to choose between two kinds of consumption with $\nu_c > 1$ determining the elasticity of substitution. (Kaplan, Moll and Violante, 2020).

4.2.3 Investment Demand

Let P_t^i denote the aggregate price for the investment. Households choose to invest in the domestic market and abroad to maximise

$$I_t = \left[(\omega_i^h)^{\frac{1}{\nu_i}} {I_t^h}^{\frac{\nu_i - 1}{\nu_i}} + (1-\omega_i^h)^{\frac{1}{\nu_i}} {I_t^f}^{\frac{\nu_i - 1}{\nu_i}} \right]^{\frac{\nu_i}{\nu_i - 1}} \tag{4.16}$$

The price index P_t^i is given by the equation

$$P_t^i = \left[\omega_i^h {P_t^h}^{1-\nu_i} + (1-\omega_i^h) {P_t^f}^{1-\nu_i} \right]^{\frac{1}{1-\nu_i}} \tag{4.17}$$

Maximising total investment in (4.16) subject to the aggregate expenditure $P_t^i I_t = P_t^h I_t^h + P_t^f I_t^f$ yields

$$I_t^h = \omega_i^h \left(\frac{P_t^h}{P_t^i}\right)^{-\nu_i} I_t \tag{4.18}$$

$$I_t^f = (1 - \omega_i^h) \left(\frac{P_t^f}{P_t^i} \right)^{-\nu_i} I_t \tag{4.19}$$

4.2.4 Firms

Wholesaler The economy consists of a continuum of firms indexed by $i \in [0;1]$ which exploits labour, capital, intermediate input, and technology to produce a differentiated good. Each intermediate good i is produced by a monopolistically competitive producer following the Cobb-Douglas production function:

$$Y_t(i) = A_t H_t(i)^{\alpha_H} M_t(i)^{\alpha_M} K_t^{1-\alpha_H-\alpha_M} \tag{4.20}$$

where A_t represents a level of total factor productivity (TFP) which follows $AR(1)$ process in log values with normal i.i.d shock, K_t denotes capital stock, α_H is the share of labour participating in the production, and α_M denotes the share of intermediate input $M_t(i)$ employed during the production process. $Y_t(i)$ is the differentiated output i produced by firm i at time t.

Given these constraints, firms will maximise their profit

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k} \left\{ Y_{t+k}(i) P_{t+k}(i) - R_t^k K_t - W_t H_t(i) - P_t^M M_t(i) \right\} \tag{4.21}$$

Knowing that firms sell their products at nominal price $P_t(i)$, the first order conditions with respect to H_t, K_t, and M_t are

$$W_t = \alpha_H MC_t \frac{Y_t(i)}{H_t(i)} \tag{4.22}$$

$$R_t^k = (1 - \alpha_H - \alpha_M) MC_t \frac{Y_t(i)}{K_t} \tag{4.23}$$

$$P_t^M = \alpha_M MC_t \frac{Y_t(i)}{M_t(i)} \tag{4.24}$$

where MC_t is the nominal marginal cost.

Capital Producers

To produce capital, firms purchase investment goods domestically as well as import them from foreign retail firms at real price $\frac{P_t^i}{P_t}$, and then they sell these produced capitals at real price Q_t to maximize profits

$$E_t \sum_{k=0}^{\infty} \beta^k \Lambda_{t+k} \left[Q_{t+k} \left(1 - \mathcal{S}(I_{t+k})\right) I_{t+k} - \frac{P_t^i}{P_t} I_{t+k} \right] \tag{4.25}$$

where $\mathcal{S}(I_t)$ is a function of investment adjustment cost, which can be shown as

$$\mathcal{S}(I_t) \equiv \frac{\eta}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \tag{4.26}$$

where η measures the intensity of investment adjustment cost.

The capital is accumulated with the following law of motion

$$K_{t+1} = (1 - \delta) K_t + (1 - \mathcal{S}(I_t)) I_t \tag{4.27}$$

where δ is the depreciation rate of capital.

Given the capital's law of motion and demand for investment in equation (4.16), the first-order condition can be derived as follow

$$\frac{P_t^i}{P_t} = Q_t(1 - \mathcal{S}(I_t) - \frac{I_t}{I_{t-1}}\mathcal{S}'(I_t)) + E_t\left[\Lambda_{t+1}Q_{t+1}\mathcal{S}'(I_{t+1})\frac{I_{t+1}^2}{I_t^2}\right] \tag{4.28}$$

We then define gross real return on capital as $\widehat{R}_t^k$, which is given by

$$\widehat{R}_t^k = \frac{(1-\alpha_H-\alpha_M)(1-\tau_t^k)\frac{Y_t(i)P_t(i)}{K_tP_t} + (1-\delta)Q_t}{Q_{t-1}} \tag{4.29}$$

where τ_t^k is the capital tax charged by the government. Finally, we assume efficient financial intermediation within the home country that implies zero arbitrage condition in the market, giving Q_t the steady state value of 1.

$$E_t\left[\Lambda_{t+1}\widehat{R}_{t+1}^k\right] = E_t\left[\frac{\Lambda_{t+1}}{\pi_{t+1}}\right]R_t^b = 1 \tag{4.30}$$

Intermediate Input Demand

Following the households' demand for consumption, and investment; firms choose their sources of input to maximise

$$M_t = \left[(\omega_m^h)^{\frac{1}{\nu_i}}M_t^{h\,\frac{\nu_m-1}{\nu_m}} + (1-\omega_m^h)^{\frac{1}{\nu_m}}M_t^{f\,\frac{\nu_m-1}{\nu_m}}\right]^{\frac{\nu_m}{\nu_m-1}} \tag{4.31}$$

The price index P_t^m is given by the equation

$$P_t^m = \left[\omega_m^h P_t^{h\,1-\nu_m} + (1-\omega_m^h)P_t^{f\,1-\nu_m}\right]^{\frac{1}{1-\nu_m}} \tag{4.32}$$

Maximising total intermediate input in (4.31) subject to the aggregate expenditure $P_t^m M_t = P_t^h M_t^h + P_t^f M_t^f$ yields

$$M_t^h = \omega_m^h \left(\frac{P_t^h}{P_t^m} \right)^{-\nu_m} M_t \tag{4.33}$$

$$M_t^f = (1 - \omega_m^h) \left(\frac{P_t^f}{P_t^m} \right)^{-\nu_m} M_t \tag{4.34}$$

Final Goods

In each sector, there is a continuum of differentiated intermediate goods i with $i \in [0; 1]$. The production function of this type of firm follows the CES form:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \tag{4.35}$$

where $Y_t(i)$ denotes the quantity of the differentiated intermediate good i across sectors, and $\epsilon > 0$ denotes the elasticity of substitution between products. These firms confront profit maximisation by optimising the amount of each intermediate good produced.

The profit maximisation of the final goods firms takes the form

$$\max_{Y_t(i)} P_t^h Y_t - \int_0^1 P_t^h(i) Y_t(i) di \tag{4.36}$$

Taking F.O.C with respect to $Y_t(i)$, we have

$$P_t^h \left(\frac{Y_t}{Y_t(i)} \right)^{\frac{1}{\epsilon}} - P_t^h(i) = 0 \tag{4.37}$$

Thus, the demand for intermediate goods is

$$Y_t(i) = Y_t \left(\frac{P_t^h(i)}{P_t^h} \right)^{-\epsilon} \tag{4.38}$$

where $P_t^h = \left[\int_0^1 P_t^h(i)^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$ is price index.

Aggregate Price Level

Firms producing intermediary goods can maximise profit by determining the optimal price following the Calvo rule. In each period, a fraction $(1 - \theta)$ of producers resets their prices $P_t^{h^o}$ while the rest of the firms keep their prices unchanged. In this context, θ can be regarded as a natural index of price stickiness. As a result, the aggregate price can be indicated as follows

$$P_t^h = \left[\theta (P_{t-1}^h)^{1-\epsilon} + (1 - \theta)(P_t^{h^o})^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \tag{4.39}$$

Optimal Price Setting

As far as the optimal price-setting behaviour is concerned, a re-optimising firm will choose the price $P_t^{h^o}$ that maximises the current market value of the profits generated while that price remains effective. Thus, the representative firm's profit maximisation problem is given by

$$\max_{P_t^{h^o}} E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} [P_t^{h^o} Y_{t+k}(i) - TC_{t+k}(Y_{t+k}(i)) \xi_{t+k}^m] \tag{4.40}$$

subject to demand constraint

$$Y_{t+k}(i) = \left(\frac{P_t^{h^o}}{P_{t+k}^h}\right)^{-\epsilon} Y_{t+k} \tag{4.41}$$

where $TC_t(\cdot)$ is the function of firm's total cost and $Y_{t+k|t}$ denotes output in period $t+k$ for a firm that last resets its price in period t. Taking F.O.C with respect to $P_t^{h^o}$, we have

$$E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} Y_{t+k}(i) \left(P_t^{h^o} {P_{t+k}^h}^{\epsilon-1} - \frac{\epsilon}{\epsilon-1} mc_{t+k} \xi_{t+k}^m {P_{t+k}^h}^{\epsilon} \right) = 0 \tag{4.42}$$

where mc_t is the real marginal cost.

Thus, the optimisation yields the following price-setting rule

$$P_t^{h^o} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {P_{t+k}^h}^{\epsilon} Y_{t+k} mc_{t+k} \xi_{t+k}^m}{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {P_{t+k}^h}^{\epsilon-1} Y_{t+k}} \tag{4.43}$$

By defining $\pi_{t+k}^h \equiv \frac{P_{t+k}^h}{P_t^h}$ as home inflation, we can re-write previous equation as

$$\frac{P_t^{h^o}}{P_t^h} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {\pi_{t+k}^h}^{\epsilon} Y_{t+k} mc_{t+k} \xi_{t+k}^m}{E_t \sum_{k=0}^{\infty} (\beta\theta)^k \Lambda_{t+k} {\pi_{t+k}^h}^{\epsilon-1} Y_{t+k}} \tag{4.44}$$

4.2.5 Commodity Sector

In this study, we modify the model to include a commodity sector that plays an important source of income in emerging countries. This is done by adding an exogenous variable Y^o, which represents the production, and net consumption of crude oil over time. Then, oil is traded on the market at the price $P_t^{o^*}$, given the exchange rate S_t; as a result, the revenue from selling oil or the cost of purchasing this material abroad will contribute directly to the government constraint (equation

4.46) and trade balance (equation 4.60) in the home country. Therefore, it is worth considering a shock to oil prices when we analyse an emerging economy. In this case, it is assumed that the oil price follows an AR(1) process

$$P_t^{o^*} = \gamma_t^{P^o} P_{t-1}^{o^*} + \epsilon_t^{P^o} \tag{4.45}$$

where $\epsilon_t^{P^o}$ is an exogenous shock and $gamma_t^{P^o}$ is the persistency of the shock.

4.2.6 Government

Fiscal Policy

The government will generate income from taxes collected from households and issue new public debt through government bonds to fund its expenditures and finance the existing debt. As a result, the nominal flow of budget constraint is given by:

$$G_t = P_t^B B_t^h - B_{t-1}^h + \tau_t^o S_t P_t^{o^*} Y^o + \tau_t^w W_t H_t + \tau_t^k R_t^k K_t \tag{4.46}$$

where $P_t^B B_t^h$ is the issuance of new government bonds at price P_t^B in time t, τ_t^o is the tax revenue collected from commodity sector. All of these taxes collected from capital τ_t^k, labour τ_t^w, commodity τ_t^o and bonds are deployed to finance its government spending (G_t), and the existing debt in the previous period B_{t-1}. It is assumed that the government keeps tax rates unchanged over the periods while adjusting its public spending following the AR(1) process

$$\log(G_t) = \gamma_g \log(G_{t-1}) + \epsilon_t^g; \tag{4.47}$$

where γ_g is the persistence of public spending in the previous period, and ϵ_t^g is the error term.

Monetary Policy

The central bank will set the nominal interest rate that takes into account the inflation rate, output, and exchange rate depreciation. The monetary rule is as follows

$$\log\left(\frac{R_t^b}{R^b}\right) = \gamma_r \log\left(\frac{R_{t-1}^b}{R^b}\right) + (1-\gamma_r)\left(\gamma_\pi \log\frac{\pi_t}{\pi} + \gamma_y \log\frac{Y_t}{Y} + \gamma_s \log\frac{\pi_t^s}{\pi^s}\right) - \epsilon_t^r \quad (4.48)$$

where γ_r is the persistence of lagged interest rate, γ_π, γ_y, and γ_{π^s} are the feedback from inflation, output, and depreciation rate respectively, and ϵ_t^r is the error term.

4.2.7 Foreign market

Let RER_t denote the real exchange rate of Vietnamese Dong (VND) against the foreign currency, i.e. US Dollar (USD), it is defined as $RER_t \equiv \frac{P_t^* S_t}{P_t}$. As a result, the foreign country faces the same problem as the home country in demanding exported goods. The demand for the export of home goods is therefore defined by this equation

$$C_t^{h^*} = (1-\omega_c^{h^*})\left(\frac{P_t^{h^*}}{P_t^*}\right)^{-\nu_c^*} C_t^* \quad (4.49)$$

By substituting S_t and P_t^* into this equation, we have

$$C_t^{h^*} = (1-\omega_c^{h^*})\left(\frac{P_t^h}{P_t RER_t}\right)^{-\nu_c^*} C_t^* \quad (4.50)$$

Besides, as the home country is small, and the law of one price implies $P_t^* = P_t^{f^*}$, we have $S_t P_t^* = P_t^f$; therefore, the real exchange rate can be derived as $RER_t = \frac{P_t^f}{P_t}$. Defining terms of trade as a ratio of the price of imported goods in the home country to that of domestic goods, $\mathcal{T}_t \equiv \frac{P_t^f}{P_t^h}$; consequently, equation (4.50) becomes

$$C_t^{h^*} = (1 - \omega_c^{h^*}) \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_c^*} C_t^* \tag{4.51}$$

This condition also holds for foreign investment demand; therefore, we have

$$I_t^{h^*} = (1 - \omega_i^{h^*}) \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_i^*} I_t^* \tag{4.52}$$

Vietnam's aggregate export is determined by foreign demand for consumption and investment in the home country's export

$$X_t = C_t^{h^*} + I_t^{h^*} \tag{4.53}$$

Given the small size of the home country's economy relative to the rest of the world, the export demand for consumption and investment are directly proportional to the aggregate consumption and investment of foreign countries; hence, we have

$$C_t^{h^*} \propto \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_c^*} C_t^* \tag{4.54}$$

$$I_t^{h^*} \propto \left(\frac{1}{\mathcal{T}_t} \right)^{-\nu_i^*} I_t^* \tag{4.55}$$

As a result, we can derive the deviation of export demand from its steady state as below

$$\frac{X_t}{X} = x_c \left(\frac{1}{\mathcal{T}_t}\right)^{-\nu_c^*} \frac{C_t^*}{C^*} + x_i \left(\frac{1}{\mathcal{T}_t}\right)^{-\nu_i^*} \frac{I_t^*}{I^*} \tag{4.56}$$

where x_c and x_i are export shares of consumption, and investment, respectively.

Now, we do not take foreign consumption level as an exogenous variable that follows AR(1) processes; we rather model a separate system for the foreign bloc so that the net export sector in home countries will be affected by the structure of the foreign economy. In that sense, we will build a New Keynesian model which determines foreign output Y_t^*, and consumption level C_t^*. As a result, the structure of the foreign economy resembles the one in the home country, which includes Ricardian and non-Ricardian households, firms with price stickiness, monetary policy and fiscal policy. However, the monetary policy in the foreign country is different as it takes into account the Zero Lower Bound feature and does not respond to the effect of exchange rate depreciation.

$$\log\left(\frac{R_t^{b^*}}{R^{b^*}}\right) = max\left[0, \gamma_r^* \log\left(\frac{R_{t-1}^{b^*}}{R^{b^*}}\right) + (1-\gamma_r^*)\left(\gamma_\pi^* \log\frac{\pi_t^*}{\pi^*} + \gamma_y^* \log\frac{Y_t^*}{Y^*}\right) - \epsilon_t^{r^*}\right] \tag{4.57}$$

In this model, any variables or parameters with superscript (*) will be used to indicate the foreign market. The reason for a disparate set of parameters in the foreign country is due to the differences in characteristics and the size of the economy between Vietnam and that foreign country, making them have different parameter values. The parameters of the foreign country will be estimated in the next section.

4.2.8 Market Clearing

In equilibrium, goods market-clearing expects the output produced net of utilisation costs to equal the demand for private as well as public consumption and investment. In other words, the aggregate demand is equal to the aggregate supply

$$Y_t = C_t + I_t + G_t + X_t \tag{4.58}$$

Foreign bond holding evolves following the law of motion

$$P_t^{B^*} S_t B_t^{f^*} = S_t B_{t-1}^{f^*} + P_t \Gamma_t \tag{4.59}$$

where $P_t \Gamma_t$ is the nominal trade balance that is equivalent to the difference between domestic output, private and public consumption, investment

$$P_t \Gamma_t = S_t P_t^{o^*} Y^o + P_t^h Y_t - P_t C_t - P_t^i I_t - P_t^m M_t - P_t^h G_t \tag{4.60}$$

4.2.9 Shock Processes

For home countries, we have technology shock, investment demand shock, and price mark-up shock. The structural shock processes in the log-linearised form are assumed to follow AR(1) processes are

$$\log(A_t) = \gamma_a \log(A_{t-1}) + \epsilon_t^a; \tag{4.61}$$

$$\log(I_t) = \gamma_i \log(I_{t-1}) + \epsilon_t^i; \tag{4.62}$$

$$\log(\xi_t^m) = \gamma_{\xi^m} \log(\xi_{t-1}^m) + \epsilon_t^{\xi^m}; \tag{4.63}$$

Similarly, the exogenous variables in foreign countries are also assumed to follow AR(1) processes

$$\log(A_t^*) = \gamma_a^* \log(A_{t-1}^*) + \epsilon_t^{a^*}; \tag{4.64}$$

$$\log(I_t^*) = \gamma_i^* \log(I_{t-1}^*) + \epsilon_t^{i^*}; \tag{4.65}$$

$$\log(\xi_t^{m^*}) = \gamma_{\xi^m}^* \log(\xi_{t-1}^{m^*}) + \epsilon_t^{\xi^m}; \tag{4.66}$$

4.3 Data and Estimation

In this section, we estimate stochastic shocks and parameters using the Bayesian method. In this estimation process, the Kalman filter is first applied to find the likelihood function of the observable variables. Next, we combine this function and the prior distribution to get the posteriors. Finally, by using the Metropolis-Hasting algorithm (MH), we compute the posterior kernel, choose a transition, and use a rejection rule to draw posterior sequences.

4.3.1 Foreign Bloc

In this study, we employ data from the US to estimate the foreign bloc. This country is chosen due to its huge size of economy and a great share of trade openness. Furthermore, the US is one of its main trading partners in Vietnam, which accounts for up to approximately 23.21% of the home country's export. In this regard, we extract the data set from the FRED database of the Federal Reserve Bank of St. Louis. The sample is collected quarterly from 1999 to 2019 and is seasonally adjusted. This time range is reasonable because the diplomatic relations between the US and Vietnam have just been formally normalised since 1995; besides, the period ends in Q4 of 2019 to get rid of the shocks caused by the COVID-19 pandemic. The interested time series are real GDP, consumption level, inflation rate, and policy rate. However, these series need to be transformed by taking the first difference to be stationary.

	Parameter	**Calibrated value**
β^*	Discount factor	0.99
δ^*	Depreciation rate of capital	0.025
g_y^*	Share of government spending	0.15

Table 4.1: Calibrated parameter values for Foreign Bloc

Before doing the estimation with real data, there are a few structural parameters that need calibrating. As a result, we fix some common parameters following the existing literature; these calibrated values can be seen in table 4.1. Accordingly, we set the US discount factor at $\beta^* = 0.99$, which is in line with the large literature on New Keynesian models. Besides, the capital assets are assumed to depreciate at the rate $\delta^* = 0.025$. Lastly, the steady-state value of US government spending g_y^* is fixed at 15% of the country's GDP.

	Description	Prior Distribution			Posterior Distribution		
		Distribution	*Mean*	*Prior SD*	*Mean*	*5%*	*95%*
	Structural parameters						
α_H^*	Share of labour	*Beta*	0.500	0.2000	0.5643	0.4810	0.6425
α_M^*	Share of intermediate input	*Beta*	0.300	0.05	0.3461	0.2590	0.4293
ω^*	Share of non-Ricardian households	*Gamma*	0.200	0.05	0.2001	0.1273	0.2705
η^*	Investment adjustment cost	*Gamma*	2.000	1.5	3.0654	1.5365	4.4760
θ^*	Calvo price stickiness	*Beta*	0.5	0.1	0.8332	0.7802	0.8973
h^*	Habit formation of consumption	*Beta*	0.5	0.1	0.5544	0.4386	0.6790
σ^*	Elasticity of intertemporal substitution for Ricardians	*Gamma*	1.5	0.3750	2.0410	1.5608	2.4866
υ^*	Elasticity of intertemporal substitution for non-Ricardians	*Gamma*	1.5	0.3750	1.4528	0.8469	2.0651
φ^*	Inverse Frisch labour elasticity for Ricardians	*Gamma*	2.0	0.75	1.1498	0.0847	2.1526
ζ^*	Inverse Frisch labour elasticity for non-Ricardians	*Gamma*	2.0	0.75	2.0620	0.8597	3.2854
γ_π^*	Feedback from inflation	*Gamma*	2.0	0.25	2.1018	1.7389	2.4795
γ_y^*	Feedback from output	*Gamma*	0.1	0.05	0.0897	0.0213	0.1575
	Autoregressive parameters						
γ_a^*	Technology	*Beta*	0.5	0.2	0.5017	0.3268	0.6856
$\gamma_{\xi^m}^*$	Mark-up	*Beta*	0.5	0.2	0.3413	0.0611	0.6249
γ_g^*	Government spending	*Beta*	0.5	0.2	0.4508	0.2242	0.6765
γ_{i^*}	Foreign investment demand	*Beta*	0.5	0.2	0.7383	0.6141	0.8641
γ_{r^*}	Monetary policy	*Beta*	0.7	0.1	0.7797	0.7151	0.8490
	Standard errors						
ϵ^{a^*}	Technology shock	*InvGamma*	0.001	0.02	0.0221	0.0113	0.0323
$\epsilon^{\xi^{m*}}$	Mark-up shock	*InvGamma*	0.001	0.02	0.0564	0.0096	0.1038
ϵ^{g^*}	Government spending	*InvGamma*	0.001	0.02	0.0150	0.0111	0.0186
ϵ^{i^*}	Investment shock	*InvGamma*	0.001	0.02	0.0289	0.0146	0.0419
ϵ^{r^*}	Monetary policy	*InvGamma*	0.001	0.02	0.0038	0.0028	0.0049

Table 4.2: Prior and posterior distribution of parameters in foreign bloc

Priors Setting

In our model, we estimate five stochastic shocks for the foreign bloc. These shocks include technology shock, price mark-up shock, spending shock by the government, foreign investment demand shock, and monetary policy shock. The estimation also requires choosing a proper type of distribution for each parameter. For instance, we have beta distribution, gamma distribution, and inverse gamma distribution. Another step is to set the prior mean of estimated parameters. Accordingly, we expect that there are 80% of people living in the US have access to the financial market. Furthermore, we set the elasticity of intertemporal substitution at $\sigma^* = \upsilon^* = 1.5$ and the elasticity of working hours has the value of 2 for both types of household. Besides, the consumption habit of households is set at $h^* = 0.5$. On the production side, we suppose that labour and intermediate input account for up to 50%, and 30%, respectively, in the process of producing goods and services.

Additionally, investment adjustment cost is assumed to equal 2; for the value of Calvo price stickiness, we set $\theta^* = 0.5$.

In terms of monetary policy, the responses from inflation and output are set at $\gamma_\pi^* = 2$, and $\gamma_y^* = 0.1$, respectively. In addition, we expect the policy to be consistent with the previous period; hence, the prior mean of γ_r^* is set at 0.7. Finally, for stochastic shocks, we set the priors of the autoregressive parameters at 0.5 so they diminish at a moderate rate while the prior means of the standard errors are kept at 0.001. The results for the prior and posterior distribution of these parameters and shocks are shown in Table 4.2.

Parameter estimates

The posterior means of the structural parameters and their corresponding 90% confidence intervals are summarised in the last three columns of Table 4.2. For instance, we do not see big differences between the prior and posterior means of labour share, intermediate input share, and share of non-Ricardian households. However, this is not the case for the posterior mean of investment adjustment cost intensity, which has the value of $\eta^* = 3.0654$, implying that the investment is more sensitive to changes in the price of capital compared to what we have expected. Likewise, we notice that the price appears to be more sticky as its value is increased from 0.5 to 0.8332 after the estimation.

Regarding the characteristics of households, the posterior mean of habit formation of consumption is close to its prior value, which is $h^* = 0.5544$. Next, it is shown that Ricardian households have a higher elasticity of intertemporal substitution and a lower rate of labour elasticity. Furthermore, it can be shown that the monetary policy rule in the US responds strongly to inflation and does not vary much with the change in output; besides, these posterior values are close to their prior means as we have $\gamma_\pi^* = 2.1018$, and $\gamma_y^* = 0.0897$. Additionally, the policy is relatively persistent because the coefficient of its lagged value is quite high with $\gamma_{r^*} = 0.7797$.

Moreover, by looking at the estimates of autoregressive parameters, we notice that technology shock and government spending shock are not as persistent over time; their posterior means are close to 0.5 accordingly. Additionally, price mark-up shock is likely to diminish at the greatest pace as its autoregressive parameter has a value as low as 0.3413. This is not the case for foreign investment demand shock, which puts great weight on its lagged value, the posterior mean of γ_{i^*} is 0.7383. Finally, it is necessary to consider the posterior means of shocks' standard errors. It is shown that price mark-up shock is the most volatile as its posterior mean of the variance has a value of 0.0564; in contrast, a shock to policy rate is the least volatile shock in this model with a posterior mean of only 0.0038. For the other shocks, their standard errors vary around 0.02.

4.3.2 Vietnam Bloc

The approach to data processing in the previous section is consistent with the case of Vietnam. For instance, we first collect relevant quarterly data from 2000 to 2019. This is because the data is not fully available before 2000, and the State Bank of Vietnam (SBV) did not set the interest rate to control monetary policy until this year. Then, these data will be made stationary in order to estimate the model. The main sources of data are extracted from the Vietnam General Statistics Office (GSO), and the World Bank which includes Real GDP, CPI, policy rate, exchange rate, and terms of trade.

Likewise, before estimating the home country bloc, we calibrate some parameters

	Parameter	Calibrated value
β	Discount factor	0.99
δ	Depreciation rate of capital	0.025
α	Share of labour	0.5
α_M	Share of intermediate input	0.3
ω	Share of non-Ricardian households	0.3
θ	Price stickiness	0.75
h	Consumption habit	0.7
σ/υ	Elasticity of intertemporal substitution	1.5
φ/ζ	Inverse Frisch labour elasticity	2.0
g_y	Share of government spending	0.11

Table 4.3: Calibrated parameter values for Vietnam Bloc

that fit Vietnam's economy; they are listed in Table 4.3. In line with the US economy, the discount factor and depreciation rate are fixed at $\beta = 0.99$, and $\delta = 0.025$, respectively. For other parameters, we set the share of non-Ricardian households at 30% of agents participating in the economy; besides, the consumption habit of households is more persistent with $h = 0.7$. Regarding the elasticity of intertemporal substitution, we set its value to 1.5 for both types of households; similarly, the value inverse Frisch labour elasticity is calibrated at $\varphi = \zeta = 2.0$. On the aspect of production activity, labour is still in the majority, which takes 50% of the total input. Another 30% is given to intermediate input, making the capital stock account for only 20% in the production process. Moreover, Calvo price stickiness has a value of 0.75, which is consistent with many macroeconomic studies. Finally, the figure for public spending accounts for 11% of Vietnam's GDP; hence, the share of government spending is $g_y = 0.11$.

Priors Setting

Regarding the priors setting, we set the mean of the investment cost in the home country to 2.0. In addition, the prior means of autoregressive parameters and the standard errors remain unchanged in the home market. The only different value is

	Description	Prior Distribution			Posterior Distribution		
		Distribution	*Mean*	*Prior SD*	*Mean*	*5%*	*95%*
	Parameters						
η	Investment adjustment cost	*Gamma*	2.0	0.75	4.3811	3.0340	5.6737
γ_π	Feedback from inflation	*Gamma*	2.0	0.25	1.4561	1.2016	1.6951
γ_y	Feedback from output	*Gamma*	0.1	0.05	0.0270	0.0133	0.0408
γ_{π^s}	Feedback from exchange rate depreciation	*Gamma*	0.1	0.05	0.0987	0.0251	0.1710
γ_a	Technology	*Beta*	0.5	0.2	0.9083	0.8513	0.9671
γ_{ξ^m}	Mark-up	*Beta*	0.5	0.2	0.8055	0.7508	0.8572
γ_g	Government spending	*Beta*	0.5	0.2	0.4944	0.1721	0.8264
γ_i	Investment demand	*Beta*	0.5	0.2	0.8270	0.7015	0.9727
γ_r	Monetary policy	*Beta*	0.7	0.1	0.5852	0.4687	0.7097
	Standard errors						
ϵ^a	Technology shock	*InvGamma*	0.001	0.02	0.0085	0.0065	0.0105
ϵ^{ξ^m}	Mark-up shock	*InvGamma*	0.001	0.02	0.0626	0.0463	0.0791
ϵ^g	Government spending	*InvGamma*	0.001	0.02	0.0008	0.0002	0.0015
ϵ^i	Investment shock	*InvGamma*	0.001	0.02	0.0099	0.0046	0.0169
ϵ^r	Monetary policy	*InvGamma*	0.001	0.02	0.0008	0.0002	0.0014

Table 4.4: Prior and posterior distribution of parameters in home country

the response to lagged interest rate, $\gamma_r = 0.7$. Besides, as the Vietnamese government also considers the value of the domestic currency when adjusting the policy rate, we need to set the prior mean for the parameter γ_{π^s}. In this sense, the State Bank of Vietnam responds strongly to the inflation rate, and weakly to both output, and depreciation rate; hence, γ_π has the value of 2.0 while γ_y, and γ_{π^s} are assigned to 0.1. The prior and posterior distribution of parameters are shown in Table 4.4.

Parameter estimates

The estimates of parameters in the home country show that the investment adjustment cost is higher in Vietnam compared to the US. For instance, the posterior estimate of η is 4.3811, making the investment in the home country even more sensitive to the price change of capital in the foreign market. Moreover, though the Central Bank of Vietnam does not put as much weight as the US does on the inflation rate when setting their policy rule, this factor is still the most significant influence on monetary policy with $\gamma_\pi = 1.4561$. On the other hand, feedback from exchange rate depreciation appears to be stronger compared to the response to output.

Besides, the posterior means of autoregressive parameters show that technology shock, price mark-up shock and investment demand are strongly persistent as they respond significantly to their lagged values. However, this is not the case for changes in fiscal policy and monetary policy, which are less persistent and diminish more quickly after the shocks. Regarding the standard errors of stochastic shocks, it appears that shocks in Vietnam are quite modest compared to the US economy; the most volatile shock in Vietnam is the price mark-up shock with $\epsilon^{\xi^m} = 0.0884$.

Variable	Coefficient	Std. Error	t-Statistic	P> |t|	5%	95%
$P^{o^*}_{t-1}$	0.2113	0.0878	2.41	0.018	0.0375	0.3850
S.E. of regression	8.8434					

Table 4.5: Estimate of Oil Price Shock

Finally, we use oil price data collected quarterly from 1990 to 2020 from the Federal Reserve Bank of St. Louis to estimate the oil price shock separately. Regarding the commodity sector, oil price follows an AR(1) process; therefore, we estimate the coefficient and standard error subsequently by fitting an autoregressive model with one lag. The result shows the magnitude of shock persistence $\gamma^*_{P^o}$ and the standard error in shock block as in Table 4.5. It is worth noting that the oil price shock is not so persistent as its effect would reduce significantly after just one period; additionally, the standard error of the shock is relatively large with $\epsilon^{P^o} = 0.0878$, suggesting high volatility in the price of oil globally.

4.4 Results and Impulse response functions

4.4.1 Variance decomposition

In this part, we investigate the variance decomposition to identify the causes that influence output growth and price level in Vietnam during the last 20 years. Accordingly, the fluctuation of these variables and their sources are shown in figure 4.3, and figure 4.4, respectively. Overall, these variations are attributed to domestic shocks, foreign shocks, oil price shocks, and term of trade shocks. Besides, the mentioned shocks have diverse effects on output growth, and price level. Finally, the term "initial values" in graphs refers to the source of variance that is caused by the unknown initial value of that state variable rather than the other smoothed shocks; the impact of these starting values usually disappears relatively quickly. (Pfeifer, 2014).

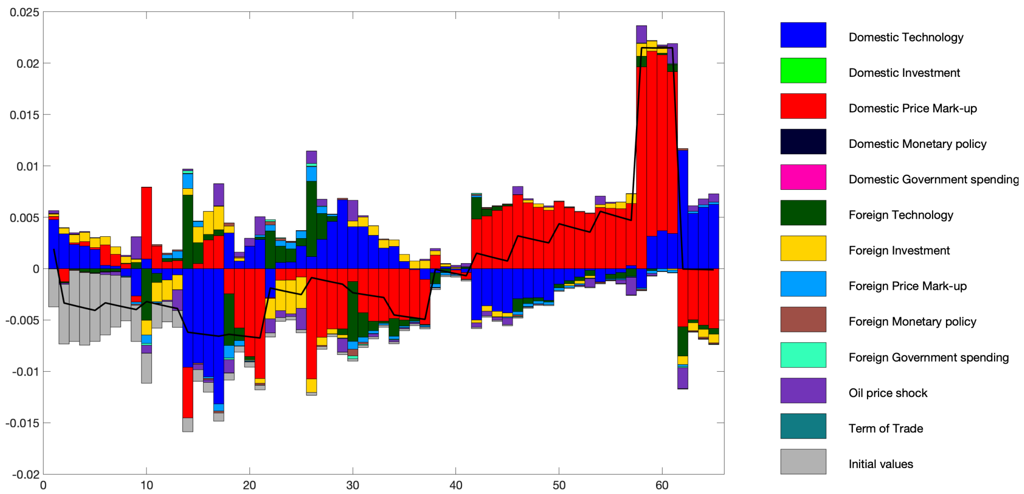

Figure 4.3: Variance decomposition of Output

Firstly, it is worth noting that output growth in Vietnam is mainly associated with domestic shocks including technology shocks and price mark-up shocks in most periods. For instance, figure 4.3 shows that the change in price mark-up contributes the most to the variance of output growth, and this is persistent over time. Besides, the contribution of technology shock to output growth appears to be smaller than that of price mark-up shock; however, it is still significant in terms of magnitude and density. More importantly, it is worth mentioning that the domestic shocks dominate the foreign shocks in the variance decomposition of Vietnamese output in the later part of the sample; in fact, output growth's variance in Vietnam does not capture many shocks in the foreign market. However, they still have their role in influencing the Vietnamese economy. In those foreign shocks, it is suggested that technology shock and investment shock arising in the US are the major sources influencing the output growth in Vietnam besides some dominant domestic shocks. For instance, their existence is clearly seen in the early periods ranging from 10 to 25, which can be explained by the global financial crisis in the US that hits Vietnam's economy in 2008.

Besides, it would be a mistake if we do not mention the impact of the oil price shock in this case. Although the size of this shock is not as large as others, it is an important factor in explaining the fluctuation in output growth in Vietnam over the last twenty years.

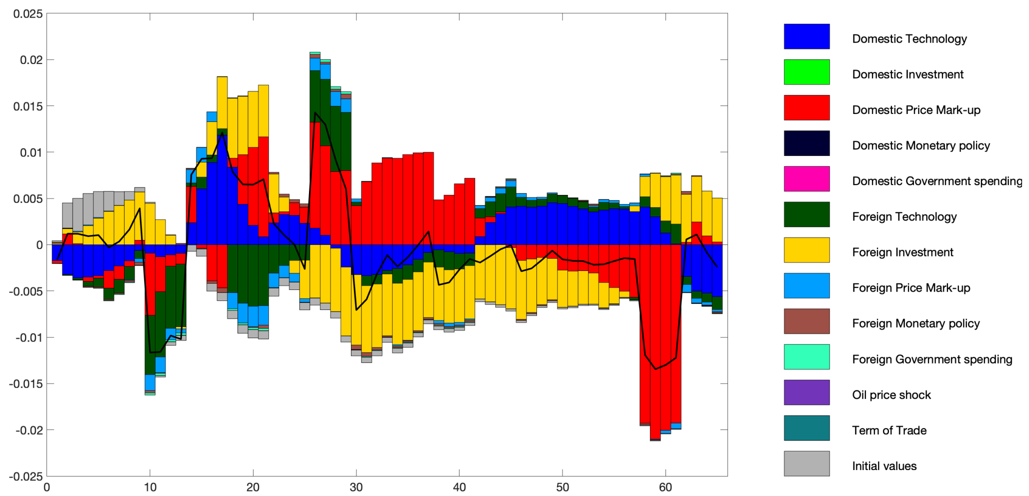

Figure 4.4: Variance decomposition of Price level

Additionally, as can be seen in figure 4.4, domestic technology and price mark-up shocks are still the main factors that drive the value of price levels in the last 20 years. On top of that, we witness a considerable influence of foreign shocks on the variance of this variable. These shocks include foreign technology shock, foreign price mark-up, and foreign investment; in those, the change in foreign investment has the greatest contribution to the fluctuation in the price level in Vietnam. Overall, it could be stated that the spillover effect of the US economy on the Vietnamese market is noticeable because any changes in investment, technology, and price mark-up in the US would contribute to the disturbance of the Vietnam economy, especially in the case of output growth and price level.

4.4.2 Impulse response functions

In this section, we consider the impulse response functions of foreign shocks to understand the transmission of the spillover effects of economic events in the US on the Vietnam economy. This also includes the investigation of oil price shocks in the domestic market. In addition, we compare the impulse response functions of domestic shocks in technology and price mark-up with those in the US to shed light on how the Vietnam economy behaves differently with various sources of shocks. The reason we choose to compare these pairs of shocks is that they are the main factors that constitute the variance of output growth and price level regardless of their origin.

Technology shock

As can be seen in table 4.2 and table 4.4, the estimated technology shock in Vietnam is much smaller than that in the US; this is expected because Vietnam is an emerging country where technology innovation is limited compared to other developed countries. Though foreign technology shock only occurs abroad, its impact is spilt over into the home country's economy. This effect is presented in figure 4.5, which compares the responses of endogenous variables concerning domestic and foreign technology shocks. For instance, while a favourable shock in technology in

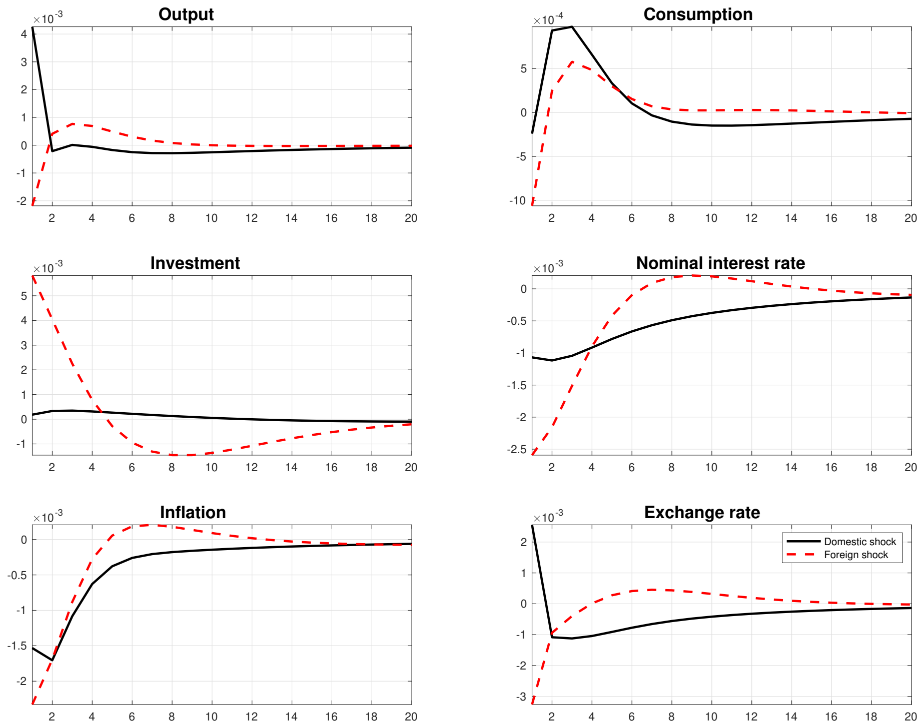

Figure 4.5: The impact of domestic and foreign technology shock

the domestic market increases output growth by 40 basis points (bps), the same shock in the foreign market reduces output growth by 20 bps. This pattern is the same for the exchange rate market where domestic and foreign technology shocks have a contrary effect on VND/USD spot rate. For other endogenous variables, each of them moves in the same direction when being struck by either domestic or foreign technology shock; however, the impact caused by the foreign one appears to be larger.

Price mark-up shock

Regarding the price mark-up shocks, we notice in figure 4.6 that the shock originating in the home country causes output growth to fall by around 50 bps; this is the same for consumption and investment level in Vietnam. Besides, as price mark-

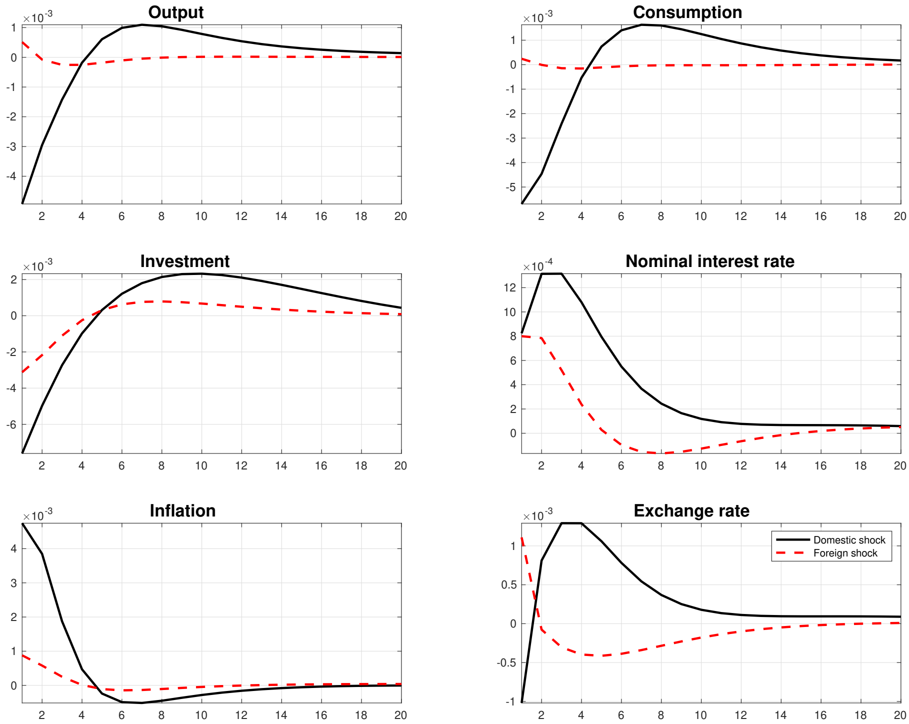

Figure 4.6: The impact of domestic and foreign price mark-up shock

up increases, the price level rises accordingly. As a result, the Central Bank of Vietnam raises their policy rate in order to tackle the increasing inflation; by doing this, a higher interest rate attracts more demand for the home currency, making it appreciate. By contrast, the foreign price mark-up shock increases output growth in Vietnam, although the impact is modest. Alternatively, this shock causes similar movements as the domestic shock does in investment level, interest rate and inflation rate; however, the effect caused by the foreign shock is smaller. It is worth noting that the local currency depreciates under foreign price mark-up shock. This can be explained by an acceleration in output growth due to the shock; hence, people demand greater consumption of imported goods as they reach a higher income. As a result, they sell VND to purchase more USD in return, making the home currency lose its value.

Foreign investment shock

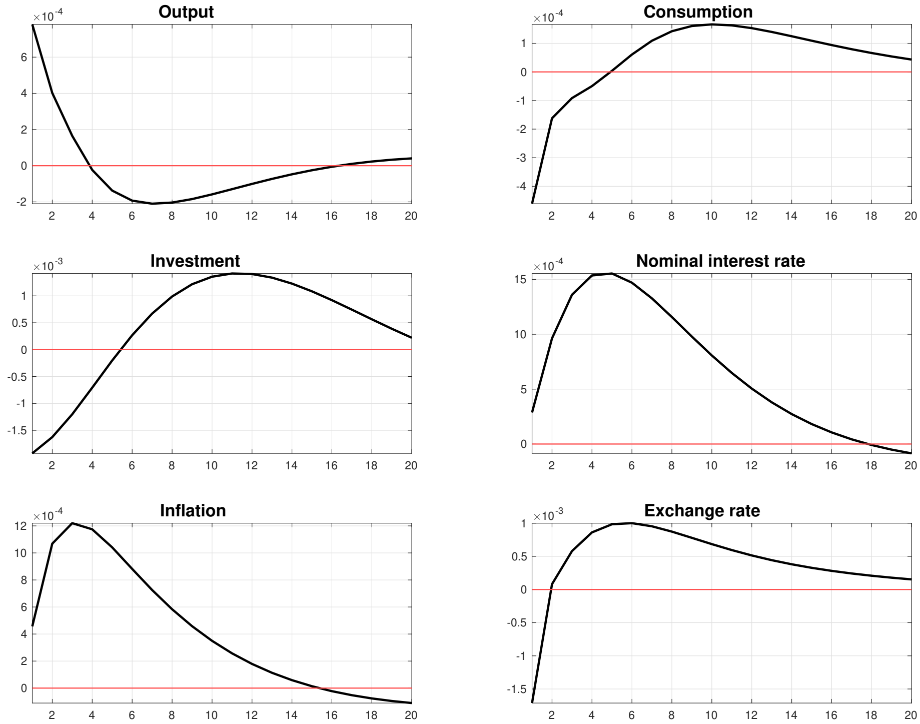

Figure 4.7: The impact of foreign investment shock

Figure 4.7 shows the spillover effect of shocks in foreign investment demand on Vietnam's economy. As this type of shock increases foreign demand for goods and services in general, net exports of the home country are improved to meet the needs of the foreign market; therefore, local output growth rises to reflect this situation. However, the impact also comes with a price; that is, the fall in the levels of consumption and investment in Vietnam after the shock. This is because an increase in investment in the US also means new opportunities for people in Vietnam; therefore, it attracts new investment from Vietnam and encourages people to cut their consumption and local investment. Another explanation is that foreign companies investing in Vietnam reduce their activities in this country and transfer their assets or replan their projects to catch this new wave of investment opportunities in the US. Another effect of the foreign investment shock is that it creates higher inflation due to the increase in output growth; hence, the central bank raises its interest rate to impede this result. Finally, it is shown that the exchange rate appreciates right after the shock and it starts to lose its value after two quarters.

Foreign monetary policy

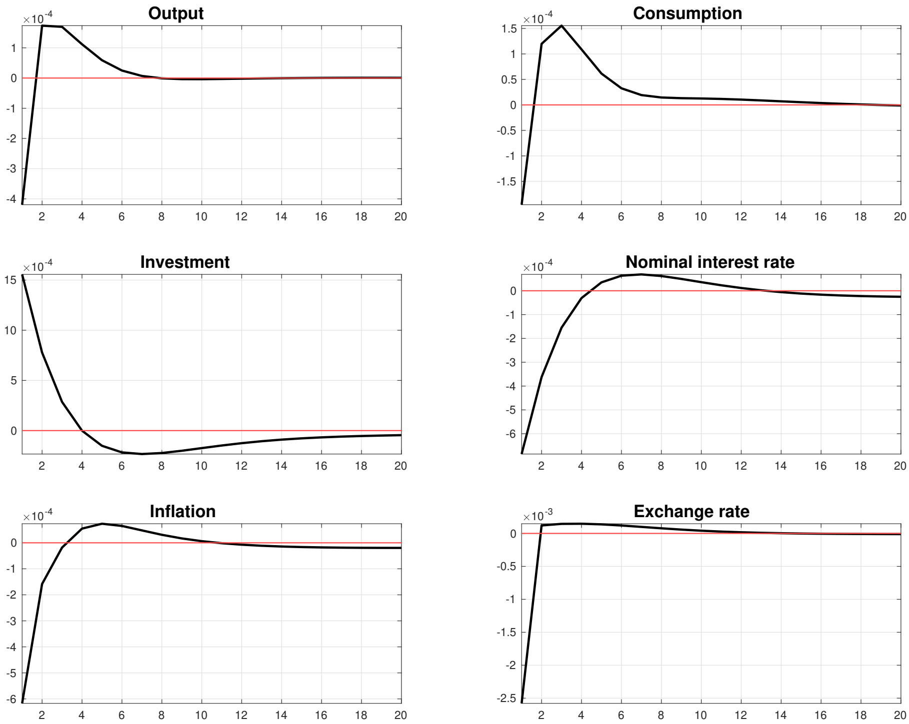

Figure 4.8: The impact of foreign monetary policy

As can be seen in figure 4.8, Vietnam's economy experiences an immediate reduction in output growth rate in response to an expansionary policy shock in the US. However, this effect is short-lived and we witness positive values in this endogenous variable after two quarters. Likewise, the nominal exchange rate appreciates only in the first two quarters after the shock. Then, it depreciates slightly for another 8 periods before returning to its steady-state value. Besides, the inflation rate decreases by 60 bps due to the shock; as the output growth rate and inflation decrease, the interest rate is set to a smaller value in order to stabilise the economy. By doing this, people have a higher incentive to invest in Vietnam; as a result, the level of investment grows by 15 bps. On the demand side, the decrease in nominal interest rate makes saving less attractive to people so they shift their current level of consumption to the following periods by investing more today; as a consequence, we have a contrary response between consumption and investment in this case.

Oil price shock

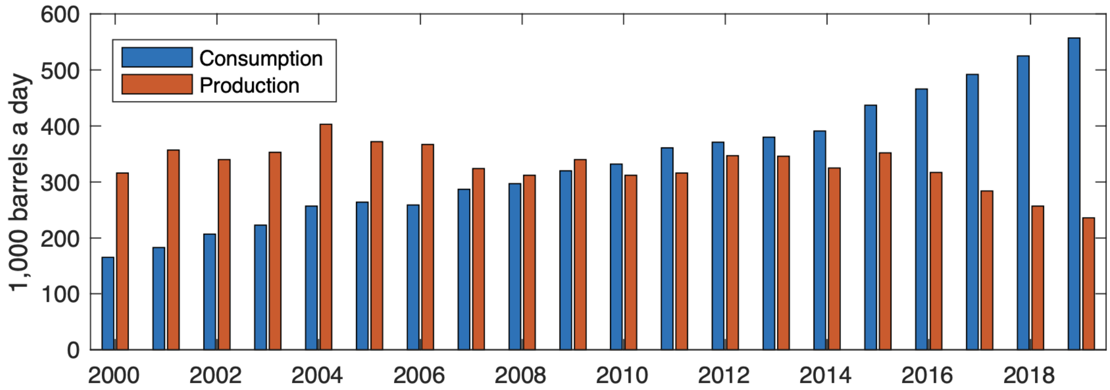

Figure 4.9: Oil Production and Consumption in Vietnam

As the production and trading of commodities play an essential role in emerging economies, a change in their prices surely disturbs the performance of these markets. For instance, it is shown in table 4.5 that the oil price shock has the standard error of 0.0884 which is greater than other domestic shocks; therefore, it is necessary to analyse the influence of an increase in the oil price on Vietnamese market. According to the GSO, Vietnam has been a net oil importer since 2010 (figure 4.9) as the demand for consumption surpasses the production capacity of Vietnam. For instance, this country produces approximately 236 thousand barrels a day while consuming up to 557 thousand barrels of oil a day in 2019. Therefore, any rise in oil prices impedes this country's economy. Specifically, figure 4.10 illustrates that a positive shock in oil price reduces the output growth rate significantly in this country. It is reasonable

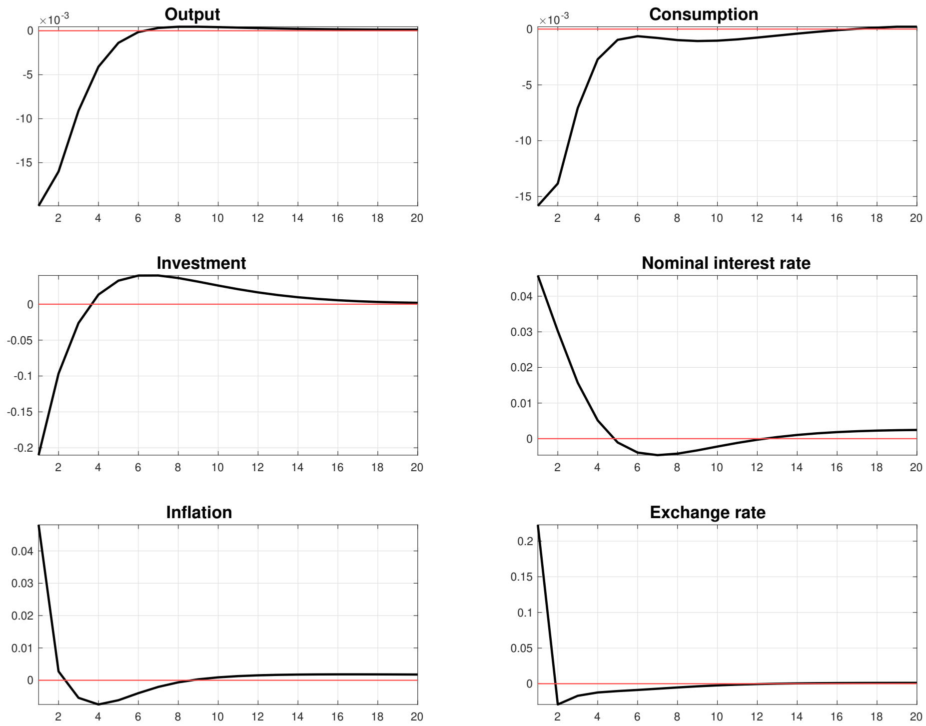

Figure 4.10: The impact of oil price shock shock

because a higher oil price means a higher cost for Vietnamese people; as a result, the levels of consumption and investment are restrained accordingly. Moreover, other impacts of the shock are a growth in the inflation rate and a depreciation of the local currency. Particularly, a rise in oil price boosts the cost of production, making prices of goods and services increase substantially. Finally, as Vietnamese people buy oil in US Dollar, a higher oil price means more foreign currency is needed in exchange for the same amount of oil; therefore, we witness a raise in demand for USD that causes VND to depreciate.

4.5 Conclusion

This chapter studies the spillover effects of US shocks on Vietnam's economy, which is a typical emerging country in the South East Asia region that has a successful economic reform. Although Vietnam has several big trading partners other than the US such as China, and Japan, we first concentrate on the relationship between Vietnam and US at this stage. In this research, we employ a DSGE model with two-country blocs to estimate the shocks in both markets and analyse the impact of these shocks on Vietnam's economy. The estimation can be done using data collected from the FRED database, the World Bank, GSO, and SBV for both the US and Vietnam from 1999 to 2019, including real GDP, consumption level, inflation rate, interest rate, and exchange rate. Generally, this study gives explanations for the sources of variations in the business cycle in Vietnam and helps people understand the attributes of Vietnam's market in an open economy setting.

Overall, the estimates show that shocks in technology, price mark-up and investment are more persistent than policy shocks in Vietnam. On the other hand, only monetary shock and investment demand shock in the US are strongly persistent. Additionally, many shocks that originate in Vietnam appear to be less volatile compared to those in the US. Regarding the commodity sector, we show that the oil price shock is not persistent, though it is highly turbulent. Furthermore, the variance decomposition suggests that besides domestic shocks in technology, and price mark-up, shocks in technology, price mark-up, and investment that arise in the US are other major sources influencing the output growth, and price level in Vietnam.

The impulse response functions of relevant shocks show that favourable shocks in technology and monetary policy in the US would cause output growth and inflation rate to fall in Vietnam. The negative effect on Vietnamese output of expansionary monetary policy in the US follows what the Fleming-Mundell model would predict. On the other hand, an increase in US price mark-up and investment demand would boost income in Vietnam but at the cost of a higher inflation rate. Finally, it is expected that a rise in oil prices will inhibit output growth, consumption, and investment in Vietnam.

In general, this finding suggests that domestic shocks play a vital role in shaping the Vietnamese economy; therefore, Vietnam should concentrate on developing technology constantly to keep up with the world and boost production productivity. Besides, it is shown that the US market does have an impact on Vietnam though the dependency of this market on the US is becoming less significant recently. This can be explained by stronger trading activities with other regional powers like China and Japan in a number of trade negotiations like RCEP and TPP. For further research, we would estimate the impact of the mentioned trading blocs on the Vietnamese economy and build a three-country model for estimating the impact of the US and China on the Vietnamese market in the future.

Chapter 5

Conclusion

This thesis focuses on using multiple DSGE models to examine the effects of exogenous shocks on the business cycles as well as the efficacy of macroeconomic interventions. By doing so, we offer some insight into how economic shocks are caused and transmitted. The main research questions that we try to answer are: (i) are active or passive fiscal policies more effective in a closed economy? (ii) what are the estimates of pandemic shocks and how they are transmitted to the economy? (iii) how do lockdown policy and furlough scheme impact the economy? and (iv) how spillover effects emerge in an emerging market?

In chapter 2, to study how fiscal components have different effects on the economy in all sectors, we build a New Keynesian DSGE model that integrates the government intervention bloc with public revenue and government expenditure. Furthermore, we include non-Ricardian households in the model to observe how they differ from the optimising households. Moreover, we learn how effective fiscal stimulus is in different policy regimes and examine the impact of each fiscal component on the economy, as well as how monetary policy interacts with fiscal measures in different settings. Finally, we investigate impulse response functions for critical structural shocks on household behaviour and other aspects of the economy.

Our research shows that fiscal policy is more successful under regime M, where the fiscal authority reacts passively to assist the central bank's mandate of price targeting. This is because expansionary fiscal shocks in regime F entail greater societal welfare loss. Furthermore, the costs of fiscal stimulus in regime F are considerable in terms of production, investment, and capital. In terms of household behaviour in regime M, positive fiscal shocks encourage non-Ricardian households to work more, given a lower wage rate and consumption level. Finally, our findings imply that fiscal policy is more favourable in terms of welfare loss in regime M, where monetary policy is active and fiscal policy is passive. Therefore, these results encourage the implementation of public policy in a passive approach in order to support the response of the central bank to the economy; this can be done by setting a strong response to inflation by the central bank, and the fiscal authority considers the level of public debt, output growth and price level in the previous period in setting the level of public expenditure and revenue.

Chapter 3 examines the impact of the pandemic on the UK economy using a DSGE model for a small open economy that has been adjusted to reflect the UK government's initiatives. A pandemic shock is composed of three external processes: a negative preferences shock on the demand side, an unfavourable technology shock, and a positive price mark-up shock on the supply side. Other economic shocks are also estimated, including monetary policy shock, government expenditure shock, and foreign consumer demand. This model also includes extensive margins of labour to reflect the furlough scheme implemented in the UK. Moreover, we also include a stochastic shock that restrains consumption level to represent lockdown policy.

According to our estimates, autoregressive parameters are rather stable over time, but technology shock and price mark-up shock appear to be very varied. Furthermore, when we examine the variance decomposition of the variation in output, we find that supply shock, which is comprised of technology shock and price mark-up shock, is the main factor causing the output to fall during the pandemic, whereas the effect of preferences shock (or demand shock) on this variable is relatively minor in the most recent period. In general, the collective impact of these shocks results in a large reduction in the growth rate of output, consumption, and investment; also, since production activities are hampered during the pandemic, the inflation rate rises proportionately. As a result, the central bank raises interest rates in order to stabilise the price level. Furthermore, we anticipate a reduction in working hours after the shock. Regarding the impact of the lockdown policy and the Coronavirus Job Retention Scheme (CJRS) implemented by the UK government, it is shown that the lockdown policy is carried out at the cost of a fall in the growth rate of output, consumption, and a rise in the unemployment rate while the use of the furlough scheme alleviates the impact on consumption though there is a risk of putting pressure on national public debt. More importantly, the latter policy also helps reduce the rate of unemployment. As a result, financial support from the government is proven to be a decent solution to relieve the stress of businesses and their employees caused by the pandemic. Therefore, such an effective policy should be welcomed in the future in case we have a similar situation.

Chapter 4 investigates the influences of US shocks on the Vietnamese economy, which is an emerging country with a successful economic reform. In this study, we use a DSGE model with two-country blocs to estimate shocks in both markets using data collected from the FRED database, the World Bank, GSO, and SBV for both the US and Vietnam from 1999 to 2019. Besides, to assess the shock in the oil price, we adapt the model to add a commodity sector. This research explains the causes of fluctuations in Vietnam's business cycle and assists individuals in comprehending the characteristics of the Vietnamese market in an open economy context.

Overall, the estimates demonstrate that technology, price mark-up, and investment shocks are more persistent than policy shocks in Vietnam. Only monetary and investment demand shocks, on the other hand, are strongly persistent in the US. Furthermore, many shocks that originate in Vietnam appear to be less volatile than those that originate in the US. In terms of the commodity sector, we show that the oil price shock, while being very volatile, is not persistent. Besides, the variance decomposition indicates that, in addition to local shocks in technology and price mark-up, shocks in technology, price mark-up, and investment that occur in the US are the key factors that impact output growth and price level in Vietnam. The impulse response functions of the related shocks reveal that favourable shocks in technology and monetary policy in the US would cause Vietnam's production growth and inflation rate to reduce. This negative effect on the Vietnamese output of expansionary monetary policy in the US is consistent with what the Fleming-Mundell model would predict. On the other hand, a rise in US price mark-up and investment demand would improve Vietnamese income at the expense of increased inflation. Finally, an increase in oil prices is predicted to suppress output growth, consumption, and investment in Vietnam. The implication for Vietnam is that the Vietnamese government should do their best to attract foreign direct investment from the US when they have a high demand for investment. This can be done by raising interest rates and demolishing some restrictions in terms of taxes and regulatory barriers. Besides, regarding the oil price shock, it is a good practice to have oil reserves at hand so that it could reduce the volatility to the economy caused by this type of shock.

Additionally, it is worth noting the novelty in our research on business cycles and macroeconomic policies. Firstly, although it is accepted that the impact multiplier of fiscal policy is an essential factor to measure its effectiveness, none have assessed the various impacts of each fiscal component on the performance of the economy individually, together with the diverse impacts of these components in different regimes. In this case, chapter 2 is successful in showing the diverse responses of the economy for shocks in public consumption, public investment, and transfer payment on the expenditure side, as well as consumption tax, labour tax, and capital tax on the revenue side. On top of that, we also investigate welfare loss due to the deviations from natural output and volatility in the inflation rate for the two regimes. Secondly, according to our knowledge, many researchers have developed theoretical frameworks to simulate the impact of the COVID-19 pandemic; however, no comprehensive work is dedicated to estimating this shock. In chapter 3, we use real data on the UK economy to estimate the shock caused by this pandemic using a DSGE model with Bayesian estimation. By doing this, we can simulate the real effect of the shock as well as investigate the impact of government policies on the economy. Finally, as far as we are aware, there are many papers working on the contagion effect of the US on emerging countries; nevertheless, there is no published analysis of the spillover effects of US shocks on Vietnam's market. As a result, chapter 4 fills in this knowledge gap by constructing a two-country DSGE model and estimating the influence of shocks arising in the US on the Vietnamese economy.

As summarised above, this thesis has examined significant features of business cycles and policies, but it also comes with some limitations. For instance, chapter 2 is purely a theoretical model with the use of calibrated parameters; besides, it does not have an open economy and ZLB features. Therefore, it still needs some improvements to make this research more relevant to the real world. Additionally, in chapter 3, we do not consider the existence of different types of households when we estimate pandemic shocks; it might be the case that households will behave differently when they are affected by this kind of shock. Furthermore, the model in this chapter only considers the economy as a whole while the pandemic has a greater effect on some sectors compared to others such as hospitality, retail, travel, and transportation; therefore, it is a drawback if we do not include heterogeneous sectors in this chapter. Finally, chapter 4 fails to incorporate the credit market in the model for the Vietnamese economy, although it is an essential sector in this country.

In general, we suggest several approaches that can improve our future research. Firstly, we could implement data and a model that represents one country in chapter 2 to make the analysis more relevant to a real economy; therefore, in this case, we can estimate the variation in the value of fiscal policy shock. Besides, the third chapter of this thesis could be improved by including other heterogeneous agents other than just household types; it can be done by integrating more sectors to understand the impact of shocks on different industries. By doing this, we could understand the behaviour of each market to the presented shocks. Furthermore, it is interesting to incorporate the epidemic framework into our model to endogenise the shocks in the pandemic with information about the number of susceptible individuals, the number of infected individuals, and the number of recovered individuals. Finally, it is worth introducing some sort of financial friction and credit constraint in chapter 4 to understand how the economy would behave with the shocks given the financial market, making the model look even more realistic.

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