Prirayani, Jagat (2020) *Essays on unconventional monetary policy and macroprudential policy*. PhD thesis.

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Essays on Unconventional Monetary Policy and Macroprudential Policy

Jagat Prirayani

Submitted in Fulfilment of the Requirements of the Degree of
Doctor of Philosophy in Economics

Adam Smith Business School
College of Social Science
University of Glasgow

2020

Supervisors: Professor Richard Dennis
Professor Charles Nolan

Abstract

This thesis consists of six chapters focusing on unconventional monetary policy and macroprudential policy. Chapter 1 introduces the motivation for the thesis. Chapter 2 provides the theoretical background and literature review. The subsequent three chapters, chapters 3, 4, and 5, are the core chapters in the thesis. The first core chapter, chapter 3, examines the optimal strategic interaction between conventional and unconventional monetary policy. Precisely, the unconventional monetary policy considered in the study is the central bank credit injection or more known as quantitative easing. Using the model from Gertler and Karadi (2011) as the reference, the chapter investigates whether conventional and unconventional monetary policy should cooperate or be set independently and whether the two policies should be operated simultaneously or in leadership manner. The study measures the policy performance using an ad-hoc loss function constructed using the squared deviation of output, inflation, credit spread, nominal interest rate, and credit injection ratio from the steady state. This section demonstrates that the interaction between the two policies set simultaneously in cooperation with a fully optimal commitment regime delivers the best policy performance. The second core chapter, chapter 4, further examines optimal simple rules for the quantitative easing policy. This chapter generates three optimal simple rules for quantitative easing, namely the optimal simple rule based on lagged information (past time horizon), based on current information (current time horizon), and based on future expectation (future time horizon). The study uses the same ad-hoc loss function as in chapter one. This section demonstrates that policy performance from the optimal simple rule based on lagged information is superior to that of the current and future time horizon. Precisely, the optimal simple policy rule is optimally constructed by past leverage, capital price, and credit spread. Furthermore, we also demonstrate that higher central bank aggressiveness can stabilise the macroeconomy, but results in a lower policy performance. Finally, in chapter 5, this thesis investigates the interaction between monetary policy and macroprudential policy in a macroeconomic model with credit supply shock. Precisely, the chapter measures policy performance when the conventional monetary policy interacts with the capital adequacy ratio and the loan-to-value ratio. Using the model from Gerali, Neri, Sessa, and Signoretti (2010), and the ad-hoc loss function from Angelini, Nerri, and Panetta (2011), the study demonstrates that macroprudential policy promotes financial stability. Multiple policy instruments perform better than a single instrument, but pose a risk of conflict. The study also demonstrates that the substitution effect among policy instruments can occur. Finally, chapter 6 provides conclusions and recommendations for future research.

Keywords: Quantitative easing, Macroprudential policy, Monetary Policy

Acknowledgment

I want to thank Professor Richard Dennis, who has allowed me to be his student and patiently guide me throughout the research process. His skills and invaluable experience have developed my skills and working discipline tremendously. Also, I want to express my gratitude to Prof. Charles Nolan as the second supervisor during conducting the research. Aside from my supervisors, I would like to thank Prof. Francesca Flamini, Prof. Ioana Moldovan, Prof. Tatiana Kirsanova, Prof. Campbel Leith, Prof. Ronald MacDonald, and Prof. Ning Zhang who have given comments and inputs on this thesis during Ph.D. workshops and Annual Progress Review. Last but not least, special gratitude is given for the examiners, Prof. Tatiana Damjanovic and Prof. James Malley, for the positive feedback and critiques on my thesis.

I also want to thank to the University of Glasgow for giving me an opportunity to work as a postgraduate research student through the College Science Scholarship and the Prof. Donald J. Robertson scholarship. The two scholarships were crucial in supporting my progress during the Ph.D. study. Finally, my gratitude goes to my family, especially Anggit, Shanum and Aruna, for their great support during my study. Also, immense gratitude is given for my mother, parents in law, and friends for their support.

Declaration

I declare that this thesis is a record of the original work carried out by myself under the supervision of Professor Richard Dennis and Professor Charles Nolan at the University of Glasgow, the United Kingdom. The copyright of this research belongs to the author under the terms of the United Kingdom copyright acts. The due acknowledgment must always be made of the use of any material contained in or derived from this thesis. The thesis has not been presented elsewhere in consideration for a higher degree.

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Signature : ____________

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CHAPTER 1

INTRODUCTION

1.1 Motivation and Research Questions

The global financial crisis that began in 2008 is inarguably one of the most impactful crises in the worldwide economy. Also considered as the most severe crisis since the U.S. great depression, the crisis created a ripple effect that quickly brought the global economy to its weakest growth. The World Bank estimated that the global annual gross domestic product (GDP) growth during the crisis was the slowest in history since 1960, which was at -1.68% in 2009, as shown in Figure 1.1.

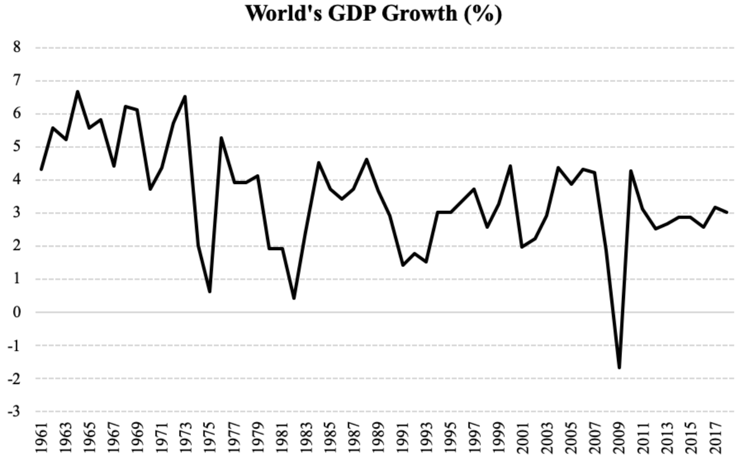

Figure 1-1: The World's Annual GDP Growth

The weakening economy in some advanced industrialised countries such as the U.S., Japan, and the Euro area, mainly contributed to the declining economy during the crisis. For instance, in 2009, the U.S. economy grew negatively by -2.53%, which was the slowest growth after decades. Furthermore, Japanese economy was contracting with growth at -5.41%, followed by the Euro area that also grew negatively by -4.50%. During the crisis, the U.S. Federal Reserve injected more than $2,000 billion of liquidity to financial markets due to the ineffectiveness of monetary policy. This activity created the largest balance sheet for the U.S. Federal Reserve throughout U.S. economic history.

Despite of the tremendous destruction on the global economy, the crisis signaled one crucial lesson: that macroeconomic policy frameworks and the regulations imposed on financial institutions at that time were not strong enough to prevent the impact of systemic risk from occuring. Hence, the crisis has raised awareness among policymakers regarding the importance of strengthening macroeconomic policy frameworks; one of them is the implementation of unconventional macroeconomic policies. Quantitative easing and macroprudential policy are two policies that have attracted much attention following the crisis.

Quantitative easing is a non-traditional monetary policy whereby the central bank purchases a large quantity of public or private bonds using cash. This policy usually takes place during a crisis and supports conventional monetary policy when the latter is less powerful to stimulate the economy. Conversely, macroprudential policy describes policies implemented to prevent a systemic crisis and to achieve financial stability.

This thesis examines the interaction between conventional monetary policy and unconventional macroeconomic policies, namely, quantitative easing policy and macroprudential policy. The quantitative easing policy is chosen to represent the unconventional monetary policy that is usually active during or after a crisis. On the other hand, macroprudential policy is chosen to represent a preventive policy that works before a crisis occurs. Hence, by presenting a preventive policy (i.e., macroprudential) and a curative policy (i.e., quantitative easing), we expect to deliver a comprehensive assessment of how these two macro policies contribute to alleviating economic distress. The research questions that this thesis aims to answer are as follows. First, what is the optimal strategic interaction between conventional monetary policy and quantitative easing policy? Second, is there an optimal simple rule for quantitative easing policy that the central bank can adopt during a financial crisis? Third, how substantial is the contribution of macroprudential policy with multiple instruments in stabilising the economy? This thesis will address the three research questions, devoting a chapter to each, as explained subsequently.

In the first core chapter, the thesis will address the optimal strategic interaction between conventional monetary policy and quantitative easing policy. Conventional monetary policy in this chapter is the monetary policy that relies on the short-term overnight interest rate as the monetary policy instrument (or also known as policy rate). On the other hand, the policy instrument used in quantitative easing policy is the credit injection ratio, which represents the fraction of credit injection from the central bank relative to the total credit available in the economy. The first core chapter employs the model from Gertler and Karadi (2011) and presents the interaction between the two policies in various strategies, such as whether the two policies should cooperate or be independent of each other; or whether the two policies should operate simultaneously or in leadership manner. Furthermore, the comparison of strategies is conducted based on the policy performance (or also called as loss value), which is calculated based on the method from Dennis (2007) and Dennis and Ilbas (2016). Based on the policy performance, this chapter is expected to inform us regarding the optimal strategic interaction between the two policies.

The second core chapter further examines the interaction between conventional monetary policy and quantitative easing. This chapter aims to develop an optimal simple rule for quantitative easing that the central bank can adopt during crisis times. Moreover, the chapter also studies whether the central bank can sufficiently construct the simple rule using information from financial variables or whether the simple rule also requires additional information of macroeconomic variables. Finally, this chapter also examines whether the construction of the optimal simple quantitative easing rule is sensitive to the change of policy rate smoothing parameter or not. The reference model in this chapter is also the one from Gertler and Karadi (2011). In this chapter, the optimal simple rule is constructed based on the optimisation of quantitative easing policy instrument under commitment, while conventional monetary policy is carried out by the central bank through the implementation of a non-optimal simple Taylor rule, which is adopted from the model of Gertler and Karadi (2011). The evaluation of the optimal simple rule's efficiency is measured based on a loss value, which is calculated using the method from Dennis (2004).

In the third core chapter, the interaction of macro policies is applied between conventional monetary policy and macroprudential policy. This last core chapter intends to measure the impact of macroprudential policy in supporting macroeconomic stabilisation. Also, the chapter is interested in examining whether optimising multiple macroprudential policy instruments is significantly better than a single instrument optimisation. If it is, then whether the interaction of multiple instruments can trigger a conflict or not. This chapter adopts the model from Gerali, Neri, Sessa, and Signoretti (2010) as a reference. The model from Gerali et al. (2010) is chosen to provide an economy where the credit supply shock plays a role. Two prominent macroprudential policy instruments are present in the model, namely the capital adequacy ratio (CAR) and the loan-to-value ratio (LTV).

The three topics presented in this thesis have widely not been examined in the current literature, either in the literature on quantitative easing policy or macroprudential policy. Hence, to our best knowledge, the topics presented in this thesis are the first or, if not, the first few examining quantitative easing and macroprudential policy with a unique perspective. Most studies of quantitative easing today have focused on the effectiveness and impact of this policy on the long-run economy, and have paid less attention to how the policy interacts with conventional monetary policy, see for example the studies by Albu, Lupu, Calin, and Popovici (2014); Bhattarai and Neely (2016); Chen, Filardo, He, and Zhu (2016); Curcuru, Kamin, Li, and Rodriguez (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); Kapetanios, Mumtaz, Stevens, and Theodoridis (2019), among others.

Similarly, literature exploring optimal simple rules for quantitative easing is not abundant. Most studies have focused on developing an optimal rule for monetary policy or fiscal policy. As for quantitative easing, only few studies have examined this topic, some of them are the studies by Cui and Sterk (2018), Sheedy (2017), Kiley (2008), and Quint and Rabanal (2017). However, such studies only focus on fully optimal rules rather than on simple rules. Finally, with regard to the literature on macroprudential policy, most literature focuses on cases where there is a single macroprudential instrument optimisation rather than multiple policy instruments, see for example the studies by Benes and Kumhof (2011), Christensen, Meh, and Mohran (2011), Collard, Dellas, Diba, and Loisel (2012), Beau, Clerc, and Mojon. (2012), Brzoza-Brzezina, Kolasa, and Makarski (2013), Ozkan and Unsal (2013), and Suh (2014), among others.

The method of measuring various scenarios based on policy performance of quantitative easing and various macroprudential instruments in this study offers a simple yet a reliable result, which gives a unique contribution to the literature on quantitative easing and macroprudential policy. As suggested by Martin and Milas (2012), the literature on quantitative easing is limited and too narrow, and hence exploration of alternative approaches to quantitative easing are required. Therefore, these three core chapters are expected to expand the literature scope of quantitative easing and macroprudential policy.

The thesis is outlined as follows. The first chapter motivates the thesis. The second chapter reviews theoretical literature. The three subsequent chapters are the core chapters, namely chapter three, four and five. Finally, the last chapter concludes and provides policy implications and recommendations for future study. The subsequent section will describe the structure of the three core chapters in more details.

1.2 Thesis Structure

1.2.1 Chapter Three: Scope and Contribution

The primary objective of this chapter is to investigate the optimal strategic interaction between conventional monetary policy and quantitative easing. To our best knowledge, this chapter is the first study assessing the optimal strategic interaction between these two policies under one institution. This chapter employs the model from Gertler and Karadi (2011) and presents two scenarios, namely, the cooperation scenario and the independent scenario (non-cooperation scenario).

The cooperation scenario is the scenario where both conventional monetary and quantitative easing policies are optimised to pursue the single central bank's objective (i.e., the central bank only has one objective function or loss function). Under the cooperation scenario, we introduce four policy regimes, namely, the fully optimal commitment regime, the discretionary policy regime, the simple policy rule regime, and the cooperating-leadership regime. The fully optimal commitment regime is the case when the authority is committed to its chosen initial policy and never reoptimises. On the contrary, in the discretionary policy regime, the authority always reoptimises every period. In the simple policy rule regime, the authority sets policy instruments based on simple rules that are directly adopted from the reference model of Gertler and Karadi (2011). The simple monetary rule chosen is the Taylor rule, while the simple quantitative easing rule is the credit policy rule. Finally, the cooperating-leadership regime is the case where one policy is optimised before the other, but they both pursue the single objective function.

On the contrary, the independent scenario (or non-cooperation scenario) is the scenario where each policy pursues different objective functions. Precisely, each policy is allowed to have its own distinct objective function. That is, monetary policy aims to achieve inflation stability, while quantitative easing policy aims to achieve credit stability. In the independent scenario, we present two policy regimes: the independent-simultaneous regime and the independent-leadership regime. The independent-simultaneous regime is the situation where the central bank simultaneously optimises the conventional monetary and quantitative easing policies to pursue different objective functions. On the other hand, in the independent-leadership regime, the policies are optimised sequentially rather than simultaneously.

The independent-leadership regime consists of two cases. The first case is when conventional monetary policy leads the interaction and the second case is when quantitative easing policy leads the interaction. When monetary policy is the leader, the central bank optimises the nominal interest rate first, which is then followed by optimising the quantitative easing policy instrument. As a follower, the quantitative easing policy instrument is optimised based on the information of the nominal interest rate from the first mover. In other words, the central bank incorporates information of the nominal interest rate into the optimisation of quantitative easing policy instrument. On the contrary, the second case is the situation when quantitative easing policy is the leader and the conventional monetary policy is the follower. In this case, the first policy that the central bank optimises is quantitative easing, which later then followed by the optimisation of conventional monetary policy. As a follower, the nominal interest rate is optimised based on information of the previously optimised quantitative easing policy instrument.

The simulations are run in such a way that we measure the policy performance of each policy regime according to a specific ad-hoc loss function. The ad-hoc loss function is constructed based on the fluctuation of output, inflation, credit spread, nominal interest rate, and credit injection ratio. Our simulations emphasise that commitment are necessary to achieve the optimal strategic interaction between conventional monetary and quantitative easing policies. That is, the best performance is achieved when the central bank is fully committed to all policy rules, never reoptimises, and pursues a single objective function. We also show that when the two policies pursue different objective functions, the leading policy can benefit more than the follower. However, our simulation points out that the leadership interaction, either cooperating or independent, performs nearly identical to that of discretionary policy regime, and perform much worse than the fully optimal commitment regime.

Moreover, we demonstrate that the interaction between conventional monetary policy and quantitative easing policy is the second-best when the central bank implements a non-optimal simple rule for both policies. However, the effectiveness of the simple policy rule regime depends on the degree of the central bank's aggressiveness in combatting the crisis. We show that excessive aggressiveness can stabilise some macroeconomic variables detracting from overall policy performance. In most policy regimes, we find that conventional monetary policy is superior to quantitative easing policy. Hence, we suggest that quantitative easing should not replace conventional monetary policy, but it is sufficient to be a secondary tool of stabilisation.

The findings from this chapter, such as the importance of commitment in quantitative easing, the negative impact of the central bank's over aggressiveness, and the superiority of the leading policy, contribute positively to the literature on quantitative easing policy. Furthermore, one of the results from this chapter, regarding the simple policy rule regime, also contributes to one of the raising issues in quantitative easing policy, namely, whether quantitative easing should be implemented in a rule like manner or using a balance sheet target. We follow up this finding in the second core chapter focusing on constructing an optimal simple rule for quantitative easing policy. Overall, the results from this chapter expand the scope of quantitative easing literature in general.

1.2.2 Chapter Four: Scope and Contribution

This chapter investigates optimal simple rules for quantitative easing policy when the central bank conducts conventional monetary policy and quantitative easing policy simultaneously. Specifically, in this chapter, we allow the central bank to only optimise credit injection ratio (which is the quantitative easing instrument) under commitment, while leaving the setting of nominal interest rate to a non-optimal simple Taylor rule. The reference model in this chapter is the unconventional monetary policy model from Gertler and Karadi (2011).

This chapter introduces two scenarios in developing the optimal simple quantitative easing rule. The first scenario is when the central bank constructs its optimal simple rule only based on information on banking variables and the second scenario is when the central bank also incorporates additional information on macroeconomic variables, namely output and inflation. The reason for introducing these two scenarios is to understand whether financial variables are sufficient to produce an effective optimal simple quantitative easing rule or whether adding output and inflation yields a more significantly efficient optimal simple rule.

Under each scenario, three cases are provided. The first case is when the central bank constructs the optimal simple rule based on lagged information or past variables (i.e., past time horizon). The second case is when the central bank constructs its optimal simple rule based on current information (i.e., current time horizon), and the the third case is when the central bank develops its optimal simple rule based on future expectation (i.e., future time horizon). Finally, the simulations are conducted under two conditions, namely when the central bank applies the policy rate smoothing parameter and when it is not. In total, the simulation involves twelve different cases.

The simulations are run in such a way that we measure the policy performance of each case according to a specific ad-hoc loss function. The ad-hoc loss function in this chapter is constructed based on the fluctuation of output, inflation, credit spread, nominal interest rate, and credit injection ratio. The benchmark model in this chapter is the fully optimal commitment rule where the central bank constructs the optimal simple rule for quantitative easing based on all endogenous economic variables in the economy. In contrast, under the optimal simple rule, the construction of the optimal simple rule is constrained by some specific economic variables.

Our simulations demonstrate that the optimal simple rule for quantitative easing can approach the performance of the fully optimal commitment rule very well. The simulations also illustrate that incorporating information of financial variables is sufficient to construct an efficient optimal simple rule of quantitative easing, either when the central bank applies a zero or non-zero smoothing parameter on the policy rate (i.e., zero smoothing parameter). Across all time horizons, our simulations demonstrate that the optimal simple quantitative easing rule constructed based on past time endogenous variables is superior to the rules based on current or future variables. Our simulations also show that, in the case of our reference model, the optimal simple rule for quantitative easing is optimally constructed by the lagged deviation of credit spread, leverage, and capital price from their steady states.

The banking variables chosen constructing the optimal simple rule are unchanged to whether the central bank smooths the policy rate or not. That is, the optimal simple rule remains to be optimally constructed by past period of credit spread, leverage, and capital price under zero or non-zero interest rate smoothing parameter. Relative to the fully optimal commitment rule, the optimal simple rule corresponds to less credit injection. However, this less credit injection consequently leads to higher fluctuations in output and credit spread than those under commitment. Output is the most volatile variable in the loss function.

Based on these findings, some recommendations stand out. First, information from the banking sector is crucial for the central bank when constructing the optimal simple rule for quantitative easing. Second, given that past information on endogenous variables is superior to current and future information, this means that ample access to historical data would give great benefit when the central bank intends to manage quantitative easing policy using an optimal simple rule. Third, the credit spread has the largest feedback coefficient in the optimal simple rule, regardless the time horizon used and the value of the interest rate smoothing parameter. Given that credit spread is the main variable amplifying the impact of financial imbalances in the banking sector, we argue that this large feedback coefficient is a feature to maintain credit spread's stability and hence dampening the moral hazard behaviour in the banking sector. Lastly, the optimal simple quantitative easing rule using past information delivers policy performance that is almost as good as that for the fully optimal commitment rule, and while being more compact and more easily communicated to the public.

We argue that this chapter positively contributes to the literature on quantitative easing policy, especially to those focusing on conventionalising the unconventional monetary policy. The finding on this chapter, such as the well-performing of optimal simple rules for quantitative easing, the negative impact of the central bank's over aggressiveness, and the role of exogenous shocks on the optimal simple rule, have contributed to the existing literature on quantitative easing. Beyond its contribution on the literature, from a practical perspective, this chapter also provides useful information for policymakers regarding the alternative structure of the optimal simple rule for quantitative easing.

1.2.3 Chapter Five: Scope and Contribution

This chapter examines the effectiveness of macroprudential policy with multiple instruments for economic stabilisation when it interacts with conventional monetary policy. Additionally, this chapter also examines the effectiveness of multiple macroprudential instruments over a single instrument optimisation, and whether optimising multiple macroprudential instruments triggers a conflict among the instruments or not. The idea of this chapter is to compare the policy performance across all possible interactions among the policy instruments. The reference model in this chapter is the one from Gerali et al. (2010). Besides offering multiple macroprudential policy instruments that meet the need of this study, the model from Gerali et al. (2010) also accommodates monetary and macroprudential policy to interact in a model where credit supply shock plays a prominent role in the economy.

We allow the central bank to implement monetary policy according to a non-optimal simple monetary policy rule while at the same time optimising its macroprudential policy instruments under commitment. There are two types of macroprudential policy instruments presented, namely, the capital adequacy ratio (CAR) and the loan-to-value ratio (LTV). These ratios are two prominent macroprudential instruments suggested by the Basel committee from the Bank of International Settlement. Furthermore, the LTV is decomposed into three types of ratios: the LTV for impatient households, the LTV for entrepreneurs, and the joint LTV. The joint LTV ratio means that the central bank equalises the log linearised of one LTV to that of the other LTV ratio.

The simulations in this chapter consist of three scenarios. The first scenario is the benchmark scenario, which is the case when the central bank only operates the conventional monetary policy and treats all macroprudential policy instruments as constants. In other words, this benchmark model reflects a situation where macroprudential policy is not active in the economy. The second scenario is when the central bank optimises only one macroprudential policy instrument. In this scenario, we measure policy performance when the central bank only implements a single macroprudential policy instrument, covering CAR, LTV for households, LTV for entrepreneurs, and the joint LTV ratio. Thus, there will be four cases in the second scenario where each case represents one macroprudential policy instrument. The third scenario is when the central bank optimises more than one macroprudential policy instrument. In this scenario, we test a situation where the central bank optimises all possible interactions among the macroprudential policy instruments. Finally, we measure the unconditional variances of the variables constructing the loss function.

The simulation are run in such a way that we measure the policy performance of each case under a specific ad-hoc loss function. The ad-hoc loss function is constructed using the fluctuations of output, inflation, loan-to-output ratio, nominal interest rate, and macroprudential policy instrument being optimised. Our simulations argue some important findings. First, we show that macroprudential policy can benefit the economy significantly more than when the central bank only relies on conventional monetary policy (i.e., when all macroprudential instruments are not active). The ability of macroprudential policy to achieve financial stability is the main reason behind the benefit. That is, we found that the presence of macroprudential policy can significantly stabilise the variation of loan-to-output ratio. Second, although a mutual benefit from interacting multiple macroprudential policy instruments is seen, the interaction can also trigger conflict among the instruments themselves. The conflict manifests in the way that the interaction can benefit some policy instruments but also attenuate the efficacy of another policy instrument.

Third, our simulations also demonstrate that there is a substitution effect between the macroprudential policy instruments. This substitution effect is seen in a way that the presence of one instrument can help stabilise the variation of another instrument, but at the cost of higher fluctuation of the instrument itself. For this model, we show that optimising CAR and the joint LTV ratio can deliver the best policy performance, but it gives a negative impact on inflation stability. Therefore, we argue that the central bank should not operate this policy. In contrast, the case when the central bank optimises CAR and the separate LTV ratios gives a second-best policy performance but it promotes inflation stability, which suggests that the implementation of this policy does not trigger a conflict with monetary policy. Hence, we establish that optimising CAR and the two LTV ratios simultaneously is the best scenario that the central bank can implement in our reference model.

Fourth, across all simulations, this chapter shows that that LTV is superior to CAR. The superiority of the LTV ratio to CAR is understood, as the mortgage market and housing prices dominate banking activity in our reference model. Finally, among all variables in the loss function, the loan-to-output ratio is the variable that contributes most significantly to the improvement in policy performance. This result indicates that macroprudential policy is useful to achieve financial stability by significantly minimising the fluctuation of the loan-to-output ratio. This finding is consistent with the recommendation from the Basel committee which suggests the central bank to employ macroprudential policy to stabilise the debt-to-GDP ratio.

The findings on this chapter, such as the positive impact of macroprudential policy through financial stability and effectiveness of various macroprudential policy instruments, contributes to the literature on macroprudential policy. This contribution is useful because relatively few studies have looked at optimising multiple macroprudential policy instruments. Furthermore, the study also gives a contribution by presenting a trade-off situation under multiple policy instruments' optimisation that most studies in macroprudential policy area have overlooked.

CHAPTER 2

LITERATURE AND METHODOLOGICAL REVIEW

Abstract

The central purpose of this thesis is to explore the role of unconventional monetary and macroprudential policies that could be implemented to combat an economic crisis, particularly regarding their interaction with the conventional monetary policy. The three topics presented concern with the interaction between conventional monetary policy and quantitative easing policy, the optimal simple rule for quantitative easing policy, and the interaction between conventional monetary policy and macroprudential policy. In investigating these topics, this chapter provides conceptual theories to support the thesis. This chapter consists of three parts The three parts focus on the assessment of conventional monetary policy, quantitative easing policy, and macroprudential policy.

Keywords: Unconventional monetary policy, Quantitative easing, Macroprudential policy.

2.1 Introduction

The terms quantitative easing and macroprudential policy have become increasingly popular after the subprime mortgage crisis that occurred in 2008. Quantitative easing was first implemented in Japan during the asset price crisis of 2001, which dragged the country into a state of long-term deflationary pressure. At the time, the government of Japan injected billions of dollars into the country's financial and real sectors with the hope of accelerating the national economy. Although the policy yielded temporary successful results, it did not ultimately help the country resolve the long-term deflation in subsequent decades. However, the strategy of liquidity injection remains in use. Even today, the Japanese government adopts the Abenomics approach to inject a massive level of quantitative easing into the economy to stimulate inflation.

A similar turn of events also occured in the U.S. when the country was combating the subprime mortgage financial crisis in 2008. Differently from the Japanese case, the quantitative easing from the U.S. Federal Reserve specifically aimed to purchase mortgage-backed securities (MBS). In November 2008, the Federal Reserve initialised its asset purchase program with a plan to buy $100 billion in government-sponsored enterprise debt (GSE) and $500 billion in MBS. Not very long after this, the U.S. Federal Reserve continued purchasing assets totalling $750 billion in MBS, $100 billion in GSE debt, and $300 billion in long-term Treasury securities. In total, this $1,725 billion is known as the first program of quantitative easing (QE1), which increased the U.S. monetary base by three times and expanded the Federal Reserve balance sheet significantly.

The second and third quantitative easing programs were implemented after the Federal Reserve and Congress found that no significant improvement had been achieved from the first instance of quantitative easing. The labour market remained sluggish, and inflation had gone down. In November 2010, the authority injected an additional $600 billion through the second program of quantitative easing (QE2), intending to further accelerate the economy and stabilise inflation. Furthermore, before going into the third program of quantitative easing (QE3), the Federal Reserve also implemented the operation called the maturity extension program (MEP) and the reinvestment policy. The MEP aimed to reduce the long-term interest rate relative to the short-term interest rate. Through this program, the Federal Reserve spent another $400 billion to purchase long-term assets, which then expanded its balance sheet by $267 billion of asset purchases in June 2012. Finally, the third program of quantitative easing (QE3) was implemented in September 2012. Through QE3, the Federal Reserve purchased $40 billion in MBS per month, as long as the labour market remained sluggish.

The crises experienced in Japan and the U.S. indicate that quantitative easing is different from conventional monetary policy. The former is usually implemented when the economy is under distress, not in normal situations. Hence, this policy is not a preventive tool but rather works as a curative policy that is activated after a state of distress is confirmed. Furthermore, quantitative easing is not a one-time policy. That is, the authorities need to observe the market's reaction every time a liquidity injection is performed and top up additional injection when the target is not achieved. The size of the injection in quantitative easing is crucial since it involves an enormous amount of liquidity that can change the monetary base substantially and impose a long-term impact on the economy. Most studies in the area of quantitative easing use various econometric models to focus on this impact, particularly regarding the effectiveness of the policy and its potential impact on the economy. Unfortunately, studies focusing on the strategic interaction between the traditional monetary policy and quantitative easing policy are not abundant, as will be discussed later.

Another policy that is a central point of this chapter is macroprudential policy. The term macroprudential policy was recognised in 1986 in the Euro-currency standing committee report released by the Bank of International Settlement (BIS), and the policy has gained massive popularity since the global financial crisis of 2008. The report defines macroprudential policy as a policy that promotes the safety and soundness of the broad financial system and payment mechanisms (World Bank, 2014). Different from the quantitative easing policy, which is implemented during a crisis, macroprudential policy is embedded in the financial system with intention to reduce the impact of systemic crises. Macroprudential policy is a new and growing type of policy relative to other existing stabilisation policies, such as monetary or fiscal policy. Also, unlike monetary policy, which already has a well-established policy instrument and intermediate objective, macroprudential policy has no consensus regarding the best policy instrument to use. This unclarity has led studies in this field to introduce various types of policy instruments, as will be shown later.

This chapter provides the theoretical background of the quantitative easing policy and macroprudential policy. Overall, this chapter consists of five parts. The first part presents the conceptual theory of conventional monetary policy. The two subsequent parts explains the conceptual theories of quantitative easing policy and macroprudential policy.

2.2 Conventional Monetary Policy

Monetary policy is a macroeconomic policy that aims to manage the amount of money circulated in the economy. The monetary authority, which is usually mandated to the central bank, has a role in operating monetary policy by managing the monetary policy instrument to change the monetary base in the economy. In general, monetary policy is primarily used to maintain price stability. However, besides for price stability, central banks in some countries also use monetary policy for other purposes. For instance, the U.S. Federal Reserve also use monetary policy to simultaneously achieve low unemployment and price stability.

Other examples of alternative objectives are interest rate stability, foreign exchange market stability, economic growth, and financial market stability. The general mechanism of conventional monetary policy is described in Figure 2.1.

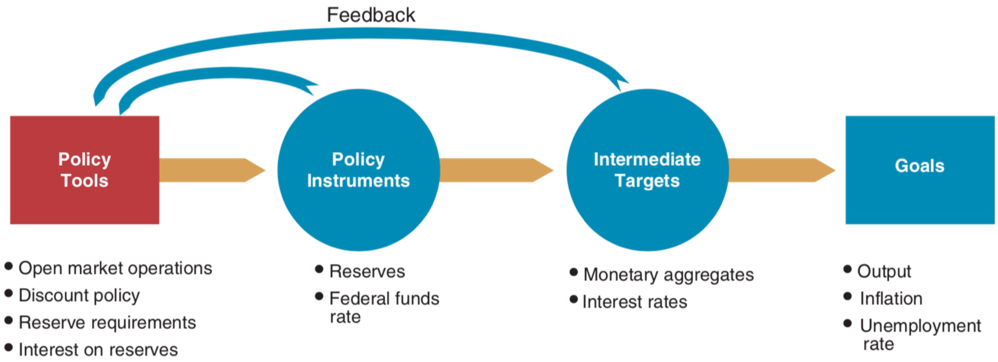

Figure 2-1: Monetary Policy Mechanism (Source: Hubbard and O'Brien, 2012)

In executing the policy, the central bank uses various policy tools, such as open-market operations, discount policy, and reserve requirement. Policy tool is the only part of the policy that the central bank can fully control. For instance, through open market operation, which is one kind of policy tools, the central bank purchases and sells government bonds to operate the expansionary or contractionary monetary policy. The central bank then uses the policy tools to achieve its intermediate targets. The intermediate targets are typically monetary aggregates or interest rates. However, the central bank is restricted to influencing the intermediate target indirectly because it is also affected by private sector-economic decisions. Hence, the central bank usually sets up another measure, known as a policy instrument, to bridge the policy tools and the intermediate goal. In operating conventional monetary policy, most major central banks use the short-term overnight interest rate as a policy instrument.

There are two types of monetary policy – namely, expansionary monetary policy and contractionary monetary policy. An expansionary monetary policy aims to expand the monetary base of an economy. The central bank commonly reduces the short-term interest rate or purchases government bonds to introduce more liquidity into the banking sector. This increase in available liquidity in the banking sector provides more room for banks to increase their assets, particularly through credit intermediation. Subsequently, a greater availability of credit in the economy is expected to make loans more affordable, thus stimulating growth in the real sector. However, an expansionary monetary policy can create an inflationary gap in the economy. On the contrary, a contractionary monetary policy aims to reduce or shrink the monetary base in the economy. The central bank implements a contractionary monetary policy when the economy is accelerating too quickly (or overheating). The authorities then increase the short-term interest rate and sell government bonds to reduce the monetary base, which, subsequently, is expected to pull money into the banking sector, increase the cost of borrowing, and eventually cool down the overheated economy.

Based on the instruments used, monetary policy can be divided into two types: conventional monetary policy and unconventional monetary policy. Conventional monetary policy is the operation of monetary policy under normal condition (i.e., a situation in which the short-term interest rate is still influential in driving the overnight lending and borrowing transactions between banks). On the other hand, unconventional monetary policy is the operation of monetary policy when the short-term interest rate functions worse than normal to stimulate banking activity. The short-term interest rate in this situation is usually very low or approaching zero. This section focuses on the conventional monetary policy, while the unconventional monetary policy will be explained in the following part.

2.2.1 Conventional Monetary Policy Tools

There are at least three conventional monetary policy tools that the central bank utilises - namely, open market operations, discount rate, and reserve requirement.

- **Open Market Operation**

Open market operation is the monetary policy tool by which the central bank manages its monetary base by purchasing and selling government bonds. This type of operation only works only in the country where its market of bonds/securities has developed. Through this operation, the central bank purchases government bonds from primary dealers when it wishes to lower the policy rate. The primary dealers consist of commercial banks, investment banks, and securities dealers. Hence, by purchasing government bonds from the market, the central bank supplies money in circulation, increases the monetary base, and lowers the policy rate. For instance, suppose the central bank intends to purchase \$10 million worth of government bonds from a commercial (Bank A). In this case, Bank A will transfer the ownership of the bonds to the central bank, and, in return, the central bank will deposit \$10 million into the account of Bank A in the central bank. A similar procedure is applied when the central bank intends to achieve a higher policy rate, in which case it needs to sell government bonds to the primary dealers.

- **Discount Rate**

Discount rate is another monetary policy instrument that the central bank implements to affect the monetary base in the economy. The discount rate is simply a charge for the loans that commercial banks have in the central bank through a scheme known as the discount window. Discount rate is also known as the base rate or repo rate. Through the discount window, the central bank allows eligible institutions to borrow money on a short-term basis to satisfy their reserve requirement in the central bank. This borrowing is usually done to offset temporary liquidity shortages. Subsequently, commercial banks can also use the loan for other purposes, such as for asset purchases or credit expansion. Hence, by changing the discount rate, the central bank can incentivise or disincentivise commercial banks from borrowing. This change of banks' preference towards central bank loans affects the monetary base in the economy. However, the discount rate's impact is smaller than that of open market operation because the central bank cannot fully control the banks's preferences to borrow loans. This case is different from the open market operation, through which the central bank has full control of the purchase or sale of government bonds at any given price to achieve its targeted interest rate.

- **Reserve Requirement**

Another instrument that the central bank uses to manage monetary policy is the reserve requirement. The reserve requirement is defined as the minimum amount of cash or cash equivalents that banks must deposit either in the central bank or in the commercial bank itself that cannot be used for lending or investing. This reserve requirement is computed as a percentage of deposits. Besides functioning as an instrument at the central bank's disposal for monetary policy management, the reserve requirement also works as a safeguard against unexpected withdrawals, such as bank runs. When the central bank decides to increase the reserve requirement ratio, commercial banks need to save more deposits in the central bank, which makes them less able to channel loans into the economy.

Hence, a higher reserve requirement corresponds with a contractionary monetary policy. Similarly, when the central bank decides to lower the reserve requirement ratio, commercial banks will have excess money, which they can use to expand their assets. However, similar to discount rate, the impact of the reserve requirement is less potent than open market operation. Also, the central bank prefers open market operation to this ratio, as the latter tends to affect the banks' business planning.

2.2.2 Policy Instruments

Policy instruments are a measure that the central bank employs to link policy tools to its intermediate targets. Policy instruments are necessary to translate policy tools into an achievable standard because the central bank is unable to control its intermediate targets. In general, most central banks use the short-term interest rate as a policy instrument. The short-term interest rate used by the central bank is the short-term nominal interest rate, which is the interest rate used between banks to lend and borrow money overnight for cash flow purposes. This nominal short-term interest rate is also generally known as the policy rate. Some countries also recognise this policy rate as the cash rate or cash rate official.

The central bank determines the policy rate based on its assessment of the current macroeconomic situation. Based on its evaluation, the central bank then conducts a high-level committee meeting to decide whether to cut or raise the current policy rate. In the U.S., this high-level meeting is known as the Federal Open Market Committee (FMOC) meeting. Once the decision is made, the central bank implements the instrument to achieve the desired level of policy rate. This is usually done through open market operation. However, policy rate is not the only policy instrument available. Reserve aggregates are another type of policy instrument. The central bank can formulate or choose a new policy instrument to link its policy tools to its intermediate targets based on several criteria. For example, the U.S. Federal Reserve has three criteria that it considers when determining what policy instruments should be used – specifically, the policy instrument must be measurable, controllable, and predictable.

2.2.3 Intermediate Targets

This subsection explains about intermediate targets in monetary policy. Although intermediate target is not directly related with the content of this research, this subsection is presented for the sake of completeness in conventional monetary theory under this chapter. Intermediate targets (or also known as nominal anchors) for monetary policy are considered a single variable that the central bank uses to lead expectations of private agents regarding the nominal price level or its path or about what the Bank might do with respect to achieving that path (Krugman, 2003). There are at least three types of nominal anchors that most central banks implement in their monetary policy: monetary aggregate targeting, price-based targeting, and exchange rate targeting.

- **Monetary Aggregate Targeting**

When the central bank employs a quantity-based nominal anchor, it usually targets the level of monetary aggregates in the economy. The target market variable for this type of nominal anchor is the growth of the money supply. This type of nominal anchor gained attention during the 1960s and 1970s when researchers and policymakers viewed nominal aggregates and inflation rate are as being connected. The U.S. Federal Reserve then accommodated this view by defining money M1 through M5.[1] This type of nominal anchor was popular during the 1970s.

However, targeting the money supply growth rate was later considered a weak strategy, as economists came to believe that there was no link between monetary aggregates and inflation. For instance, in the mid-1970s, econometrics estimates of M1 money demand relationships began to break down. This was true not only for inflation, but the stable relationship between monetary aggregates with other nominal variables was also questioned – which is called as "the case of missing money." In the U.S., the missing link between monetary aggregates and inflation occurred because of financial innovation, deregulation, and other factors that led to recurrent instability in the relationship between various monetary aggregates and other nominal variables (Bernanke, 2006). Similarly, Hubbard and Obrien (2012) explain that most economists believe that the breakdown occurs because the nature of M1 and M2 changed after 1980 due to financial innovations. For instance, the automated transfer of saving accounts has moved checkable deposit balances into higher-interest certificates of deposit each night and then back into checkable deposits in the morning.

- **The Price Based Targeting**

The second type of nominal anchor is known as the price-based nominal anchor. There are two variables within this type of nominal anchor: inflation and price-level targeting. With inflation targeting, the central bank considers the particular rate of change in the consumer price index (CPI). Contrarily, with price-level targeting, the central bank focuses on a specific level of CPI. Through this type of targeting, the central bank explicitly announces its inflation target to the public. Subsequently, the public and government observe the performance of the central bank at the end of the period when the actual amount of inflation is released. If the government and public believe that the central bank will commit to achieving inflation at the announced inflation target, they will adjust their expectation for future prices and will eventually bring inflation to the central bank's target level. In that circumstance, the central bank is seen as credible. However, when the central bank is not seen as credible, the government and public will not adjust their expectations.

Proponents of inflation targeting believe that inflation targeting can promote the accountability and credibility of the central bank, hence, helps improve the effectiveness of the monetary policy. In contrast, opponents of inflation targeting argue that rigid numerical inflation targets can cause the central bank to be relatively inflexible in its pursuit of other

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[1] M1 is currency and demand deposits at commercial banks. M2 was M1 plus commercial bank savings and small time deposits, and M3 was M2 plus deposits at mutual savings banks, savings and loans, and credit unions. M4 was M2 plus large time deposits. M5 was M3 plus large time deposits (Board of Governors of the Federal Reserve System, 1976).

goals besides those related to inflation. However, currently, inflation targeting is the most widely adopted nominal anchor. New Zealand was the first country to implement this nominal anchor, followed by other countries such as the United Kingdom, Australia, India, and South Africa.

- **Exchange Rate Targeting**

The last common type of intermediate targeting is exchange rate targeting. Under this nominal anchor, the central bank attempts to fix the nominal exchange rate at a certain level based on an anchor nation. The choice of anchor nation depends on based on trade relationship, openness, capital mobility, and other economic factors. There are various types of exchange rate targeting, such as a system of fiat fixed rates, a system of fixed convertibility, a system of fixed exchange rates, and dollarisation.

Under a system of fiat fixed rates, once the authority declares a fixed exchange rate, the determination of the exchange rate is based on the interactions between various economic activities, such as international trade or capital control. Hence, under this system, the authority does not actively intervene with the exchange rate. On the contrary, in a system of fixed convertibility, the authority is actively involved in the intervention of the exchange rate. The authority, which is usually the central bank, sets a fixed band within which the central bank will intervene to ensure that the exchange rate fluctuates within the band.

In a system in which the exchange rate is fixed, the authority will peg the local currency to the currency of the anchor country (thus, this currency is known as the anchor currency). The anchor country is usually chosen based on its trade and economic relationship with the country implementing the exchange rate targeting strategy. In this system, every unit of local currency is backed by a unit of foreign currency. The country that implements this targeting used usually has the sufficient foreign reserves. Finally, the dollarisation implies that the local economy can freely use a foreign currency (usually the U.S. dollar), together with the local currency. This targeting is usually implemented when people have lost faith in the local currency.

2.2.4 Transmission Channel of Monetary Policy

The transmission channel of monetary policy is the process that links the intermediate targets to the monetary policy goals. This transmission channel explains how the economy is affected after the central bank implements the monetary policy. In general, the transmission channel of monetary policy consists of two stages. The first stage has to do with the impact of policy rate on other interest rates in the economy. The second stage of the transmission relates to how the interest rates subsequently affect other economic variables, such as output, inflation, and unemployment. Among others, the following points explain five types of transmission channels that connect monetary policy to real economic variables.

- **Saving and Investment Channel**

Through the saving and investment channel, the change in interest rates can influence the behaviour of households and investors through intertemporal effects. For instance, suppose the central bank raises the policy rate, which is then followed by a rise in the lending rate. The higher lending rate increases the cost of borrowing, hence, disincentivises households from demanding loans and encourages them to save. This saving decision will reduce their consumption spending and, thus, decelerate economic growth. In contrast, when the central bank lowers the policy rate and forces the lending rate downward, the cost of borrowing today becomes cheaper and encourages investors to borrow from banks. This pattern then drives investment and increases economic growth.

- **Cash Flow Channel**

The cash flow channel explains how changes in interest rates affect the spending decisions of households and businesses. For instance, under an accommodative monetary policy, lowering interest rates can reduce the interest on debt and also the interest received from deposits. This lower interest rate then affects the amount of cash flow that households intend to spend on consumption.

- **Asset Prices Channel**

Lower interest rates can drive up asset prices, which then stimulate demands for assets. This process happens because lower interest rates increase the present discounted value of the assets' future income flows. Hence, by purchasing more assets, households receive more wealth. Furthermore, through the wealth effect, households tend to increase their consumption spending. Also, the reduction in interest rates can increase collateral value, which subsequently expands borrowing capacity. Thus, in the end, banks can provide more loans and eventually stimulate economic growth.

- **Exchange Rate Channel**

Lower interest rates decrease the return on assets and disincentivise investors from purchasing them. Investors can sell their assets and reallocate the money in the local currency to buy other assets in foreign currency. Thus, a lower interest rate can decrease the demand for local currency and, thus, depreciates the local currency. Local currency depreciation makes local products more competitive in foreign countries but causes international products in the local market to be more expensive. This situation can lead to an increase in exports and a decrease in imports, thus increasing the net exports, and bolstering GDP growth.

- **Inflation Expectation**

A low interest rate is an indicator of an expansionary monetary policy. At this rate, through the expectation channel, the public can assume that the central bank tends to expand the economy and will create an inflationary gap in the future. With rising inflation expectations, firms will adjust prices so that they increase. Higher prices then generate profitability for firms and stimulate economic growth. Similarly, lower interest rates cause households to expect higher inflation in the future, which leads them to increase their consumption spending before the prices rise. This activity eventually stimulates economic growth.

2.3 Quantitative Easing

Conventional monetary policy works through a policy instrument that affects the interest rate and eventually affects the economy via various channels. These channels include the saving and investment channel, the cash flow channel, the asset prices channel, the exchange rate channel, and the inflation expectation channel. However, there is no guarantee that all these channels will always work. For instance, during the global financial crisis, the efficacy of monetary policy in influencing banking activity diminished significantly. When monetary policy is either weak, ineffective, or poorly functioning, the unconventional monetary policy has been used to purchase a significant scale of assets in the financial market. This activity is widely known as quantitative easing. This process is considered unconventional because it is used when monetary policy is less effective than usual.

Quantitative easing policy is the purchase of a large amount of private or public securities beyond the level required in return for liquidity injection. This policy intends to keep the short-term interest rate extremely low. This policy was started at a large scale in Japan in 2001-2006 and was later adopted by other central banks such as the U.S. Federal Reserve and the Bank of England, during economic crises. Woodford (2012) explains that there is a linkage between the monetary base and aggregate expenditure. In his paper, Woodford (2012) illustrates the pure quantitative theory explaining that the increase in the monetary base – that entirely under control of the central bank – should be able to stimulate aggregate expenditure regardless of the change in overnight interest rates. The quantitative easing policy changes the composition of the central bank’s balance sheet; hence, it is also called the central bank balance sheet policy. By receiving a liquidity injection, private banks can resume their business activities – especially those conducted to expand credit to customers – and eventually stimulates economic growth.

A quantitative easing policy can also be related to fiscal policy (i.e., when quantitative easing purchases government securities instead of private securities). This policy can also have an expansionary fiscal policy effect, as the government can use the resultant liquidity to stimulate real growth. A quantitative easing policy is different from open market operations, as the latter is constrained by the policy instrument used (usually policy rate), while the former is intended to trigger economic growth. The quantitative easing policy also influences the economy by changing the monetary base, and this occurs at a level that is much more significant than is the case with open market operations. Hence, the basic mechanism of quantitative easing policy is basically similar to that of the conventional monetary policy, as described in Figure 2.1. The difference is that the quantitative easing policy does not recognise policy rate as the policy instrument.

2.3.1 Transmission Mechanism of Quantitative Easing

Bowdler and Radia (2012) describe three main channels that explain the mechanism of the quantitative easing policy in relation to the real economy. These channels are the portfolio rebalancing channel, the liquidity channel, and the policy signalling channel. These three channels will affect the real economy – specifically, economic output, and inflation – through asset prices. Figure 2.2 describes this mechanism.

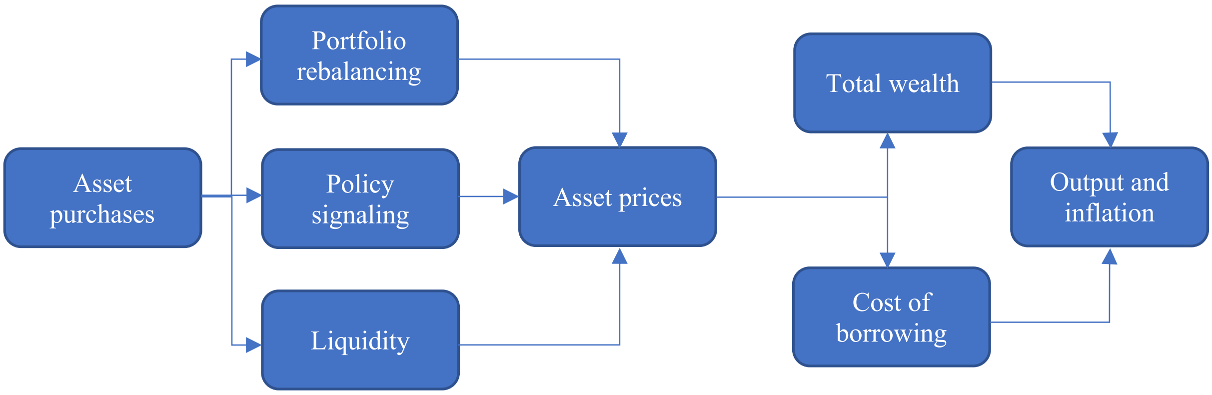


Figure 2-2: Transmission Mechanism of Unconventional Monetary Policy (Source: Bowdler and Radia, 2012)

- **Portfolio Rebalancing Channel**

This channel works based on two theories: the preferred habitat theory and the portfolio balance theory. The preferred habitat theory explains that the financial market participants basically have preferences regarding the maturity of assets. The portfolio balance theory asserts that assets of different maturities are imperfect substitutes because of frictions that inhibit arbitrage across maturities (Williamson, 2017). Based on these two theories, through this channel, private banks rebalance their investment portfolios due to the number of large asset purchases from the central bank. Specifically, when the central bank purchases long-term securities from private banks, private banks are encouraged to replace the purchased securities with other assets that offer higher returns while retaining or reducing their portfolio risk.

However, Peersman (2014) argues that the effectiveness of the portfolio rebalancing depends on the substitutability of assets and the extent to which changes in the relative supply of specific assets impact absolute and relative returns. For instance, if the assets purchased by the central bank and the assets available in the market are perfect substitute, investors will sell their holdings and rebalance their portfolios via assets from the central bank. This transaction will not have any impact on the overall economy, but the central bank's balance sheet will have expanded dramatically. Even worse, this situation can lead the economy into a liquidity trap.

However, a more significant impact on the broader economy can be seen when the assets available in the market (including those sold by the central banks) and the assets purchased by the central bank are imperfect substitutes. That is, when the central bank purchases a large number of securities from private banks, the private banks will rebalance their portfolios by purchasing other assets that are better substitute for the sold ones. This happens because there is an unmet risk appetite, which is then balanced by the increasing demand for riskier assets (Lim and Mohapatra, 2016). When private banks receive liquidity in return for the purchased assets, the exchange process rebalances the financial institutions' portfolio such that they can shift the liquidity to higher-risk assets that give more returns (e.g., loans). Hence, the conversion from liquidity to loans can increase investment and consumption and can stimulate the economy (Fernandez, Bortz, and Zeolla, 2018; Vayanos and Vila, 2009). Besides using loans, private banks can also use the liquidity to purchase other assets with the same portfolio duration. For instance, a pension fund or insurance company might prefer long-term securities - such as corporate bonds - to money or short-term securities. This raises the prices and reduces the yields of these other assets, which then stimulates aggregate demand (Peersman, 2014).

- **Signalling Channel**

Another transmission mechanism of the quantitative easing policy is the signalling channel. The idea behind the signalling channel is based on the signalling theory, which states that committing to future monetary policy can affect economic outcomes in the present and that quantitative easing is one way to express this commitment (Williamson, 2017). The signalling channel works through the public expectation for future economic policy when the central bank commits to purchasing significant assets. That is, large-scale asset purchases represent a credible commitment to keep the short-term interest rate low during the recovery process from an economic crisis (Bauer and Rudebusch, 2013; Clouse et al., 2003). Such a signaling channel can reduce yields by lowering the average expected short-rate component of long-term rates (Bauer and Rudebusch, 2013; Eggertsson and Woodford, 2003; Joyce et al., 2011). A quantitative easing is usually invoked when a conventional monetary policy is not functioning well (i.e., when the short-term interest rate is near zero). As such, Eggertsson and Woodford (2003) argue that one key action to dealing with such a situation is for the central bank to credibly manage public expectations. An essential precondition for this action is for the central bank to clearly understand the kind of history-dependent behaviour to which it should be seen to be committed so that it can communicate and act consistently with the principles that it wishes the private sector to understand (Eggertsson and Woodford, 2003).

Several studies demonstrate the important role that signalling plays in the quantitative easing program. Krishnamurthy and Vissing-Jorgensen (2011) argue that signalling is an essential channel of quantitative easing during a subprime mortgage crisis. Hendrickson and Beckworth (2013) are also in favour of the signaling effect, arguing that it can improve household and business sentiments by diminishing concerns regarding deflationary pressure in the future. Similarly, Christensen and Rudebusch (2012) also state that signalling is an important communication strategy for the central bank during the massive asset purchase program. However, Christine and Rudebusch suggest that the contribution impact between the portfolio rebalancing channel and the signalling channel hinges on the forward guidance strategy pursued by the central bank.

However, a study by Bauer and Rudebusch (2013) shows that during the subprime mortgage crisis, the signalling effect is substantial only in the first program of quantitative easing (QE1), but then its impact diminishes for subsequent injections. The impact diminishes because the public expects the low policy rate in the upcoming future time horizon. Nevertheless, the role of signalling in channeling the quantitative easing policy to the real economy remains essential. The signaling channel provides a confidence effect to bolster investment activity (Lim and Mohapatra, 2016). However, asset purchases seem to change purchasers' expectations about future policies if the purchasers are rationally related to the future policy that they are intended to signal (Woodford, 2012).

- **Liquidity Channel**

The final transmission channel for quantitative easing is the liquidity channel (Gagnon et al., 2011; Joyce et al., 2011; Krishnamurthy and Vissing-Jorgensen 2011). The liquidity channel works based on the liquidity risk premium. The idea behind the liquidity channel is that quantitative easing can compress the liquidity premium on multiple assets (Garabedian, 2018). When financial markets are incomplete or segmented, central banks can influence term, risk, and liquidity premiums by altering the relative supply of securities (Peersman, 2014). The liquidity risk premium is an additional return that investors demand in addition to illiquid assets. An asset is known to be illiquid when its liquidity premium is high.

Gagnon et al. (2011) describe that the liquidity channel is crucial during the early stages of quantitative easing during a subprime mortgage crisis. At that time, the agency-related assets were mostly illiquid and extensively widened the yields gap between the assets relative to treasury securities. A high liquidity premium also reflects the degree of trust between investors over their traded assets. Hence, by purchasing a significant amount of assets in the market through quantitative easing, the central bank can increase the amount of liquidity in the market, rebuild trust among investors, and gradually lower the liquidity premium. Garabedian (2018) argues that a decline in the liquidity premium results in a decline in borrowing costs and drives up the overall credit intermediation of investors.

2.4 Macroprudential Policy

The term macroprudential policy was recognised in 1986 in a BIS Euro-currency Standing Committee Report, though the policy did not gain massive popularity until the global financial crisis of 2008. The report defines macroprudential policy as a policy that promotes the safety and soundness of the overall financial system and payment mechanism (World Bank, 2014). Macroprudential policy aims to improve stability, which is defined as the robustness of the financial system from exogenous or endogenous shocks resulting from personal financial distress (Allen and Wood, 2006; Schinasi, 2004; Borio and Drehman, 2009a). The BIS and the International Monetary Funds (as cited in Zhang, 2015) characterised macroprudential policy as a policy that restricts systemic financial risk and prevents critical economic disruption by increasing the funding costs of firms.

Furthermore, Crockett (2000) argues that the focus of macroprudential policy is the whole financial system and its aim to minimise macroeconomic costs and financial distress. The primary functions of macroprudential policy are to manage financial risk, suppress measured risks related to economic booms, and increase measured risks during economic busts (Brunnermeier et al., 2009). Moreover, macroprudential policy also plays a role in reducing negative externality in the financial system by dissuading banking activities and strategies that trigger the impact of systemic risk (Perotti and Suarez, 2009).

As shown in Table 2.1, macroprudential policy is different from microprudential policy in the sense that the former concentrates on policy implementation at the larger scale of the whole financial system, while the latter focuses on individual financial institutions. The ultimate objective of macroprudential policy is to reduce or avoid any macroeconomic costs due to financial instability, while microprudential policy aims to protect consumers.

Table 2-1: Macroprudential versus Microprudential Perspectives (Borio, 2003)

Aspects	Macroprudential	Microprudential
Proximate objective	Limit financial system-wide distress	Limit distress of individual institutions
Ultimate objective	Avoid macroeconomics costs linked to financial instability	Consumer (investor/depositor) protection
Characterization of risk	"Endogenous" (dependent on collective behaviour)	"Exogenous" (independent of individual agents' behaviour)
Correlations and common exposures across institutions	Important	Irrelevant
Calibration of prudential controls	In terms of system-wide risk; top-down	In terms of risks of individual institutions; bottom-up

The scope of macroprudential policy is broad, as it captures all institutions in the financial sector. Due to this extensive coverage, it is difficult for a consensus to be reached regarding this kind of policy because it has to aggregate various financial institutions that might behave and interact in an intricate patterns. For instance, agreements pertaining to monetary policy have been reached regarding its policy instruments, such as the short-term overnight interest rate. Fiscal policy is also well known to manage aggregate demand via government spending and taxes. In contrast, macroprudential policy does not have a primary instrument to represent its policy goal. However, as noted by Galati and Moessner (2014), more analyses are still needed to elaborate on the appropriate macroprudential instruments, macroprudential policy's transmission mechanism, and its policy impacts. The following section explains some alternative policy instruments that can be used in macroprudential policy.

2.4.1 Macroprudential Policy Instruments

As explained previously, macroprudential policy is focused on achieving financial stability. However, Galati and Moessner (2013) argue that there is no commonly shared definition of financial stability. Gallati and Moessner (2013) also survey that the origin of financial instability can be related to exposure to the evolution of systematic risk over time, which is closely linked to the business cycle, as explained in Borio (2003). Hence, one reason for the absence of a consensus regarding macroprudential policy instruments is the vast sources of financial instability.

Nevertheless, although no consensus has been reached, efforts to present the choices of macroprudential policy instruments have been conducted by various authors. One survey from Carreras, Davis, and Piggot (2016) provide some taxonomies of macroprudential policy instruments based on different perspectives. For instance, Benanni, Despres, Dujardin, Duprey, and Kelber (2014) classify macroprudential policy instruments based on the time dimension and cross-sectional dimension. They divided the instruments into three types: capital, asset, and liquidity. The capital-type macroprudential instruments include countercyclical capital buffers and dynamic provisioning. Asset-type macroprudential instruments include loan-to-value ratio and debt-to-income ratio. Finally, liquidity-types policy instruments include loan-to-deposit ratio (LDR) and liquidity ratio. Table 2.2 presents a comprehensive list of the sample instruments.

Table 2-2: Macroprudential Instruments Classification (Bennani et al., 2014)

	Time Dimension	**Cross-sectional dimension**
Capital	Countercyclical capital buffer Dynamic provisioning Sectoral capital requirements Sectoral risk weights Countercyclical leverage ratio	G-SII and O-SII buffer Systemic risk buffer Leverage ratio
Assets	Loan to value caps Loan to income caps Debt to income caps	Large exposure measures Concentration limits
Liquidity	Limits on loan to deposit ratio Time-varying liquidity ratio Time-varying margin requirement	Systemic liquidity surcharge Liquidity coverage ratio Net stable funding ratio

The capital-based instrument is usually used to address externalities related to strategic complementarities associated with the accumulation of credit risks. This instrument is meant to equip credit institutions with buffers that can be used in the contractionary phase of the financial cycle (Bank of Slovenia, 2017). Similarly, asset-based instruments are usually implemented to handle instability related to interconnectedness. This type of policy instrument is also implemented for a specific market, such as the housing market. For instance, when mortgage activity over accelerates, the authority can put a cap on the loan-to-value ratio to dampen the housing demand. Finally, liquidity-based instruments are employed to reduce banking vulnerabilities related to funding shocks and unstable sources of financing (Bank of Slovenia, 2017). For instance, the loan-to-deposit ratio (LDR) indicates the ability of banks to channel credit. A low LDR indicates that a bank cannot easily convert deposits into credit. This can be caused by a trouble in funding activity. On the other hand, an excessive LDR indicates that a bank is over-lending. In cases when the LDR is too high, the authority can limit the ratio and dampen credit activity. Consequently, banks are directed to hold the money as funds.

Furthermore, differently from Benanni et al. (2014), Claessens, Ghosh, and Mihet (2013) classify macroprudential policy instruments based on the phases of the cycle rather than based on a time or cross-sectional dimension. That is, macroprudential policy instruments can be classified into expansionary phase, contractionary phase, and propagation of shocks. Table 2.3 illustrates the complete list of these instruments. As presented in Tables 2.2. and 2.3, the choice of macroprudential policy instruments is broad, and the best choice depends on the objective that the macroprudential policy is hoped to achieve. For instance, the BIS suggests that capital requirement ratio should be the macroprudential instrument when credit growth is the primary source of instability. On the other hand, when housing prices are the major source of instability, the general macroprudential policy instrument suggested is the loan-to-value ratio rather than a capital requirement. Other countries also implement varied capital weights to alleviate concerns regarding the housing market (Carreras, 2016).

Table 2-3: Macroprudential Instruments (Claessens, Ghosh and Mihet, 2014)

	Restriction related to borrower, instrument or activity.	Restrictions on financial sector balance sheet (assets, liabilities)	Buffer based policies	Other	
				Taxation, levies	Other (including institutional infrastructure)
Expansionary phase	-Time-varying caps on: -Debt to income -Loan to income -Loan to value -Credit growth -Margin haircut	Time-varying caps on: -Mismatches (FX or interest rate) -Reserve requirement	Countercyclical capital requirements, leverage restrictions, general provisioning.	Levy/tax on specific assets and/or liabilities	-Accounting such as varying rules on mark to market -changes to compensation, governance, market discipline
Contractionary phase: fire-sales, credit crunch	-Adjustments to specific loans -loss provisioning, -margins or haircuts	Liquidity limits such as net stable funding ratio, liquidity coverage ratio	Countercyclical capital requirements, general provisioning	Levy/tax on non-core liabilities	Standardized products, safety net, OTC vs n exchange
Contagion, or shock propagation from SIFIs or networks	Varying restrictions on asset composition, activities	Institution-specific limit on financial exposures, balance-sheet measure	Capital surcharges linked to systemic risk	Tax/levy varying by externality	Institutional infrastructure Resolution Varying information

Finally, the other complete list of macroprudential policy instruments that are widely referenced is the list released by the BIS (Table 2.4). The BIS has accommodated the formation of the Basel Committee on Banking Supervision (BCBS) to regulate and develop the international standard for commercial banking operations, particularly those regarding the regulation of capital adequacy in commercial banks across countries. In strengthening the resilience of the financial and banking sector, the Basel standard requires the capital-to-asset ratio to be above the minimum international standard. In addition to regulating capital requirement, the BCBS also regulates the global standard for financial reporting.

Table 2-4: Macroprudential Instrument (Gallati and Moessner, 2013; adapted from BIS, 2008)

Macroprudential instruments	Examples
1. Risk measurement methodology	
By banks	Risk measures calibrated through the cycle or the cyclical through
By supervisors	Cyclical conditionality in supervisory ratings of firms; develop measures of systemic vulnerability (e.g. commonality of exposures and risk profiles, intensity of inter-firm linkages) as basis for calibration of prudential tools; Communication of official assessments of systemic vulnerability and outcomes of macro stress tests.
2. Financial reporting	
Accounting standards	Use of less procyclical accounting standards; dynamic provisions.
Prudential filters	Adjust accounting figures as a basis for calibration of prudential tools; Prudential provisions as add-on to capital; smoothing via moving averages of such measures; time-varying target for provisions or for maximum provision rate.
Disclosures	Disclosures of various types of risk (e.g. credit, liquidity), and of uncertainty about risk estimates and valuations in financial reports or disclosures.
3. Regulatory capital	
Pillar 1	Systemic capital surcharge; Reduce sensitivity of regulatory capital requirements to current point in the cycle and with respect to movements in measured risk; Introduce cycle-dependent multiplier to the point-in-time capital figure; Increased regulatory capital requirements for particular exposure types (higher risk weights than on the basis of Basel II, for macroprudential reasons).
Pillar 2	Link of supervisory review to state of the cycle.
4. Funding liquidity standards	Cyclicality-dependent funding liquidity requirements; Concentration limits; FX lending restrictions; FX reserve requirements; currency mismatch limits; open FX position limits.
5. Collateral arrangements	Time-varying loan to value ratios; conservative maximum loan to value ratios and valuation methodologies for collateral; limit extension of credit based on increases in asset values; through the cycle margining.
6. Risk concentration limits	Quantitative limits to growth of individual types of exposures; (Time-varying) interest rate surcharges to particular types of loans.
7. Compensation schemes	Guidelines linking performance-related pay to ex ante longer-horizon measures of risk; back-loading of pay-offs; Use of supervisory review process for enforcement.
8. Profit distribution restrictions	Limit dividend payments in good times to help build up capital buffers in bad times.
9. Insurance mechanisms	Contingent capital infusion; pre-funded systemic risk insurance schemes financed by levy related to bank asset growth beyond certain allowance; pre-funded deposit insurance with premia sensitive to macro (systemic risk) in addition to micro (institution specific) parameters.
10. Managing failure and resolution	Exit management policy conditional on systemic strength; Trigger points for supervisory intervention stricter in booms than in periods of systemic distress.

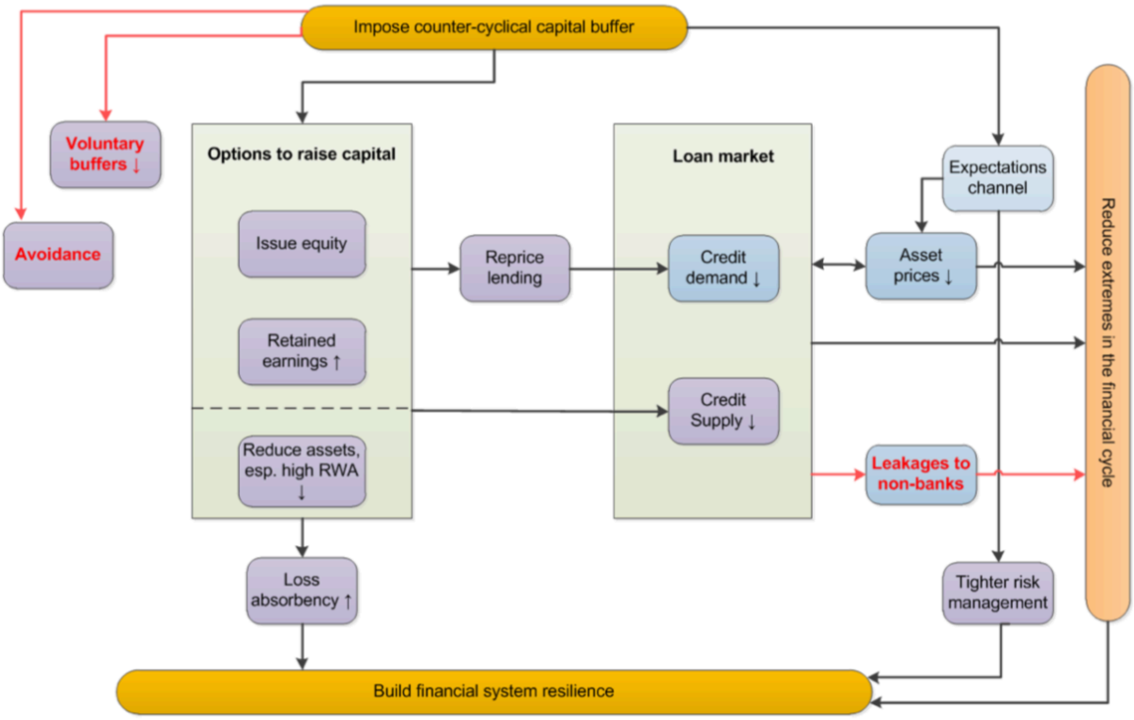
In conclusion, as a new developing macroeconomic policy, macroprudential policy is equipped with broad policy instruments to work with. Consequently, different policy instruments have different impacts on the economy. This situation then calls for the importance of the macroprudential authority to carefully select the best policy instrument as a response to a specific type of instability. More importantly, macroprudential policy must also be implemented based on interactions with existing macroeconomic policies, such as monetary or fiscal policy. Understanding their interactions can help us to observe the extent of macroprudential policy in affecting the economy. The subsequent section explains the transmission mechanism of macroprudential policy.

2.4.2 Transmission Mechanism of Macroprudential Policy

Unlike monetary policy, the formal transmission mechanism for macroprudential policy is not commonly shared. This is because different macroprudential policy instruments can provide a unique transmission mechanisms that link between the instrument to the policy goal. However, their goals are practically the same – namely, to improve financial sector resiliency and to minimise the impact of systemic risks. Some works of literature provide the transmission channel of macroprudential policy such as Rogers (2013), Carerras (2016), and Karamysheva and Saragina (2018), among others. Due to the wide array of available macroprudential policy instruments, not all mechanisms of macroprudential policy instruments can be described thoroughly here. This section will present three samples of the transmission channel, which cover capital-, asset-and liquidity-based macroprudential policy instruments.

- **Capital Based Macroprudential Policy Instruments**

Figure 2.3 illustrates the transmission mechanism of macroprudential policy when the authority increases the countercyclical capital buffer during an excessive credit period, which is adopted from Roger (2013). The idea underlying capital-based macroprudential instruments is to cushion the banking sector with increased capital during an excessive credit period and reduce the capital during a slow credit period. Once the authority observes that the impact of systemic risks in the financial sector has elevated, the capital requirement ratio is raised. As shown Figure 2.3, banks can raise their capital by issuing equities to private market, increasing retained earnings, and reducing their assets holdings. All these actions can increase the loss absorbency of banking sector, strengthen the banking solvency, and eventually improves the resiliency of the financial system. The opposite mechanisms are applied when the authority reduces the countercyclical capital buffer.



Key: purple background – bank reactions; blue background – market reactions; red text – policy leakages

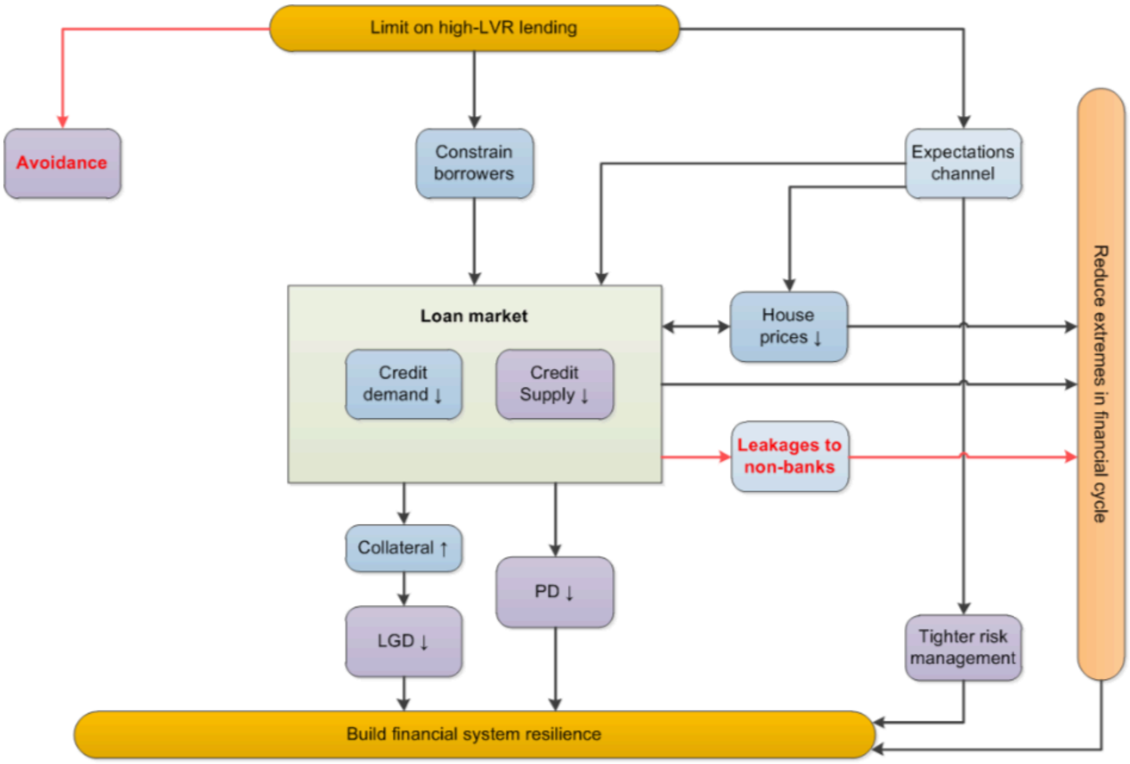
Figure 2-3: Transmission Mechanism of Raising Capital Requirements (Roger, 2013)

The decision to raise capital will negatively affect the credit supply. That is, banks are restrained from lending credit and accumulating it as capital instead. This falling credit supply will increase funding costs and, hence, reduce the credit demand. The credit demand suppresses asset prices and then reduces risks in the financial sector. However, through this policy, policy ineffectiveness can also happen through the leakages. That is, once borrowers observe that banks are no longer able to lend credit, they can turn to demand loans from non-banking financial institutions instead.

The transmission channel of a higher capital requirement ratio can also impact the policy goal through the expectation channel. That is, banks and market participants can increase their banking capital before the announcement to raise capital requirement reaches the end of notice period. This way, the rise of capital requirements can affect the financial sector (in terms of stronger banking resilience and lower systemic risks) more quickly than expected. Empirical studies show that a high capital requirement ratio can reduce the impact of systemic risks in the financial sector.

- **Assets Based Macroprudential Policy Instruments**

Figure 2.4 illustrates the transmission mechanism channel when the authority decides to lower the loan-to-value ratio. The loan-to-value ratio is the ratio of total credit relative to the market collateral values. Hence, a high loan to value ratio corresponds to a wide access for borrowers to take out loans from banks.



Key: purple background – bank reactions; blue background – market reactions; red text – policy leakages

Figure 2-4: Transmission Mechanism of Raising Loan to Value ratio (Roger, 2013)

The purpose of implementing this policy instrument is to raise the ratio during slow credit conditions and dampen the ratio during excessive credit conditions. Figure 2.4 illustrates the mechanism when the authority sets a limit on lending with a high loan to value ratio.

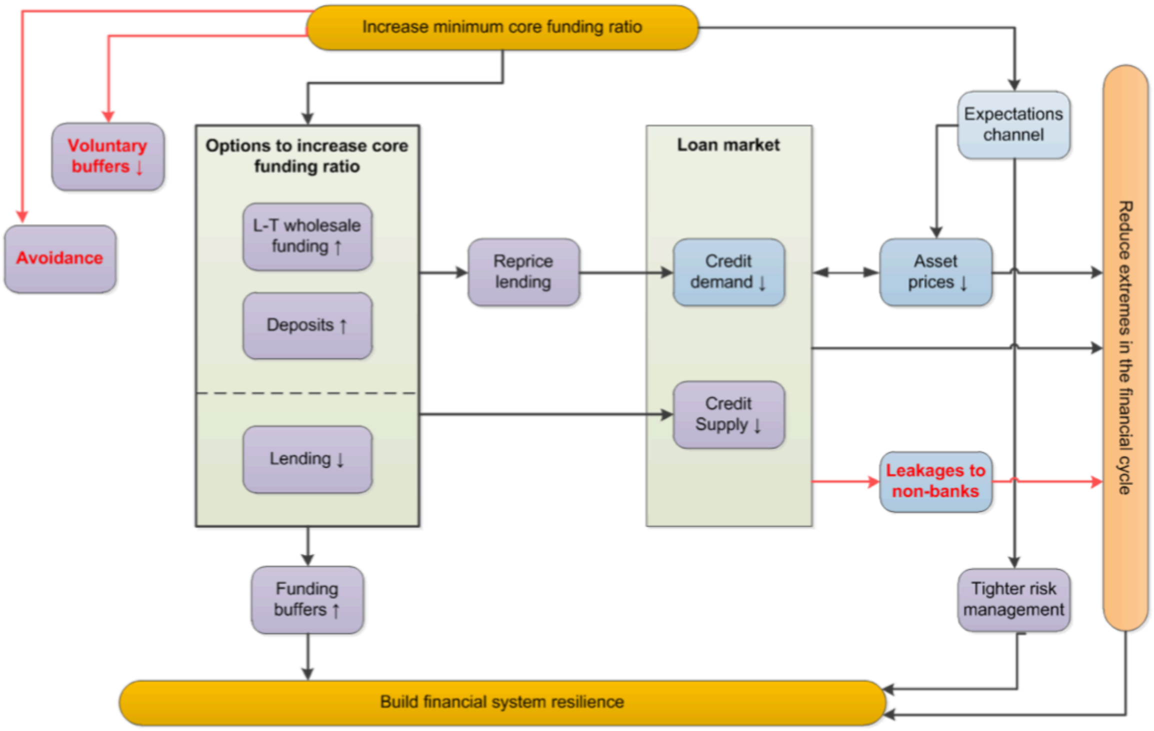
The restriction policy constrains potential borrowers from demanding such credits from banks. This policy negatively affects both credit demand and credit supply and finally results in lower equilibrium of loans in the credit market. Also, the collateral value rises when the authority imposes a higher limit. The rising value of collateral can strengthen the ability of banks to manage credit defaults and, hence, reduces the loss-given-default (LGD). At the same time, the probability-of-default (PD) of customers can also be dampened. This situation can help to increase the resilience of the financial system resilience. With regards to the policy's impact on the systemic risks, a weakening demand for credit and a smaller credit supply negatively affect housing prices.

In addition to the asset prices channel, policy restriction can also impact the financial sector through the expectation channel. That is, banks can limit credit via a high loan-to-value ratio before the policy restriction reaches its notice period. This way, the impact of the policy can be realised more quickly than expected. However, the expectation channel can also bring an adverse effect when borrowers practice forward borrowing (or when banks practice forward lending), which can temporarily increase credit demand and housing prices temporarily. In anticipating this issue, the authority needs to implement tighter risk management strategies by setting a short notice period (e.g., two weeks). As shown in the figure, the potential for leakages exists during the implementation of this strategy. That is, when the mortgage from banks is no longer acceptable, borrowers can turn their assets to non-bank financial institutions and offset the impact of policy restrictions. However, empirical studies show that policy restrictions are still effective in reducing the impact of systemic risks.

- **Liquidity Based Macroprudential Policy Instruments**

The final sample of the transmission channel in the macroprudential policy is given using liquidity-based macroprudential policy instruments. Figure 2.5 illustrates the transmission channel when the authority decides to elevate the core funding ratio. The core funding ratio works as a funding buffer to protect banks from liquidity shocks. Hence, banks increase the core funding ratio during excessive credit periods and lower the ratio during the slowing credit periods.

Figure 2.5 describes the transmission channel when the authority increases the minimum core funding ratio, which means that the economy is in an excessive credit period. The bank can increase the funding ratio through two channels – namely, by increasing the wholesale funding (deposits) and by reducing lending, or both. These activities boost deposits, increase the funding buffer, and strengthen the financial system’s resilience. The increased funding buffer consequently reduces the credit supply, which subsequently suppresses credit demand.



Key: purple background – bank reactions; blue background – market reactions; red text – policy leakages

Figure 2-5: Transmission Mechanism of Raising Core Funding Ratio (Roger, 2013)

A high core funding ratio can also affect the financial sector through the expectation channel. That is, the announcement to increase the ratio stimulates banks to increase funding faster than expected due to the expectation effect. However, this expectation channel could also have a negative consequence. Specifically, banks could have increased lending before the regulation officially takes place. This action can accelerate loans temporarily and boost asset prices. Hence, in anticipating this issue, the authority requires tighter risk management practices, such as carefully monitoring banks to ensure that all banks are acting in full compliance with the short notice period. As with the other two macroprudential policy instruments, leakage can happen when borrowers obtain loans from non-banking financial institutions. A similar instrument (i.e., the net stable funding ratio) has been shown to have an impact on the credit cycle.

CHAPTER 3

THE STRATEGIC INTERACTION BETWEEN CONVENTIONAL AND UNCONVENTIONAL MONETARY POLICY

Abstract

This chapter examines the optimal strategic interaction between conventional and unconventional monetary policy using the model from Gertler and Karadi (2011). The unconventional monetary policy considered in the model is quantitative easing, where the authority injects a direct loan into the banking sector. Two scenarios are introduced, namely the cooperation scenario and the independent scenario. Under the cooperation scenario, we present four policy regimes: the fully optimal commitment regime, the discretionary policy regime, the simple policy rule regime, and the cooperating-leadership policy regime. Under the independent scenario, we present the independent-simultaneous regime and the independent-leadership regime. Policy performance is evaluated based on the ad-hoc loss function constructed by the fluctuation of inflation, output, credit spread, nominal interest rate, and credit injection ratio. The study found that the cooperation between conventional monetary policy and quantitative easing policy in the fully optimal commitment regime delivers the best policy performance. Adopting non-optimal simple policy rules for conventional monetary and quantitative easing policies resulted in a second-best performance. However, the simple policy rules' second-best result depends upon the level of a central bank aggressiveness in combatting a crisis. If two independent policies work sequentially, the leading policy performs better than the following. However, when the two independent policies work simultaneously, monetary policy is superior.

Keywords: Monetary policy, Quantitative easing policy, Policy interaction, Policy performance.

3.1 Introduction

An economic crisis is a situation where the economic performance of a region or country deteriorates sharply. Many types of risks can trigger economic crises to erupt; one of those is financial instability. An example of event causing financial instability is the collapse of a major bank that deteriorates the movement of credit flow between banks and borrowers, which then negatively affects investment, production, and consumption. An economic crisis results in a majority of populace being worse off. During the 19th and 20th centuries, most financial crises were triggered by banking panic, stock market crash, asset price bubble, or sovereign default. Prominent crises are well-known: the Japanese 'lost decade', the Asian financial crisis, the U.S. subprime mortgage crisis, and the European debt crisis. These crises highlight the fragility of the financial sector and how severe the impacts can be.

During a crisis, the general practice is for the governmental authority to implement various efforts to stabilise the economy back to normal. The implementation of macro stabilisation policies such as monetary policy or fiscal policy is one of the efforts. The central bank, through monetary policy, usually responds to a crisis by cutting their policy rate to help banks accelerate lending activity. This action is known as expansionary monetary policy. On the other hand, the government will activate accommodative fiscal policy by relaxing tax regulations to stimulate investment and drive real sector economic activity. Theoretically, these actions should bring the economy back to equilibrium. However, that is not always the case. For example, during the U.S. global financial crisis in 2008, traditional monetary policy was less effective in encouraging lending and borrowing between banks, which then aggravated credit intermediation to the public even when the short-term overnight interest rate was extremely low. Consequently, when the traditional interest rate monetary policy is weak or poorly functioning, government and central bankers step in by activating unconventional monetary policy. In most crises, the central bank activates unconventional monetary policy in the form of quantitative easing.

Quantitative easing is the central bank action to purchase a substantial volume of private or government bonds or securities using cash. This policy essentially intends to flood the dried financial sector with fresh liquidity that banks can use to accelerate lending. In normalising the economy from the global financial crisis, the U.S. Federal Reserve injected more than $2 trillion to purchase private and public securities, particularly mortgage-backed securities. Although the policy is believed to be useful in reviving credit activity, some criticise that quantitative easing is not meant to replace conventional monetary policy as it can invite negative long-term consequences on the economy. Such policy effects might include long run inflationary pressures, higher impact of systemic risks, widening income inequality, and increasing moral hazard rate (Curdia and Woodford, 2010; Cui and Sterk, 2018; Fernandez, Bortz, and Zeolla, 2018). Therefore, a careful implementation and exploration of quantitative easing is crucial, particularly in conjunction with an existing macroeconomic policy such as monetary policy.

Unfortunately, studies related to quantitative easing policy are limited. Martin and Milas (2012) argue that the literature in quantitative easing policy is limited and too narrow; hence exploration of alternative approaches to quantitative easing is required. Recent literature on quantitative easing policy focuses mostly on the effectiveness and impact of the policy on the economy. For instance, Albu, Lupu, Calin, and Popovici (2014); Bhattarai and Neely (2016); Chen, Filardo, He, and Zhu (2016); Curcuru, Kamin, Li, and Rodriguez (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); and Kapetanios, Mumtaz, Stevens, and Theodoridis (2019), among others.

In contrast, only few studies that focus on the optimal strategic interaction between conventional monetary policy and quantitative easing policy, but they do not specifically simulate the interaction between these two policies. For example, studies from Reifschneider (2016); Chung, Laforte, Reifschneider, and Williams (2012); and Engen, Laubach, and Reifschneider (2015) that examine the impact of quantitative easing but do not consider how the quantitative easing interacts with the setting of the short-term interest rate. Another example is a study from Carlstorm, Fuerst, and Paustian (2016) that examines the role of quantitative easing in a Dynamic Stochastic General Equilibrium (DSGE) model but does not present the interaction between the quantitative easing and conventional monetary policy.

Although papers on the topic of quantitative easing and monetary policy are limited, fortunately some studies comparing the effectiveness between traditional interest rate monetary policy and quantitative easing policy provide useful information regarding the benefit and loss from the interaction of these two macro policies. Among others, some studies describing such interaction are those by Cui and Sterk (2018); Kiley (2008); Sheedy (2016), and Quint and Rabanal (2017). Ellison and Tischbirek (2014) also suggest that the central bank should coordinate conventional and unconventional monetary policy. Similarly, Cui and Sterk (2018) emphasise that the optimal and simultaneous interaction between quantitative easing policy and interest-rate policy is one of the essential questions to further explore.

This chapter examines the optimal strategic interaction between conventional monetary policy and quantitative easing policy. That is, we are interested to investigate in what circumstance the interaction between conventional monetary policy and quantitative easing policy produces the best performance. In this study, we allow the central bank to manage both policies and has full authority to optimise the two policies. The model used as a reference for this chapter is the unconventional monetary policy model from Gertler and Karadi (2011). We consider this model sufficient to describe how the central bank implements quantitative easing policy during a financial crisis, which is in line with the need of this research. The monetary policy instrument utilised in the model is the nominal interest rate, while the policy instrument representing quantitative easing policy is the credit injection ratio. A credit injection ratio is defined as the percentage (or fraction) of credit injected by a central bank relative to the total credit available in the economy. For instance, a credit injection ratio by 0.2 means that the portion of banking credit from the central bank is 20% of the total credit available in the economy. In addition to these two policy instruments, the model also features monopolistic competition and nominal rigidity in the manner of Calvo's pricing.

Among many similar papers in quantitative easing, this study is closely related to a study by Cui and Sterk (2018). However, our study is different from most papers in quantitatve easing policy in terms of the way we articulate the interaction. That is, we generate various patterns of interactions, including the possibility where the central bank assigns a leadership role on each policy, where other studies of quantitative easing policy do not incorporate. Our study is also different from Cui and Sterk (2018) and most similar studies in terms of the way we measure optimality level of the interaction. This study measures optimality of the interaction based on the policy performance or unconditional loss value. The unconditional loss value is a single number reflecting the total variation of variables in the loss function that calculated based on all exogenous shocks coming into the economy, not only conditional on a specific shock. The highest policy performance (or the lowest loss value) indicates the most optimal strategic interaction, and vice versa. Finally, the method to measure the policy performance (or loss value) is adopted from the algorithm developed by Dennis (2007), and Dennis and Ilbas (2016).

This chapter examines the interaction between conventional monetary policy and quantitative easing policy through two different scenarios, namely, the cooperation scenario and the independent scenario. The cooperation scenario is a situation where both monetary and quantitative easing policies pursue a single objective. The central bank has a single objective function which the two policies simultaneously aim to minimise. In contrast, the independent scenario is the situation where monetary policy and quantitative easing policy pursue different objective functions.

Under the cooperation scenario, we present four policy regimes: the fully optimal commitment regime, the discretionary policy regime, the simple policy rule regime, and the cooperating-leadership regime. The fully optimal commitment regime is where the central bank is committed to implement the chosen initial policy to all subsequent periods without reoptimising. On the contrary, under a discretionary policy regime, the central bank always reoptimises the policy instruments in every period. Furthermore, in the simple policy rule regime, the central bank does not optimise policy instruments but sets them based on the non-optimal simple monetary and quantitative easing rules. Finally, in the cooperating-leadership regime, one policy is optimised before the other policy. The cooperating-leadership regime consists of two parts, namely the cooperating monetary policy leadership regime, and the cooperating quantitative easing leadership regime.

In the independent scenario, we present two policy regimes: the independent-simultaneous regime, and the independent-leadership regime. The independent-simultaneous regime is the situation when conventional monetary policy and quantitative easing policy optimise their own policy instruments at the same time, but they pursue different objective functions. Thus, the independent setting is characterised as when a central bank designs a specific objective function for each policy. Under the independent scenario, monetary policy aims to stabilise inflation, while quantitative easing policy aims to stabilise credit activity.

Furthermore, the independent-leadership regime consists of two regimes, namely the independent monetary policy leadership regime and the independent quantitative easing leadership regime. In the former case, monetary policy is optimised first, followed by the optimisation of quantitative easing in the subsequent period. When optimising the quantitative easing in the second period, the central bank incorporates the nominal interest rate from the first mover into the optimisation process of the credit injection ratio. The quantitative easing leadership regime first optimises quantitative easing, followed by the optimisation of monetary policy in a subsequent period.

This study demonstrates that the fully optimal commitment regime under the cooperation scenario gives the best policy performance. However, the role of commitment is more important than coordination, as our result shows that the discretionary policy regime has the worst policy performance although cooperation takes place. Thus, if the authority implements a discretionary policy, the cooperation becomes less valuable. However, we show that although commitment regime offers the smallest loss value, its ability to stabilise inflation is less potent than simple policy rule regime. This implies that simple rule regime outperforms the commitment and discretionary regime in stabilising inflation. However, the commitment regime is superior in stabilising output, credit spread, and the nominal interest rate. Finally, the fluctuation of the credit injection ratio is found to be the smallest in the discretionary regime and results in the slowest recovery after an economic crisis. The performance of the discretionary policy regime is also identical to that of the cooperating-leadership regime, either when monetary policy is implemented first or when quantitative easing is the leading policy. If the two policies are independent of each other, the simulation demonstrates that the leading policy performs better than the follower.

Interestingly, our simulation shows that the simple policy rule regime is superior to the discretionary and leadership regime. However, its performance is conditional on the level of the central bank's aggressiveness in combatting the crisis. Our simulation illustrates that the simple policy rule regime outperforms the discretionary regime and all regimes under the independent scenario if the credit parameter is below 15. Simulations of impulse response functions under various shocks demonstrate that credit injection under the commitment and discretionary regime is smaller than that under the simple policy rule regime. In general, our simulation on the impulse response function under various shocks shows that credit injection is the largest under the simple rule regime. Overall, we discover that monetary policy performs better than quantitative easing in most policy regimes. This finding suggests that conventional monetary policy has a greater impact than quantitative easing policy, which confirms earlier findings in the literature that quantitative easing policy is not meant to replace conventional monetary policy (Cui and Sterk, 2018; Kiley, 2008, Curdia and Woodford, 2010). Thus, quantitative easing has a role as a secondary tool that works when conventional monetary policy is functioning poorly.

This chapter contributes through several ways. First, this study contributes to the literature regarding the importance of commitment in quantitative easing policy, which support studies by Woodford (2012), Ugai (2007), Beriel and Mendes (2015), Khrisnamurthy and Vissing-Jorgensen (2011), and Oda and Ueda (2007), among others, who argue that commitment is an essential factor in the operation of quantitative easing policy. Second, this study also contributes to the set of literature supporting superiority of monetary policy over quantitative easing policy, such as studies from Curdia and Woodford (2018), Cui and Sterk (2018), Sheedy (2016), and Kiley (2018), among others. Finally, the finding on this study, regarding the superiority of the leading policy and the negative impact of massive quantitative easing, also support the finding from Cui and Sterk (2018).

The rest of the chapter is structured as follows. Section two describes the literature review. Section three describes the reference model in detail. Section four contains the results and analysis, including the loss value report and the simulation of the impulse response function under various shocks. Finally, section five provides the conclusion.

3.2 Literature Review

Literature regarding the interaction between conventional monetary policy and quantitative easing policy cannot be separated from studies examining the effectiveness of quantitative easing policy in stabilising the global financial crisis. Currently, assessing the effectiveness and impact of quantitative easing policy on the economy is the central theme in the literature on unconventional monetary policy. See, for example, studies from Albu et al (2014); Bhattarai and Neely (2016); Chen et al. (2016); Curcuru et al. (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); and Kapetanios et al (2019), among others.

The literature reveals various conditionality factors for quantitative easing policy. For instance, Woodford (2012) argues that quantitative easing is not only about the large-scale asset purchased by the central bank; it also reflects the central bank's effort in signalling its commitment to lower the short-term overnight interest rate within a measured period. Therefore, this balance-sheet policy is closely linked with the central bank's forward guidance policy. However, Kuttner (2018) argues that forward guidance and quantitative easing are not substitutes, as they operate through the same expectation transmission channel. Martin and Milas (2012) argue although quantitative easing can reduce government bond rates, this effect is only temporary and negligible if bond rates are already low. The literature highlights that the investigation of quantitative easing policy's effectiveness should consider the impacts of other policy variables. This study, however, does not consider the forward guidance policy but only focuses on the interaction between quantitative easing and interest rate policy.

Studies focusing on the strategic interaction between conventional monetary policy and quantitative easing policy are not abundant. For example, Reifschneider (2016); Chung et al. (2012); and Engen, Laubach, and Reifschneider (2015) examine the impact of quantitative easing, but the studies do not consider how quantitative easing interacts with the short-term interest rate. Another example is the study from Carlstorm, Fuerst, and Paustian (2016), that examines the role of quantitative easing but does not present the interaction between quantitative easing and the interest-rate rule. Some researchers argue that the interaction between these two macro policies is essential. For instance, Cui and Sterk (2018) maintain that the optimal and simultaneous interaction between quantitative easing policy and interest-rate policy is an interesting further research question to explore. Similarly, Ellison and Tischbirek (2014) suggest that the central bank should coordinate conventional and unconventional monetary policy, where the former responds to inflation, and the latter responds to output gap fluctuation. Although few studies examine the topic of this paper, some works examining the comparison between conventional monetary policy and quantitative easing policy provide useful information to support our effort to investigate the optimal strategic interaction between these two policies. See the studies from Cui and Sterk (2018), Kiley (2008), Sheedy (2016), and Quint and Rabanal (2017).

Our study has a close relationships to Cui and Sterk (2018) and Kiley (2018). Cui and Sterk (2018) focus their study on comparing the role of conventional and unconventional monetary policy during an economic crisis. They present a quantitative New Keynesian model that allows for household heterogeneity and assets, an incomplete market, and different degrees of liquidity. Based on their study, the authors demonstrate that a quantitative easing policy can impose a powerful impact on macroeconomic stabilisation. However, the optimal quantitative easing policy tends to deliver lower welfare performance than that of the optimal interest-rate rule. The lower performance happens because quantitative easing can create a strong side effects that exacerbate inequality, which make the policy is inadvisable from a welfare perspective. Also, the study argues that quantitative easing is not desirable to replace conventional monetary policy. Cui and Sterk (2018) also demonstrate that aggressive quantitative easing is not recommended. That is, the more aggressive the central bank is in executing the quantitative easing, the more severe the adverse impacts are that the policy brings to the future. Finally, the study demonstrates that quantitative easing benefits the economy only when conventional monetary policy does not exist.

Similar to Cui and Sterk (2018), a study from Kiley (2008) also found that quantitative easing is not welfare-improving if the steady state of interest rates is high. However, if the steady state interest rate is low, quantitative easing policy can offset some of the negative impacts of the lower bound interest-rate policy. The finding also advised that quantitative easing policy can be useful when output falls below potential and when the short-term interest rate is at the effective lower bound. However, the efficacy of quantitative easing policy is enhanced when it is sizeable enough and deployed quickly by the time the crisis erupts. Hence, Kiley (2008) suggests quantitative easing to be a secondary tool and not to replace the interest rate policy.

Curdia and Woodford (2010) argue that there are at least two main reasons why thinking of quantitative easing as a substitute for interest rate policy is dangerous. First, this thinking directs attention away from the most relevant costs and benefits when thinking of the appropriate scale, timing, and allocation for a quantitative easing policy. Second, this thinking can allow the central bank not to adjust the target criterion for interest rate policy due to the zero lower bound. The ineffectiveness of quantitative easing policy under some circumstances is also argued by Sheedy (2016). Based on an economic model that adopts various types of unconventional monetary policy instruments, the author argues that quantitative easing policy is a poor substitute for the conventional nominal interest rate policy. The author further suggests that the ineffectiveness of quantitative easing policy is due to an intertemporal trade-off. That is, the use of unconventional monetary policy today can be detrimental for economic stability in the future.

Quint and Rabanal (2017) maintain that quantitative easing policy is ineffective under ordinary business cycle shocks. That is, benefits from using unconventional monetary policy under traditional supply and demand shocks are minimal. Results from Cui and Sterk (2018), Kiley (2008), and Sheedy (2016) contradict the finding. The studies reveal that quantitative easing policy is found to be welfare-improving when it reacts to a financial shock that affects banking capital. This finding is similar to those from Wallace (1981) and Eggertsson and Woodford (2003), that demonstrate that expansion in the monetary base before a crisis does not affect real variables. Quint and Rabanal (2017) investigate this issue using a general equilibrium model based on the model from Justiniano, Primiceri, and Tambalotti (2013) and augment the model with a banking sector in the same fashion as Gertler and Karadi (2011) and Andreasen, Ferman, and Zabczyk (2013). The unconventional monetary policy in the model is designed to target credit spread, which is similar to one of the variables used in an ad-hoc loss function in this study. Moreover, Quint and Rabanal (2017) posit that either providing credit for the private sector or purchasing government bonds has a very similar effect on the economy. Woodford (2012) show that the most effective type of balance-sheet policies is to directly channel credit to particular segments of the market, which is similar to the credit injection ratio instrument used in the study.

In conclusion, studies in the area of quantitative easing are currently polarised in the efforts to assess the long-run impacts of the policy on the economy. Among the literature found, our study has a close relationship with Cui and Sterk (2018) and Kiley (2018). Common understanding signals that quantitative easing is only present unconventionally when traditional monetary policy is less effective. This understanding seems to have demotivated the possibility of investigating the two policies’ interaction in greater detail. Hence, this chapter contributes to the literature by presenting a unique perspective when the traditional monetary policy is not entirely dull and actively interacts with the quantitative easing policy in combatting the economic crisis.

3.3 Model

The reference model in this study is the unconventional monetary policy model developed by Gertler and Karadi (2011). The economy under this model contains seven agents: households, financial intermediaries (or banks), intermediate goods firms, final goods firms (retailers), capital goods producer, government, and the central bank. The model contains five types of shocks, namely technology shock, capital quality shock, net worth shock, monetary policy shock, and credit injection policy shock.

3.3.1 Households

There is the continuum of identical households in the economy with the sum of unity. Each household consists of two members with different occupation as workers and bankers. The workers supply labour in the intermediate good firms, while the bankers manage financial intermediaries. In each period, the members may switch their occupation, i.e. households can be a banker and vice versa, regardless of how often they changed their job previously. Households are the owner of both intermediate good firms and financial intermediaries. Correctly, the profit that workers receive is returned to households. Likewise, the bankers also transfer any earnings from financial intermediaries back to households. Each family additionally consumes and save besides supplying labour. There is perfect consumption insurance within each household that both workers and bankers are guaranteed to consume. Furthermore, each household saves fund in the financial intermediaries. The fund is then channeled to firms.

In each period, members in the household can switch their occupation. In the aggregate level, at each period t, the fraction of $(1-f)$are workers, and the fraction of f are bankers. There is a probability θ for each banker at period t to remain as a banker at period $(t+1)$, regardless their previous occupation. Nevertheless, in ensuring that no bankers can fund all investments from their capital, $(1-f)f$ bankers exit and become workers at each period. In the same way, their job is also replaced by the quantities of workers switching to be bankers by the rule that the relative proportion of workers and bankers in the economy is fixed all the time. Consequently, there are two types of bankers in the economy: the existing bankers and the new bankers. The new bankers start working by receiving the endowed start-up funds from households.

In each period of t, household i chooses the level of consumption (C_t) and labour (L_t) to maximise the utility, which is given by

$$E_t\left[\sum_{i=0}^{\infty}\beta^i\left(log(C_{t+i}-hC_{t+i-1})-\frac{\chi}{1+\varphi}L_{t+i}^{1+\varphi}\right)\right], \tag{3.1}$$

where $0 < \beta < 1$ is the discount factor, $0 < h < 1$ is the consumption habit formation, $\chi > 0$ is the relative utility weight of labour and $\varphi > 0$ is the Frisch elasticity of labour supply. In aggregate level, households maximise their preference subject to the budget constraint, which is given by

$$C_t + B_t + T_t = W_t L_t + \Pi_t + R_t B_t, \quad \textbf{(3.2)}$$

where W_t is the real wage in period t, B_t is the amount of saving in period t, T_t is the lump sum tax paid and R_t is the real return of bonds from period $(t-1)$ to period t. Note that the bonds are one period riskless bonds that pays the gross real return R_t in one period. This budget constraint implies that the source of income that households receive come from the workers labour income $(W_t L_t)$, the dividend from the ownership of financial intermediaries (Π_t), and the interest income from the previous saving in bonds $(R_t B_t)$. Furthermore, the income is then used for consumption (C_t), saving in one period bonds (B_t) and pay lumpsum taxes (T_t).

The first order condition on labour and consumption from the above optimisation problem results in the labour market equilibrium and marginal utility of consumption, respectively, as given below

$$\varrho_t W_t = \chi L_t^{\varphi}, \quad \textbf{(3.3)}$$

$$\varrho_t = (C_t - hC_{t-1})^{-1} - \beta h E_t (C_{t+1} - hC_t)^{-1}, \quad \textbf{(3.4)}$$

where ϱ_t denotes the marginal utility of consumption at period t. Furthermore, the first order condition with respect to saving delivers the optimal real interest rate as follow

$$\beta E_t(\Lambda_{t,t+1}) R_t = 1, \quad \textbf{(3.5)}$$

$$\Lambda_{t,t+1} \equiv \frac{E(\varrho_{t+1})}{\varrho_t}, \quad \textbf{(3.6)}$$

where $\Lambda_{t,t+1}$ denotes the growth of marginal utility of consumption. As shown above, the marginal utility of consumption in period t. depends on the current, past and the expectation of future consumption.

3.3.2 Financial Intermediaries

Financial intermediaries in the model are the whole banking sector that covers both commercial banks and investment banks. The intermediaries operate to channel funds from depositors to non-financial firms. Specifically, they convert short-term liabilities into long-term assets through a lending activity. Under this model, perfect information is assumed to hold between financial intermediaries and non-financial firms. The amount of credit obtained by firms are equal to the number of financial claims held by financial intermediaries. The constraint of financial intermediaries during their operation is given by,

$$Q_t S_{jt} = N_{jt} + B_{jt}, \tag{3.7}$$

where S_{jt} denotes the number of financial claims held by intermediary j at period t, Q_t is the relative price of each claim and N_{jt} is the amount of net worth of intermediary j at the end of period t.

It is also important to note that financial claims held by the intermediaries can be coming from households $\left(S_{pt}\right)$ and macroprudential authority $\left(S_{gt}\right)$. Macroprudential authority is assumed to inject funds to the intermediaries at period t by the fraction of ψ_t of the total intermediated assets. Hence,

$$Q_t S_{jt} = Q_t S_{pjt} + \psi_t Q_t S_{jt}, \tag{3.8}$$

which implies

$$(1 - \psi_t) Q_t S_{jt} = Q_t S_{pjt}. \tag{3.9}$$

Equation (9) implies that the authority injects funds to financial intermediaries by the percentage ψ_t from the total credit in the economy. The authority intermediates credit by issuing bonds to households that gives households riskless rate at R_t and requires non-financial firms as a lender to pay back the authority at market lending rate R_{kt+1}.

The model assumes that the objective of the financial intermediaries is to maximise the banking net worth V_t, which is given by

$$V_t = E_t\left[\sum_{i=0}^{\infty} (1 - \theta)\theta^i \beta^{i+1} \Lambda_{t,t+1+i}\left(N_{jt+1+i}\right)\right], \tag{3.10}$$

where the banks net worth is defined as the difference between earnings on asset and interest payments on liabilities, that is

$$N_{jt+1} = R_{kt+1} Q_t S_{pjt} - R_t B_{jt}. \tag{3.11}$$

Furthermore, recall from (3.7) that the deposit funds received by bank j is equal to the amount of credit given and the banks net worth, then the above equation can be decomposed into

$$N_{jt+1} = E_t(R_{kt+1} - R_t) Q_t S_{pjt} + R_t N_{jt}. \tag{3.12}$$

As shown in equation (3.12), banking net worth depends on the premium $(R_{kt+1} - R_t)$ and the amount of financial claim $Q_t S_{jt}$. Thus, the preference of the financial intermediaries in the economy can be expressed in greater detail as

$$V_t = E_t\left[\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^i\Lambda_{t,t+i}\left((R_{kt+1+i}-R_{t+i})Q_{t+i}S_{jt+i}+R_{t+i}N_{jt+i}\right)\right]. \quad \textbf{(3.13)}$$

Furthermore, in aggregate terms, the value of banks net worth above can be expressed as the linear combination as follow

$$V_t = v_tQ_tS_t + \eta_tN_t, \quad \textbf{(3.14)}$$

where v_t is defined as the marginal gain from expanding assets and η_t is the marginal gain from adding one unit of net worth. The v_t and η_t are defined as

$$v_t = E_t\{(1-\theta)\beta\Lambda_{t,t+1}(R_{kt+1}-R_t)+\theta\beta\Lambda_{t,t+1}x_{t,t+1}v_{t+1}\}, \quad \textbf{(3.15)}$$

$$\eta_t = (1-\theta)+E_t(\beta\Lambda_{t,t+1}\theta z_{t+1}\eta_{t+1}), \quad \textbf{(3.16)}$$

where v_t denotes the marginal gain received by the intermediary for increasing the asset S_t, holding net worth N_t constant. While η_t denotes the marginal gain received by the intermediary for increasing net worth N_t, holding asset constant. Moreover, $z_{t,t+1}$ denotes the growth of banking net worth and $x_{t,t+1}$ denotes the growth of intermediation fund which are respectively defined as follows

$$z_{t,t+1} = \frac{N_{t+1}}{N_t} \;, \quad \textbf{(3.17)}$$

$$x_{t,t+1} = \frac{Q_{t+1}S_{t+1}}{Q_tS_t} \;. \quad \textbf{(3.18)}$$

As shown in equation (3.15), the optimisation problem for financial intermediaries depends on the discounted risk adjusted premium $\beta^{i+1}\Lambda_{t,t+1+i}(R_{kt+1+i}-R_{t+i})Q_{t+i}$. To the extent that the discounted risk adjusted premium is positive, the model assumes that the intermediary will always intend to broaden its assets indefinitely by borrowing additional funds from households. Specifically, everything else equal, the intermediaries will keep expanding asset by borrowing funds from depositors and channel it as credit to non-financial firms until the marginal gain from doing so, v_t, is zero.

3.3.3 Agency Problems

The model introduces a moral hazard problem in the banking sector which creates friction between households and financial intermediaries. This moral hazard is introduced in such a way that bankers always have an option to divert the fraction λ of the total asset back to themselves than channeling the fund to non-financial firms. This moral hazard can force the banks into bankruptcy due to the decreasing banking profitability. Therefore, in minimising the possibility of moral hazard, the intermediaries are obligated to satisfy an incentive constraint to enable them obtain funds from households. Specifically, the incentive constraint is formulated such that depositors can only lend funds to banks as long as the value of banks capital is higher or equal to the gain from doing the moral hazard. That is,

$$V_t \geq \lambda Q_t S_{pt}, \tag{3.19}$$

which implies that

$$V_t = v_t Q_t S_{pt} + \eta_t N_t \geq \lambda Q_t S_{pt}. \tag{3.20}$$

Recall that $(1-\psi_t)Q_t S_t = Q_t S_{pt}$, then the equation above can be expressed as

$$Q_t S_t \leq \frac{\eta_t N_t}{(\lambda - v_t)(1-\psi_t)}. \tag{3.21}$$

Therefore, if the constraint binds, then the assets that bankers can acquire from households must at least satisfy

$$Q_t S_t = \phi_t N_t, \tag{3.22}$$

where $\phi_t = \frac{\eta_t}{(\lambda - v_t)(1-\psi_t)}$ denotes the leverage, which is simply known as the ratio of privately intermediated assets to equity.

This constraint limits the intermediaries leverage ratio to the extent that bankers' incentive to cheat is exactly balanced by the cost. Thus, given the net worth $N_t > 0$, the constraint is binding as long as $0 < v_t < \lambda$, which is the range where expanding assets is profitable. The leverage shows that higher value of v_t corresponds to lower probability for bankers to conduct the moral hazard. In case the value of v_t is larger than λ, the constraint does not bind (i.e., that the gain from expanding asset is always higher than the gain from doing moral hazard). Given the definition of leverage above, the relationship of banking net worth can then be expressed as follow

$$N_{t+1} = \left((R_{kt+1} - R_t)(1-\psi_t)\phi_t + R_t\right)N_t. \tag{3.23}$$

Using the new evolution of banking net worth, the growth of banking net worth $z_{t,t+1}$ and the growth of intermediation funds $x_{t,t+1}$ can be expressed in the more specific form as follow

$$z_{t,t+1} = \frac{N_{t+1}}{N_t} = (R_{kt+1} - R_t)(1-\psi_t)\phi_t + R_t, \tag{3.24}$$

which now the banks net worth depends on the leverage ratio ϕ_{ct} and the realization of premium $(R_{kt+1} - R_t)$. Furthermore, the expression of credit growth can be derived as follow

$$x_{t,t+1} = \frac{Q_{t+1} S_{t+1}}{Q_t S_t} = \left(\frac{\phi_{t+1}}{\phi_t}\right) z_{t,t+1}, \tag{3.25}$$

which now is expressed as the function of leverage and the growth of banking net worth.

3.3.4 Intermediate Goods Producers

Intermediate goods firms produce intermediate goods in the economy which then are sold to final goods firms. That is, at the end of period t, intermediate good firms receive credit from financial intermediaries and use the fund to acquire capital K_t to produce intermediate output in subsequent period. Once the intermediate outputs are produced in period $(t+1)$, intermediate good firms have an option to sell the remaining capital to capital good producers. Intermediate good firms are assumed to operate in a competitive market. Perfect information is assumed to hold between financial intermediaries and intermediate goods firms. Hence, no agency problem or friction exists between the two agents. For the firms, the amount capital acquired is exactly equal to the amount of credit given, that is

$$Q_t K_t = Q_t S_t. \tag{3.26}$$

In each period t, intermediate good firms produce intermediate output by following the Cobb-Douglas production function as follow

$$Y_{mt} = A_t (U_t \xi_t K_{t-1})^{\alpha} L_t^{1-\alpha}, \tag{3.27}$$

where Y_{mt} denotes intermediate output produced at period t, U_t denotes the capacity utilisation rate chosen at period t, $\xi_t K_{t-1}$ denotes the effective capital acquired in period $(t-1)$ and α is the effective capital share. Furthermore, there are two stochastic disturbances within the production function namely technology shock A_t and the capital quality shock ξ_t. The capital quality shock in this model is defined as economic depreciation of capital. Taking the first derivative of the production function towards labour results in the labour demand as follow

$$P_{mt}(1-\alpha)\frac{Y_{mt}}{L_t} = W_t, \tag{3.28}$$

where P_{mt} is the price of intermediate output. Furthermore, the optimal capacity utilisation rate can also be derived by taking the first derivative of the production function towards U_t, which is given by

$$P_{mt}\alpha\frac{Y_{mt}}{U_t} = \delta'(U_t)\xi_t K_{t-1}. \tag{3.29}$$

Since $\delta(U_t)$ the reference model defines depreciation rate as

$$\delta(U_t) = \delta_c + \frac{\partial_\delta}{1+\zeta} U_t^{(1+\zeta)}, \tag{3.30}$$

where ζ is the elasticity of marginal depreciation with respect to the utilisation rate and ∂_δ is defined as

$$\partial_\delta = \frac{\alpha \bar{P}_m \bar{Y}_m}{\bar{K}}. \qquad \textbf{(3.31)}$$

Then, $\delta'(U_t)$ is given as

$$\delta'(U_t) = \partial_\delta U_t^{\zeta}. \qquad \textbf{(3.32)}$$

Accordingly, the capacity utilization rate is given by

$$U_t^{(1+\eta)} = \frac{P_{mt}\alpha Y_{mt}}{\partial_\delta \xi_t K_{t-1}}. \qquad \mathbf{(3.33)}$$

Next, given that the intermediate good firms operate in the perfect competitive market, hence the optimal profit for the firms in each period t is zero. Recall that the profit for firms Π_t^F can be formulated as follow

$$\Pi_t^F = \alpha P_{mt} Y_t + (Q_t - \delta(U_t))\xi_t K_t - R_{kt} Q_{t-1} K_t, \qquad \textbf{(3.34)}$$

where $\alpha P_{mt} Y_t$ is the capital share of revenue, $(Q_t - \delta(U_t))\xi_t K_t$ is the effective capital that left over and $R_{kt} Q_{t-1} K_t$ is the credit cost that firms must pay to financial intermediaries. Since in the competitive market the profit for firms is equal to zero state by state, the market lending rate that firms need to pay to financial intermediaries in period t can be defined as follow

$$0 = \alpha P_{mt} Y_t + (Q_t - \delta(U_t))\xi_t K_{t-1} - R_{kt} Q_{t-1} K_t, \qquad \textbf{(3.35)}$$

hence,

$$R_{kt} = \frac{P_{mt}\alpha Y_t}{K_t Q_{t-1}} + \frac{\xi_t}{Q_{t-1}}\big(Q_t - \delta(U_t)\big). \qquad \textbf{(3.36)}$$

Given this return on capital information, we can define the credit spread ϑ_t as follows

$$\vartheta_t = \frac{E_t R_{kt+1}}{R_t}, \qquad \mathbf{(3.37)}$$

which represents the difference between lending rate and deposit rate when the formula is loglinearized as

$$\tilde{\vartheta}_t = E_t\big(\tilde{R}_{kt+1} - \tilde{R}_t\big). \qquad \textbf{(3.38)}$$

3.3.5 Capital Goods Producers

Recall that at the end of period t, intermediate good firms have an option to sell used capital to capital producing firms. Capital producing firms will purchase the capital and harness it to refurbish the depreciated capital as new capital, which then are sold back to intermediate good firms. The model assumes that there is flow adjustment cost associated with producing new capital. The capital producing firms will maximise their preference, which is given by

$$E_t\left[\sum_{i=t}^{\infty}\beta^t\Lambda_{t,i}\left\{(Q_t-1)I_{nt}-f\left(\frac{I_{ni}+I_{ss}}{I_{ni-1}+I_{ss}}\right)(I_{ni}+I_{ss})\right\}\right], \qquad \textbf{(3.39)}$$

subject to

$$I_{nt}\equiv I_t-\delta(U_t)\xi_tK_{t-1}, \qquad \textbf{(3.40)}$$

where I_{nt} denotes net investment, I_t denotes gross investment and I_{ss} denotes the steady state of gross investment. The $\delta(U_t)\xi_tK_{t-1}$ denotes the quantity of depreciated capital. The gross investment I_t is determined by following the law motion of capital K_t as follow,

$$I_t=K_t-K_{t-1}\xi_t(1-\delta(U_t)). \qquad \textbf{(3.41)}$$

As shown above, the capital acquired to produce output at period $(t+1)$ depends on the effective capital in period t and the gross investment. The first order condition from the optimisation problem in equation (3.34) and (3.35) gives the function of capital price Q_t as follow,

$$Q_t=1+\frac{\eta_i}{2}\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}}-1\right)^2+\eta_i\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}}-1\right)\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}}\right)$$

$$-E_t\left[\beta\Lambda_{t,t+1}\eta_i\left(\frac{I_{nt+1}+I_{ss}}{I_{nt}+I_{ss}}-1\right)\left(\frac{I_{nt+1}+I_{ss}}{I_{nt}+I_{ss}}\right)^2\right], \qquad \textbf{(3.42)}$$

where η_i denotes the elasticity of investment adjustment cost.

3.3.6 Final Goods Producers

There is a continuum of final good producers (retailers) that sums at unity in the economy. Final good producers acquire intermediate output from intermediate good firms to be repackaged as final output. The retailers simply repackage intermediate output by the rule that it requires one unit of intermediate output to produce one unit of retail output. The retailers then aggregate final output through the CES composite aggregator which is given by

$$Y_t=\left(\int_0^1 Y_{f,t}^{\frac{(\varepsilon-1)}{\varepsilon}}\right)^{\frac{\varepsilon}{(\varepsilon-1)}}, \qquad \textbf{(3.43)}$$

where $Y_{f,t}$ is the final output produced by retailer f at period t and ε is the elasticity of substitution. Maximising total output Y_t given in equation (3.43) with respect to the total expenditure $X_t=\int_0^1 P_{ft}\,Y_{ft}df$ results in a relationship between the individual retailer final output and the aggregate final output as follow

$$Y_{ft}=\left(\frac{P_{ft}}{P_t}\right)^{-\varepsilon}Y_t, \qquad \textbf{(4.44)}$$

$$P_t = \left(\int_0^1 P_{ft}^{1-\varepsilon}\, df \right)^{\frac{1}{(1-\varepsilon)}}. \tag{3.45}$$

Furthermore, the retailers are assumed to operate in a monopolistic environment with nominal rigidities ala Calvo. Specifically, in each period retailers are able to adjust price optimally with probability $(1-\gamma)$ with the price indexation follows the lagged rate of inflation. The retailers then set the reset price $P_t^*$to solve the following optimisation problem

$$E_t \left[\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1+\pi_{t+k-1})^{\gamma_p} - P_{mt+i} \right] Y_{ft+i} \right]. \tag{3.46}$$

The first order condition is given by

$$E_t \left[\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1+\pi_{t+i-1})^{\gamma_p} - \left(\frac{\varepsilon}{\varepsilon-1} \right) P_{mt+i} \right] Y_{ft+i} \right] = 0. \tag{3.47}$$

By the law of large numbers, the evolution of the price level can be derived as given by

$$P_t = \left((1-\gamma) P_t^{*(1-\varepsilon)} + \gamma \left(\pi_{t-1}^{\gamma_p} P_{t-1} \right)^{(1-\varepsilon)} \right)^{\frac{1}{(1-\varepsilon)}}, \tag{3.48}$$

which can be simplified into

$$\pi_t = \left((1-\gamma) \pi_t^{*(1-\varepsilon)} + \gamma \left(\pi_{t-1}^{\gamma_p} \right)^{(1-\varepsilon)} \right)^{\frac{1}{(1-\varepsilon)}}, \tag{3.49}$$

which defines inflation.

3.3.7 Resource Constraint

In the resource constraint, the production of output is divided into private consumption, investment, government consumption, adjustment cost of capital and the government intermediation. The resource constraint is given by the following equation

$$Y_t = C_t + I_t + G_t + \tau \psi_t Q_t K_t + \left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} - 1 \right)^2 (I_{nt} + I_{ss}), \tag{3.50}$$

where $\psi_t Q_t K_t$denotes the amount of government intermediation, which is generated by the authority to be supplied to financial intermediaries. The model also assumes that the efficiency cost by τ per unit supplied exists during the government intermediation process. This cost basically reflects activities during the lending process such as the cost of raising funds via government debt or the cost of selecting the eligible private firms. Furthermore, G_t denotes the government consumption, which is set purposively fixed as

$$G_t = G_{ss}, \tag{3.51}$$

where G_{ss} is the steady state of government consumption, which is defined as 0.2 times of output. Furthermore, government expenditures are financed by lump sum taxes and government intermediation. Specifically,

$$G_{ss} + \tau\psi_t Q_t K_t = T_t + (R_{kt} - R_t)B_{gt-1}, \tag{3.52}$$

where B_{gt-1} denotes government bonds which finance total government intermediated assets, $\psi_t Q_t K_t$.

3.3.8 The Central Bank

It is assumed that there is a central bank that manages two economic policies in the economy namely the conventional monetary policy and the quantitative easing policy simultaneously. In managing the monetary policy, the central bank is assumed to follow a simple Taylor rule with the interest rate smoothing ρ_i, which is given by

$$R_{nt} = (1-\rho_i)\left[\kappa_\pi \pi_t + \kappa_y\left(\frac{MC_t}{\left(\frac{\varepsilon-1}{\varepsilon}\right)}\right)\right] + \rho_i R_{nt-1} + \varepsilon_t^R, \tag{3.53}$$

where R_{nt} denotes the nominal interest rate, MC_t is marginal cost at period t and ε_t^R is monetary policy shock. It is important to note that marginal cost and intermediate goods price have an inverse relationship

$$MC_t = \frac{1}{P_{mt}}. \tag{3.54}$$

The nominal interest rate also needs to follow the Fisher equation, which is given by

$$R_{nt} = R_t E_t(\pi_{t+1}) . \tag{3.55}$$

On the other hand, the central bank manages the quantitative easing policy by setting up the level of the credit injection ratio ψ_t in the economy by following a credit policy rule which is given by

$$\psi_t = \psi + \kappa\big(log(R_{kt+1}) - log(R_{t+1}) - (logR_k - logR)\big) + \varepsilon_t^S , \tag{3.56}$$

where ε_t^S denotes credit injection shock and ψ is the steady state of the credit injection ratio. Hence, under the simple policy rule regime, the credit injection ratio is defined as a change of spread between lending rate and deposit rate towards their steady state.

3.3.9 Exogenous Shock

The economy is assumed to be hit by four different exogenous shocks namely technology shock (ε_t^A), capital quality shock (ε_t^K), banking net worth shock (ε_t^N), monetary policy shock (ε_t^R) and credit injection shock (ε_t^S). Two of shocks with a persistence are technology shock and capital quality shock, which are given as follows

$$A_t = 0.95A_{t-1} + \varepsilon_t^A \tag{3.57}$$

$$\xi_t = 0.66\xi_{t-1} + \varepsilon_t^K, \tag{3.58}$$

where A_t is technology and ξ_t is capital quality. On the other hand, banking net worth shock and monetary policy shock have no persistence.

3.3.10 Parameter Values

The model is calibrated following the U.S. economic parameter values on the quarterly basis. The parameter values used in the model are shown in the Table 3.1, which mostly follow those in the original model of Getler and Karadi (2011). However, some parameters are emphasised. For example, we set the steady state of the credit injection ratio in the economy by zero which reflects that under normal condition, no quantitative easing policy is necessary. In other words, under normal condition, all credit in the economy come from the banking sector.

Table 3-1: Model Parameters

Parameters	Values	Description
β	0.99	Discount rate
σ	1	Intertemporal elasticity of substitution
h	0.815	Habit formation parameters
χ	3.4	Starting value for the labour utility weight
φ	0.276	Inverse Frisch elasticity of labour supply
η	7.2	Elasticity of marginal depreciation with respect to the utilisation rate
λ	0.3815	Starting value of divertible fraction
ω	0.002	Starting value of proportional starting up funds
θ	0.971	The survival probability
α	0.33	Capital share
δ	0.025	Depreciation rate
η_i	1.728	Elasticity of investment adjustment cost
ε	4.167	Elasticity of substitution between goods
γ	0.779	Calvo parameter
γ_p	0.241	Price indexation parameter
ρ_i	0	Interest rate smoothing parameter
κ_π	1.5	Inflation coefficient in simple monetary rule
κ_y	-0.125	Output gap coefficient in simple monetary rule
κ	10	Credit Parameter
τ	0.001	Costs of credit policy
ε_t^A	-0.01	Shock on technology
ε_t^K	-0.05	Shock on capital quality
ε_t^N	-0.01	Shock on banking net worth
ε_t^R	0.25	Shock on nominal interest rate
ε_t^S	0.072	Shock on credit injection

In this chapter, we also assume that the interest rate smoothing parameter in the simple monetary policy rule to be zero, which reflects that the central bank does not prefer to smooth interest rate when setting the monetary policy instrument. Although a non-zero interest rate smoothing parameter is also possible, we only present the case when the central bank is not smoothing the policy rate. Finally, in the simple policy rule regime, the central bank implements a credit policy rule with credit parameter 10. This credit parameter is important as it represents the central bank's level of aggressiveness in combatting crisis. Other parameter values are standard. For example the discount rate is 0.99, the capital share is 0.33, and the habit formation parameter is 0.815.

3.4 Result and Analysis

3.4.1 Scenario Map

This section explains the simulation map of policy interaction between conventional monetary policy (MP) and quantitative easing (QE) policy. The scenario map is described in Figure 3.1 below.

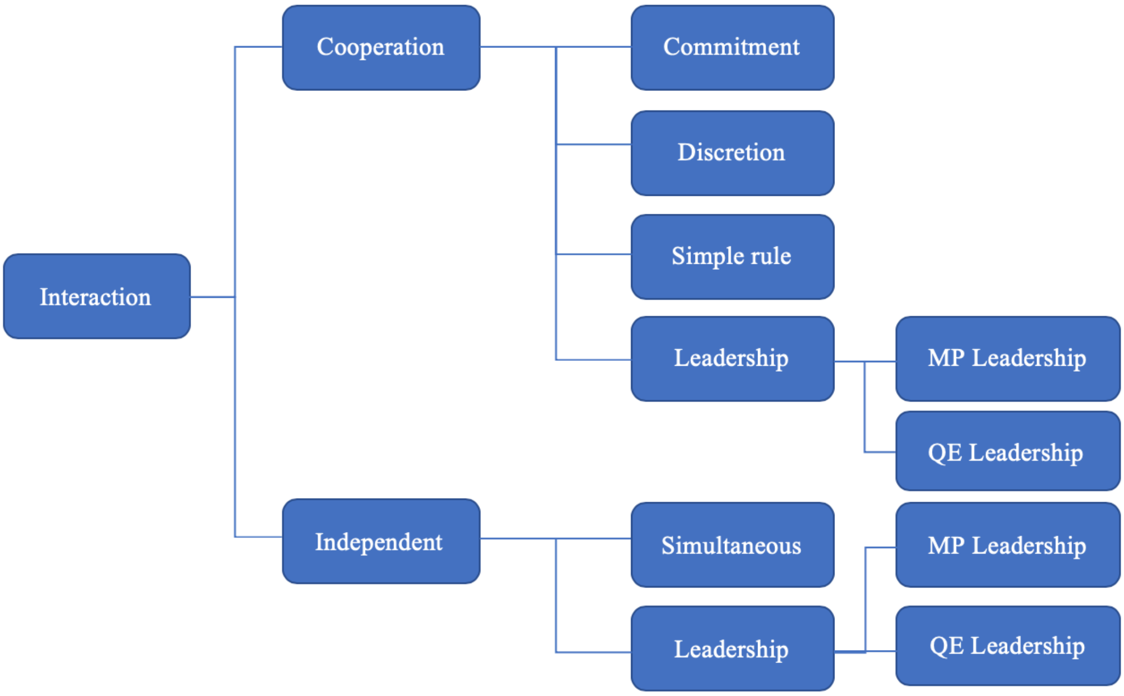


Figure 3-1: The Map of Simulation

The simulation is classified into two scenarios: the cooperation scenario and the independent scenario. The cooperation scenario is the situation where conventional monetary policy and quantitative easing policy cooperate; meaning that the two policies pursue a single objective function of the central bank. This situation contrasts with the independent scenario where the two policies pursue different objective functions. Throughout this study, the terms ‘policy objective’, ‘loss function’, and ‘objective function’ have the same meaning and are used interchangeably. We suppose this separation of objective functions under the same institution is possible due to crisis circumstances. The construction of objective functions for the two policies will be provided in the subsequent section.

Within the cooperation scenario, we present four policy regimes. The first policy regime is the fully optimal commitment policy regime (commitment regime). Under this regime, the central bank optimises the nominal interest rate and the credit injection ratio simultaneously according to a fully optimal commitment policy regime. The fully optimal commitment policy regime means that the central bank is assumed to adhere to all policy rules from the initial period and implement all rules in all subsequent periods without reoptimising. In the end, the optimal rule for the nominal interest rate and the credit injection ratio will contain all endogenous information from the economic model, the shocks, and the lagrange multipliers. Lagrange multipliers are present in the commitment rule to indicate the cost that the central bank must bear from implementing the commitment policy (Dennis, 2007). The commitment regime allows the central bank to extract all available information from the economic model completely. In contrast, the second policy regime within the cooperation scenario is the discretionary policy regime (discretion regime). We describe discretion as where the policymaker optimising today is the Stackelberg leader, and the private sector agents and future policymakers are the Stackelberg followers (Dennis, 2007). Differing from the commitment regime, the discretion regime assumes the central bank reoptimises in every period.

The third policy regime under the cooperation scenario is the simple policy rule regime. In this policy regime, we assume the central bank implements non-optimal simple rules in setting the level of policy instruments. That is, the central bank implements a simple taylor rule to determine the level of nominal interest rate and uses the credit policy rule in setting up the level of credit injection ratio. The simple Taylor rule follows the equation (3.48) while the credit policy rule follows the equation (3.51). Hence, we assume that the nominal interest rate is determined based on the deviation of inflation and output from their steady state. As for the credit injection ratio, its level is determined based on the deviation of return on capital and real interest rate from their steady state. All parameters in the two simple rules are adopted from the original model of Gertler and Karadi (2011). For instance, no interest rate smoothing parameter is given in the simple taylor rule, which means that the policy rate that the central bank determines today is independent from the policy rate that the central bank set yesterday. In the non-optimal simple quantitative easing rule (i.e., credit policy rule), the level of central bank's aggressiveness is set to be 10.

In the cooperating-leadership regime, we assume that the central bank sets the level of one policy instrument earlier, which is then followed by another policy instrument. Due to the cooperation, the follower has full information regarding the leader's movement and hence incorporates the information to set up its policy instrument. The cooperating-leadership regime consists of two regimes. The first one is the monetary policy regime, where the nominal interest rate is set before the credit injection ratio. The second one is the quantitative easing policy regime, where the nominal interest rate, as a follower, is optimised after the credit injection ratio is determined. Under the cooperating-leadership regime, the two policies have their own policy objectives, but the structure of their policy objectives is identical.

The independent scenario consists of two policy regimes. The first is the independent-simultaneous regime. In this regime, we suppose that the two policies target different loss functions, but are optimised simultaneously. Hence, although the same authority optimises the two policies simultaneously, the independence of the two policies is plausible because they have different policy objectives. Similarly, in the independent leadership regime, the two policies also target different loss functions. This independent-leadership regime consists of two types of regimes, namely the monetary policy leadership regime and the quantitative easing leadership regime. In the monetary leadership policy regime, the central bank first determines the level of the nominal interest rate, which is then followed by optimising the level of the credit injection ratio. In this regime, the follower remains to incorporate information from the leader but will use that information to pursue a different objective function.

In summary, there are eight policy regimes entering the simulation in our study. Namely, (1) the fully optimal commitment regime; (2) the discretionary policy regime; (3) the simple policy rule regime; the cooperating-leadership regime ((4) monetary policy leadership and (5) quantitative easing leadership); (6) the independent-simultaneous regime, and the independent-leadership regime ((7) monetary leadership and (8) quantitative easing leadership).

3.4.2 Loss Function

This section explains the basic construction of the loss function used in the study. As explained previously, we introduce two scenarios, namely the cooperation and the independent scenarios. Under cooperation, the central bank holds dual mandates: to stabilise inflation and to achieve credit stability. In the loss function, credit stability is represented by the fluctuation of credit spread, while inflation stability is represented by the fluctuation of inflation. Under the fully optimal commitment regime, the discretionary policy regime, and the simple rule regime, these dual mandates are constructed as a single loss function to reflect the importance of maintaining cooperation between the two policies. Hence, in addition to output and inflation, the loss function also includes the quadratic sum of the squared deviation from the credit spread, nominal interest rate, and credit injection ratio from their steady state, as shown below:

$$LOSS = E_0\left[\sum_{t=0}^{\infty} \beta^t\left(\pi_t^2 + \lambda_Y \tilde{Y}_t^2 + \lambda_\vartheta \tilde{\vartheta}_t^2 + \lambda_{Rn} \tilde{R}_{nt}^2 + \lambda_\psi \tilde{\psi}_t^2\right)\right], \qquad \mathbf{(3.59)}$$

where $\lambda_Y, \lambda_\vartheta, \lambda_{Rn}$, and λ_ψ are weights assigned to the corresponding variables relative to inflation. Under this study, those weights are set equal to one, which assumes that the central bank equally prioritises all variables in the loss function. Assigning the same weights also mean that credit stability is as important as inflation stability. The loss function under the cooperating-leadership regime also follows equation (3.59).

Given the simulation is conducted under different scenarios, the loss function is adjusted to capture the interaction between conventional monetary policy and quantitative easing policy. If both policies are working cooperatively, the construction of the loss function follows the loss in (3.59). However, when the two authorities work independently, the loss function between the two policies is designed differently. That is, the loss function (3.59) is split into two different functions as given in equation (3.60) and (3.61).

$$LOSS^{MP} = E_0\left[\sum_{t=0}^{\infty} \beta^t\left(\pi_t^2 + \lambda_Y \tilde{Y}_t^2 + \lambda_{R_n} \tilde{R}_{nt}^2\right)\right] \qquad \mathbf{(3.60)}$$

$$LOSS^{QE} = E_0\left[\sum_{t=0}^{\infty} \beta^t\left(\tilde{\lambda}_Y \tilde{Y}_t^2 + \tilde{\lambda}_\vartheta \tilde{\vartheta}_t^2 + \tilde{\lambda}_\psi \tilde{\psi}_t^2\right)\right], \qquad \mathbf{(3.61)}$$

where the notations in the loss function (3.60) and (3.61) are defined similarly to the loss function in equation (3.54). The equation (3.60) is the loss function for the conventional monetary policy, while equation (3.61) is the loss function given for quantitative easing policy. The two loss functions above imply that when conventional monetary policy and quantitative easing policy work independently, the composition of the loss function is different. The different composition reflects a different goal from each policy. Conventional monetary policy focuses on minimising the fluctuation of inflation, output, and policy rate. On the other hand, quantitative easing policy focuses on minimising the fluctuation of output, credit spread, and credit injection ratio. We set both independent policies to target minimising output in their loss function, as real sector growth is always a top priority during an economic crisis.

There are some assumptions made to the loss function above. First, the loss function is purposively designed to contain observed variables. Unlike the fully optimal loss function that harnesses the full information of the model, the ad-hoc loss function is built by assuming that not all endogenous variables in the economy can be observed by the central bank. For example, some variables like the marginal utility of consumption, depreciation rate, or capacity utilisation rate are harder to observe than output or inflation. Hence, only focusing on key observed variables makes the ad-hoc loss function more realistic and implementable. Second, the loss function is categorised with two objectives: inflation stability and credit stability objective. As explained in Woodford (2011), the target criterion (3.59) implies that the central bank should be willing to sacrifice a certain degree of inflation stability to gain greater credit stability, and vice versa. Therefore, an ad-hoc loss function encompassing the two policy instruments can illustrate this welfare transfer in a straightforward yet traceable way.

Third, the use of credit spread to represent credit stability is provided to suit the model from Gertler and Karadi (2011), who claims that the only source that amplifies the financial imbalance in the model is moral hazard, which is triggered by ambitious bankers to gain higher profits. Therefore, the movement of credit spread in the economy influences the path of credit intermediation from banks; that is., the credit spread above (below) its steady state can incentivise bankers to excel (dampen) credit. Hence, we believe that stabilising credit spread is preferred to maintain credit stability in the financial markets. Finally, the quantitative easing policy instrument, that is, the credit injection ratio, is included in the loss function because the central bank would always want to minimise the amount of credit injection. This study does not explicitly state where the credit injection comes from: it could be from the central bank reserves, banking fees, or even from printing money. Regardless of its sources, over credit injection will expand the central bank's balance sheet and potentially expose the economy to the risk of detrimental future consequences. Therefore, the existence of the credit injection ratio in the loss function works as a penalty that reduces policy performance if the central bank injects credit too aggressively.

The disadvantage of excessive credit injection is mentioned in studies such as Cui and Sterk (2018); Kiley (2008); and Fernandez, Bortz, and Zeolla (2018). The incorporation of the policy instrument in the loss function also appears in Paoli and Paustian (2013), even though the study is about macroprudential policy. They found that incorporating macroprudential instruments in the loss function can reduce welfare loss. Hence, we submit that incorporating the quantitative easing policy instrument is possibly able to minimise the loss. Similarly, the presence of a monetary instrument in the loss function enhances certainty for bankers in operating their business by minimising the fluctuation of the official interest rate (a highly fluctuating policy rate can punish the central bank with a smaller policy performance). Finally, since this study utilises an ad-hoc loss function, it is very important to note that the result of simulation is highly dependent on the weights assigned to the variables in the loss function. The simulation can deliver different results for different weights assigned. Hence, the result from this study is valid under the assumption that the central bank equalises its concern towards all variables in the loss function, and where the weight given to inflation is equal to that of other variables.

3.4.3 Policy Performance Under the Cooperation Scenario

The comparison of performance across all policy regimes is conducted based on a measure called the unconditional loss value, also known as policy performance. Hence, the terms ‘loss value’ or ‘policy performance’ are used interchangeably throughout this thesis. The smaller number of the loss value indicates a better policy performance. The loss is called as unconditional as it is calculated based on all innovations in the model, in which in our model consists of five types of shocks: technology shock, capital quality shock, net worth shock, monetary policy shock, and credit injection policy shock. The last two shocks only present in the simple policy rule regime. For commitment and discretion regime, the calculation of the loss value under cooperation scenario follows the method from Dennis (2007), while the method that calculates the loss in independent simultaneous and leadership regime follows the method from Dennis and Ilbas (2016). Based on these methods, Table 3.2 provides the simulation result of policy performance under the cooperation scenario.

Table 3-2: The Simulation Result Under the Cooperation Scenario

Policy Regime	LOSS
Fully optimal commitment	0.2973
Simple policy rule	4.9035
Discretionary policy	6.1530
Monetary policy leadership	6.1530
Quantitative easing leadership	6.1530

The loss in the fully optimal commitment regime is 0.2973, which is much smaller than the other two policy regimes. The simple policy rule regime is the second best with a loss at 4.9035, while the discretionary policy regime ranked the worst of the previous two with a loss value of 6.1530. Finally, the two cases of leadership with cooperation produce identical policy performance to the discretion regime at 6.1530. These results suggest that having the central bank managing two policy instruments simultaneously under the commitment regime is superior to the other policy regimes. The result also implies that setting up the policy instruments without commitment can deteriorate policy performance significantly. For instance, the loss in the simple rule regime is twenty times higher than that of the fully optimal commitment regime. On the other hand, optimising the policy instrument under the discretionary policy regime results in a policy performance that thirty times worse than that of the fully optimal commitment regime. Similarly, policy performance declines substantially when the two policies interact under a leadership manner, although the two policies target a single objective function.

The positive impact of commitment in quantitative easing is similar to what was argued by Ugai (2007), Beriel and Mendes (2015), Khrisnamurthy and Vissing-Jorgensen (2011), and Oda and Ueda (2007), among others, who argue that commitment is an essential factor in the operation of quantitative easing policy. Our finding regarding the important role of commitment also support the argument from Woodford (2012) who argues that quantitative easing is not only about the large-scale asset purchased by the central bank, but also reflects the central bank's effort in signalling its commitment to the public. However, it is natural that the commitment regime produces the best policy performance. Under commitment, the central bank can extract all available information from the economy and observe all exogenous shocks thoroughly. Unfortunately, having a central bank that can harness information in the economy completely is not something relevant in practice, especially under an economic crisis. Therefore, the fully optimal commitment regime should ideally work only as a benchmark. Accordingly, if the commitment regime is a benchmark, then an interesting result is shown between the simple policy rule regime and the discretionary policy rule regime.

The comparison of policy performance between these two regimes reveals that the simple policy rule regime can perform 20% better than the discretionary policy regime. This result suggests that using a non-optimal simple rule for monetary policy and quantitative easing policy is better than letting the central bank to reoptimise in every period. The result is interesting because in practice quantitative easing is not determined based on a simple rule but rather is based on a balance-sheet target from a committee meeting. This finding is valid under the assumption of the non-optimal simple rule, which is adopted from the orginal model of Gertler and Karadi (2011). Therefore, the superiority of the simple policy rule regime to the discretion regime indicates that there could be an optimal simple rule to represent the quantitative easing policy.

Although the simple policy rule regime performs better than the discretionary policy regime, this result is only conditionally valid on a specific credit parameter κ. Recall that the simple quantitative easing rule used in the simulation is defined as

$$\psi_t = \psi + \kappa\big(log(R_{kt+1}) - log(R_t) - (logR_k - logR)\big) + e_t^s \, . \qquad \textbf{(3.62)}$$

The result of our simulation is when the credit parameter κ in the simple rule is 10. The credit parameter in the simple quantitative easing rule in the model reflects the central bank's aggressiveness to combat the crisis, which means that a higher value of credit parameter indicates that the central bank is more aggressive in combatting the crisis. Considering that the level of the central bank's aggressiveness in combatting the economic crisis is an exogenous factor, we need to see what happen when the simple policy rule regime counts on the degree of the central bank's aggressiveness. Table 3.3 illustrates the policy performance of the simple policy rule regime when the credit parameter in the simple quantitative easing rule is gradually changed. Under this simulation, we assume that the the central bank does not smooth the policy rate (that is, the interest rate smoothing parameter in the simple monetary policy rule is set to be zero).

Table 3-3: Simple Policy Rule Regime Under Various Credit Parameters

Credit parameter	LOSS
1	3.7372
10	4.9035
15	6.2565
50	19.8216
100	51.5304

As shown in the table above, the policy performance in the simple policy rule regime varies when the credit parameter is gradually changed. More precisely, the policy performance worsens when the credit parameter in the simple quantitative easing rule rises. And, policy performance deteriorates quickly. For example, the loss when the credit parameter is equal to one is 3.7372, while in the case when the central bank is very aggressive (that is, when credit parameter is 100), the loss significantly jumps to 51.5394, which is 16 times worse than the former. Hence, at this rate the discretionary policy regime performs better than the simple policy rule regime. Equivalently, the result in Table 3.3 implies that a finding that the loss in the simple policy rule regime is better than that of the discretionary policy regime is conditional on the level of the central bank's aggressiveness in combatting a crisis. The more aggressive the central bank in combatting a crisis, the smaller policy performance of a simple policy rule regime will be.

Another insight from the finding in Table 3.2 is that the gap between the fully optimal commitment regime and other policy regimes is expansive. For example, the loss difference between the commitment regime and that of the discretionary policy regime is enormous, which is 0.2973 and 6.1530, respectively. To further observe which policy instrument drives such a significant difference, we disentangle the fully optimal commitment regime into two cases. The first case is when the central bank only minimises the loss function using the nominal interest rate according to a fully optimal commitment, while the level of the credit injection ratio is determined by a simple quantitative easing policy rule from equation (3.62). In the second case, the central bank minimises loss function by optimising only the credit injection ratio under a fully optimal commitment, while the nominal interest rate is determined by the simple monetary Taylor rule. Table 3.4 demonstrates the comparison between these two cases.

Table 3-4: The Simulation Result Under One Institutional Setting

Optimal Commitment Regime	**LOSS**
Case I : optimising nominal interest rate	0.4177
Case II : optimising credit injection ratio	3.4163

As shown in Table 3.4 above, in the first case, which is the case when the central bank only optimises the nominal interest rate and has the credit injection ratio determined by a simple quantitative easing rule, policy performance is delivered at 0.4177. In the second case, which is the case when the central bank only optimises the credit injection ratio and determines the nominal interest rate through the simple monetary Taylor rule, policy performance deteriorates to 3.4163. Therefore, policy performance significantly deteriorates when the central bank neglects to optimise the conventional monetary policy under the commitment regime and only focuses on optimising the quantitative easing policy alone. Comparing this result to the policy performance of the fully optimal commitment regime in Table 3.2, this result suggests that optimising the nominal interest rate alone (monetary policy) without optimising the credit injection ratio (quantitative easing policy) can worsen policy performance by 40.49%, which is derived from

$$Inefficiency = \left(1 - \frac{LOSS_{Commitment}}{LOSS_{Case\ I}}\right) = \left(1 - \frac{0.2973}{0.4177}\right) x\ 100\% = 40.49\% \qquad \textbf{(3.63)}$$

On the other hand, using a similar method (3.58) to the second case in Table 3.4, we can find that optimising quantitative easing policy alone without monetary policy can worsen the policy performance 10.49 times worse than that of the fully optimal commitment regime. Based on the policy performance, this result suggests that optimising monetary policy instrument remains superior to optimising the quantitative easing policy alone, even amid an economic crisis when the monetary policy is theoretically less functional. Hence, the large gap between the performance of the fully optimal commitment regime with the other policy regimes ultimately occurs because the impact of optimal monetary policy is more significant than the impact of quantitative easing policy on the economy. This finding suggests that monetary policy should still be the primary tool in the economy, even when it interacts simultaneously with quantitative easing policy.

Although the loss value derived in the second case is worse than the first case, optimising the credit injection ratio alone outperforms the discretionary policy regime. Specifically, the loss from optimising quantitative easing policy alone is 3.4163, while the loss from the discretionary policy regime is 6.1530. Similarly, the policy performance of the second case is also better than the performance of the simple policy rule regime in Table 3.2. That is, given that the loss value of the simple policy rule regime is 4.9035, the method (3.58) in the second case improves policy performance by 30.32% over that of the simple policy rule regime. This finding suggests that although quantitative easing is less powerful than conventional monetary policy, optimising quantitative easing policy alone under fully optimal commitment is still better off than leaving it nonoptimally under discretion, in a non-optimal simple policy rule regime, or a cooperating-leadership regime.

The third insight from the simulation is that the leadership under the coordination setting equals performance of the discretionary policy regime. This result suggests that leadership does not contribute anything to policy performance as long as the two policies pursue the single objective function. Hence, no matter which policy instrument the central bank optimises first, the final policy performance will be identical to the case when the two policy instruments interact under the discretionary policy regime. However, this result differs when the two policies are independent, as will be explained subsequently.

3.4.4 Policy Performance in the Independent Scenario

In this scenario, we allow a situation where conventional monetary policy and quantitative easing policy interact independently. As explained previously, the independence is defined as a situation when each policy pursues a different objective function. That is, monetary policy aims to stabilise inflation, the nominal interest rate, and output, while quantitative easing policy aims to stabilise credit spread, output, and the credit injection ratio. We allow the two policies to stabilise output to emphasise the importance of output growth during an economic crisis[2]. However, although the two loss functions contain output, their independence is well maintained because the central bank does not have a single objective function.

This scenario introduces three policy regimes: the independent-simultaneous regime, the independent monetary policy leadership regime, and the independent quantitative easing leadership regime. In the simultaneous interaction, the two independent policies optimise their own policy instrument at the same time. In contrast, in the leadership interaction, the two policies do not move simultaneously, but one policy instrument is optimised after the optimisation of the other. The policy acting as a follower optimises its policy instrument by importing information from the leader's policy instrument into the optimisation problem. Using the method from Dennis and Ilbas (2016), the simulation of these three policy regimes is given in Table 3.5.

Table 3-5: The Simulation Result Under One Institutional Setting

Policy Regime	**Independent**	
	LOSS^{MP}	**LOSS^{QE}**
Simultaneous	5.7868	6.0693
Monetary policy leadership	5.7849	6.0670
Quantitative easing leadership	6.0722	5.7888

As shown in the table above, when the two policies interact independently, the simulation demonstrates that the performance of the two policies is no longer identical. Under independent-simultaneous policy regime, conventional monetary policy performs better with a loss value of 5.7868, which is smaller than that of the quantitative easing policy at 6.0693. If conventional monetary policy has a chance to move first, it still performs better than quantitative easing policy. In our study, the monetary policy loss value is 5.7849, which is better performance than that of quantitative easing at 6.0670. Finally, when quantitative easing acts as a leader, the situation is reversed. That is, quantitative easing policy performs better with a loss of 5.7888, which outperforms monetary policy at 6.0722.

The simulation result delivers some critical findings. First, interacting two independent policies is slightly better than operating the two policies simultaneously under discretion and cooperation, although it is still worse than the performance of the fully optimal commitment regime. For instance, the policy performances of monetary policy and

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[2] The ad-hoc loss function for conventional monetary policy generally contains inflation and output, as given in Gali (2008). On the other hand, quantitative easing policy intends to reduce the cost of borrowing (Gertler and Karadi, 2011), which eventually is expected to increase economic growth. Thus, both policies eventually expect to revive real sector activity, and output is a measure that indicates how effective the two policies perform.

quantitative easing policy under the independent-simultaneous regime are 5.7868 and 6.0693, respectively, and both results are better than the loss value under discretion at 6.1530. However, in comparison to the simple policy rule regime, the independent scenario is underperforming. That is, the simple policy rule regime can deliver loss at 4.9305, which is better than having them interact independently under leadership. Note that the simple quantitative easing rule is assumed to use the credit parameter by 10.

Second, the impact of monetary policy on the economy remains stronger than that of the quantitative easing policy even when the two policies are independent yet move simultaneously. Recall from the previous section that when the central bank only optimises the nominal interest rate, their policy performance is 0.4177, which confirms that monetary policy remains more impactful than quantitative easing policy. A similar finding resulted even when the two independent policies interact simultaneously. Under this circumstance, the monetary policy's performance is 5.7868, while quantitative easing policy performs at 6.0693. However, the superiority of monetary policy no longer holds when quantitative easing overtakes the leadership, as explained subsequently.

Third, switching from a simultaneous to an independent-leadership regime can make the leading policy better off. The simulation on the leadership regime illustrates that the leading policy can earn higher benefit in the form of a smaller loss value than the case when the two independent policies interact simultaneously. For instance, the loss value of quantitative easing policy decreases from 6.0693 to 5.7888 (4.62%) when the policy regime is switched from simultaneous to a quantitative easing leadership regime. On the other hand, the monetary policy loss value only declines from 5.7868 to 5.7849 (0.03%) when the policy regime is switched from simultaneous to the monetary policy leadership regime. Therefore, the improvement of quantitative easing policy under leadership is better than monetary policy. However, as shown in the example, the improvement is only modest.

Fourth, in the independent-leadership regime, our simulation demonstrates that the policy leader performs better than the follower. For instance, when the central bank optimises the nominal interest rate before optimising the credit injection ratio, conventional monetary policy performs with loss 5.7849, which is better than that of quantitative easing policy with a loss of 6.0670. Equivalently, when the central bank optimises the credit injection ratio in the first period, quantitative easing policy also performs better than monetary policy. That is, quantitative easing policy performs with a loss of 5.7888, while monetary policy performs with a loss of 6.0722. Besides indicating that the leader is superior, this finding also indicates that incorporating information from the first mover does not automatically cause the follower better off. This is most likely because now the follower's policy instrument must now face another extra constraint from the presence of the first mover. On the contrary, the leader is superior because it faces less constraint from the absence of the follower in the initial period.

In conclusion, the comparison of simulation between the cooperation scenario and the two independent scenario presents some findings. First, having monetary policy and quantitative easing policy to interact cooperatively under commitment is superior to all policy regimes. The positive impact of commitment in quantitative easing is similar to what was argued by Ugai (2007), Beriel and Mendes (2015), Khrisnamurthy and Vissing-Jorgensen (2011), and Oda and Ueda (2007), among others, who argue that commitment is an essential factor in the operation of quantitative easing policy. Our finding regarding the important role of commitment also support the argument from Woodford (2012) who argues that quantitative easing is not only about the large-scale asset purchased by the central bank, but also reflects the central bank's effort in signalling its commitment to the public.

Second, conditional on the level of the central bank's aggressiveness, the simple policy rule regime offers second-best performance. Our simulation demonstrates that the simple policy rule regime performs better than the discretionary policy regime if the credit parameter in the simple quantitative easing policy rule is below 15, everything else equal. The simple quantitative easing policy rule used is the original credit policy rule adopted from the model of Gertler and Karadi (2011). In contrast, when the credit parameter is higher than 15 (i.e., when the central bank's aggressiveness increases), the policy performance is declining. Our finding regarding the falling policy performance, which also reflects the declining economic welfare, is in line wit the study from Cui and Sterk (2018) who state that although quantitative easing is a powerful instrument to stabilise inflation and output, it can substantially lower social welfare.

Third, interacting two independent policies is less recommended than having them managed under cooperation with commitment or a simple policy rule regime. However, the independent interaction setting, in either a simultaneous or a leadership setting, performs almost identically to that of the discretionary policy regime. This finding indicates that differing the two policies' loss function with leadership will not give significant result to the case when the central bank manages a single loss function under discretion regime. Fourth, the role of leadership is beneficial for the policy leader. However, when the two independent policies interact simultaneously, conventional monetary policy remains superior. This result contributes to the literature indicating that quantitative easing policy is not meant to replace conventional monetary policy, which is in accordance the studies from Cui and Sterk (2018), Sheedy (2016), Kiley (2018), Curdia and Woodford (2018), among others.

3.4.5 Unconditional Variances

This section decomposes the policy performance into the unconditional variances of the variables in the loss function. Table 3.6 illustrates the detailed unconditional variances for three policy regimes under the cooperation scenario.

Table 3-6: Unconditional Variance Under One Institution Setting

Regime	**Unconditional Variances**				
	$\boldsymbol{\pi}$	$\widetilde{\boldsymbol{Y}}$	$\widetilde{\boldsymbol{\vartheta}}$	$\widetilde{\boldsymbol{R}}_{\boldsymbol{n}}$	$\widetilde{\boldsymbol{\psi}}$
Fully optimal commitment	0.0789	0.2184	0.0030	0.0473	0.0102
Simple policy rule	0.0292	2.5834	0.0289	0.0898	2.6393
Discretionary policy	0.1684	3.9857	0.4614	1.7295	0.0000

The simple policy rule in te table is the case when the central bank implements Taylor rule and credit policy rule, respectively, as follows:

$$R_{nt} = (1-\rho_i)\left[\kappa_\pi \pi_t + \kappa_y \left(\frac{MC_t}{\left(\frac{\varepsilon-1}{\varepsilon}\right)}\right)\right] + \rho_i R_{nt-1} + \varepsilon_t^R, \tag{3.62}$$

$$\psi_t = \psi + \kappa\big(log(R_{kt+1}) - log(R_{t+1}) - (logR_k - logR)\big) + \varepsilon_t^S, \tag{3.63}$$

We only simulate the cooperation scenario since the discretionary policy regime and the regimes under leadership scenario produce similar policy performance. Recall that the loss function contains two objectives. The first one is the inflation objective, which contains the quadratic of inflation, and the second one is the credit stability objective, which is constructed by the quadratic of credit spread.

As shown from the table above, variables in the loss function fluctuate with different variances across different policy regimes. For instance, in the fully optimal commitment regime, the unconditional variance for inflation is 0.0789, which is higher than 0.0292 in the simple policy rule regime, and it is 0.1684 in the discretionary policy regime. Although the commitment regime is the best performing policy regime, the simple policy rule regime outperforms the other two policy regimes when it comes to the role of minimising inflation fluctuation.

The fully optimal commitment regime is also best stabilising output credit spread, and the nominal interest rate. As an illustration, the variance of output under commitment is 0.2184, which is much reduced volatility compared to fluctuations under the simple policy rule regime and the discretionary policy regime. Therefore, the commitment regime results in more stabilised output relative to the simple policy rule regime and the discretionary policy rule regime. The commitment regime also works effectively to dampen the fluctuation of the nominal interest rate and credit spread. The variances for these two variables are 0.0030 and 0.0473, respectively, which are also smaller than those in the other policy regimes. Finally, the credit injection ratio displays low volatility in the discretionary policy regime, which is the smallest value out of all the policy regimes. This tiny fluctuation suggests that quantitative easing policy is underperforming under discretion.

Despite the differences mentioned above, the simulation also provides some similarities. First, except in the simple policy rule regime, output has the highest volatility out of all variables in the loss function. For instance, under the fully optimal commitment regime, output fluctuates with a variance by 0.2184, which is higher than the other variables in the loss function. Similarly, the fluctuation of output in the discretionary policy regime is 3.9857, which is the highest of all variables in the loss function. Second, another finding is that credit injection ratio largely fluctuates in the simple policy rule regime. This result implies that the presence of the simple quantitative easing rule in the economy forces the authority to inject considerably more credit into the economy, which is far more significant than under the commitment regime and the discretion regime. However, everything else equal, this higher credit injection dampens the fluctuation of inflation more effectively than other policy regimes.

3.4.6 Impulse Response Functions

This section illustrates the impulse response function for the economy under various shocks. This part only introduces policy regimes under the cooperation scenario, because the impulse response function under the independent scenario is similar to that under discretion. Five types of shocks are present in the simulation – namely, minus one percent technology shock, minus five percent capital quality shock, minus one percent net worth shock, one percent increase of the nominal interest rate, and 7.2% increase of credit injection. The last two shocks are called monetary policy shock and credit injection shock, respectively, which are only present in the simple policy rule regime.

- **Technology Shock**

Figure 3.2 illustrates the impulse response function for key economic variables when a minus one percent technology shock, or also known as productivity shock, hits the economy. As show in equation (3.52), technology A_t is given in the form of first autoregressive as follows

$$A_t = 0.95A_{t-1} + \varepsilon_t^A \tag{3.64}$$

The only channel through which the technology shock can affect the economy is the production function.

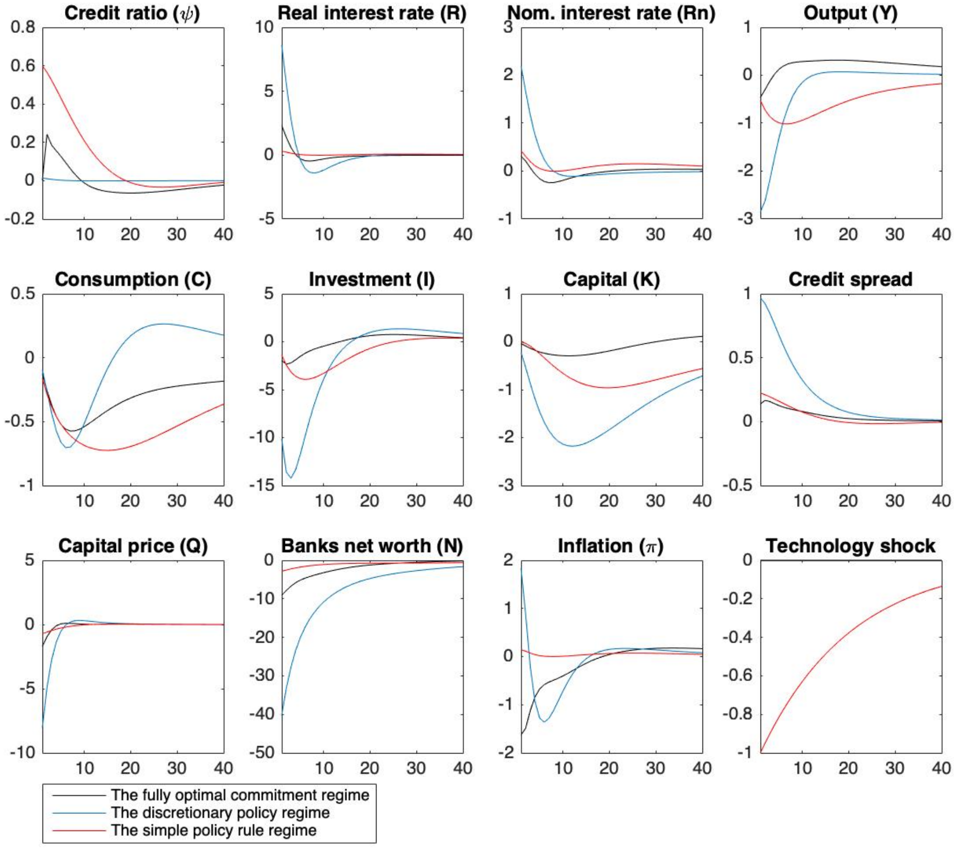

Figure 3-2: Impulse Response Function of Economy Under Minus One Percent Technology Shock

By affecting this function, the adverse productivity shock decreases output across all policy regimes. The fall of output under the discretion regime is the deepest, while it is moderate under the simple policy rule regime, and the softest under commitment. This response of output is in line with the unconditional variances in Table 3.6.

All else equal, decreasing production also affects firms' profitability, which can generate several impacts. First, smaller profits can reduce the amount of dividends sent to households. Consequently, households will earn less dividend revenues and also consume less, everything else equal. This explains why consumption falls at a similar extent across all policy regimes. Second, besides affecting households, smaller profits also attenuate firms' ability to repay loans and hence diminish their creditworthiness. Given that debt is the chief source of financing for firms to purchase new capital, a productivity shock thus hampers firms from purchasing more new capital, which explains why investment across all policy regimes declines. Furthermore, everything else equal, the falling investment activity also triggers capital stock to decline.

Smaller household income and weakening loan repayments from firms causes the banking sector to supply fewer loans to the economy because banks become more selective in choosing their borrowers. Considering that the supply of loans in the model is equal to capital stock, credit supply behaves similarly to the response of capital, which declines in all policy regimes. This falling credit supply inevitably reduces banking profitability and erodes banks' net worth, everything else equal. The impulse response function illustrates that banks' net worth under the discretion regime plummets deeper than those under the commitment or the simple policy rule regime.

As a result of the increasing losses, banks' lending rates elevate, which widen the credit spread, all else being equal. The rising credit spread from its steady state is substantial in the discretion regime but is very modest under the commitment regime. The higher lending rate corresponds to a higher return on capital and lower capital prices. Falling capital prices then reduces the profitability of capital goods producers and disincentivizes them from creating more new capital in the economy. Without new capital goods produced, production falls even more and then reduces inflation. The impulse response function illustrates that inflation tends to decline under the commitment and simple policy rule regime, while it initially increases under the discretion regime before it gradually declines.

In managing an economy back to equilibrium, a banking authority optimises policy instruments employing conventional monetary policy and quantitative easing policy. The central bank implements monetary policy by increasing the nominal interest rate. Everything else equal, following the Fisher equation, a higher nominal interest rate is followed by a rise in the real interest rate, which further stimulates households to save more deposits and thus provides more funds for intermediaries to expand credit. Additionally, the central bank increases credit by elevating the credit injection ratio. These two countercyclical policies are expected to guide banks net worth back to its steady state, which subsequently empowers credit activity, increases new capital purchases, and stimulates production in the economy. Eventually, higher production corresponds to increased profitability for firms and raised household incomes, which sparksand consumption.

In conclusion, although each policy regime demonstrates a different response to the shock, they tend to move in a similar pattern. The impulse response function shows that output, inflation, credit spread, tnominal interest rate rate, and the credit injection ratio move consistently with the unconditional variances in our simulation. Variables under the commitment predominantly express less volatility than those under the discretion and simple rule regimes. For quantitative easing policy, the central bank in the simple policy rule regime injects the most credit into the economy, which is much more aggressive than other policy regimes. In contrast, the role of this ratio is hardly observed under discretion, which may explain why the economy under this regime recovers slowly.

- **Capital Quality Shock**

Figure 3.3 illustrates the impulse response function of some key economic variables in the economy under a minus five percent capital quality shock. As show in equation (3.53), technology ξ_t is given in the form of first autoregressive as follows

$$\xi_t = 0.66\xi_{t-1} + \varepsilon_t^K \tag{3.65}$$

The adverse capital quality shock is an exogenous factor that diminishes the amount of productive capital used in the economy. One example of this shock is broken physical capital sold in the market.

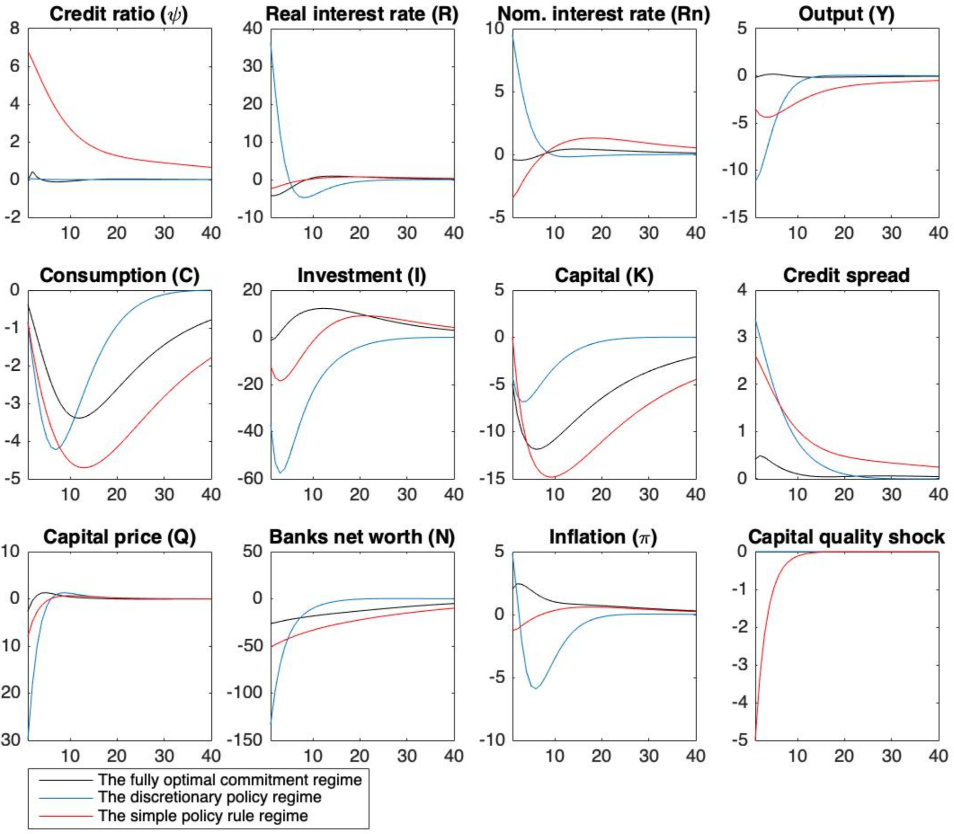

Figure 3-3: Impulse Response Function of Economy Under Minus Five Percent Capital Quality Shock

Compared to the other shocks, the adverse capital quality shock has the most channels to affect an economy. These channels include the production function, capital accumulation equation, new bankers' net worth accumulation, return on capital, and the optimal capacity utilisation rate. Overall, as will be shown, the impact of the shock is minimal under the commitment regime but is severe under the discretion regime. In the real sector, the shock diminishes capital acquired by firms across the three policy regimes. Capital in the simple policy rule regime falls almost three times deeper than that in the discretion regime, and it declines by two times deeper under the commitment regime.

The fall in capital stock negatively affects firms' production activity, and hence reduces output. Under discretion and the simple policy rule regime, output notably falls under the discretion and simple policy rule regimes, but is relatively unaffected under commitment. The falling output also reduces firms' profitability and thus decreases dividends for households. Everything else being equal, smaller income from dividends will corresponds to lower consumption. This explains why consumption falls across all policy regimes. The reduction of consumption is the deepest under the simple policy rule regime. The adverse capital quality shock also impacts capital prices negatively. That is, capital prices in all policy regimes plummet, with the discretionary policy regime posing the most significant fall. Reduced capital prices disincentivises capital good producers from producing new capital since falling capital prices curtail profits. As a result, investment in all policy regimes deteriorates. Investment also plummets deeply under the discretion regime due to the most profound decline of capital prices.

In the financial sector, reductions in new capital production and capital purchased by firms hinder banks from intermediating more credit into the economy, which reduces banks' profitability. Everything else equal, declining profit margin for banks triggers banks' net worth to fall, which occurs across all policy regimes. Banks' net worth falls most significantly under the discretion regime. Furthermore, the credit spread responds to declining net worth for banks by widening the range between the return on capital and the real interest rate, meaning the credit spread is widened. The credit spread reaches its highest deviation from the steady state under the discretionary policy regime.

In normalising the economy, the central bank under the discretion regime elevates the nominal interest rate, which is then followed by a higher real interest rate, everything else equal. The higher real interest rate then stimulates households to save more deposits in banks, which allows banks to expand more credit, achieve higher profit, and improve net worth accumulation. On the contrary, the central bank under the simple policy rule regime normalizes the economy by cutting the nominal interest rate, which then suppresses the real interest rate, everything else equal. However, quantitative easing policy takes a prominent role in this regime. That is, the central bank in the simple rule regime injects more credit into the economy than under the commitment or discretion regimes.

In conclusion, every policy regime responds to a capital quality shock in different ways. The fully optimal commitment regime is the least affected regime by the shock, while the discretion regime is the most affected. As for economic recovery after the shock, the commitment regime recovers more quickly than the other two policy regimes. Under the commitment regime, output, inflation, credit spread, nominal interest rate, and the credit injection ratio return to their steady state more quckly than those in other policy regimes.

Regarding the role of policy instruments, quantitative easing is the most active under the simple policy rule regime.

- **Net Worth shock**

Figure 3.4 illustrates the impact of a minus one percent of net worth shock on the economy. Net worth shock comes to the economy without persistence. The adverse net worth shock is as an exogenous factor that decreases banking capital. An example of this shock is a high non-performing loan that erodes banking capital. The net worth shock comes through one channel, namely the existing bankers' net worth accumulation.

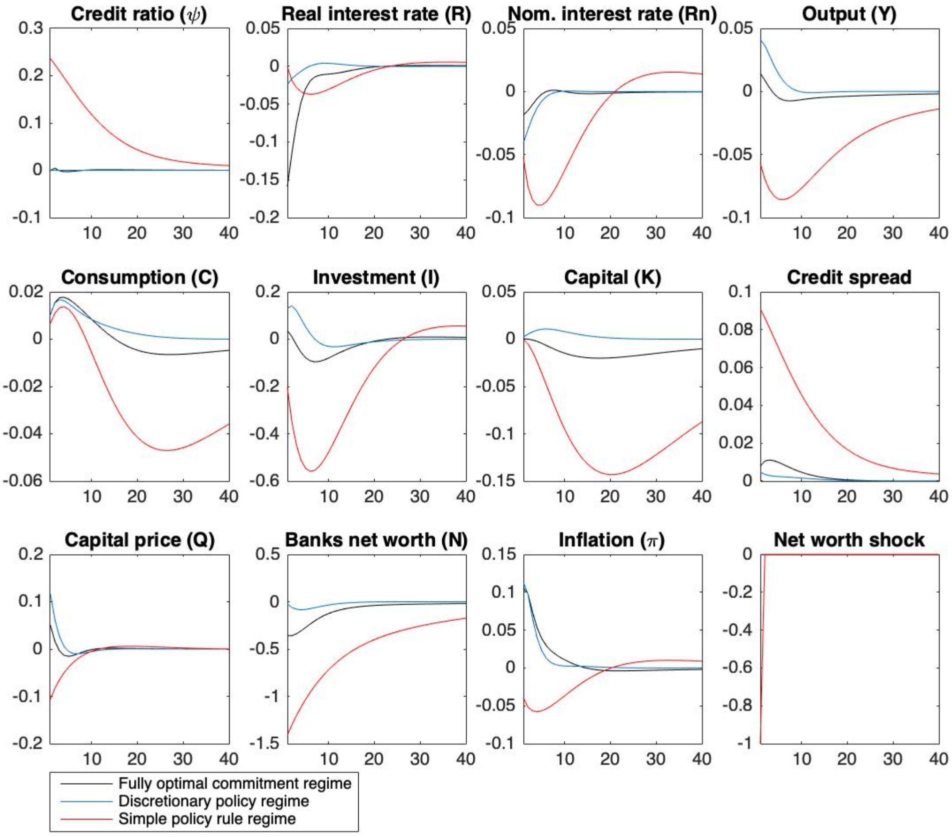

Figure 3-4: Impulse Response Function of Economy Under Minus One Percent Net Worth Shock

The new bankers' net worth declines across all policy regimes when an adverse net woth shock emerges. Everything else being equal, the fall in new bankers' net worth decreases the total net worth for banks as well. This decline in banking net worth then elevates risk in banks, which can result in a higher leverage across all policy regimes. Leverage in the simple policy rule regime increases to a higher degree than in the commitment and discretionary policy regimes.

In a net worth shock, credit activity is not affected substantially in the initial period, but gradually decreases as time passes. Depending on the response of capital prices, reductions in banking net worth influence the way banks intermediate credit. For instance, in the simple policy rule regime, the shock pressures capital prices downward which then disincentivises capital goods producers from creating more new capital. As a result, credit intermediation weakens, which can be seen in the decline in capital purchased up to -15% below its steady state. In contrast, capital prices under the commitment and discretion regimes initially rise when the shock is present but then gradually declines in subsequent periods. We contend that this situation indicates that the fully optimal commitment regime and discretionary policy regime can delay investment from falling.

The positive response of capital prices under the commitment and discretion regimes encourage capital good producers to introduce more new capital into the economy. As a result, credit activity under these two policy regimes is not affected substantially. Thus, the credit spread rises only modestly to keep banks profitable. On the contrary, the credit spread must increase significantly in the simple policy rule regime because the credit supply is affected considerably. The different response among policy regimes is also seen in the output variable. Output under the commitment and discretion regimes respond positively to the shock in the initial period, but then declines below the steady state after some periods. Everything else equal, the positive response of output in the initial period also drives consumption temporarily at the beginning, but then declines to a level below the steady state in subsequent periods.

In normalising the economy, the central bank under three policy regimes manages the nominal interest rate and the credit injection ratio. From the monetary policy perspective, the central bank across regimes behave similarly, which is to cut the policy rate. This decision causes real interest rate to fall, everything else equal. However, from a quantitative easing perspective, the credit injection ratio rises substantially only under the simple policy rule regime. In contrast, credit injection is very small under the commitment and discretion regimes. Thus, under this type of shock, the role of quantitative easing is minuscule and the central bank relies more on monetary policy to stabilise the economy.

In conclusion, each policy regime responds to the net worth shock in different ways. The commitment regime remains superior, either regarding variable fluctuation or speed of recovery. The impact of shock is very small under the commitment and discretion regimes, but substantial under the simple policy rule regime. Credit activity is less affected under the commitment and discretion regimes, but fall substantially in the simple policy rule regime. Based on the volatility of most key economic variables, the economy under the fully optimal commitment regime and discretionary policy regime performs better than the simple policy rule regime when the adverse net worth shock is present in the economy.

- **Interest Rate Shock**

Figure 3.5 illustrates the impulse response function for some key economic variables under the impact of one percent increase of nominal interest rate on the economy. Interest rate shock comes to the economy without persistence. The interest (ε_t^i) shock only affects the economy through the non-optimal Taylor simple rule as follows:

$$R_{nt} = (1-\rho_i)\left[\kappa_\pi \pi_t + \kappa_y \left(\frac{\mu_t}{\left(\frac{\varepsilon-1}{\varepsilon}\right)}\right)\right] + \rho_i R_{nt-1} + \varepsilon_t^R \qquad \textbf{(3.66)}$$

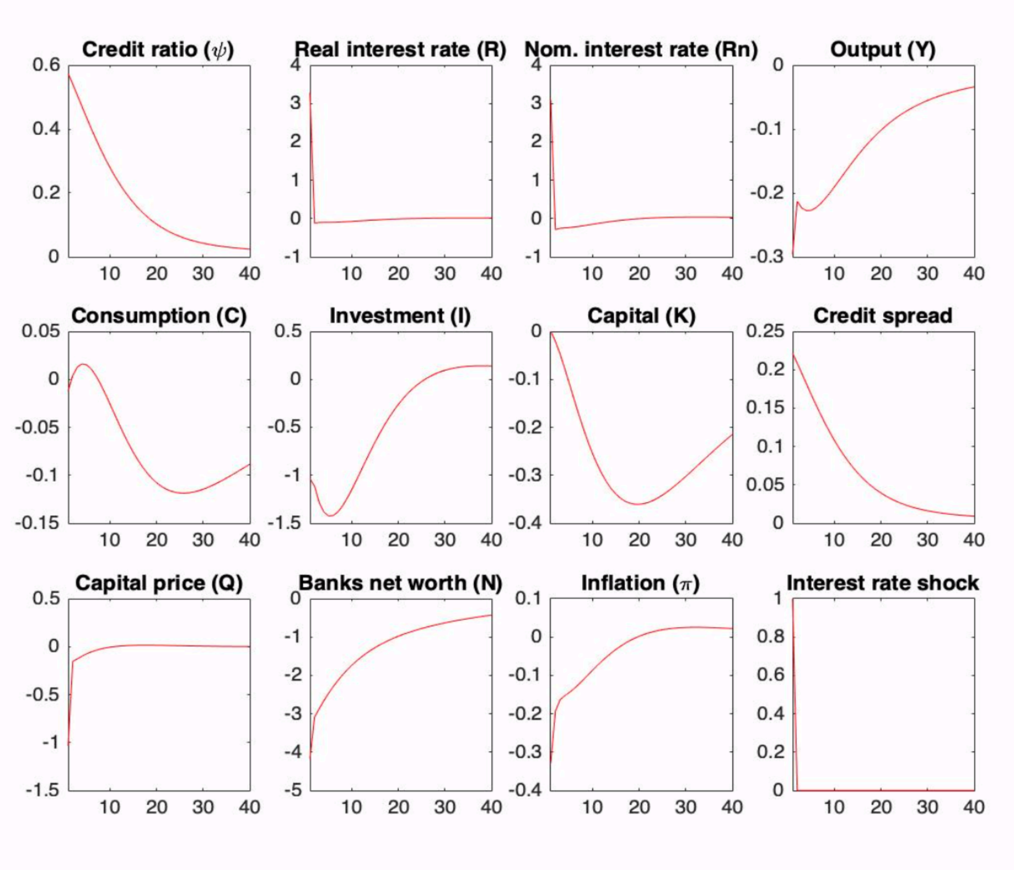

Figure 3-5: Impulse Response Function of Economy Under One Percent Interest Rate Shock

This type of shock is only present under the simple policy rule regime, as the sudden increase of the nominal interest rate comes to the economy only through a simple monetary policy rule. In practice, an example of this shock is the unanticipated increase of a policy rate from the central bank, which elevates the nominal interest rate. This shock also represents a situation where the central bank committee decision is totally beyond market expectation. By the Fisher equation, the higher nominal interest rate corresponds to the higher real interest rate, holding inflation unchanged.

Given higher real interest rates increase the return on deposits, the return on capital should also increase to keep banks remaining profitable. As a result, everything else equal, the credit spread increases by 25% from the steady state when the shock emerges. The higher return on capital also suggests that borrowing costs now become more expensive. Therefore, firms can only purchase fewer capital than usual. As shown, capital acquired by firms declines up to 30% below the steady state after some periods, although it is relatively unchanged in the initial period. Everything else equal, a higher return on capital reduces capital prices, which then disincentivises capital good producers from generating more new capital. As a result, investment in the economy plummets when the shock occurs. Another impact from decreasing investment is that banks now issue less debt to firms due to the lower capital availability in the economy. Moreover, since credit is the primary source of banking profit, this situation pressures banks' net worth as well. Also, given that banking credit is the primary source for firms to purchase capital, this shock also negatively affects production, which subsequently reduces inflation.

In normalising the economy, the central bank implements quantitative easing policy by injecting credit into the economy. Notably, the credit injection ratio is not optimised but is determined by a simple quantitative easing rule, which is adopted from the original credit rule from Gertler and Karadi (2011). When the interest rate shock presents, the credit injection ratio increases by 60% of the total credit. From the monetary policy perspective, the central bank cuts the nominal interest rate to slightly below zero percent in a few periods after the shock emerges, which then suppresses the real interest rate, everything else equal. The lower real interest rate can help lower future lending rates and also narrow the credit spread. As the credit spread goes down, lending rates decline and loans become more affordable for firms. As an effect, firms can purchase more new capital to increase production. Everything else equal, more capital acquired is helpful to improve production, increase output, and drives consumption. Expanding credit also improves banking capital and capital prices upward.

In conclusion, the presence of a positive monetary policy shock in the simple policy rule regime generates a negative impact on the economy. The shock disturbs economic equilibrium by making credit less affordable for firms, which subsequently pressures capital prices, investment, output, and consumption. Under the simple policy rule regime, the role of quantitative easing is observable in the form of a higher credit injection into the economy. However, since this shock only holds in the simple policy rule regime, it is hard to compare the impulse response of key economic variables under this shock to the other policy regimes.

- **Credit Injection Shock**

Figure 3.6 depicts the impulse response function for some key economic variables under a 7.2% credit injection shock. A credit injection shock is a sudden increase of credit provided to the economy, or, a sudden quantitative easing decision. Credit injection shock comes the economy in the form of first autoregressive process as follows

$$\xi_t^S = 0.66\xi_{t-1}^S + \varepsilon_t^K, \tag{3.67}$$

where ξ_t^S represents credit injection shock. Although a surprising injection of quantitative easing is not commonplace (because quantitative easing must always be preannounced), we provide the impulse response function under this shock for for thoroughness in our simulation. The only channel for this shock to enter the economy is through the simple credit policy rule. Hence, this shock is only valid under the simple policy rule regime.

The credit policy shockt (ε_t^S) shock only affects the economy through the non-optimal Taylor simple rule as follows:

$$\psi_t = \psi + \kappa\big(log(R_{kt+1}) - log(R_{t+1}) - (logR_k - logR)\big) + \varepsilon_t^S \tag{3.68}$$

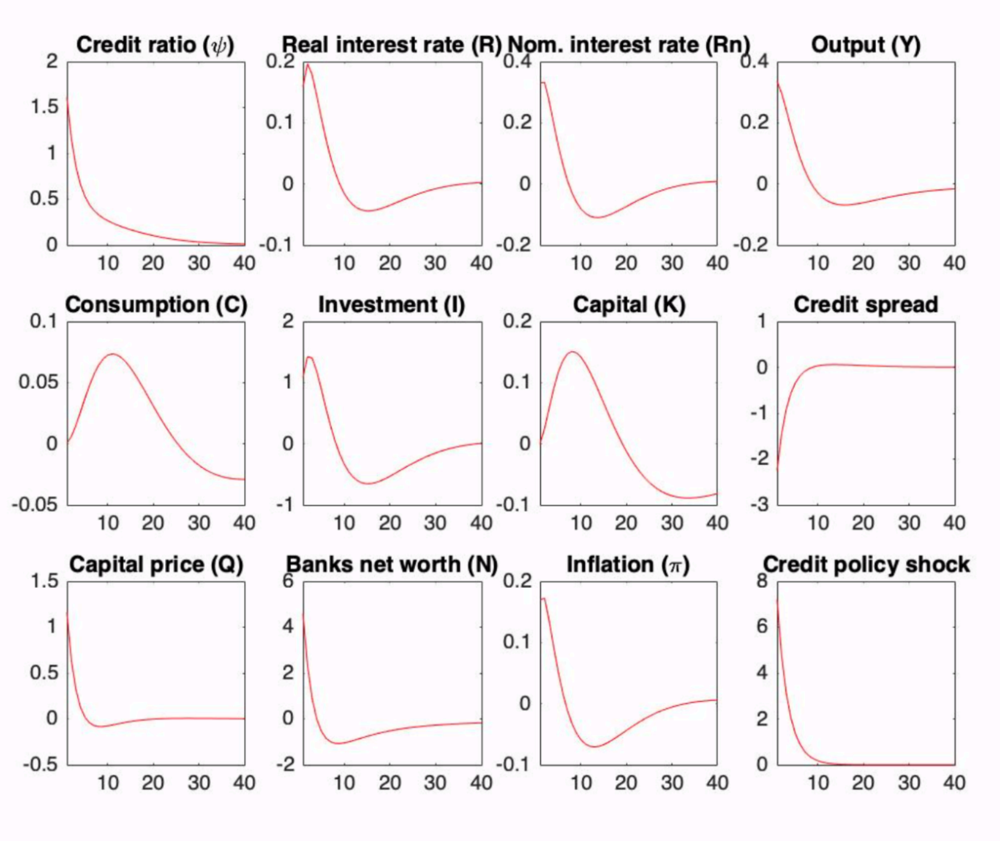

Figure 3-6: Impulse Response Function of Economy Under Adverse Macroprudential Policy Shock

The first variable affected when the shock comes to the economy is the credit injection ratio, which jumps positively in the initial period. This credit injection to financial intermediaries affects banking net worth positively, such that banking capital increases up to four times higher than its steady state. Subsequently, higher banking net worth enables intermediaries to inject more credit into the economy. Besides affecting banking net worth, the shock also rises capital prices. Higher capital prices reduce the return on capital, which means credit becomes more affordable due to a lower lending rate. The higher capital prices also incentivise capital goods producer to generate more new capital in the economy, which then stimulates investment. With rising banking net worth and higher production of new capital, banks are able to expand lending to the economy. Therefore, the capital acquired by firms also increases. Everything else equal, having more capital in the economy also helps firms to hire more labors and increase output. This positive rise in output then drives up consumption, everything else equal. As consumption is growing, inflation also rises above its steady state.

In conclusion, the presence of a credit policy shock in the form of significant credit injection contributes positively for some macroeconomic variables. For financial intermediaries, the shock can help banks expand credit, which then accelerates production and subsequently induces positive, investment, output, and consumption. However, as explained in the previous section, although a high quantitative easing injection can benefit an economy, its presence can deteriorate policy performance.

3.5 Concluding Remarks

This study focuses on the interaction between conventional monetary policy and quantitative easing policy in the economy using the unconventional monetary policy model from Gertler and Karadi (2011). There are two scenarios presented in this study: the cooperation scenario and the independent scenario. The cooperation scenario offers four policy regimes: the fully optimal commitment regime, the simple policy rule regime, the discretionary policy regime, and the cooperating-leadership regime. The cooperating-leadership regime consists of the monetary policy leadership regime and the quantitative easing leadership regime. Furthermore, two policy regimes are introduced in the independent scenario, namely the independent-simultaneous regime and the independent-leadership regime. The independent-leadership regime consists of the monetary policy leadership regime and the quantitative easing leadership regime.

The loss function used in the model is an ad-hoc loss function constructed by quadratic deviation of output, inflation, credit spread, nominal interest rate, and the credit injection ratio from their steady state. Under the cooperation regime, both conventional monetary policy and quantitative easing policy pursue a single central bank's objective function, while under the independent scenario, the central bank uses a different objective function for each policy. The interaction algorithm and performance measurement across regimes are conducted by following studies from Dennis (2007) and Dennis and Ilbas (2016).

This work demonstrates that the commitment regime under the cooperation scenario produces the best policy performance while the discretion regime performs the worst. This finding is in line with studies by Woodford (2012), Ugai (2007), Beriel and Mendes (2015), Khrisnamurthy and Vissing-Jorgensen (2011), and Oda and Ueda (2007), among others, who argue that commitment is an essential factor in the operation of quantitative easing policy. Moreover, the conventional monetary policy and quantitative easing policy that interact under the leadership setting perform identically and similar to the performance of the discretionary policy regime.

However, when they interact independently using leadership, the study found that the leading policy performs better than the follower, but their difference in performance relative to the discretionary policy regime is unremarkable. The finding that quantitative easing is better off when it plays as a leader (i.e., when it is optimised before the presence of monetary policy) supports the finding from Cui and Sterk (2018) who argue that an optimal rule of quantitative easing is welfare enhancing when conventional policy is unavailable. Overall, we argue that the simple policy rule regime could be the second-best choice, in that its performance is the second best after the commitment regime. However, this second-best policy performance is conditional on the level of the central bank's aggressiveness in combatting the crisis. Our simulation shows that the simple policy rule regime outperforms the discretionary policy regime as long as the credit parameter is below 15.

The study also measures the unconditional variances for the variables in the loss function under the cooperation scenario. We argue that although commitment regime offers the best policy performance (which means the smallest loss value), its ability to stabilise inflation is less potent than the simple policy rule regime. In other words, the simple rule regime outperforms the commitment and discretion regimes when it comes to the job of stabilising inflation. Although its ability to dampen inflation is not significant, the commitment regime is superior in stabilising output, credit spread, and the nominal interest rate to other policy regimes. Finally, the fluctuation of the credit injection ratio is found to be the smallest in the discretionary policy regime but causes this regime to recover slowly after a crisis.

The findings from this study generate some policy recommendations. Under this model, the cooperation between conventional monetary policy and quantitative easing policy is more advantageous than interacting the two policies independently. However, this only applies when the central bank can be committed to policy rules. If the central bank is unable to commit and implements a discretionary policy regime instead, cooperation becomes less valuable. Unfortunately, managing the fully optimal commitment regime is not possible in practice because the central bank is of course unable to observe complete information and exogenous shocks in an economy. Hence, an alternative policy is to implement a simple policy rule managing the two policy instruments. Under this study, the non-optimal simple rules from the original model of Gertler and Karadi (2011) perform better than the discretionary policy regime but worse than having no quantitative easing policy in the model. This finding opens the possibility for future research regarding the optimal simple rule for the quantitative easing policy, especially considering that most liquidity injections are rarely conducted using a rule.

Finally, this study suggests that under this model, conventional monetary policy is more impactful than quantitative easing policy. This finding echoes current literatures stating that quantitative easing policy is not meant to replace conventional monetary policy (Curdia and Woodford, 2018; Cui and Sterk, 2018; Sheedy, 2016; Kiley, 2018). However, quantitative easing can work as a secondary tool to employ when the traditional monetary policy is underperforming. The simulation of impulse response functions under various shocks demonstrates that credit injection under a commitment or a discretion is minimal but the size is substantial under the simple policy rule regime.

CHAPTER 4

OPTIMAL SIMPLE RULE FOR QUANTITATIVE EASING POLICY

Abstract

This study investigates the optimal simple rule for quantitative easing policy when the conventional monetary policy and quantitative easing policy cooperate simultaneously. The reference model in this study is the model from Gertler and Karadi (2011), in which the credit injection ratio is the quantitative easing instrument, and the nominal interest rate is the monetary policy instrument. The loss function in this study is an ad-hoc loss function constructed by the squared deviation of output, inflation, credit spread, nominal interest rate, and credit injection ratio from their steady states. This study generates three optimal simple rules for quantitative easing: the optimal simple rule based on lagged information (past time horizon), the optimal simple rule based on current information (current time horizon), and the optimal simple rule based on future expectation (future time horizon). This study identifies that the optimal simple rule under a past time horizon, which is optimally constructed by past leverage, capital price, and credit spread, produces the best policy performance. Furthermore, incorporating macroeconomic variables such as inflation and output only modestly improves the performance of the optimal simple rule. Finally, this study argues that an increased credit injection into the economy can dampen the fluctuation of some economic variables but at the cost of a worsened policy performance.

Keywords: Optimal simple rule, Quantitative easing policy, Monetary policy

4.1 Introduction

Quantitative easing played a prominent role in combatting the financial imbalance resulting from the 2008 global financial crisis. During the crisis, the U.S. Federal Reserve Board implemented unconventional monetary policies by injecting more than \$1.75 trillion to purchase public and private bonds, particularly mortgage-backed securities. In 2010, a further injection of approximately \$600 billion entered the financial market, which contributed to reduced lending rates and reinforced credit intermediation. Although economists and policymakers have concerns regarding the negative long-run consequences of the policy, credit injection is inarguably a useful tool that recuperated the U.S. financial system from the crisis. Since then, awareness and studies regarding quantitative easing have been growing, with a focus on assessing the effect of the policy on the economy, for example the studies by Albu, Lupu, Calin, and Popovici (2014); Bhattarai and Neely (2016); Chen, Filardo, He, and Zhu (2016); Curcuru, Kamin, Li, and Rodriguez (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); and Kapetanios, Mumtaz, Stevens, and Theodoridis (2019), among others.

In addition to focusing on the impact of the policy, the increasing importance of quantitative easing policy also drives some studies to assess its optimal rule, especially when it interacts with the conventional monetary policy (Sheedy, 2016; Curdia and Woodford, 2010; Quint and Rabanal, 2017). The role an optimal policy rule plays in the economy has widely been studied within the framework of monetary policy or fiscal policy, but unfortunately its application to quantitative easing policy only attracted little attention. One reason for the lack of studies on this topic could be that this policy is only active during economic crises, and it is usually implemented when the conventional monetary policy is functioning poorly. Consequently, unlike the Taylor rule of conventional monetary policy, consensus regarding an optimal simple rule for quantitative easing policy is not available.

An optimal policy is a policy that aims to minimise economic loss by harnessing all available information in the economy. The optimal policy is usually considered the best choice of policy as it utilises all constraints of the economic model. However, the optimal policy is sometimes considered complicated and non-implementable as it contains unobserved economic variables. Hence, implementing a simple policy rule is becoming more preferable because it is considered more implementable and robust than the fully optimal policy rule. Also, the optimal simple rule is popular because it provides a compact representation of the policymaker's decision rule (Dennis, 2004).

Unfortunately, the performance of a simple policy rule is questioned as it only harnesses a subset rather than complete information of the economic model. Therefore, it is necessary to construct an optimal simple policy rule that can replicate or approach the performance of the fully optimal policy. Within a monetary policy framework, various authors have conducted studies regarding the topic, such as Levin, Wieland, and Williams (1998); Dennis (2004); Williams (2003); Schmidt-Grohe and Uribe (2006); and Taylor and Williams (2011), among others. In general, these studies demonstrate that developing a simple policy rule that performs as efficiently as the optimal policy rule is possible by customising the feedback coefficients in the simple rule equation.

This study presents an effort to contribute to the literature on quantitative easing by focusing on developing an optimal simple rule for a quantitative easing policy. The reference model used in this study is the unconventional monetary policy model from Gertler and Karadi (2011), which is specifically designed to accommodate the economic model under financial distress. Under this model, the economy contains a single authority, the central bank, that manages both the conventional monetary policy and quantitative easing policy. The monetary policy instrument in the economy is the nominal interest rate, while the quantitative easing policy instrument is the credit injection ratio. The latter is defined as the fraction of the central bank's direct credit in the banking sector relative to the total credit in the economy.

This study examines the optimal simple quantitative easing rule under commitment where the central bank adheres to initial policy rules, never reoptimises, and implements the rules in all subsequent periods. The central bank manages the nominal interest rate using the simple Taylor rule, which is the simple monetary policy rule adopted from Gertler and Karadi (2011). The central bank also manages credit injection through the optimal simple quantitative easing rule, the construction of which is the objective of this study. The method for determining the optimal simple rule in the study is adopted from Dennis (2004). Finally, the loss function in this study is the ad-hoc loss function assembled by the quadratic deviation of inflation, output, credit spread, policy rate, and credit injection ratio from their steady states. The benchmark of this study is the fully optimal commitment rule where the central bank only optimises the credit injection ratio using all economic variables in the model, but does not optimise the nominal interest rate.

Among many similar papers in the area of unconventional monetary policy, this study is closely related to Sheedy (2017). However, our study is different in terms of the way we formulate the optimal simple rules. First, we construct the optimal simple rule as a linear combination of the deviation of some endogenous variables in the economic model from their steady states. Second, this chapter is also different from most similar studies in the way we construct various alternatives of optimal simple rules by presenting the rule under three time horizons: past, present, and future time horizons, which we believe is a more comprehensive method. Finally, our study is also different in the the way we measure the simple rule performance. This study measures the performance of an optimal simple rule based on the unconditional loss value. The unconditional loss value is a single number reflecting the total variation of variables in the loss function that incorporates multiple exogenous shocks coming into the economy, not only conditional on a specific shock. The higher policy performance (or the lower loss value) of an optimal simple rule indicates the more efficient that simple rule. The method to measure the policy performance (or loss value) is adopted from the algorithm developed by Dennis (2004).

We introduce two approaches in constructing the optimal simple rule: when the central bank only relies on banking variables and when the central bank also incorporates additional information from macroeconomic variables, namely, inflation and output. Both approaches present three time horizons: a past time horizon, a current time horizon, and a future time horizon. A past time horizon is a scenario in which the central bank constructs the optimal simple quantitative easing rule based on lagged information regarding banking variables and macroeconomic variables. The scenario of a current time horizon is when the central bank uses current information about banking variables and macroeconomic variables. Finally, a future time horizon scenario is when the central bank only incorporates future information when constructing the optimal simple rule.

Compared to the fully optimal commitment rule, this study found that the optimal simple quantitative easing rule under past time horizon (lagged endogenous variables), which is optimally constructed by lagged deviation of leverage, capital price, and credit spread from their steady states, delivers the best policy performance. However, this study also demonstrates that incorporating information from inflation and output can also improve the policy performance, but the improvement is not significant. We also present the optimal simple rule under two conditions: when the central bank smooths the policy rate and when it does not. Our simulation demonstrates that the variables the central bank must consider when constructing the optimal simple rule remain the same regardless of the value of the interest rate smoothing parameter. Based on our simulation of the unconditional variances of the variables in the loss function, output significantly causes the economic loss increases. We also argue that the central bank's aggressiveness is useful to stabilise the economy but worsens policy performance. Finally, we also argue that productivity shocks play a significant role in the optimal simple rule across all time horizons, but the impact is minimal.

The contribution of this chapter are as follow. First, this study contributes to the literature regarding the formulation of quantitative easing rule and the literature on the convensionalisation of unconventional monetary policy (sheedy, 2016; Curdia and Woodford, 2018; Quint and Rabanal, 2017). Second, this study also contributes to the set of literature supporting the negative impact of massive quantitative easing, as argued by Cui and Sterk (2018); Kiley (2008); and Fernandez, Bortz, and Zeolla (2018). Third, the study shows that managing quantitative easing based on banking variables is sufficient, which is in line with argument frm Borio and Zabai (2016). Finally, the finding regarding the benefit from introducing quantitative easing policy in the economy is also in line with studies from Bhattarai and Neely (2016); Chen et al. (2016); Curcuru et al. (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); and Kapetanios et al. (2019), among others.

The rest of the paper is presented as follows. Section two consists of the literature review. Section three describes the detailed reference model. Section four presents the results and analyses, including the loss value report and the simulation of impulse response functions. The concluding remarks are presented in section five.

4.2 Literature Review

The literature regarding the optimal simple rule for quantitative easing is not abundant, but it is closely related to efforts to conventionalise the policy to operate routinely rather than only during crises. A recent investigation in this area is given in a study by Quint and Rabanal (2017), which questions whether unconventional monetary policy should become conventional. Using the general equilibrium model based on Justiniano et al. (2013), Quint and Rabanal (2017) formulate a rule for unconventional monetary policy that targets credit spread. The study demonstrates that there are welfare benefits derived from using this policy rule to address the effects of financial shocks on the economy. The results presented by Quint and Rabanal (2017) are comparable to the design of the non-optimal simple quantitative easing rule in Gertler and Karadi (2011), by which the percentage of direct lending from the central bank is affected by the deviation of credit spread from its steady state. The preference for using the rule for unconventional monetary policy is also discussed in Kuttner (2018). In his study, Kuttner explains that unconventional monetary policy should be conducted in a rule-like manner rather than by involving significant and infrequent discrete adjustments to the balance sheet targets.

However, attempts to generate a formal rule for unconventional monetary policy are rare. Sheedy (2016) explores the challenges to formulating the rules of unconventional monetary policy. The author develops a simple economic model that can adopt various types of unconventional monetary policy instruments and argues that following such a rule is difficult because the unconventional monetary policy has more significant distributional effects than the conventional policy. Furthermore, even when a policy adopts various unconventional instruments, the policy is still less effective in stabilising the economy than conventional instruments. Consequently, unconventional monetary policy is a poor substitute for the conventional nominal interest rate policy.

Curdia and Woodford (2010) argue that there are at least two main reasons why thinking of quantitative easing as a substitute for interest rate policy is dangerous. First, this thinking directs attention away from the most relevant costs and benefits when considering the appropriate scale, timing, and allocation of active quantitative easing policy. Second, this thinking can allow the central bank to adjust the target criterion for interest rate policy as a result of zero lower bound. Hence, rather than formulating a simple rule built by endogenous variables, Curdia and Woodford (2010) and Cui and Sterk (2018) develop unconventional monetary policy rules using reserve targeting.

The debate regarding conventionalising quantitative easing policy is ongoing. However, this does not necessarily mean that efforts to develop an optimal simple rule for quantitative easing are futile. Many empirical studies demonstrate that the impact of quantitative easing on specific financial and macroeconomic variables is substantial. The idea is that if unconventional monetary policy can significantly affect particular economic variables, then incorporating the information from such variables into a simple rule can be useful to determine the path of unconventional monetary policy itself.

For example, a survey conducted by Bhattarai and Neely (2016) indicates that the U.S. unconventional policy announcements have strongly influenced the global bond yields, exchange rates, and equity prices. Also, the policy has had a significant impact on macroeconomic variables, such as output and inflation. Yao (2014) further demonstrates that the successful transmission of quantitative easing policy to achieve its ultimate targets significantly relies on reducing the cost of borrowing and interbank lending rates. Furthermore, Pereira (2016) studies the effectiveness of quantitative easing policy in the euro area and demonstrates that the policy has a significant impact on the real and nominal interest rate.

Casiraghi, Gaiotti, Rodano, and Secchi (2016) assess the impact of unconventional monetary policy from the European Central Bank on the financial sector and macroeconomic conditions in Italy. The results suggest that in the financial sector, quantitative easing has a substantial impact that counteracts the increase in government bond yields, increases credit supply, and improves money market conditions. Meanwhile, in the macroeconomic sector, the policy has a substantial positive effect on output through the credit channel. Fisher, Ramcharan, and Yu (2015) investigate the impact of unconventional monetary policy on firm financing constraints and found that the policy helps to relax financing constraints and stimulate economic activity in part by affecting the pricing of risk in the bond market.

Furthermore, although some studies have reflected on the positive assessment of unconventional monetary policy regarding macroeconomy, Borio and Zabai (2016) argue that the policy has a substantial influence in the financial sector but that its ultimate impact on output and inflation is less obvious. Their results suggest that information provided by financial sector variables send more critical information regarding the optimal simple rule than information provided by macroeconomic variables.

In conclusion, developing an optimal simple rule for a quantitative easing policy is rarely conducted in the literature of unconventional monetary policy today. However, the efforts of some studies in conventionalising quantitative easing policy, as well as the expanding research question of whether the policy can replace the conventional monetary policy in a normal economic situation, indicate that it is possible to develop an optimal simple rule for quantitative easing policy. Moreover, according to some of the the literature mentioned above, some financial and economic variables have the potential to provide useful information to help the central bank determines the size of liquidity injection through an optimal simple policy rule.

4.3 Model

The model reference in this study is the unconventional monetary policy model developed by Gertler and Karadi (2011). The economy under this model contains seven agents namely households, financial intermediaries, intermediate goods firms, final goods firms (retailers), capital good producers, government, and the central bank. In the absence of credit policy rule, the model contains four types of shocks, namely, technology shock, capital quality shock, net worth shock, and monetary policy shock.

4.3.1 Households

There is the continuum of identical households in the economy with the sum of unity. Each household consists of two members with different occupation as workers and bankers. The workers supply labour in the intermediate good firms, while the bankers manage financial intermediaries. In each period, the members may switch their occupation, i.e. households can be a banker and vice versa, regardless of how often they changed their job previously. Households are the owner of both intermediate good firms and financial intermediaries. Correctly, the profit that workers receive is returned to households. Likewise, the bankers also transfer any earnings from financial intermediaries back to households. Each family additionally consumes and save besides supplying labour. There is perfect consumption insurance within each household that both workers and bankers are guaranteed to consume.

Furthermore, each household saves fund in the financial intermediaries. The fund is then channeled to firms.

In each period, members in the household can switch their occupation. In the aggregate level, at each period t, the fraction of $(1-f)$are workers, and the fraction of f are bankers. There is a probability θ for each banker at period t to remain as a banker at period $(t+1)$, regardless their previous occupation. Nevertheless, in ensuring that no bankers can fund all investments from their capital, $(1-f)f$ bankers exit and become workers at each period. In the same way, their job is also replaced by the quantities of workers switching to be bankers by the rule that the relative proportion of workers and bankers in the economy is fixed all the time. Consequently, there are two types of bankers in the economy: the existing bankers and the new bankers. The new bankers start working by receiving the endowed start-up funds from households.

In each period of t, household i chooses the level of consumption (C_t) and labour (L_t) to maximise the utility, which is given by

$$E_t\left[\sum_{i=0}^{\infty}\beta^i\left(log(C_{t+i}-hC_{t+i-1})-\frac{\chi}{1+\varphi}L_{t+i}^{1+\varphi}\right)\right], \tag{4.1}$$

where $0<\beta<1$ is the discount factor, $0<h<1$ is the consumption habit formation, $\chi>0$ is the relative utility weight of labour and $\varphi>0$ is the Frisch elasticity of labour supply. In aggregate level, households maximise their preference subject to the budget constraint, which is given by

$$C_t+B_t+T_t=W_tL_t+\Pi_t+R_tB_t, \tag{4.2}$$

where W_t is the real wage in period t, B_t is the amount of saving in period t, T_t is the lump sum tax paid and R_t is the real return of bonds from period $(t-1)$ to period t. Note that the bonds are one period riskless bonds that pays the gross real return R_t in one period. This budget constraint implies that the source of income that households receive come from the workers labour income (W_tL_t), the dividend from the ownership of financial intermediaries (Π_t), and the interest income from the previous saving in bonds (R_tB_t). Furthermore, the income is then used for consumption (C_t), saving in one period bonds (B_t) and pay lumpsum taxes (T_t).

The first order condition on labour and consumption from the above optimisation problem results in the labour market equilibrium and marginal utility of consumption, respectively, as given below

$$\varrho_tW_t=\chi L_t^{\varphi}, \tag{4.3}$$

$$\varrho_t = (C_t - hC_{t-1})^{-1} - \beta h E_t (C_{t+1} - hC_t)^{-1}, \quad \textbf{(4.4)}$$

where ϱ_t denotes the marginal utility of consumption at period t. Furthermore, the first order condition with respect to saving delivers the optimal real interest rate as follow

$$\beta E_t(\Lambda_{t,t+1}) R_t = 1, \quad \textbf{(4.5)}$$

$$\Lambda_{t,t+1} \equiv \frac{E(\varrho_{t+1})}{\varrho_t}, \quad \textbf{(4.6)}$$

where $\Lambda_{t,t+1}$ denotes the growth of marginal utility of consumption. As shown above, the marginal utility of consumption in period $t.$ depends on the current, past and the expectation of future consumption.

4.3.2 Financial Intermediaries

Financial intermediaries in the model are the whole banking sector that covers both commercial banks and investment banks. The intermediaries operate to channel funds from depositors to non-financial firms. Specifically, they convert short-term liabilities into long-term assets through a lending activity. Under this model, perfect information is assumed to hold between financial intermediaries and non-financial firms. The amount of credit obtained by firms are equal to the number of financial claims held by financial intermediaries. The constraint of financial intermediaries during their operation is given by,

$$Q_t S_{jt} = N_{jt} + B_{jt}, \quad \textbf{(4.7)}$$

where S_{jt} denotes the number of financial claims held by intermediary j at period t, Q_t is the relative price of each claim and N_{jt} is the amount of net worth of intermediary j at the end of period t.

It is also important to note that financial claims held by the intermediaries can be coming from households (S_{pt}) and macroprudential authority (S_{gt}). Macroprudential authority is assumed to inject funds to the intermediaries at period t by the fraction of ψ_t of the total intermediated assets. Hence,

$$Q_t S_{jt} = Q_t S_{pjt} + \psi_t Q_t S_{jt}, \quad \textbf{(4.8)}$$

which implies

$$(1 - \psi_t) Q_t S_{jt} = Q_t S_{pjt}. \quad \textbf{(4.9)}$$

Equation (4.9) implies that the authority injects funds to financial intermediaries by the percentage ψ_t from the total credit in the economy. The authority intermediates credit by issuing bonds to households that gives households riskless rate at R_t and requires non-financial firms as a lender to pay back the authority at market lending rate R_{kt+1}.

The model assumes that the objective of the financial intermediaries is to maximise the banking net worth V_t, which is given by

$$V_t = E_t\left[\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}\left(N_{jt+1+i}\right)\right], \tag{4.10}$$

where the banks net worth is defined as the difference between earnings on asset and interest payments on liabilities, that is

$$N_{jt+1} = R_{kt+1}Q_tS_{pjt} - R_tB_{jt}. \tag{4.11}$$

Furthermore, recall from (4.7) that the deposit funds received by bank j is equal to the amount of credit given and the banks net worth, then the above equation can be decomposed into

$$N_{jt+1} = E_t(R_{kt+1} - R_t)Q_tS_{pjt} + R_tN_{jt}. \tag{4.12}$$

As shown in equation (12), banking net worth depends on the premium $(R_{kt+1} - R_t)$ and the amount of financial claim Q_tS_{jt}. Thus, the preference of the financial intermediaries in the economy can be expressed in greater detail as

$$V_t = E_t\left[\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^i\Lambda_{t,t+i}\left((R_{kt+1+i} - R_{t+i})Q_{t+i}S_{jt+i} + R_{t+i}N_{jt+i}\right)\right]. \tag{4.13}$$

Furthermore, in aggregate terms, the value of banks net worth above can be expressed as the linear combination as follow

$$V_t = v_tQ_tS_t + \eta_tN_t, \tag{4.14}$$

where v_t is defined as the marginal gain from expanding assets and η_t is the marginal gain from adding one unit of net worth. The v_t and η_t are defined as

$$v_t = E_t\left\{(1-\theta)\beta\Lambda_{t,t+1}(R_{kt+1} - R_t) + \theta\beta\Lambda_{t,t+1}x_{t,t+1}v_{t+1}\right\}, \tag{4.15}$$

$$\eta_t = (1-\theta) + E_t\left(\beta\Lambda_{t,t+1}\theta z_{t+1}\eta_{t+1}\right), \tag{4.16}$$

where v_t denotes the marginal gain received by the intermediary for increasing the asset S_t, holding net worth N_t constant. While η_t denotes the marginal gain received by the intermediary for increasing net worth N_t, holding asset constant. Moreover, $z_{t,t+1}$ denotes the growth of banking net worth and $x_{t,t+1}$ denotes the growth of intermediation fund which are respectively defined as follow

$$z_{t,t+1} = \frac{N_{t+1}}{N_t} \ , \tag{4.17}$$

$$x_{t,t+1} = \frac{Q_{t+1}S_{t+1}}{Q_tS_t} \,. \tag{4.18}$$

As shown in equation (4.15), the optimisation problem for financial intermediaries depends on the discounted risk adjusted premium $\beta^{i+1}\Lambda_{t,t+1+i}(R_{kt+1+i} - R_{t+i})Q_{t+i}$. To the extent that the discounted risk adjusted premium is positive, the model assumes that the intermediary will always intend to broaden its assets indefinitely by borrowing additional funds from households. Specifically, everything else equal, the intermediaries will keep expanding asset by borrowing funds from depositors and channel it as credit to non-financial firms until the marginal gain from doing so, v_t, is zero.

4.3.3 Agency Problems

The model introduces a moral hazard problem in the banking sector which creates friction between households and financial intermediaries. This moral hazard is introduced in such a way that bankers always have an option to divert the fraction λ of the total asset back to themselves than channeling the fund to non-financial firms. This moral hazard can force the banks into bankruptcy due to the decreasing banking profitability. Therefore, in minimising the possibility of moral hazard, the intermediaries are obligated to satisfy an incentive constraint to enable them obtain funds from households. Specifically, the incentive constraint is formulated such that depositors can only lend funds to banks as long as the value of banks capital is higher or equal to the gain from doing the moral hazard. That is,

$$V_t \geq \lambda Q_t S_{pt}, \tag{4.19}$$

which implies that

$$V_t = v_t Q_t S_{pt} + \eta_t N_t \geq \lambda Q_t S_{pt}. \tag{4.20}$$

Recall that $(1 - \psi_t)Q_tS_t = Q_tS_{pt}$, then the equation above can be expressed as

$$Q_tS_t \leq \frac{\eta_t N_t}{(\lambda - v_t)(1-\psi_t)} \,. \tag{4.21}$$

Therefore, if the constraint binds, then the assets that bankers can acquire from households must at least satisfy

$$Q_tS_t = \phi_t N_t, \tag{4.22}$$

where $\phi_t = \frac{\eta_t}{(\lambda - v_t)(1-\psi_t)}$ denotes the leverage, which is simply known as the ratio of privately intermediated assets to equity.

This constraint limits the intermediaries leverage ratio to the extent that bankers' incentive to cheat is exactly balanced by the cost. Thus, given the net worth $N_t > 0$, the constraint is binding as long as $0 < v_t < \lambda$, which is the range where expanding assets is profitable. The leverage shows that higher value of v_t corresponds to lower probability for bankers to conduct the moral hazard. In case the value of v_t is larger than λ, the constraint does not bind (i.e., that the gain from expanding asset is always higher than the gain from doing moral hazard). Given the definition of leverage above, the relationship of banking net worth can then be expressed as follow

$$N_{t+1} = \big((R_{kt+1} - R_t)(1 - \psi_t)\phi_t + R_t\big)N_t. \qquad \textbf{(4.23)}$$

Using the new evolution of banking net worth, the growth of banking net worth $z_{t,t+1}$ and the growth of intermediation funds $x_{t,t+1}$ can be expressed in the more specific form as follow

$$z_{t,t+1} = \frac{N_{t+1}}{N_t} = (R_{kt+1} - R_t)(1 - \psi_t)\phi_t + R_t, \qquad \textbf{(4.24)}$$

which now the banks net worth depends on the leverage ratio ϕ_{ct} and the realization of premium $(R_{kt+1} - R_t)$. Furthermore, the expression of credit growth can be derived as follow

$$x_{t,t+1} = \frac{Q_{t+1}S_{t+1}}{Q_t S_t} = \left(\frac{\phi_{t+1}}{\phi_t}\right) z_{t,t+1}, \qquad \textbf{(4.25)}$$

which now is expressed as the function of leverage and the growth of banking net worth.

4.3.4 Intermediate Goods Producers

Intermediate goods firms produce intermediate goods in the economy which then are sold to final goods firms. That is, at the end of period t, intermediate good firms receive credit from financial intermediaries and use the fund to acquire capital K_t to produce intermediate output in subsequent period. Once the intermediate outputs are produced in period $(t+1)$, intermediate good firms have an option to sell the remaining capital to capital good producers. Intermediate good firms are assumed to operate in a competitive market. Perfect information is assumed to hold between financial intermediaries and intermediate goods firms. Hence, no agency problem or friction exists between the two agents. For the firms, the amount capital acquired is exactly equal to the amount of credit given, that is

$$Q_t K_t = Q_t S_t. \qquad \textbf{(4.26)}$$

In each period t, intermediate good firms produce intermediate output by following the Cobb-Douglas production function as follow

$$Y_{mt} = A_t (U_t \xi_t K_{t-1})^{\alpha} L_t^{1-\alpha}, \qquad \textbf{(4.27)}$$

where Y_{mt} denotes intermediate output produced at period t, U_t denotes the capacity utilisation rate chosen at period t, $\xi_t K_{t-1}$ denotes the effective capital acquired in period

$(t-1)$ and α is the effective capital share. Furthermore, there are two stochastic disturbances within the production function namely technology shock A_t and the capital quality shock ξ_t. The capital quality shock in this model is defined as economic depreciation of capital. Taking the first derivative of the production function towards labour results in the labour demand as follow

$$P_{mt}(1-\alpha)\frac{Y_{mt}}{L_t} = W_t, \tag{4.28}$$

where P_{mt} is the price of intermediate output. Furthermore, the optimal capacity utilisation rate can also be derived by taking the first derivative of the production function towards U_t, which is given by

$$P_{mt}\alpha\frac{Y_{mt}}{U_t} = \delta'(U_t)\xi_t K_{t-1}. \tag{4.29}$$

Since $\delta(U_t)$ the reference model defines depreciation rate as

$$\delta(U_t) = \delta_c + \frac{\partial_\delta}{1+\zeta}U_t^{(1+\zeta)}, \tag{4.30}$$

where ζ is the elasticity of marginal depreciation with respect to the utilisation rate and ∂_δ is defined as

$$\partial_\delta = \frac{\alpha\bar{P}_m\bar{Y}_m}{\bar{K}}. \tag{4.31}$$

Then, $\delta'(U_t)$ is given as

$$\delta'(U_t) = \partial_\delta U_t^{\zeta}. \tag{4.32}$$

Accordingly, the capacity utilization rate is given by

$$U_t^{(1+\eta)} = \frac{P_{mt}\alpha Y_{mt}}{\partial_\delta \xi_t K_{t-1}}. \tag{4.33}$$

Next, given that the intermediate good firms operate in the perfect competitive market, hence the optimal profit for the firms in each period t is zero. Recall that the profit for firms Π_t^F can be formulated as follow

$$\Pi_t^F = \alpha P_{mt}Y_t + (Q_t - \delta(U_t))\xi_t K_t - R_{kt}Q_{t-1}K_t, \tag{4.34}$$

where $\alpha P_{mt}Y_t$ is the capital share of revenue, $(Q_t - \delta(U_t))\xi_t K_t$ is the effective capital that left over and $R_{kt}Q_{t-1}K_t$ is the credit cost that firms must pay to financial intermediaries. Since in the competitive market the profit for firms is equal to zero state by state, the market lending rate that firms need to pay to financial intermediaries in period t can be defined as follow

$$0 = \alpha P_{mt} Y_t + (Q_t - \delta(U_t))\xi_t K_{t-1} - R_{kt} Q_{t-1} K_t, \tag{4.35}$$

hence,

$$R_{kt} = \frac{P_{mt}\alpha Y_t}{K_t Q_{t-1}} + \frac{\xi_t}{Q_{t-1}}\big(Q_t - \delta(U_t)\big). \tag{4.36}$$

Given this return on capital information, we can define the credit spread ϑ_t as follows

$$\vartheta_t = \frac{E_t R_{kt+1}}{R_t}, \tag{4.37}$$

which represents the difference between lending rate and deposit rate when the formula is loglinearized as

$$\tilde{\vartheta}_t = E_t\big(\tilde{R}_{kt+1} - \tilde{R}_t\big). \tag{4.38}$$

4.3.5 Capital Goods Producers

Recall that at the end of period t, intermediate good firms have an option to sell used capital to capital producing firms. Capital producing firms will purchase the capital and harness it to refurbish the depreciated capital as new capital, which then are sold back to intermediate good firms. The model assumes that there is flow adjustment cost associated with producing new capital. The capital producing firms will maximise their preference, which is given by

$$E_t\left[\sum_{i=t}^{\infty} \beta^t \Lambda_{t,i} \left\{(Q_t - 1) I_{nt} - f\left(\frac{I_{ni}+I_{ss}}{I_{ni-1}+I_{ss}}\right)(I_{ni} + I_{ss})\right\}\right], \tag{4.39}$$

subject to

$$I_{nt} \equiv I_t - \delta(U_t)\xi_t K_{t-1}, \tag{4.40}$$

where I_{nt} denotes net investment, I_t denotes gross investment and I_{ss} denotes the steady state of gross investment. The $\delta(U_t)\xi_t K_{t-1}$ denotes the quantity of depreciated capital. The gross investment I_t is determined by following the law motion of capital K_t as follow,

$$I_t = K_t - K_{t-1}\xi_t(1 - \delta(U_t)). \tag{4.41}$$

As shown above, the capital acquired to produce output at period $(t + 1)$ depends on the effective capital in period t and the gross investment. The first order condition from the optimisation problem in equation (4.34) and (4.35) gives the function of capital price Q_t as follow,

$$Q_t = 1 + \frac{\eta_i}{2}\left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} - 1\right)^2 + \eta_i\left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} - 1\right)\left(\frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}}\right)$$

$$-E_t\left[\beta \Lambda_{t,t+1} \eta_i \left(\frac{I_{nt+1}+I_{ss}}{I_{nt}+I_{ss}} - 1\right)\left(\frac{I_{nt+1}+I_{ss}}{I_{nt}+I_{ss}}\right)^2\right], \tag{4.42}$$

where η_{i} denotes the elasticity of investment adjustment cost.

4.3.6 Final Goods Producers

There is a continuum of final good producers (retailers) that sums at unity in the economy. Final good producers acquire intermediate output from intermediate good firms to be repackaged as final output. The retailers simply repackage intermediate output by the rule that it requires one unit of intermediate output to produce one unit of retail output. The retailers then aggregate final output through the CES composite aggregator which is given by

$$Y_t = \left(\int_0^1 Y_{f,t}^{\frac{(\varepsilon-1)}{\varepsilon}}\right)^{\frac{\varepsilon}{(\varepsilon-1)}}, \tag{4.43}$$

where $Y_{f,t}$ is the final output produced by retailer f at period t and ε is the elasticity of substitution. Maximising total output Y_t given in equation (4.43) with respect to the total expenditure $X_t = \int_0^1 P_{ft}\, Y_{ft} df$ results in a relationship between the individual retailer final output and the aggregate final output as follow

$$Y_{ft} = \left(\frac{P_{ft}}{P_t}\right)^{-\varepsilon} Y_t, \tag{4.44}$$

$$P_t = \left(\int_0^1 P_{ft}^{1-\varepsilon}\, df\right)^{\frac{1}{(1-\varepsilon)}}. \tag{4.45}$$

Furthermore, the retailers are assumed to operate in a monopolistic environment with nominal rigidities ala Calvo. Specifically, in each period retailers are able to adjust price optimally with probability $(1-\gamma)$ with the price indexation follows the lagged rate of inflation. The retailers then set the reset price $P_t^*$to solve the following optimisation problem

$$E_t\left[\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i}\left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1+\pi_{t+k-1})^{\gamma_p} - P_{mt+i}\right] Y_{ft+i}\right]. \tag{4.46}$$

The first order condition is given by

$$E_t\left[\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i}\left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1+\pi_{t+i-1})^{\gamma_p} - \left(\frac{\varepsilon}{\varepsilon-1}\right) P_{mt+i}\right] Y_{ft+i}\right] = 0. \tag{4.47}$$

By the law of large numbers, the evolution of the price level can be derived as given by

$$P_t = \left((1-\gamma) P_t^{*(1-\varepsilon)} + \gamma\left(\pi_{t-1}^{\gamma_p} P_{t-1}\right)^{(1-\varepsilon)}\right)^{\frac{1}{(1-\varepsilon)}}, \tag{4.48}$$

which can be simplified into

$$\pi_t = \left((1-\gamma) \pi_t^{*(1-\varepsilon)} + \gamma\left(\pi_{t-1}^{\gamma_p}\right)^{(1-\varepsilon)}\right)^{\frac{1}{(1-\varepsilon)}}, \tag{4.49}$$

which defines inflation.

4.3.7 Resource Constraint

In the resource constraint, the production of output is divided into private consumption, investment, government consumption, adjustment cost of capital and the government intermediation. The resource constraint is given by the following equation

$$Y_t = C_t + I_t + G_t + \tau\psi_t Q_t K_t + (\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}} - 1)^2(I_{nt} + I_{ss}), \qquad \textbf{(4.50)}$$

where $\psi_t Q_t K_{t+1}$denotes the amount of government intermediation, which is generated by the authority to be supplied to financial intermediaries. The model also assumes that the efficiency cost by τ per unit supplied exists during the government intermediation process. This cost basically reflects activities during the lending process such as the cost of raising funds via government debt or the cost of selecting the eligible private firms. Furthermore, G_t denotes the government consumption, which is set purposively fixed as

$$G_t = G_{ss}, \qquad \textbf{(4.51)}$$

where G_{ss} is the steady state of government consumption, which is defined as 0.2 times of output. Furthermore, government expenditures are financed by lump sum taxes and government intermediation. Specifically,

$$G_{ss} + \tau\psi_t Q_t K_t = T_t + (R_{kt} - R_t)B_{gt-1}, \qquad \textbf{(4.52)}$$

where B_{gt-1} denotes government bonds which finance total government intermediated assets, $\psi_t Q_t K_{t+1}$.

4.3.8 Policy Authority

It is assumed that there is a central bank that manages two economic policies in the economy namely the conventional monetary policy and the quantitative easing policy simultaneously. In managing the monetary policy, the central bank is assumed to follow a simple Taylor rule with the interest rate smoothing ρ_i, which is given by

$$R_{nt} = (1-\rho_i)\left[\kappa_\pi \pi_t + \kappa_y\left(\frac{MC_t}{\left(\frac{\varepsilon-1}{\varepsilon}\right)}\right)\right] + \rho_i R_{nt-1} + \varepsilon_t^R, \qquad \textbf{(4.53)}$$

where R_{nt} denotes the nominal interest rate, MC_t is marginal cost at period t and ε_t^R is monetary policy shock. It is important to note that marginal cost and intermediate goods price have an inverse relationship

$$MC_t = \frac{1}{P_{mt}}. \qquad \textbf{(4.54)}$$

The nominal interest rate also needs to follow the Fisher equation, which is given by

$$R_{nt} = R_t E_t \pi_{t+1}\ . \tag{4.55}$$

On the other hand, the central bank manages quantitative easing policy by setting up the level of the credit injection ratio ψ_t in the economy. The construction of simple policy rule that manages ψ_t is the objective of this study.

4.3.9 Exogenous Shock

The economy is assumed to be hit by four different exogenous shocks namely technology shock (ε_t^A), capital quality shock (ε_t^K), banking net worth shock (ε_t^N) and monetary policy shock (ε_t^R). The formulation of shocks is given as follow.

$$A_t = \rho_A A_{t-1} + \sigma_A \varepsilon_t^A, \tag{4.56}$$

$$\xi_t = \rho_\xi \xi_{t-1} + \sigma_\xi \varepsilon_t^K\ , \tag{4.57}$$

where A_t is technology, ξ_t is capital quality, is ρ_A the shock persistence of technology shock, ρ_ξ is the persistence of capital quality shock, σ_A is a productivity shock multiplier, and σ_ξ is a capital quality shock multiplier. On the other hand, banking net worth shock, and monetary policy shock have no persistence.

4.3.10 Parameter Values

The parameter values used in the model are shown in the Table 4.1. The model is parameterised using the quarterly frequency. The parameter values utilised in this study mostly follow those in the original model of Getler and Karadi (2011) but some differences are added to represent the operation of macroprudential policy. For example, we assume that the steady state of the credit injection ratio in the economy is 10%, which is logically small for the central bank's contribution in the credit market. The small value of steady state, rather than zero, indicates that the central bank's liquidity has already existed in the economy. This pre-existing credit injection from the central bank suggests that a small portion of credit in the economy might be present from the activities of central bank under normal condition, for example an open market operation. Furthermore, in this chapter, we also offers two ways of the central bank when managing monetary policy. The first one is when the interest rate smoothing parameter is zero, and the second one is when the interest rate smoothing parameter is 0.8. This way, we will investigate whether the structure of the optimal simple rule is invariant to the changed interest rate smoothing parameter. We consider this issue is important because the structure of the optimal simple rule should be stable regardless the interest smoothing rate value. Other parameter values are standard, such as the discount rate is 0.99, the capital share is 0.33, and the habit formation parameter is 0.815.

Table 4-1: Model Parameters

Parameters	**Values**	**Description**
β	0.99	Discount rate
h	0.815	Habit formation parameters
χ	3.4	Starting value for the labour utility weight
φ	0.276	Inverse Frisch elasticity of labour supply
η	7.2	Elasticity of marginal depreciation with respect to the utilisation rate
λ	0.3815	Starting value of divertible fraction
ω	0.002	Starting value of proportional starting up funds
θ	0.971	The survival probability
α	0.33	Capital share
δ	0.025	Depreciation rate
η_i	1.728	Elasticity of investment adjustment cost
ε	4.167	Elasticity of substitution between goods
γ	0.779	Calvo parameter
γ_p	0.241	Price indexation parameter
ρ	0	Interest rate smoothing parameter
κ_π	1.5	Inflation coefficient in simple monetary rule
κ_y	-0.125	Output gap coefficient in simple monetary rule
τ	0.001	Costs of credit policy
G/Y	0.2	Steady state proportion of government expenditures
ρ_A	0.95	Persistence of technology shock
ρ_ξ	0.66	Persistence of capital quality shock
σ_A	1	Technology shock multiplier
σ_ξ	1	Capital quality shock multiplier
ε_t^A	-0.01	Shock on technology
ε_t^K	-0.05	Shock on capital quality
ε_t^N	-0.01	Shock on banking net worth
ε_t^R	0.01	Shock on nominal interest rate

4.4 Result and Analysis

4.4.1 Scenario Map

The study introduces two approaches: the banking variables approach and the macroeconomic variables approach. Under each approach, three scenarios take place – namely the scenario of past information, current information, and future information. A detailed scenario map is shown in Figure 4.1.

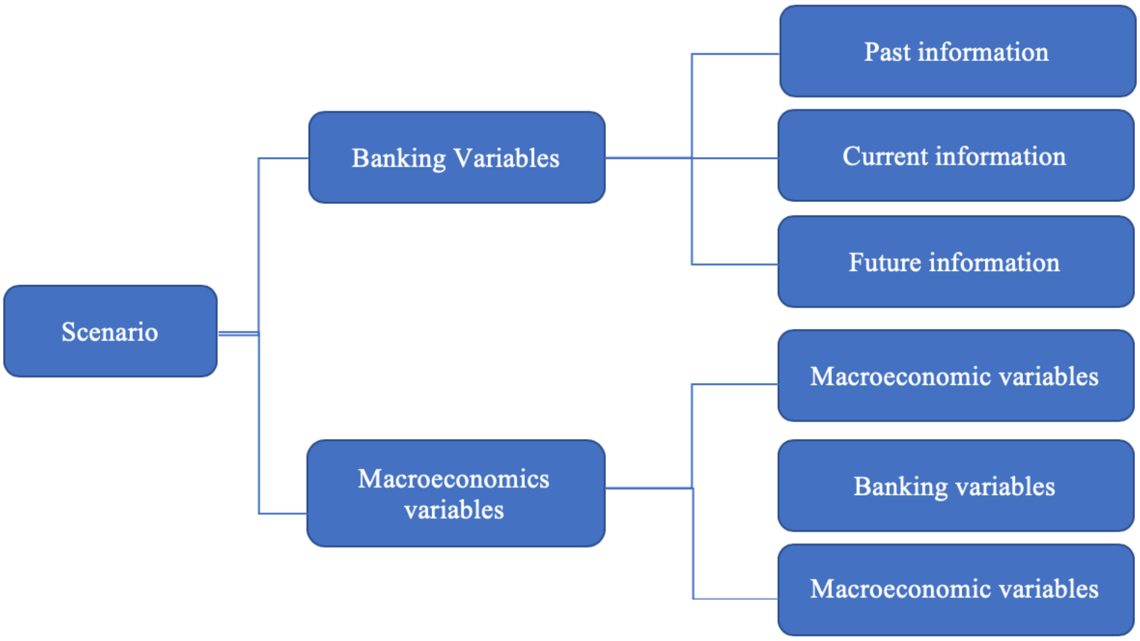

Figure 4-1: Scenario Map

In the first approach, we assume that the central bank designs the optimal simple quantitative easing rule only based on information from the banking sector. Hence, seven banking variables are involved in the simulation: capital (amount of credit), banking net worth, asset prices, leverage, credit spread, deposit rate, and lending rate. These banking variables are the variables related to the financial sector in the reference model. In the second approach, in addition to banking variables, we inspect whether adding macroeconomic variables can improve the performance of the optimal simple rule. Thus, in the second approach, inflation and output will enter the simulation in addition to banking variables. The ultimate objective of these two approaches is to check whether information from the banking sector is sufficient to construct the optimal simple rule or whether overseeing broader macroeconomic variables can provide more significant benefits.

In the past time horizon scenario, the central bank is situated to construct the optimal simple rule by harnessing information from variables of past periods, which are lagged banking variables or with additional lagged macroeconomic variables. Similarly, under the current time horizon scenario, the central bank constructs the optimal simple rule by only using the current state of banking variables or with additional macroeconomic variables. Finally, in the case of the future time horizon, the central bank constructs the optimal simple rule using future expectation of banking variables or with additional macroeconomic variables. These three time horizons aim to ensure that the simulation covers all possible scenarios when the central bank operates the quantitative easing policy. This study does not simulate the optimal simple rule with the cross-time horizon. All simulations assume that the central bank is committed to implementing the optimal simple rule using endogenous variables from the same time horizon. The performance of the optimal simple policy rule is calculated relative to that of the fully optimal commitment rule using the following formula:

$$Efficiency = \left(1 - \frac{L_{SR}}{L_C}\right) x100\% \,, \qquad (\mathbf{4.58})$$

where L_{SR} denotes the loss of the optimal simple policy rule, and L_C denotes the loss of the fully optimal commitment rule. Since L_C is always less than L_{SR}, the sign of efficiency will always be a negative in percentage, which means that the simple policy rule is less efficient by some percentage value than the loss in the fully optimal commitment rule.

In summary, in the banking variables approach, seven banking variables are considered in the simulation: capital (the amount of credit), leverage, banking net worth, capital price (the value of credit), credit spread, real interest rate, and lending rate (return on capital). In the macroeconomic variables approach, the simulation involves two additional variables: output and inflation. The performances of the simple rules are compared based on the level of policy performance, where the best optimal simple rule is the one that produces the lowest loss value (i.e., the highest policy performance).

4.4.2 Loss Function

This section explains the construction of the loss function utilised in the study. Recall that this study formulates the optimal simple quantitative easing rule when the central bank optimises the credit injection ratio under fully optimal commitment while setting the nominal interest rate based on the simple Taylor rule. Thus, as a single authority, the central bank holds dual mandates: to stabilise inflation and to achieve credit stability. In the loss function, the sum of squared deviation of credit spread from its steady state represents credit stability, while the sum of quadratic deviation of inflation from its steady state represents price stability. The loss function is given in the following equation:

$$L = E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\pi_t^2 + \lambda_Y \tilde{Y}_t^2 + \lambda_\vartheta \tilde{\vartheta}_t^2 + \lambda_{Rn} \tilde{R}_{nt}^2 + \lambda_\psi \psi_t^2 \right) \right], \qquad (\mathbf{4.59})$$

where $\lambda_Y = \lambda_\vartheta = \lambda_{Rn} = \lambda_\psi = 1$ denotes the weight given to the output, credit spread, nominal interest rate, and credit injection ratio, respectively, relative to inflation. When the same weights are given, this implies that the central bank prioritises all variables in the loss function equally, which also means that credit stability is as important as inflation stability.

The loss function contains some assumptions. First, the loss function is designed purposively to contain observed variables. Unlike the fully optimal loss function, which harnesses full information of the model, the ad-hoc loss function is built by assuming that the central bank is practically unable to observe all endogenous variables in the economy. For example, some variables, including the marginal utility of consumption, depreciation rate, or capacity utilisation rate, are harder to observe than output or inflation. Hence, focusing only on critical observed variables makes the ad-hoc loss function more realistic and implementable.

Second, we purposively combine the dual mandates for the central bank – namely the inflation stability objective and the credit stability objective – in a single loss function to observe whether a trade-off between the two objectives exists. As explained in Woodford (2011), the target criterion (4.53) implies that the central bank should be willing to sacrifice a certain degree of inflation stability to gain greater credit stability, and vice versa. Therefore, the ad-hoc loss function containing the two policy instruments can illustrate this welfare transfer in a straightforward yet traceable way.

Third, credit spread is used in the loss function to suit the model proposed by Gertler and Karadi (2011), who determine that the only source of financial imbalance in the model is a moral hazard, which is triggered by ambitious bankers who wish to increase their profits. The movement of credit spread in the economy influences the path of credit intermediation from banks. That is, a credit spread of above (or below) its steady state can incentivise bankers to excel (or dampen) credit. Hence, we assume that stabilising credit spread is sufficient to maintain credit stability in the financial market.

Finally, we assume that the credit injection ratio should be present in the loss function to support empirical evidence that excessive quantitative easing is detrimental to the economy (Cui and Sterk, 2018; Fernandez, Bortz, and Zeolla, 2018). Therefore, placing this variable in the function works as a penalty that reduces policy performance if the central bank begins to inject credit too aggressively. Similarly, the policy rate is present in the loss function as a penalty to avoid the excessive fluctuation of policy rate by punishing the central bank with a greater loss. This way, the stable policy rate can give the banking sector a certainty to operate their business.

4.4.3 The Fully Optimal Commitment Rule

The benchmark used in this study is the fully optimal commitment rule, which when the central bank optimises quantitative easing policy instrument subject to all available information in the model. As for the monetary policy, the central bank adopts the non-optimal simple Taylor rule from the original model. Thus, the fully optimal quantitative easing rule incorporates all endogenous variables and exogenous shocks in the model. Following Dennis's (2007) method, the policy performance and some variables to consider when constructing the fully optimal commitment rule are given in Table 4.2.

Table 4-2: The Fully Optimal Commitment Macroprudential Policy Rule (x10^{-2})

N_{t-1}	K_{t-1}	π_{t-1}	R_{nt-1}	I_{nt-1}	D_{t-1}	Q_{t-1}	C_{t-1}	A_{t-1}	ξ_{t-1}	ε_t^A	ε_t^K	ε_t^N	ε_t^R	LOSS
0.30	-0.36	-0.08	-0.77	0.27	-0.53	-1.06	0.30	2.55	1.42	2.68	2.15	0.30	-0.70	265.72
-	-	-	-	-	-	-	-	-	-	-	-	-	-	362.31

The first row in Table 4.2 above illustrates the policy performance and feedback coefficients in the optimal simple quantitative easing rule under commitment. In contrast, the second row in the table illustrates the situation when quantitative easing does not exist in the model, which means that the central bank only manages the economy using the conventional monetary policy where the instrument is determined by a simple Taylor rule. It is necessary to mention that the fully optimal commitment rule in the table above also contains some feedback coefficients related to Lagrange multipliers, but these are not shown in the equation. These Lagrange multipliers' coefficient represents the cost that the central bank must bear due to the commitment policy.

Some results from the fully optimal quantitative easing rule above stand out. First, the fully optimal commitment rule delivers a policy performance of 2.6572. Note that this number reflects the performance when the central bank optimises the credit injection ratio and manages the policy rate using a simple Taylor rule. Second, with respect to the absence of quantitative easing rule in the economy (i.e., the second row of the table), the simulation produces a policy performance of 3.6231. Therefore, the comparison of the two policy rules above suggests that the nonexistence of quantitative easing policy can worsen the economy by 36.35% relative to the fully optimal commitment rule (i.e., if the quantitative easing policy is present), which is calculated using the following equation:

$$Loss = \left(1 - \frac{LOSS_{\ without\ quantitative\ easing}}{LOSS_{\ with\ quantitative\ easing}}\right) x100\%. \qquad \mathbf{(4.60)}$$

Third, the simulation results indicate that the fully optimal commitment rule depends on 14 variables, eight of which are lagged endogenous variables. The endogenous variables in the rule are banking net worth, capital, inflation, policy rate, net investment, price dispersion, asset prices, and consumption. Of these eight endogenous variables, only banking net worth, capital, and asset prices are closely related to the operation of financial intermediaries. Finally, the fully optimal commitment rule above also contains information about exogenous shocks. Regarding these exogenous shocks, technology shocks are found to be the shocks that have the most powerful effect on the credit injection ratio, other things being equal.

The fully optimal commitment rule above performs best when the central bank has access to all information in the economy. Unfortunately, this rule is not the best choice for several reasons. First, the fully optimal commitment rule is less realistic. That is, the central bank will not able to observe all information in the economy completely. Second, the fully optimal commitment rule above is dependent on exogenous shocks, while in reality the central bank should not be able to observe them. Third, the simplicity of the fully optimal commitment rule does not hold up, as seen from the number of variables in the rule. A simple rule usually contains only a few variables. For instance, a simple Taylor rule in the original model from Getler and Karadi (2011) only contains three variables: policy rate, inflation rate, and output gap. Moreover, the model only uses three variables in its credit policy rule, namely the credit injection ratio, lending rate, and deposit rate. Also, too many variables in the simple rule can complicate how the central bank communicates the optimal simple rule to the public. Finally, the fully optimal commitment rule only incorporates variables from a past time horizon, while the central bank could have achieved a similar level of performance using the current or future expectations of endogenous variables. Therefore, in this study, the fully optimal commitment rule only works as a benchmark.

4.4.4 The Optimal Simple Quantitative Easing Policy Rule

This part presents the final results of the simulation regarding the best candidates for the optimal simple quantitative easing rule. In this study, the simulation is conducted under three different time horizons: a past time horizon, a current time horizon, and a future time horizon. More precisely, for instance, the optimal simple quantitative easing rule under a past time horizon aims to explain what lagged endogenous variables can optimally explain the central bank’s decision to inject credit into the present economy. Similarly, for the optimal simple quantitative easing rule under a current time horizon, the simulation will only include the current state (contemporaneous) of endogenous variables within the rule. Likewise, the optimal simple rule operating under a future time horizon aims to explain what future expectation of variables that optimally construct the level of credit injection in the present.

- **Approach I: Banking Variables**

In the first approach, we simulate all possible combinations of the optimal simple rule using seven banking variables. The number of simple rule candidates formed using the variable n is equal to $_{7}C_{n}$. For example, when we construct the optimal simple rule using two variables (which means $n = 2$, there will be 42 candidates for the optimal simple rules. Thus, for $n = 2$, we have 126 candidates for the simple rule that cover three time horizons. We stop the simulation when the marginal performance as a result of adding one more variable to the rule is less than when the variable is not added. Suppose L denotes the loss value; in that case, we stop the simulation when the following condition is satisfied:

$$|L_{n+2} - L_{n+1}| < |L_{n+1} - L_n|, \tag{4.61}$$

where n denotes the initial number of variables. For example, suppose we start the simulation using one variable ($n = 1$), then we stop the simulation when the change of loss (i.e., marginal loss) between '*the simple rule using three variables* (L_{n+2}) *and the the simple rule using two variables* (L_{n+1})' is less than the marginal loss between '*the simple rule using two variables* (L_{n+1}) *and the simple rule using one variable* (L_n)'. Using this method, we found that lagged leverage ($\boldsymbol{\phi}$), capital price ($\boldsymbol{Q}$), and credit spread ($\tilde{\boldsymbol{\vartheta}}$) are the most critical variables for constructing the optimal simple rule under this approach. Table 4.3 illustrates the optimal simple rule across three-time horizons in detail.

Table 4-3: The Optimal Simple Quantitative Easing Rule Without Macroeconomic Variables

Time horizon	Simple Rule			Loss	Efficiency
Past time	$\tilde{\boldsymbol{\phi}}_{t-1}$	$\tilde{\boldsymbol{Q}}_{t-1}$	$\tilde{\boldsymbol{\vartheta}}_{t-1}$	2.6654	0.308%
	-0.0624	0.3354	5.0009		
Current time	$\tilde{\boldsymbol{\phi}}_{t}$	$\tilde{\boldsymbol{Q}}_{t}$	$\tilde{\boldsymbol{\vartheta}}_{t}$	2.7085	1.930%
	0.0314	0.0946	0.0000		
Future time	$\boldsymbol{E_t(\tilde{\phi}_{t+1})}$	$\boldsymbol{E_t(\tilde{Q}_{t+1})}$	$\boldsymbol{E_t(\tilde{\vartheta}_{t+1})}$	2.7088	1.941%
	0.0322	0.1619	0.0000		

As shown in the table above, the rule when the central bank relies on the lagged deviation of leverage, capital price, and credit spread from their steady states delivers a policy performance of 2.6654, which is only 0.308% less efficient than that of the commitment rule. Of the three variables in the optimal simple rule, credit spread shows the largest feedback coefficient. Everything else equal, the 1% increase of past credit spread from its steady state corresponds to the present credit injection ratio that is approximately 5% higher than its steady state. Recall that the steady state of credit injection ratio in this chapter is 10% of the total credit in the economy. Hence, everything else equal, the 1% increase of past period capital price from its steady state corresponds to the increase of credit injection ratio, which is 0.3354% higher than its the steady state. Finally, the 1% increase of past leverage corresponds to the decline of the central bank's credit injection in the present economy by 0.0624% higher than its steady state, everything else being equal.

Credit spread is only present in the rule using past information, and its impact is minuscule under the current and future time horizons. Thus, leverage and capital prices are the only two variables that are present in the current and future optimal simple rules. No other banking variables can significantly improve the policy performance of these two simple policy rules . The case when the rule relies on current information produces a loss value of 2.7085, which is 1.930% less efficient than that of the commitment rule. Finally, the simple rule performs worse when the central bank relies on future information with a loss of 2.7088, which is 1.941% less efficient than that of the commitment rule. Therefore, based on the policy performance, these two simple rules are less performing than the rule under the past time horizon. The current and future optimal simple rules also demonstrate that capital price is more influential than leverage in affecting credit injection. However, the impact of capital price on the current and future simple rules is smaller than under the past time horizon.

- **Approach II: Macroeconomic Variables**

This approach explains the simulation when the central bank also considers macroeconomic variables, namely inflation and output, in the design of the optimal simple rule for quantitative easing policy. Given that the first approach is stopped at three variables, this second approach further investigates whether additional macroeconomic variables can improve policy performance. There are several reasons this second approach is necessary.

First, in practice, inflation and output are two major macroeconomic indicators observed intensively during an economic crisis. Although there are other potential variables, such as investment or consumption, these two variables (investment and consumption) have been incorporated within output by the resource constraint in the equation (4.45). Hence, the output already includes information regarding investment and consumption. Second, inflation and output are also present in the loss function. Considering the loss function contains the quadratic deviation of inflation, output, credit spread, nominal interest rate, and credit injection ratio, incorporating inflation and output into the simulation can enable the simple rule to capture all information in the loss function comprehensively.

Third, inflation and output are two variables in the simple monetary rule used in the model. In practice, suppose two different departments in the central bank manage the conventional monetary policy and quantitative easing policy; the central bank would want to coordinate the two departments before announcing the policy. Hence, output and inflation have a greater chance of being incorporated into optimal simple quantitative easing rule than other possible macroeconomic variables. Table 4.4 shows the simulation results when output and inflation are present in the simulation. Overall, the simulation demonstrates that the presence of output and inflation only minimally improves the policy performance of the optimal simple rule. Relative to the simple rule under past time horizon, incorporating output and inflation into the rule only improves the policy performance from 0.308% to 0.297%, which is only 0.011%. We argue that this number is not significant.

Table 4-4: The Optimal Simple Quantitative Easing Rule in the Second Approach

Time horizon	**Simple Rule**					**Loss**	**Efficiency**
Past time	$\tilde{\boldsymbol{\phi}}_{t-1}$	$\tilde{\boldsymbol{Q}}_{t-1}$	$\tilde{\boldsymbol{\vartheta}}_{t-1}$	$\tilde{\boldsymbol{Y}}_{t-1}$	$\tilde{\boldsymbol{\pi}}_{t-1}$	2.6651	0.297%
	-0.0612	0.2778	4.2288	-0.1477	-0.0738		
Current time	$\tilde{\boldsymbol{\phi}}_{t}$	$\tilde{\boldsymbol{Q}}_{t}$	$\tilde{\boldsymbol{\vartheta}}_{t}$	$\tilde{\boldsymbol{Y}}_{t}$	$\tilde{\boldsymbol{\pi}}_{t}$	2.6658	0.323%
	0.0022	0.2308	0.0000	-1.4842	-0.2202		
Future time	$\boldsymbol{E_t(\tilde{\phi}_{t+1})}$	$\boldsymbol{E_t(\tilde{Q}_{t+1})}$	$\boldsymbol{E_t(\tilde{\vartheta}_{t+1})}$	$\boldsymbol{E_t(\tilde{Y}_{t+1})}$	$\boldsymbol{E_t(\tilde{\pi}_{t+1})}$	2.6653	0.304%
	0.0025	0.4336	0.0000	-1.6292	-0.2339		

However, more substantial improvement is found when output and inflation are present in the rule under current and future time horizons. That is, relative to the first scenario, incorporating output and inflation under a current time horizon can improve policy performance from 1.930% to 0.323%. Similarly, under a future time horizon, the second scenario can improve performance from 1.941% to 0.304%. However, although the improvement rates in the current and future time horizons are substantial, we argue that the chosen rule from the first scenario remains superior because it can deliver a similar performance (i.e. 0.308%, see Table 4.3) with a smaller number of variables. The latter maintains the simplicity aspect of an optimal simple rule. Thus, we argue that information from the banking sector is sufficient for the central bank to formulate an optimal simple quantitative easing rule.

Table 4.4 also demonstrates that feedback coefficients of output and inflation in the optimal simple rule are all negative, which indicates that these two macroeconomic variables are inversely related to the credit injection ratio. For instance, under the past time horizon, the 1% decline in lagged output from its steady state incentivises the central bank to elevate credit injection today by 0.1477% higher than its steady state, everything else equal. Similarly, under the current time horizon, the 1% output contraction corresponds to the increase of credit injection ratio by 1.4842% higher than its steady state, everything else equal. Finally, under the future time horizon, the 1% percent contraction in the expectation of output corresponds to a 1.629% increase of the central bank's credit injection from its current steady state. The simulation also demonstrates that the presence of output and inflation does not change the sign of feedback coefficients of leverage, capital price, and credit spread.

Finally, it would be interesting to evaluate what happens if the central bank neglects banking variables entirely and only focuses on output and inflation when managing quantitative easing. Table 4.5 illustrates this result.

Table 4-5: The Optimal Simple Quantitative Easing Rule with Output and Inflation

Time horizon	**Simple Rule**		**Loss**	**Efficiency**
Past time	$\tilde{Y}_{t-1}$	$\tilde{\pi}_{t-1}$	2.6732	0.602%
	-0.1746	-0.8486		
Current time	$\tilde{Y}_{t}$	$\tilde{\pi}_{t}$	2.6906	1.256%
	-0.1656	-0.5254		
Future time	$E_t(\tilde{Y}_{t+1})$	$E_t(\tilde{\pi}_{t+1})$	2.6968	1.490%
	-0.1703	-0.4307		

The result demonstrates that when the central bank only focuses on output and inflation, policy performance worsens compared to when the central bank adheres to information regarding banking variables. For example, under the past time horizon, the optimal simple rule performs at 2.6732, which is 0.602% less efficient than that of the fully optimal commitment rule or approximately twice than that of the optimal simple rule with banking variables. This result confirms that the optimal simple quantitative easing rule constructed by past leverage, capital price, and credit spread is sufficient for the central bank when executing the quantitative easing policy.

In conclusion, simulating the optimal simple quantitative easing rule with two different approaches delivers some important results. First, knowledge regarding the banking sector is crucial for the central bank when managing the quantitative easing policy. This is reflected by the fact that incorporating macroeconomic variables, such as inflation and output, insignificantly improves policy performance. Second, past information is superior to current and future information when it comes to managing the quantitative easing policy, meaning that wide access to historical data would be beneficial for the central bank when managing the quantitative easing policy.

Third, credit spread has the largest feedback coefficient, in absolute value, in the optimal simple quantitative easing rule. This result is in line with the fact that credit spread is a variable that significantly influences moral hazard in the banking sector, which is the main source of risk in the financial sector (Gertler and Karadi, 2011). Hence, the increase of credit spread, which activates higher credit injection, is also beneficial for decreasing instances of moral hazard behaviour in the banking sector. Lastly, the optimal simple quantitative easing rule using past information is able to deliver policy performance that is almost as efficient as that of the fully optimal commitment rule, which would help the central bank to communicate this simple rule to the public.

4.4.5 Unconditional Variances

This section investigates the contribution of variables in the loss function to the policy performance when the central bank implements the optimal simple quantitative easing rule using lagged deviation of leverage, capital price, and credit spread. We also intend to determine which variables contribute significantly to the policy performance. We measured the unconditional variance of the variables in the loss function when the discount factor approaches one. Table 4.6 details the result.

Table 4-6: Unconditional Variances of the Loss Function

Time horizon	**Approach I**				
	π	$\tilde{Y}$	$\tilde{\vartheta}$	$\tilde{R}_n$	ψ
The fully optimal commitment rule	0.0322	2.6807	0.0442	0.0996	0.1040
The optimal simple rule under past time horizon	0.0326	2.6927	0.0458	0.1007	0.0955

As shown in the table, relative to the fully optimal commitment rule, the optimal simple rule can lead the central bank to stabilise credit injection, which consequently injects amounts of credit that are less than they ideally should be. The variance of the credit injection ratio falls from 0.1040 in the commitment rule to 0.0955 in the optimal simple rule, which is a decrease of 8.17%. However, less credit injection consequently leads to greater fluctuation in the rest of the variables in the loss function than those in the fully optimal commitment rule. For example, the variance in output increases from 2.6807 to 2.6927 (0.80%); from 0.0442 to 0.0458 (3.61%) for the credit spread; from 0.0322 to 0.0326 (1.24%) for the inflation, and from 0.0996 to 0.1007 (1.104%) for the policy rate. In conclusion, the results indicate that other variables in the loss function tend to fluctuate more when credit injection decreases. Output is found to be the most fluctuating variable in the loss function. This finding also suggests that the central bank could have achieved better policy performance if the weight assigned to output relative to inflation in the loss function is reduced.

4.4.6 The Optimal Simple Rule Under Interest Rate Smoothing

Recall that the optimal simple quantitative easing rule generated previously assumes that the central bank does not smooth the policy rate, meaning that the central bank determines the current state of the policy rate without using its lagged value (i.e., the interest rate smoothing parameter in the simple Taylor rule (4.48) is set at zero).

However, not smoothing the policy rate is not the only option for the central bank when managing the economy. During a crisis, the central bank has a choice in managing the policy rate: either to use information from the lagged policy rate ($\rho_i \neq 0$) or set an entirely new policy rate without harnessing its past information (ρ_i=0). In this part, we investigate what happens to the optimal simple quantitative easing rule when the interest rate smoothing parameter in the simple monetary policy rule is set at 0.8 (ρ_i=0.8). This way, we will investigate whether the structure of the optimal simple rule is invariant to the changed interest rate smoothing parameter. We consider this issue is important because we hypothesize that the structure of the optimal simple rule should be stable regardless the value of interest smoothing parameter.

Changing the interest rate smoothing parameter inevitably changes the loss of the fully optimal commitment rule. Table 4.7 illustrates the policy performance of the fully optimal commitment rule (first row) and policy performance when quantitative easing is absent (second row). It is necessary to mention that in addition to the feedback coefficients displayed above, there are also some feedback coefficients related to the Lagrange multipliers, which are not shown in the table. The Lagrange multipliers coefficients function as the cost that the central bank must bear due to the commitment policy.

Table 4-7: The Fully Optimal Commitment Macroprudential Policy Rule (x10^{-2}) when $\rho_i = 0.8$

N_{t-1}	K_{t-1}	π_{t-1}	R_{nt-1}	I_{nt-1}	D_{t-1}	Q_{t-1}	C_{t-1}	A_{t-1}	ξ_{t-1}	ε_t^A	ε_t^K	ε_t^N	ε_t^R	**LOSS**
0.37	-0.58	-0.09	-4.36	0.32	-0.56	1.33	0.41	2.76	1.52	2.91	2.31	0.37	-4.25	269.45
-	-	-	-	-	-	-	-	-	-	-	-	-	-	394.38

As shown in Table 4.7, a change in the interest smoothing parameter from 0 to 0.8 corresponds a loss value that slightly increases from 2.6572 to 2.6945, where the difference is only small. Similarly, the loss when quantitative easing is not present in the model is 3.9438, which is also higher than when no smoothing action is taken. Hence, using formula (4.54), the benefit from introducing quantitative easing policy with a non-zero smoothing interest parameter is 31.66% better than having no use of quantitative easing in the economy. Compared to te case when the central bank implements a zero interest smoothing parameter, the fully optimal commitment rule is slightly more beneficial by 5%.[3]

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[3] According to Table 4.2, the benefit in the case when the central bank implies a zero interest smoothing parameter is 26.66% better off than having no macroprudential policy. Hence, the difference between

In the first approach, the simulation shows that leverage, capital price, and credit spread continue to play the critical roles in the optimal simple rule. Table 4.8 illustrates the simple rule across three time horizons in detail.

Table 4-8: The Optimal Simple Quantitative Easing Rule with Banking Variables when $\rho_i = 0.8$

Time horizon	**Simple Rule**			**Loss**	**Efficiency**
Past time	$\boldsymbol{\tilde{\phi}_{t-1}}$	$\boldsymbol{\tilde{Q}_{t-1}}$	$\boldsymbol{\tilde{\vartheta}_{t-1}}$	2.7088	0.527%
	-0.0422	0.2373	3.7703		
Current time	$\boldsymbol{\tilde{\phi}_{t}}$	$\boldsymbol{\tilde{Q}_{t}}$	$\boldsymbol{\tilde{\vartheta}_{t}}$	2.7397	1.677%
	0.0325	0.1118	0.0000		
Future time	$\boldsymbol{E_t(\tilde{\phi}_{t+1})}$	$\boldsymbol{E_t(\tilde{Q}_{t+1})}$	$\boldsymbol{E_t(\tilde{\vartheta}_{t+1})}$	2.7390	1.651%
	0.0329	0.1884	0.0000		

As shown in Table 4.8, in the first approach, the best optimal simple quantitative easing rule is when the central bank uses the lagged deviation of leverage, capital price, and credit spread from their steady states. This optimal simple rule delivers a policy performance of 2.7088, which is only 0.527% less efficient than that of the fully optimal commitment rule. Furthermore, the rule under the current time horizon can deliver a higher loss of 2.7397, which is 1.677% less efficient than that of the fully optimal commitment rule. Finally, the loss in the optimal rule under the future time horizon is 2.7390, which is 1.651% less efficient than that under commitment. Therefore, based on the policy performance, the optimal simple rule with the past time horizon is still superior to those under the current and future time horizons even though the smoothing interest rate parameter is changed.

Furthermore, in the case when the central bank incorporates output and inflation, the result demonstrates that adding the two variables can improve policy performance, as shown in Table 4.9.

Table 4-9: The Optimal Simple Quantitative Easing Rule with Banking Variables when $\rho_i = 0.8$

Time horizon	**Simple Rule**					**Loss**	**Efficiency**
Past time	$\boldsymbol{\tilde{\phi}_{t-1}}$	$\boldsymbol{\tilde{Q}_{t-1}}$	$\boldsymbol{\tilde{\vartheta}_{t-1}}$	$\boldsymbol{\tilde{Y}_{t-1}}$	$\boldsymbol{\tilde{\pi}_{t-1}}$	2.7072	0.471%
	-0.0601	0.2290	3.7415	-0.0818	-0.1132		
Current time	$\boldsymbol{\tilde{\phi}_{t}}$	$\boldsymbol{\tilde{Q}_{t}}$	$\boldsymbol{\tilde{\vartheta}_{t}}$	$\boldsymbol{\tilde{Y}_{t}}$	$\boldsymbol{\tilde{\pi}_{t}}$	2.7251	1.135%
	0.0100	0.1727	0.0000	-0.8334	-0.1959		
Future time	$\boldsymbol{E_t(\tilde{\phi}_{t+1})}$	$\boldsymbol{E_t(\tilde{Q}_{t+1})}$	$\boldsymbol{E_t(\tilde{\vartheta}_{t+1})}$	$\boldsymbol{E_t(\tilde{Y}_{t+1})}$	$\boldsymbol{E_t(\tilde{\pi}_{t+1})}$	2.7218	1.013%
	0.0103	0.3418	0.0000	-1.1987	-0.2248		

31.66% and 26.66% is 5%. However, this comparison does not conclude that a non-zero interest smoothing parameter is better than a zero smoothing parameter.

Under the past time horizon, the optimal simple quantitative easing rule constructed using lagged deviation of leverage, capital price, credit spread, output, and inflation only performs at 2.7072, which is 0.471% less efficient than that under commitment. This result suggests that involving output and inflation can increase the optimal simple rule performance from 0.527% to 0.471%, which means 0.056% of improvement. We argue that this level of improvement, i.e. 0.056%, is insignificant. A similar result also occurs under current and future time horizons. Under the current time horizon, the optimal simple rule can improve the policy performance from 1.677% to 1.135%, which means 0.542% of improvement. We consider this improvement is small. Furthermore, under future time horizon, the rule improves policy performance from 1.651% to 1.013%, which means 0.516% of improvement, which is considered small. Overall, since considering output and inflation in the optimal simple rule under the past time horizon only results in insignificant improvement, we argue that incorporating information from these two variables is not influential when the central bank smooths the policy rate. Besides, the policy performance of the optimal simple rule without smoothing the interest rate remains superior.

Compared to the case of the zero interest-rate smoothing parameter, these findings indicate that the critical information gleaned from banking variables remains the same, namely leverage, capital price, and credit spread. Likewise, the simulation demonstrates that incorporating output and inflation into the simple rule has no significant impact. Furthermore, the simulation illustrates that the value of feedback coefficients under a non-zero interest rate smoothing parameter are generally lower than those under a zero parameter. However, although the feedback parameters in the simple rule are changed, credit spread remains having the greatest feedback coefficient in the simple rule, followed by capital price and leverage. Therefore, in conclusion, this part confirms that the structure of the optimal simple rule is invariant to the the central bank's decision to smooth the policy rate.

4.4.7 The Impact of Exogenous Shock on Policy Performance

This section investigates the effect of exogenous shocks on the policy performance of the optimal simple quantitative easing rule. There are four types of exogenous shocks introduced in the model: capital quality shock, technology shock (productivity shock), banking net worth shock, and interest rate shock (monetary policy shock). Exogenous shocks are naturally unobserved and ideally should not present in the formal presentation of the optimal simple policy rule. However, below we argue why this section is necessary.

First, although exogenous shocks are naturally unobserved, the central bank may still able to prevent shocks from bursting. In practice, most central banks own surveillance teams that regularly and comprehensively monitor the development of the domestic economy. We argue that these surveillance teams would be able to detect the presence and approximate the shocks. Although the shock magnitude is not estimated accurately, the central bank would be able to approximate the shock to improve the policy performance. Hence, we believe that incorporating shocks into the optimal simple rule should benefit the central bank.

Second, information regarding which shock would most substantially affect policy performance can help the central bank to formulate the optimal simple rule more efficiently than neglecting all shocks in the economy. For instance, suppose the central bank observes the threat of a negative productivity shock; then the central bank could gain more benefit by implementing the optimal simple rule containing a productivity shock in the equation.

Third, it would be theoretically interesting to understand the role of exogenous shocks in the optimal simple rule, mainly to determine whether the shocks can affect feedback coefficients in the rule or not. If they can, it would be interesting to observe to what extent the coefficients are changed and whether such changes occur in the optimal simple rules across all time horizons. Table 4.10 illustrates the simulation result regarding the impact of exogenous shocks on the optimal simple quantitative easing rule.

Table 4-10: Impact of Shock on the Optimal Simple Macroprudential Rule

$\widetilde{\boldsymbol{\phi}}_{t-1}$	$\widetilde{\boldsymbol{Q}}_{t-1}$	$\widetilde{\boldsymbol{\vartheta}}_{t-1}$	$\boldsymbol{A_t}$	$\boldsymbol{\xi_t}$	$\boldsymbol{\varepsilon_t^N}$	$\boldsymbol{\varepsilon_t^R}$	**LOSS**
-0.0624	0.3354	5.0009					2.6654
-0.0609	0.3309	4.9150	-0.0542				2.6653
-0.0627	0.3312	5.0336		0.0209			2.6653
-0.0624	0.3354	5.0009			0.0031		2.6654
-0.0624	0.3354	5.0009				-0.0072	2.6654

Some results from Table 4.10 above are notable. First, no exogenous shocks significantly affect the optimal simple quantitative easing rule. The simulation reveals that the policy performances are almost identical when all shocks are present in the rule, for instance, the case when the central bank's response to a technology shock delivers a policy performance of 2.6653, which is very similar to the cases of optimal simple rules without shocks. Likewise, policy performances under other exogenous shocks remains similar when the simple rules do not contain any shocks.

Second, although the policy performances are not significantly affected, the feedback coefficient of credit spread is slightly affected. For example, the feedback coefficient of credit spread in the case when the central bank observes a technology shock is 4.9150, which is smaller than that when no shock is present, which is 5.0009. However, the difference is minor. This finding confirms that even if the central bank has a chance to respond to a particular shock, responding to exogenous shocks will not significantly affect the performance of the optimal simple rule.

4.4.8 The Impact of Central Bank's Aggressiveness

This section examines whether the central bank should be aggressive when managing the optimal simple quantitative easing rule or not. The aggressiveness is characterised by the presence of a constant called a credit parameter (κ) in the optimal simple rule. Hence, a higher credit parameter reflects a situation when the central bank more aggressively injects credit for banks. This type of aggressiveness is also used in the Gertler and Karadi's (2011) original model.

However, the presence of a credit parameter in the optimal simple rule has one significant consequence, which is that it will inevitably unbind the optimality of the simple quantitative easing rule, as the feedback coefficient in the optimal simple rule will be changed. An inspection of the impact of aggressiveness is carried out in this section by comparing unconditional variances among variables in the loss function for various levels of credit parameters. Specifically, the optimal simple rule used in the simulation is given in equation (4.56) below.

$$\psi_t = \kappa\left[-0.0422\,\tilde{\phi}_{t-1} + 0.3354\tilde{Q}_{t-1} + 5.0009\,\tilde{\vartheta}_{t-1}\right] \qquad \mathbf{(4.62)}$$

Accordingly, Table 4.11 provides the simulation of unconditional variances under the chosen optimal simple quantitative easing rule for various levels of credit paramaters.

Table 4-11: Unconditional Variances of The Optimal Simple Rule Under Various Credit Parameter

Credit parameter ($\boldsymbol{\kappa}$)	**Unconditional variance**					**LOSS**
	$\boldsymbol{\pi}$	$\boldsymbol{\tilde{Y}}$	$\boldsymbol{\tilde{\vartheta}}$	$\boldsymbol{\tilde{R}_n}$	$\boldsymbol{\tilde{\psi}}$	$\boldsymbol{\beta \to 1}$
1	0.0326	2.6927	0.0458	0.1007	0.0955	2.9672
5	0.0272	2.5388	0.0325	0.0849	0.0325	3.1406
10	0.0257	2.4524	0.0264	0.0803	0.7754	3.3602
50	0.0245	2.4618	0.0246	0.0768	0.8208	3.4085
100	0.0243	2.4572	0.0240	0.0763	0.8517	3.4335

Some findings from the simulation above are of note. First, increasing aggressiveness deteriorates policy performance. As shown in Table 4.11, policy performance increases when the credit parameter rises from 1 to 100. At this rate, optimality is no longer binding, and the policy performance is worsening. The credit injection ratio itself mainly contributes to the worsening of policy performance, which means that the loss function penalizes central bank with greater extent when its aggressiveness elevates. That is, this ratio fluctuates considerably as the credit parameter increases. The increasing credit injection reflects the central bank's increased aggressiveness when injecting abundant credit into the economy.

Second, however, although it worsens policy performance, a higher credit injection into the economy stabilises the variables in the loss function. We found that the variance of output, inflation, credit spread, and the nominal interest rate all decline when the credit parameter increases from 1 to 100. For instance, the inflation fluctuation falls from 0.0326 to 0.0243 (25.46%). The fluctuation of output also declines from 2.6927 to 2.4572 (8.73%). Similarly, credit spread and policy rate are also stabilised by 47.59% and 24.23%, respectively. When aggressiveness increases from 1 to 100, the credit injection ratio's variance soars from 0.0955 to 0.8517 (791.83%), and policy performance deteriorates from 2.9672 to 3.4335 (15.71%). Considering that policy performance deteriorates more quickly than the improvement of variables in the loss function, we argue that over-aggressiveness is detrimental to the economy. Although increased aggressiveness can benefit macroeconomic stabilisation, this benefit is accompanied by worsened policy performance.

The main point from this finding is that aggressiveness can promote inflation and credit stabilisation but at the cost of worsened policy performance. Also, increased credit injection can dampen the fluctuation of output and policy rate. Figure 4.2 illustrates an example of the economic response for two level of central bank's aggressiveness ($\kappa = 10$ and $\kappa = 100$) when a negative five percent capital quality shock enters the economy.

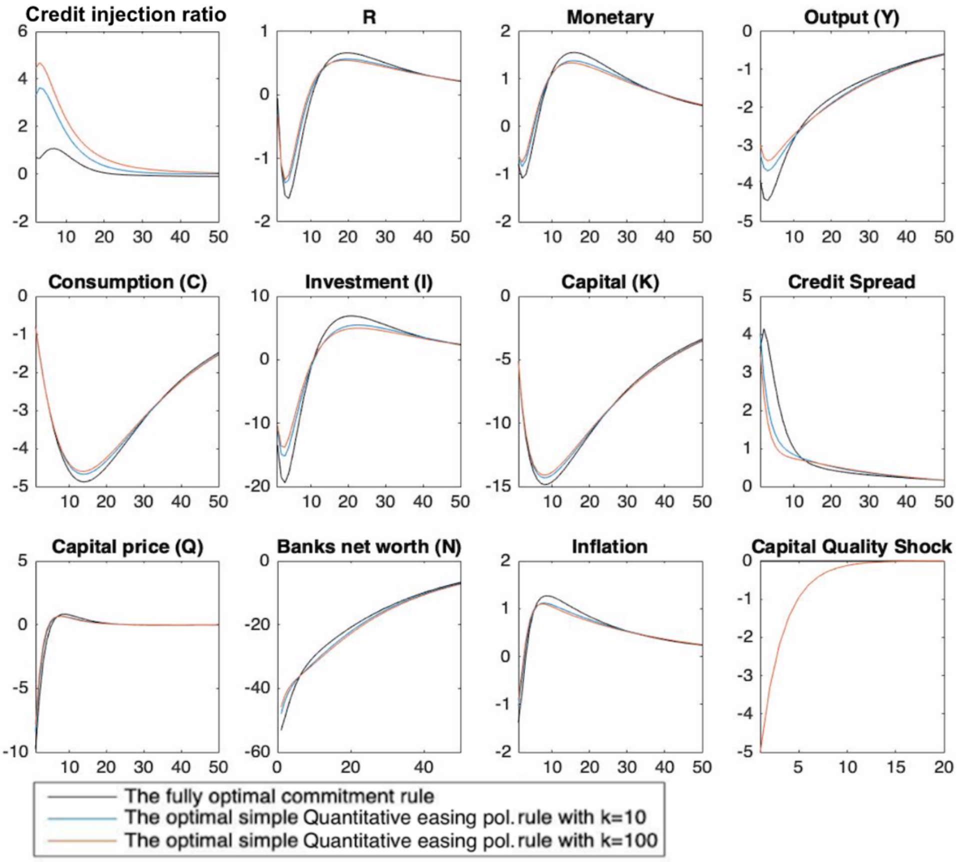

Figure 4-2: Impulse Response Under Minus Five Percent Capital Quality Shock

Figure 4.2 illustrates three simulations: the fully optimal commitment rule, the optimal simple quantitative easing rule with a credit parameter of 10, and the optimal simple quantitative easing rule with a credit parameter of 100. Precisely, the optimal simple quantitative easing rule with a credit parameter 10 is defined as

$$\psi_t = \left[-0.422\, \tilde{\phi}_{t-1} + 3.354\tilde{Q}_{t-1} + 50.009\, \tilde{\vartheta}_{t-1} \right] \qquad (\mathbf{4.63})$$

while the the optimal simple quantitative easing rule with a credit parameter of 100 is defined as

$$\psi_t = \left[-4.22\, \tilde{\phi}_{t-1} + 33.54\tilde{Q}_{t-1} + 500.09\, \tilde{\vartheta}_{t-1} \right]. \qquad (\mathbf{4.64})$$

As shown in the figure, in general, being aggressive causes the central bank to inject more abundant credit into the economy. The central bank injects the highest amount of credit when it is very aggressive with a credit parameter of 100. This injection can moderate the negative impact of the shock on macroeconomic variables.

For instance, in the first period, the variables like capital, inflation, consumption, investment, output, and asset prices are more stable than those under commitment. However, this stabilisation is a consequence of a massive liquidity injection into the economy, which could have brought negative consequences in the future. Recall that the loss function (4.59) contains the credit injection ratio within its structure, which serves as a penalty for an excessive quantitative easing decision: thus, over-aggressiveness inevitably deteriorates policy performance.

In conclusion, this simulation illustrates that over-aggressiveness unbinds optimality in the simple quantitative easing rule. This occurs because the presence of a credit parameter increases the feedback coefficients in the rule, which consequently worsens loss value due to higher credit injection into the economy. However, as demonstrated by the unconditional variance and the example of impulse response function in Figure 4.2, although excessive aggressiveness when combatting a crisis deteriorates policy performance, the decision helps stabilise the fluctuation of economic variables in the loss function and also benefits the macroeconomy in general. That is, output, inflation, credit spread, and policy rate fluctuate less. However, this occurs at the cost of worsened policy performance.

4.4.9 Impulse Response Function

This section explains the simulation of impulse response functions under various shocks. The impulse describes the response of the economy under the best optimal simple quantitative easing rule, which is the optimal simple rule that is constructed by the past deviation of leverage, capital price, and credit spread. The simulation introduces four types of shocks: minus five percent capital quality shock, minus one percent technology shock, minus one percent net worth shock, and one percent increase of nominal interest rate shock.

- **Capital Quality Shock**

Figure 4.3 depicts the impact of a minus five percent capital quality shock on the economy under the optimal simple rule, relative to the fully optimal commitment rule. Precisely, the optimal simple quantitative easing rule presented with this figure is the one constructed by past deviation of endogenous variables defined as

$$\psi_t = \left[-0.0422\,\tilde{\phi}_{t-1} + 0.3354\tilde{Q}_{t-1} + 5.009\,\tilde{\vartheta}_{t-1}\right] \qquad \mathbf{(4.65)}$$

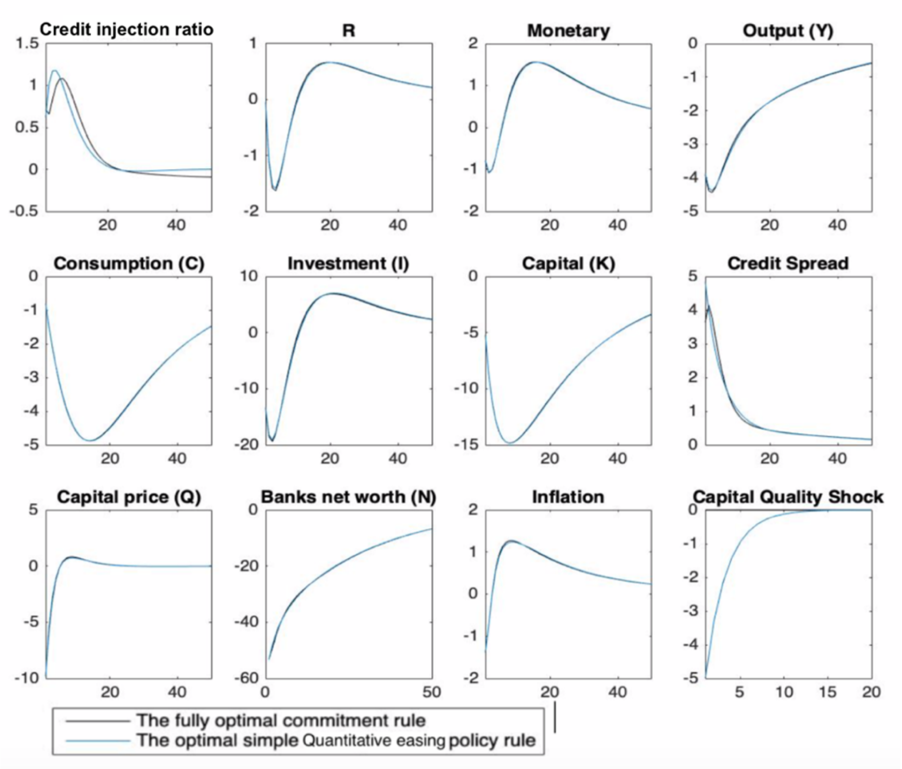

Figure 4-3: Impulse Response Under Minus Five Percent Capital Quality Shock

A capital quality shock enters the economy through various channels, namely the capital accumulation equation, the production function, new bankers net worth accumulation, and investment. In comparison to the other types of shocks, this shock has the most channels by which it can affect the economy.

Under the adverse capital quality shock, the economic responses of the two policy rules are identical. In the real sector, firms experience a decline of capital purchased by five percent from its steady state when the shock presents. In the labour market, the shock on capital quality also decreases labour hired. Thus, everything else equal, the fall in capital and labour contributes to the decline of production and causes output in the economy declines. Everything else equal, the fall in production corresponds to the fall of intermediate good prices and hence inflation. The simulation demonstrates that inflation falls by –3% when the shock presents, which is identified either in the fully optimal commitment rule or in the optimal simple rule.

The declining production activity also causes firms to gain less profit, which means less dividend given to households. This then results in less funds available for consumption and less deposit creation in intermediaries. Therefore, consumption decreases by –1% below the steady state when the shock hits the economy. The simulation also shows that the shock negatively affects capital good producers and pressures investment by more than 20% from its steady state. Hence, under this shock, production declines because capital producers can only contribute less new capital to the economy. However, given that capital purchased by firms is equal to the amount of credit given by banks, the fall of purchased capital also attenuates credit activity in the banking sector. Consequently, banking profitability falls.

Everything else equal, falling banking profit reduces the total banking net worth. The fall of banking net worth under commitment and the optimal simple rule are identical. From a monetary policy perspective, the presence of shock causes the central bank to cut the policy rate, which subsequently decreases the real interest rate (deposit rate). The fall in deposit rate then disincentivises households from creating more deposits, which then negatively affects banking credit activity. From the quantitative easing perspective, the central bank responds to the adverse capital quality shock by increasing the credit injection ratio. The shock increases the credit injection ratio identically under both commitment and the optimal simple rule. This higher injection provides additional funds for intermediaries to accelerate their credit activity. As credit progresses positively, credit spread gradually decreases and reduces bankers’ incentive to divert funds.

A higher credit supply also enables firms to demand more capital in the economy, which stimulates capital good producers to produce more new capital for firms. As more new capital is produced, credit becomes more affordable, which further increases output. These more affordable credit gradually increases the future expectation of the lending rate and thereby increases credit spread positively. As the credit spread increases gradually, banking profitability also advances and brings banking net worth back to its steady state. Moreover, the growing production also drives firm’s profit, increases dividends for households, and enhances consumption. Accelerating economic activity gradually increases inflation. Overall, the economic recovery speed of the fully optimal commitment rule and the optimal simple rule under this shock is identical.

- **Technology Shock**

Figure 4.4 depicts the impact of the minus one percent technology shock on the economy under the optimal simple rule relative to the fully optimal commitment rule. The only channel through which the shock can affect the economy is through production function of intermediate good firms. In general, under this shock, the two policy rules behave similarly, but not identically. Precisely, the optimal simple quantitative easing policy rule presented in this figure is the one constructed by past deviation of endogenous variables defined as

$$\psi_t = \left[-0.0422\,\tilde{\phi}_{t-1} + 0.3354\tilde{Q}_{t-1} + 5.009\,\tilde{\vartheta}_{t-1}\right] \qquad (\mathbf{4.66})$$

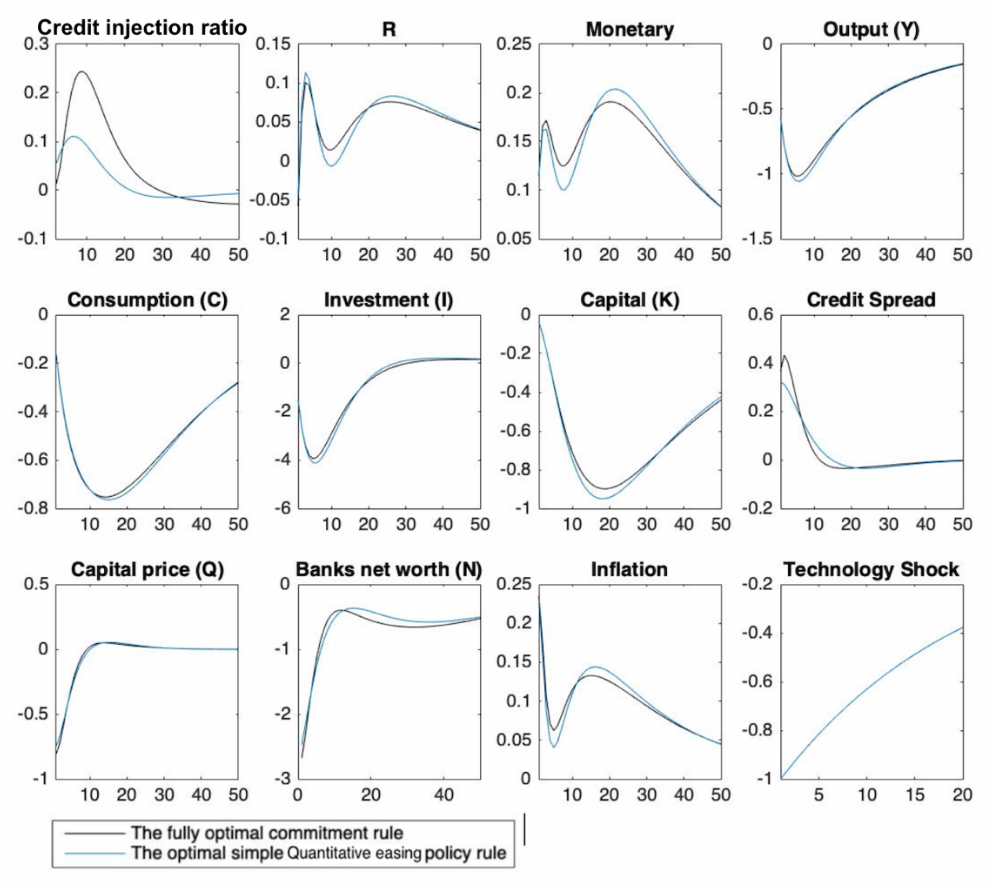

Figure 4-4: Impulse Response Under Minus One Percent Technology Shock

In the real sector, the shock reduces output in both policy regimes. Everything else equal, the weakening production disincentivises capital goods producers from creating more new capital, which reduces investment. The falling investment causes capital prices to decline. Hence, when only less capital are available in the economy, production is affected. The falling production then increases intermediate goods prices, which then triggers inflation to rise, everything else equal. This weaker production activity generates less profitability for firms and less dividends for households to consume. Therefore, consumption also decreases. In the financial sector, less dividends received by households corresponds to less deposit creation in intermediaries, and hence less funds for credit intermediation. Reduced credit intermediation then negatively affects banking net worth. Furthermore, less credit activity raises the future expectation of the lending rate, which then significantly increases credit spread.

The shock triggers the central bank to expand credit injection. The credit injection under commitment increases up to 23%, while it only increases up to 10% under the optimal simple rule. In contrast, the monetary policy responds to the shock by increasing the policy rate above its steady state, which subsequently incentivises households to create more deposits and provides more funds. The credit injection also helps intermediaries increase their credit activity. Given that banks now intermediate more credit into the economy, firms can receive more credit to purchase new capital for their production. Everything else equal, as purchased capital increases, firms can produce more goods and increase output.

Simultaneously, more credit received by firms for purchasing capital also strengthens their demand for capital and incentivises capital goods producers to produce more new capital in the economy. Increasing capital demand also stimulates the growth of capital prices. Everything else equal, when credit accelerates, the future expectation of lending rate falls and gradually returns the credit spread to its steady state. Furthermore, increased output also pressures intermediate goods prices and reduces inflation. Inflation then rebounds positively when the economy accelerates.

- **Net Worth Shock**

Figure 4.5 illustrates the impact of a minus one percent net worth shock on the economy under the optimal simple rule relative to the fully optimal commitment rule. The adverse net worth shock affects the economy through the financial sector, specifically via the channel of the existing bankers' net worth accumulation. Precisely, the optimal simple quantitative easing policy rule presented in this figure is the one constructed by past deviation of endogenous variables defined as

$$\psi_t = \left[-0.0422\, \tilde{\phi}_{t-1} + 0.3354 \tilde{Q}_{t-1} + 5.009\, \tilde{\vartheta}_{t-1} \right] \qquad \mathbf{(4.67)}$$

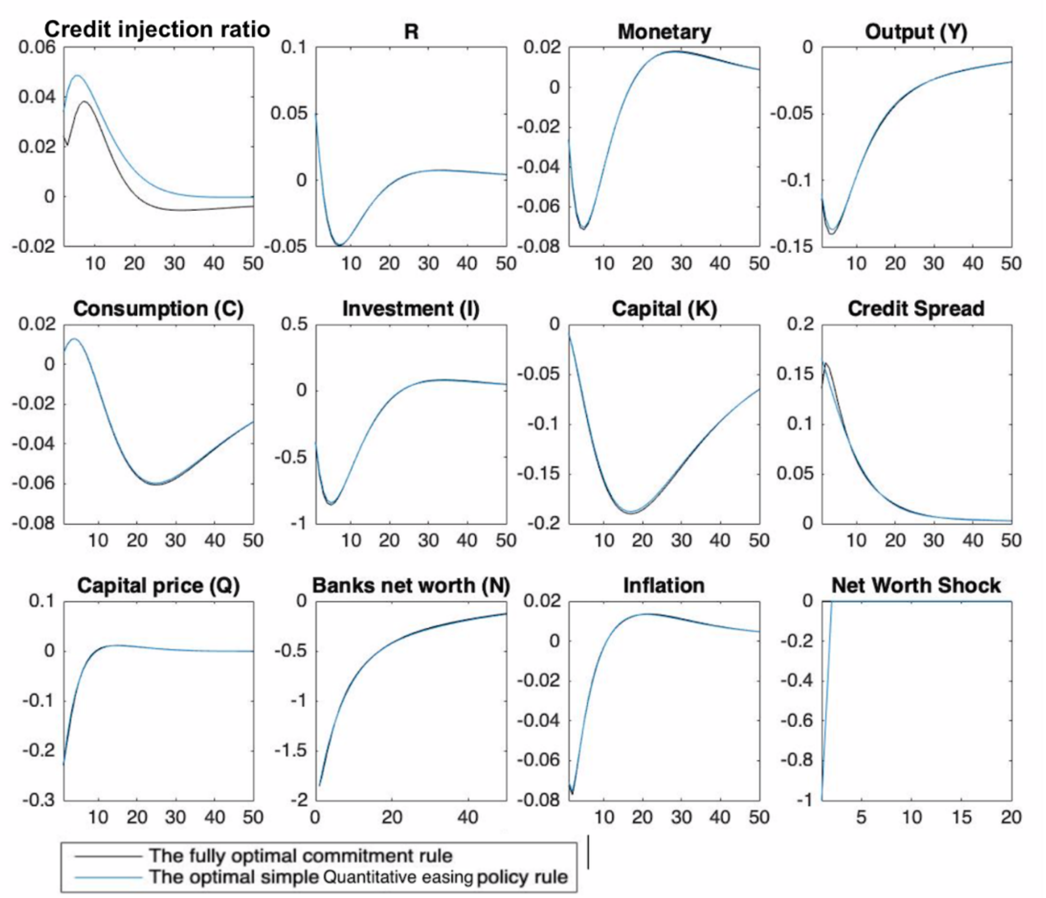

Figure 4-5: Economic Response Under Minus One Percent Net Worth Shock

The economic response under the optimal simple rule is identical to that under commitment, with the exception of the response of the credit injection ratio. In the following section, the terms banking net worth and banking capital are used interchangeably. Everything else equal, the fall in existing bankers net worth decreases total banking capital, which attenuates banking credit intermediation. Hence, the amount of credit given to firms is falling. Given that credit supply is equal to capital purchased by firms, the shock also causes capital stock to fall.

In the real sector, less credit intermediation from banks causes capital purchased by firms to decline. Everything else equal, less purchased capital results in a deceleration of production activity. Falling production activity causes firms' demand for capital to decline, which subsequently disincentivises capital goods producers from creating more new capital in the economy. The latter explains why investment falls. Falling investment then pressures capital prices, raises the expectation of lending rate, and hence elevates credit spread. In protecting banking credit from further decline, the central bank expands the credit injection ratio. The central bank elevates the ratio twice as high as it does under commitment. The central bank also cuts the policy rate to respond to the shock, which then reduces the deposit rate in both rules, everything else equal. Thus, a lower deposit rate prompts deposit creation in the economy.

Quantitative easing helps banks promote credit activity. Given that banks now intermediate more credit into the economy, firms can receive more credit to purchase new capital for their production. Everything else equal, as purchased capital increases, firms can produce more goods and increase output. Simultaneously, it strengthens the firms' demand for capital and incentivises capital goods producers to produce more new capital in the economy, which then increases investment. Increasing capital demand also stimulates the growth of capital prices, which then positively affects the lending rate, everything else equal. As credit is accelerating, the future expectation of lending rate is falling and gradually reduces credit spread back to its steady state. Higher production activity then gives firms more profit, increases dividends for households, and boosts consumption.

- **Interest Rate Shock**

Figure 4.6 illustrates the impulse response under monetary policy shock, namely a sudden increase of the nominal interest rate by one percent. The economic response under the optimal simple rule is identical to that under commitment, with the exception the response of the credit injection ratio. Precisely, the optimal simple quantitative easing policy rule presented in this figure is the one constructed by past deviation of endogenous variables defined as

$$\psi_t = \left[-0.0422\,\tilde{\phi}_{t-1} + 0.3354\tilde{Q}_{t-1} + 5.009\,\tilde{\vartheta}_{t-1}\right] \tag{4.68}$$

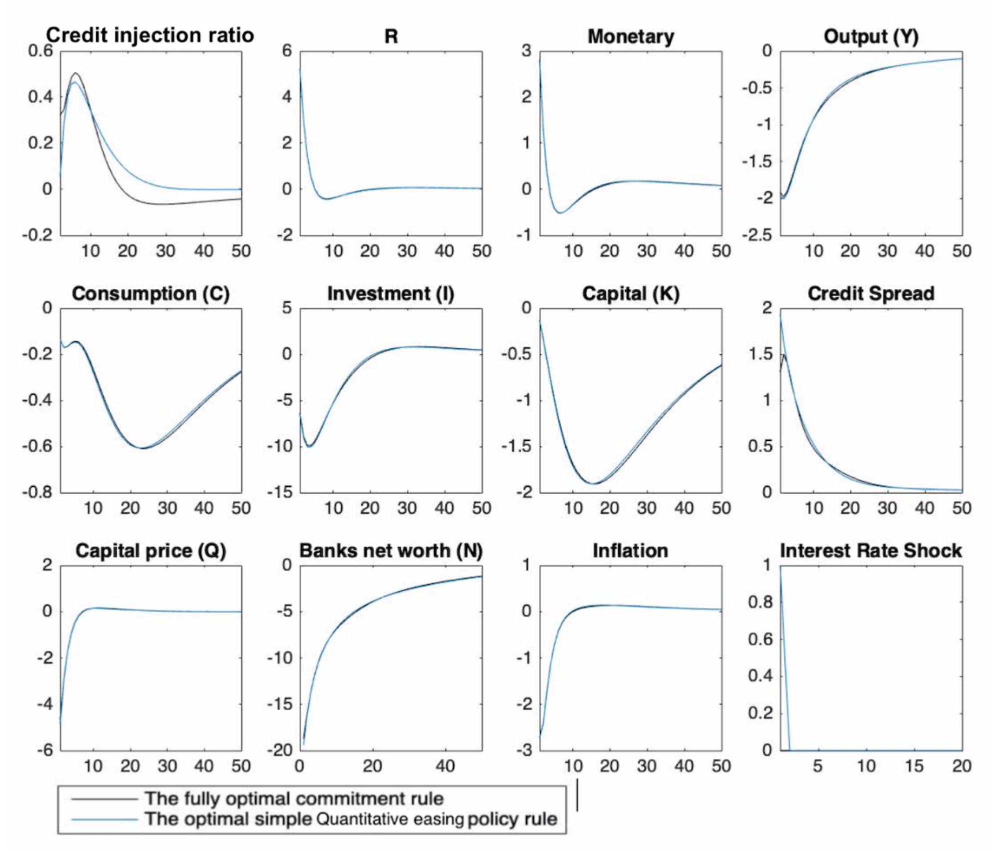

Figure 4-6: Economic Response Under One Percent Interest Rate Shock

The shock in the nominal interest rate hits the economy through the simple monetary policy rule, i.e., the Taylor rule, implemented by the central bank. Moreover, according to the Fisher equation, the increase of the nominal interest rate will influence the deposit rate and affect the amount of deposit created in the banking sector. Given the higher deposit rate, households will trade their consumption for more significant deposit in the future such that consumption in the initial period falls, where the fall of consumption under the optimal simple policy rule and the commitment rule are identical.

In the financial sector, intermediaries anticipate the shock by elevating the lending rate in order to gain more profits. As a consequence, the lending rate rises, which makes credit become more expensive. The expectation of a higher future lending rate elevates credit spread and causes credit intermediation to fall. Given that credit is equal to capital purchased by firms, this explains why capital diminishes. Everything else equal, by production function, the output decreases. When firms receive less credit, their demand for new capital decreases, which then reduces investment and capital prices.

The central bank injects more loans into the economy by raising the credit injection ratio. This injection helps banks increase their lending to firms such that firms can purchase more capital for their production. Everything else equal, as purchased capital increases, firms can produce more goods and increase output. At the same time, more loans received by firms also strengthen their demand for capital and incentivises capital goods producers to create more new capital in the economy, followed by an increase in investment. Increasing investment then stimulates capital prices and reduces the lending rate and credit spread. Finally, accelerated production also increases firms' profitability, dividends given to households, and consumption.

4.5 Concluding Remarks

This study investigates the optimal simple rule for quantitative easing policy. The reference model in this study is the unconventional monetary policy model from Gertler and Karadi (2011). The study uses the credit injection ratio as the quantitative easing policy instrument, which represents the share of credit injected from the central bank relative to the total credit in the economy. The central bank optimises the credit injection ratio under commitment while implementing a monetary policy using the simple Taylor rule.

The loss function in the study is the ad-hoc loss function constructed by the deviation of output, inflation, credit spread, nominal interest rate, and the credit injection ratio from their steady states. The simulation illustrates two approaches. The first approach is when the central bank only focuses on banking variables, and the second approach is when the central bank also incorporates macroeconomic variables. For each approach, this study generates three optimal simple rules: the optimal simple rule under anpast time horizon, under a current time horizon, and under a future time horizon.

This study contributes to the literature regarding the formulation of quantitative easing rule and the literature on the convensionalisation of unconventional monetary policy (sheedy, 2016; Curdia and Woodford, 2018; Quint and Rabanal, 2017). This study demonstrates that in the first approach, the optimal simple rule is optimally constructed by lagged deviation of leverage, capital price, and credit spread from their steady states. In the second approach, the study shows that incorporating output and inflation only minorly improves policy performance. By comparing these two approaches, using the fully optimal commitment rule as a benchmark, this study identifies that the optimal simple rule under a past time horizon is superior. Furthermore, when the central bank utilises a non-zero interest rate smoothing parameter, the structure of the optimal simple rule under the first approach remains the same, which is constructed by past leverage, capital price, and credit spread, and incorporates information regarding output and inflation is still insignificant. Relative to the fully optimal commitment rule, the optimal simple rule corresponds to less credit injection than under commitment. However, less credit injection consequently leads to higher fluctuations in output and credit spread. Across all variables in the loss function, output is the most fluctuating variable that contributes significantly to level of policy performance.

Some other findings also stand out. First, knowledge of the banking sector is crucial for the central bank when managing the optimal simple rule for quantitative easing, which is in line with argument from Borio and Zabai (2016). Second, past information is superior to current and future information, which means that ample access to historical data would be beneficial for the central bank when managing quantitative easing. Third, credit spread has the greatest feedback coefficient in the simple quantitative easing rule. This result is in line with our reference model, which indicates that credit spread is a variable that significantly influences moral hazard in the banking sector. Hence, the increase of credit spread, which activates higher credit injection, is also beneficial for decreasing instances of moral hazard behaviour in the banking sector. Lastly, the optimal simple quantitative easing rule using past information can deliver policy performance almost as efficiently as the fully optimal commitment rule, which would help the central bank communicates the simple rule to the public.

This study also investigates the impact of an exogenous shocks on the policy performance of the optimal simple quantitative easing rule. Some conclusions from this section are notable. First, no exogenous shocks significantly affect the optimal simple quantitative easing rule. The simulation reveals that when any particular shock is incorporated into the optimal simple rule, the policy performances are almost identical. Second, although policy performance is not significantly affected, the feedback coefficient of credit spread is slightly affected. However, the difference is just minuscule. Thus, even if the central bank were aware of a particular shock, the knowledge of shock would not change how the optimal simple quantitative easing rule performs.

This study also found that the central bank's aggressiveness creates a trade-off between optimality and stability in the economy, which is similar to argument by Cui and Sterk (2018); Kiley (2008); and Fernandez, Bortz, and Zeolla (2018). The aggressiveness unbinds the optimality under the optimal simple rule because a higher credit parameter changes the feedback coefficients in the optimal simple rule. A higher credit parameter consequently leads to higher loss due to higher credit injection into the economy. However, although aggressiveness deteriorates policy performance, it reduces the fluctuation of the variables in the loss function – except the credit injection ratio – and benefits the macroeconomy. In the example in which a minus five percent capital quality shock hits the economy, the impulse shows that higher aggressiveness (higher credit parameter) moderates macroeconomic fluctuation, such as output and inflation, but causes the credit injection ratio to soar. Thus, we argue that excessive aggressiveness is not recommended in quantitative easing policy. Finally, the finding regarding the benefit from introducing quantitative easing policy in the economy is also in line with studies from Bhattarai and Neely (2016); Chen et al. (2016); Curcuru et al. (2018); Maggio, Kermani and Palmer (2016); Fisher, Ramcharan, and Yu (2015); and Kapetanios et al. (2019), among others.

CHAPTER 5

MACROPRUDENTIAL POLICY WITH MULTIPLE POLICY INSTRUMENTS

Abstract

This study examines the interaction between conventional monetary policy and macroprudential policy in a macroeconomic model where credit supply plays a prominent role. The model reference in this study is the one outlined by Gerali, Neri, Sessa, and Signoretti (2010) that provides three macroprudential policy instruments: capital adequacy ratio, loan-to-value ratio for households, and loan-to-value ratio for entrepreneurs. The study presents two scenarios: the scenario with a single policy instrument and the multiple policy instruments. We measure policy performance based on the ad-hoc loss function constructed by the summed quadratic of deviaton of output, inflation, nominal interest rate, loan-to-output ratio, and macroprudential policy instruments from their steady states. The findings demonstrate that the presence of macroprudential policy can benefit the economy by ensuring financial stability. Furthermore, optimising multiple policy instruments can deliver a better performance than a single instrument optimisation, but there is a risk of there being conflict among the policy instruments. The study also demonstrates that the substitution effect among macroprudential instruments can occur under multiple policy instruments interaction.

Keywords: Macroprudential policy, Policy instrument, Capital adequacy ratio, Loan to value ratio

5.1 Introduction

In the aftermath of the U.S. global financial crisis, the need for macroprudential policy to protect the financial system from systemic crisis was paramount. Macroprudential policy is understood as a policy that aims to generate stability and reduce risk in the financial sector (Gallati and Moissner, 2003). This policy focuses on the stability of the broad financial sector rather than an individual institution. However, as it is a new and evolving policy, the implementation of macroprudential policy still requires many improvements.

For instance, there is no formal consensus on whether the mandate of macroprudential policy should be given to a single or separate institution. Every country has different guidelines for uniting or separating the institutions receiving the macroprudential policy mandate. In Europe, the European Systemic Risk Board (ESRB) is separate from the central bank, but the central bank plays a prominent role in decision making process. In the U.S., macroprudential authority is mandated to a new institution, namely the Financial Stability Oversight Council (FSOC), while monetary policy remains in the U.S. Federal Reserve. Lastly, the U.K. mandates both monetary and macroprudential policies within the Bank of England. Although it is not an absolute rule, many studies assume that macroprudential policy should be mandated into a single institution and simultaneously managed with monetary policy, for example, studies conducted by Angeloni and Faia (2013); Bianchi (2010); Meh and Mohran (2009); Benigno, Chen, Otrok, Rebucci, and Young (2011); Kannan, Rabanal and Scott (2012); Quint and Rabanal (2013); Rubio and Carrasco-Gallego (2015); Collard, Dellas, and Loise (2014), and Zhang and Zoli (2016), among others.

In addition, there is no consensus regarding macroprudential policy's primary instrument. One reason for this issue is that because the scope of the policy itself is broad. For instance, the policy aims to reduce the impact of systemic risk, while the systemic risk itself is broadly defined. Systemic risks can emerge in many forms, such as moral hazard, productivity shock, or asset price bubble. Therefore, no single macroprudential policy instrument can wholly represent the causes of a systemic crisis. However, although no formal consensus is available, the capital adequacy ratio (CAR) and the loan-to-value ratio (LTV) are two of the most popular instruments in macroprudential policy. The Bank of International Settlement (BIS) regulates these two ratios in the Basel Accord, which has become an international standard.

The LTV is the ratio between the loan and its market collateral value, while the CAR is the ratio between the capital and weighted risked assets. Some studies employ one of these types of policy instrument. For example, the study carried out by Angelini, Neri, and Panetta

(2014) focusing on using time-varying CAR as a macroprudential instrument. Gerali, Neri, Sessa, and Signoretti (2010) also use the LTV ratio with a stochastic process, but the CAR is designed as a constant. Kannan, Rabanal, and Scott (2012) also design a macroprudential instrument that allows the central bank to change the CAR. Other similar studies include those by Lambertini, Mendizino, and Punzi (2013) and Rubio and Carrasco-Gallego (2014), among others. However, one significant gap in the literature, found across the studies, is that most studies only use a single macroprudential policy instrument in their models.

Macroprudential policy covers a wide range of policy instruments. Therefore, using multiple macroprudential policy instruments in the economy should be possible. However, it is rare to find studies that focus on multiple macroprudential instruments in their models. This study is interested in filling this gap in the literature by focusing on the interaction between conventional monetary policy and macroprudential policy, when the latter simultaneously implements more than one policy instrument. There are three research questionss in this study. Firstly, how much does the economy benefit from implementing macroprudential policy relative to a scenario in which the policy does not exist? Secondly, to what extent macroprudential policy with multiple policy instruments can benefit the economy, relative to the performance with a single instrument? Finally, is there a trade-off between policy instruments when they are optimised simultaneously?

The reference model used in this study was taken from Gerali et al. (2010), which is also the model used by Angelini, Neri, and Panetta (2014). However, this study adopts the reference model from Gerali et al. (2010) with a small modification. In this study, a minor modification was applied to the model. We set the CAR in the model to be time-varying rather than constant, and we designed LTVs not to be dependent on exogenous shocks. This model is chosen for various reasons. Firstly, the fundamental issue motivating the implementation of macroprudential policy in this model is considered to be relevant in practice, which is to create financial soundness and stabilise credit supply. Secondly, this model also provides a representative banking-oriented model that allows multiple macroprudential instruments to interact, which suits our research questions. Thirdly, and interestingly, the reference model also provides heterogeneous households and allow macroprudential authority to implement two different LTVs: LTV for impatient households, and LTV for entrepreneurs.

Among many similar papers in macroprudential policy, this study is closely related to a study by Angelini et al. (2011). However, our study is different in the way the number of policy instruments being optimised. This study is also different in terms of loss function used, where we assume that the mandate of macroprudential policy is given to a single institution, namely the central bank which manages both monetary and macroprudential policies simultaneously, while Angelini et al. (2011) differentiates the authority into two separate institutions. Our study is also different from Angelini et al. (2011) where we optimise all macroprudential policy instruments under commitment and introduce a joint LTV ratio as a new instrument. Finally, our study is different in the way we measure optimality level of the interaction between policy instruments. That is, this study measures optimality of the interaction based on the unconditional loss value. The unconditional loss value is a single number reflecting the total variation of the variables in the loss function that incorporates multiple exogenous shocks coming into the economy, not only conditional on a specific shock. The highest policy performance (or the lowest loss value) indicates the better performance of a macroprudential policy instrument. Finally, the method to measure the policy performance (or loss value) is adopted from the algorithm developed by Dennis (2007).

We allow the central bank to optimise the CAR and the LTVs under fully optimal commitment and manages monetary policy through a non-optimal simple Taylor rule. Therefore, the central bank only optimises macroprudential policy instruments to minimise the loss function. The loss function for this study is the one used by Angelini et al. (2011), which is designed as an ad-hoc loss function constructed by the variation of inflation, output, loan-to-output ratio, monetary policy instruments, and macroprudential policy instruments.

Our study demonstrates some critical findings. Firstly, implementing macroprudential policy can benefit the economy. Our simulation demonstrates that the policy shows an improvement in performance of up to 72.75% higher than in the case when there is no macroprudential policy active. The benefit from implementing macroprudential policy is derived from its ability to promote financial stability through loan-to-output ratio stabilisation. Secondly, we argue that optimising multiple macroprudential policy instruments is better than only optimising a single policy instrument. The study also demonstrates that the substitution effect among macroprudential policy instruments can occur when multiple policy instruments optimisation take place. However, although optimising multiple policy instruments performs positively, it can also introduce a risk of there being in conflict between the instruments. In other words, the presence of one macroprudential policy instrument can affect the efficacy of another instrument. Finally, we found that LTV is more impactful than CAR, especially when minimising the fluctuation of the loan-to-output ratio.

This chapter contributes through several ways. First, this study contributes to the literature regarding the positive impact of macroprudential policy on welfare, which support studies by Boar et al. (2017); Akinci and Olmstead-Rumsey (2015); Lim et al. (2011), Dell' Ariccia et al. (2012); Galati and Moessner (2014); Quint and Rabbanal (2013); Angelini, Neri and Panetta (2012); Kannan and Rabanal (2012); Rubio and Carrasco-Gallego (2016), Mendicino and Punzi (2014), and Basto, Gomes, and Lima (2018), among others. Specifically, the efficacy of macroprudential policy in stabilising macroeconomy through loan-to-output ratio is also in line with Basel III recommendation, and some studies such as Angelini et al. (2014), Reinhart and Rogoff (2008), and Borio and Drehman (2009). Second, the study also contributes to the literature by presenting the finding that trade-off among policy instruments is present when the central bank manages multiple macroprudential policy instrument under a single objective function. Finally, this study also contributes to the literature arguing the efficacy of LTV ratio for macroeconomic stabilisation, which is a similar argument to studies by Rubio and Carrasco-Gallego (2014); Basto, Gomes, and Lima (2018), and Lambertini, Mendicino, and Punzi (2013), among others.

The rest of the paper is presented as follows: Section two describes the literature study. Section three describes the reference model in detail. Section four contains the results and analyses, including the loss value report and the simulation of the impulse response function. Section five is the conclusion.

5.2 Literature Review

One of the main differences between macroprudential policy and the other stabilisations policy is their respective scopes. Macroprudential policy aims to limit system-wide distress, and, hence, creates financial stability, not only concerning on individual institutions but also all institutions within the financial sector at the same time. This wide scope nature means that the operation of macroprudential policy cannot be supported by only one policy instrument, for instance like policy rate in monetary policy. Hence, as part of a recently growing policy, alternative policy instruments are being developed to support macroprudential policy. This section describes literature that has focused on three areas, namely, the formal regulation on macroprudential policy, the role of CAR, and the role of LTV ratio.

5.2.1 Formal Regulation on Macroprudential Policy

The formal law regulating the standard practices for banks in the banking industry was created by the Basel Committee on Banking Supervision (BCBS), from the Bank for International Settlement (BIS), in the form of the Basel Capital Accord. The first Basel Capital Accord ("Basel I") was published in July 1988 and was based on the work of the BCBS. It was enacted in the U.S. by the end of 1992. The second accord ("Basel II") was finalised by the BCBS in June 2004 to overcome some major shortcomings of the previous standard, most notably with reference to the risk-weighting system (Masera, 2013). Basel I and II required a minimum CAR of 8%.

After the global financial crisis, the BIS strengthened Basel II and classified macroprudential policy instruments into ten important categories, namely risk measurement methodologies, financial reporting, regulatory capital, funding liquidity standards, collateral arrangements, risk concentration limits, compensation schemes, profit distribution restrictions, insurance mechanisms, and managing failures and resolution. Among the ten categories, regulatory capital and collateral arrangements stand out as the two most prominent aspects of macroprudential policy.

Regulatory capital is concerned with the strength of banking capital in relation to buffer risks on credit intermediation. Regarding this, the BIS (2008) strengthened Basel II, which is the international regulatory framework for banks, as a response to the global financial crisis. Subsequently, the strengthened accord Basel III was produced to increase regulatory capital requirements for particular exposure types, which provides greater risk weights than Basel II, for macroprudential reasons. Basel III adds a dynamic macroprudential element in the form of a countercyclical capital buffer of up to another 2.5% of capital, which requires banks to hold more capital in good times to prepare for downturns in the economy. Basel III also introduces a mandatory capital conservation buffer of 2.5%, which elevates the capital requirement buffer to 10.5% (Rubio, and Carrasco-Gallego, 2016). On the other hand, the collateral arrangement is related to the borrowers' repayment capacity, which is measured as the ratio of loans to collateral value. Regarding this, the BIS (2008) advises firms to design a time-varying loan-to-value for collateral based on appropriate valuation methodologies. Hence, among all macroprudential policy instruments, the CAR and LTV are the two most prominent. These two macroprudential instruments have been utilised by many central banks worldwide.

In banking operations, the CAR and LTV basically have a similar primary objective, which is to affect banking credit behaviour. Changing the CAR directly affects banks, which subsequently affects borrowers. On the contrary, LTV ratio first affects borrowers and subsequently affects banking profitability. For instance, imposing higher capital requirements means that banks need to allocate more capital to support credit intermediation to private-sector firms. Hence, with all else equal, a higher capital requirement dampens credit intermediation, which is why it is known as a countercyclical capital buffer. Differently, lowering the CAR incentivises banks to expand the credit market, and in such a case, banks need to allocate a smaller amount of capital. On the other hand, expanding (or lowering) the LTV ratio means giving more (or less) allowance for borrowers to access more credit.

5.2.2 Interaction between Monetary and Macroprudential Policy

Besides using Gerali et al. (2010) as a reference model, this chapter is also close with the work from Angelini, Neri and Panetta (2012). Angelini et al. (2012) study the policy coordination between monetary policy and macroprudential policy under cooperative and non-cooperative settings. The study incorporates macroprudential policy rules into the macroeconomic model developed by Gerali et al. (2010). Monetary authority uses a short-term interest rate as a policy instrument while macroprudential regulator uses capital requirements as the policy instrument. The loss function of monetary authority is calculated by the weighted sum of variation in inflation and output growth. Meanwhile, the loss function of macroprudential authority is calculated by the weighted sum of the variation in the loan-to-output ratio, capital requirement and output growth.

The cooperative setting of the two authorities is modelled to suppose that there is only one single institution that minimises the joint loss function of the two authorities. The financial constraints in the model are assumed to be always binding. The results show that under a cooperative setting, the welfare loss of depositors is greater under technology shocks than under financial shocks. However, the welfare loss of borrowers is relatively equal under both types of shocks. The study illustrates that cooperation between monetary and macroprudential authorities is not significant under normal circumstances triggered by technology shocks but is beneficial under financial shocks. Under financial shocks, the central bank deviates from its target and tends to place more focus on macroprudential policy issues.

Quint and Rabbanal (2013) study the optimal mix of monetary policy and macroprudential policy in the euro area. The authors utilise the Dynamic Stochastic General Equilibrium (DSGE) model with two types of financial intermediaries: domestic and international intermediaries. The model follows the financial accelerator model of Bernanke, Gilchrist and Gertler (1999). The monetary policy instrument used in the model is a short-term interest rate within two types of Taylor rules, namely the simple Taylor rule and the extended Taylor rule, which reacts to nominal credit growth and credit-to-GDP ratio. The macroprudential policy instrument used in the study is an exogenous variable that limits the loans given out to borrowers. This exogenous variable could be given in terms of increasing loan provisions, capital requirements, reserve requirements, or loan-to-value ratios. Instead of formulating the welfare loss function, the study defines the welfare function as the sum of the welfare of savers and borrowers, where each welfare function is derived by taking the second order approximation to the utility function and subtracting it by the utility value at a steady state level. The results show that macroprudential and monetary policy coordination increases welfare under housing demand shocks and risk shocks. However, macroprudential policy reduces welfare under technology shocks and propagates the countercyclical behaviour of the lending-deposit spread.

Bailiu, Meh, and Zhang (2015) study the interaction between macroprudential and monetary policy under financial imperfection and financial shocks. The model is developed by the DSGE in a closed economy estimated based on Canadian data. The model is simulated under four scenarios: a standard Taylor rule regime, representing monetary policy focusing on price stability only; an augmented Taylor rule regime, representing monetary policy focusing on price stability and financial imbalance; a macroprudential policy regime with a standard Taylor rule, focusing on the interaction between macroprudential policy and monetary policy to maintain price stability; and a macroprudential policy with augmented Taylor rule regime, focusing on the interaction between macroprudential policy and monetary policy to maintain price stability and to prevent financial imbalances. It was found that monetary policy results in more welfare when its objective goes beyond price stability, either through fighting financial imbalances or interacting with macroprudential policy.

Kannan, Rabanal, and Scott (2012) study the coordination of monetary policy and macroprudential policy within the framework of a macroeconomic mode,l focusing on a housing price boom. The study was conducted in the spirit of Iacoviello (2005) and Iacoviello and Nerri (2010). The monetary and macroprudential policies were assumed to be mandated to a central bank. Within the study, the authors develop four combinations of policy rules: a simple Taylor rule (which serves as a baseline), an augmented Taylor rule, an augmented Taylor rule with macroprudential policy, and an optimised augmented Taylor rule with macroprudential policy. The four rules are then ranked based on traditional welfare criteria, minimising the variation of inflation and output gap. The monetary policy instrument in the model is policy rate, while the macroprudential policy instrument is the lagged nominal credit changes.

The results show that the the knowledge of the actual source of the housing price boom determines the efficacy of a macroprudential policy towards welfare. Under a productivity shock, macroprudential policy plays no role in the coordination, while it increases welfare when the economy is hit by a demand shocks. Furthermore, based on the welfare criterion comparison, the ranking of rules is influenced by the type of shocks that hit the economy. Under a housing shock or technology shock, the augmented Taylor rule is preferred, while under a financial shock, the augmented Taylor rule with macroprudential policy is preferred.

5.2.3 The Role of Capital Adequacy Ratio

Although few studies have focused on the interactions between multiple macroprudential instruments, many studies have focused on the role of CAR or LTV ratio in the economy. In general, both policy instruments contribute positively to create financial stability.

The capital requirements affect the economy through the credit intermediation activity in the banking sector. In principle, greater capital requirements are introduced when the economy is in a boom phase, while lower requirements are recommended when the economy is in a bust phase. Economic theory suggests that if an increase in capital requirements is binding and the Miller-Modigliani theorem fails, then the affected bank will either need to either raise capital or reduce risk-weighted assets to satisfy the new requirements (Uluc and Wieladek, 2018). Francis and Osborne (2012), in their studies focusing on the U.K. financial sector, shows that the bank-specific capital requirements, set by the regulator, are an important determinant of banks' internal capital targets, and that banks' capitalisation relative to an internal target is an important determinant of balance sheet growth and lending activity. The country's economy is stable when the activity of credit intermediation is manageable. Therefore, the close relationship between capital requirements and banks' lending activity leads to an understanding that capital requirements can be used to stabilise the financial sector when lending activity is stabilised as well.

Angeloni and Faia (2013) used two terms to explain how capital requirements affect the economy: procyclical and anti-cyclical. Procyclical capital requirements are considered when banks decrease the capital buffer in a contractionary economy, while the anti-cyclical capital requirement is relevant in a situation in which banks accumulate a capital buffer under an expansionary economic cycle. A study by Angeloni and Faia (2013), which focuses on fragile banks, points out that the procyclical capital requirement reduces welfare, while the anti-capital requirement enhances welfare. The decline of welfare under a procyclical capital requirement is caused by an increase in the volatility of inflation and in the output towards of exogenous shock.

The effectiveness of the CAR in creating financial stability – and, in turn, stabilising lending activity – has also been examined in many studies. For instance, Rubio and Carrasco-Gallego (2016) utilises the CAR to investigate the interaction of Basel I, II, and III regulations with monetary policy. Using the ratio, the study demonstrates that the interaction between capital requirements and monetary policy results in a more stable economic and financial system, which is in accordance with Basel I and Basel II. The author also demonstrates that the optimal way to implement the countercyclical capital buffer is to follow a rule that responds to the deviation of credit from its steady state. This result is slightly from that obtained by Yoshino and Hirano (2011), who demonstrate that the Basel capital adequacy ratio should depend on various economic factors such as the cyclical stage of GDP, credit growth, stock prices, interest rates, and land prices. However, Yoshino and Hirano (2011) emphasise that the CAR should be designed differently across countries due to the different banking behaviours and macroeconomic structures present in different countries.

The link between CAR and banking behaviour, as well as macroeconomic conditions, indicates that, ideally, the ratio is to be designed as time varying rather than constant, which is also consistent with the recommendation of Basel III. The time-varying capital requirement is also suggested in a study conducted by Francis and Osborne (2012). In examining the role of capital requirements in all U.K. banks, the study demonstrates that capital requirements that include firm-specific, time-varying add-ons set by supervisors can affect banks' desired capital ratios. Besides banking behaviour and macroeconomic conditions, the way in which the CAR affects banks' lending behaviour – and, hence, the economy – also depends on its interaction with monetary policy. A study by Uluc and Wieladek (2018), focusing on the impact of interactions between monetary policy and capital requirements, demonstrates that increasing capital requirements leads to decrease in mortgage loans in U.K. banking sector. Surprisingly, the detrimental impact of a higher capital adequacy ratio on mortgage loans is larger for existing customers than for new ones. The study also demonstrates that monetary policy helps to mitigate the effect of higher capital requirements.

5.2.4 The Role of Loan-to-Value Ratio

In many studies, the LTV is strongly associated with the housing market, housing prices, and mortgage loan activity. LTV is the ratio between debt and the collateral value, which also represents the coverage ratio from households' debt relative to the market collateral value. Besides functioning as a coverage ratio, the LTV ratio is also useful in controlling credit availability, changing how agents behave, and determining how housing market prices evolve (Antunes and Prado, 2018). In Asian countries, LTV ratio also helps to curb housing price growth, credit growth, and bank leverage (Zhang and Zoli, 2015).

Many studies explore the role of loan-to-value ratio in the economy through its interaction with monetary policy. Some studies have found that LTV ratio affects welfare. For instance, Mendicino and Punzi (2014) study the impact of the interaction of monetary policy and macroprudential policy with social welfare in a two-country economic model.

The macroprudential tool in the study is represented by LTV ratio and shows that it countercyclically responds to house price dynamics. The results reveal that the additional use of a countercyclical LTV ratio in monetary policy operations improves welfare. With regards to this, Mendicino and Punzi (2014) defines welfare as the sum of variation from inflation and output.

In another study, Basto, Gomes, and Lima (2018) evaluate the impact of changes in the LTV ratio on macroeconomic variables in the model with financial frictions and the banking sector. Their findings suggest that permanent LTV ratio tightening leads to a long-term decline in banking lending to the private sector. In contrast, the impact of LTV ratio on macroeconomic variables in the short run depends heavily on the policy design. The study also points out that a temporary change of LTV ratio has milder recessionary effects on lending activities. These results essentially demonstrate that the impact of LTV ratio on an economy improves welfare.

Similar results were also gathered by the study from Punzi and Rabitsch (2018), who study the impact of LTV ratio on the macroeconomy in heterogeneous households. Punzi and Rabitsch (2018) demonstrate that LTV ratio improves welfare regardless of whether households are homogenous or heterogeneous. However, the study found that the implementation of LTV ratio improves welfare to a greater extent when the authority targets only highly leveraged borrowers. The authors define LTV ratio as a countercyclical tool that limits the supply of credit relative to the debt-to-GDP ratio. Hence, this study supports the targeting of LTV ratio to a specific group of borrowers, as doing so improves welfare more than when all types of borrowers are homogenised.

The welfare-improving effect of implementing LTV is also found in the study from Rubio and Carrasco-Gallego (2014). The researchers focus on the implications of macroprudential and monetary policy interactions regarding business cycles and shows that the the interaction between the two policies improves welfare for society and promotes financial sector stability. The authors also define the optimal feedback parameter in the rule for LTV ratio as a macroprudential instrument and nominal interest rate as a monetary policy instrument, and then present the losses under the coordinated and non-coordinated policy regime. LTV ratio is presented as a countercyclical tool and defined as a macroprudential rule that responds to credit growth. Thus, a lower LTV ratio is imposed during a credit boom to restrict excessive credit growth. In their study, Rubio and Carrasco-Gallego (2014) uses a consumption equivalent to measure welfare, which is derived from the second order approximation from the utility function following Mendicino and Pescatori (2007).

Lambertini, Mendicino, and Punzi (2013) explore the effectiveness of countercyclical LTV ratios as a macroprudential tool designed to achieve financial and macroeconomic stabilisation. Lambertini, Mendicino, and Punzi (2013) study the potential gains of monetary and macroprudential policies that lean against house prices and credit cycles. The study reveals that under monetary policy, borrowers and savers are better off when the interest rate optimally responds to credit growth. However, when monetary policy interacts with LTV ratio as a macroprudential instrument, the benefit received from the interaction depends on the degree of welfare heterogeneity among agents. The study shows that an optimal LTV ratio is achieved when it responds countercyclically to credit growth, as this is the condition that most effectively stabilises credit relative to GDP. In contrast, the optimal policy for savers features a constant LTV ratio coupled with an interest rate response to credit growth. LTV ratio rules face a trade-off between savers' and borrowers' welfare, as they respond to the GDP of house-prices growth in a countercyclical manner.

Kannan, Rabanal, and Scott (2012) also study the benefits derived from the use of LTV ratio as a macroprudential instrument that interacts with monetary policy. The study demonstrates that using an LTV ratio that is specifically designed to dampen credit market cycles can provide stabilisation benefits under financial shocks and housing demand shocks. However, the study also shows that no benefits are derived from macroprudential policy under productivity shocks. The welfare loss function is assumed to be constructed by the volatility of inflation and the output gap.

In conclusion, studies in the area of macroprudential policy mostly demonstrate that the policy is benefitting the macroeconomy in general. The LTV and CAR are two prominent policy instruments employed in understanding the impact of macroprudential policy. Furthermore, the implementation of mactoptudential policy is examined under its interaction with conventional monetary policy where mostly employs a single macroprudential instrument optimisation.

5.3 Model

The model we develop follows Gerali et al. (2010) who introduces collateral constraint following Iacoviello (2005). The primary features of the model are the monopolistic banking sector, the balance sheet constraint, and the interest rate stickiness. There are two macroprudential policy instruments used in the model, namely loan to value ratio and capital requirement. The original model designs LTV ratios, both for impatient household and entrepreneurs, as a stochastic process with shock, while the capital adequacy ratio is set as a constant. In this study, the two LTV ratios are no longer designed as a stochastic process, but it remains to be a time-varying variable, in which its value is to be determined based on the fully optimal commitment rule. Furthermore, the capital adequacy ratio is also no longer as a constant, but it is designed as a time-varying variable, in which its value is also determined based on the fully optimal commitment rule. The conversion of capital adequacy ratio from constant to be a time-dependent variable was also conducted by Angelini et al. (2011), but the value of ratio in their study is determined based on a simple macroprudential rule rather than through the optimisation.

The model contains seven economic agents, namely households, entrepreneurs, retailers, wholesale banks, retail banks, capital goods producers, and the central bank. Households are classified into two types, namely patient households and impatient households. In their daily life, patient households consume, work and save deposit in banks. On the other hand, impatient households consume, work, and borrow loan from banks. Hence, households provide differentiated labour types, which then are aggregated by perfectly competitive labour unions who assemble them in a CES aggregator and sell the homogeneous labour to entrepreneurs. Banking sector is divided into wholesale banks and retail banks. Each unit of bank consists of one wholesale bank and two retail banks, namely deposit retail bank and loan retail bank. Deposit retail banks function to receive deposit from patient households, while loan retail banks function to give loan to impatient households and entrepreneurs. Finally, the wholesale banks function to intermediate funds from deposit retail banks to loan retail banks.

Entrepreneurs and impatient households are both borrowing money from the loan retail banks. The loan retail banks are allowed to set higher lending rate than the original rate given by the wholesale bank by a certain markup. However, the retail banks must bear the adjustment cost due to the changing the lending rate. Similarly, the adjustment cost is also beared by the deposit retail banks whenever they change different deposit rate from the wholesale deposit rate. Loan are used by entrepreneurs to purchase capital from capital good producers, which then is used to produce intermediate goods. Entrepreneurs produce intermediate goods using capital bought from capital goods producers and sell it to retailers. Final goods firms bundle the intermediate goods and sell the final good to households and capital good producers. Moreover, both entrepreneurs and retailers are assumed to live in perfect competitive setting. Monopolistic competitive market is introduced in banking sector, where banks have the ability to adjust interest rate spread between lending rate and deposit rate.

5.3.1 Households

- **Patient Households**

Patient households own houses and earn income by supplying labour to entrepreneurs. They use their income to purchase consumption and save deposit in banks. Patient households maximise their expected lifetime utility derived from consumption and housing, in which the problem is given by

$$max\, E_0 \sum_{t=0}^{\infty} \beta_P^t \, U\left(c_t^p, h_t^p, l_t^p\right) \,, \tag{5.1}$$

where the utility function is formulated by

$$U\left(c_t^p, h_t^p, l_t^p\right) = (1 - a^p)\varepsilon_t^z \, log(c_t^p - a^p c_{t-1}^p) + j\varepsilon_t^h \, log\, h_t^p - \frac{l_t^{p(1+\phi)}}{1+\phi} \,, \tag{5.2}$$

where β_P^t denotes discount factor of patient households, c_t^p is the level of consumption, h_t^p denotes housing, and l_t^p denotes hours worked with parameter ϕ. Following Gerali et al. (2010), two disturbances are also added into the model, namely shock on consumption ε_t^z, and shock on housing demand ε_t^h. There is also a habit formation in the household consumption denoted by the habit coefficient a^p. The utility function is maximized with respect to

$$c_t^p + q_t^h \Delta h_t^p + d_t^p \leq w_t^p l_t^p + \frac{\left(1 + r_{t-1}^d\right) d_{t-1}^p}{\pi_t} + \frac{JR_t}{\gamma_p} \,. \tag{5.3}$$

The budget constraint (5.3) implies that patient households earn income at period t from three sources: from labour income $w_t^p l_t^p$ by working for entrepreneurs, from lumpsum transfer JR_t as dividend from retailers and banks, and from previous period deposit d_{t-1}^p including its deposit interest income at rate r_{t-1}^d; γ_p is the share of patient households. Using the income earned, patient households use it to purchase consumption c_t^p, accumulate investment in housing by $q_t^h \Delta h_t^p(i)$, where q_t^h denotes housing price at period t, and deposit some of them in banks by d_t^p.

- **Impatient Households**

Impatient households earn income from working and by borrowing fund from banks. Similar to patient households, impatient households maximise their expected lifetime utility function derived from consumption, housing, and disutility of labors, which is given by

$$max\, E_0 \sum_{t=0}^{\infty} \beta_I^t\, U\left(c_t^i, h_t^i, l_t^i\right), \qquad (\mathbf{5.4})$$

where the utility function is formulated by

$$U\left(c_t^i, h_t^i, l_t^i\right) = (1 - a^i)\varepsilon_t^c\, log(c_t^i - a^i c_{t-1}^i) + j\varepsilon_t^h\, log\, h_t^i - \frac{l_t^{i(1+\phi)}}{(1+\phi)}, \qquad (\mathbf{5.5})$$

where β_I^t denotes discount factor of impatient households, c_t^I is the level of consumption, h_t^I denotes housing, and l_t^I denotes hours worked with parameter ϕ. There is also a habit formation for impatient households, denoted by habit coefficient a^I. Impatient households face the budget constraint as follow

$$c_t^i + q_t^h \Delta h_t^i + \frac{\left(1 + r_{t-1}^{bh}\right) b_{t-1}^i}{\pi_t} \leq w_t^i l_t^i + b_t^i \qquad (\mathbf{5.6})$$

The budget constraint implies that income at period t, which is derived from labour income $w_t^i l_t^i$ and new loan b_t^i with lending rate r_t^{bh}, is used to purchase consumption c_t^i, housing investment $q_t^h \Delta h_t^i$ and the repayment of previous loan, including its interest, $(1 + r_{t-1}^{bh}) b_{t-1}^i$. In addition, impatient households also face collateral constraint, which is determined by the next period housing value. This collateral constraint depends on the loan to value ratio (LTV) for households set by the authority.

The collateral constraint is given by

$$\left(1 + r_t^{bh}\right) b_t^i = LTV_t^H E_t\left(q_{t+1}^h\right) h_t^i E(\pi_{t+1}) \qquad (\mathbf{5.7})$$

where δ^h is an exogenous depreciation rate for house and LTV ratio is assumed to follow an exogenous stochastic process.

5.3.2 Labor Market

The model assumes that households provide differentiated labors to entrepreneurs through labour unions. Households must pay the union fees in order to receive this facility. There are two labour unions in the model, namely labour union for patient households and labour union for impatient households. Labor unions then sell the labors to perfectly competitive labour packers who assemble them in a CES aggregator with stochastic parameter ε_t^l where the labour packer sells them to the entrepreneurs. Suppose labour type is denoted by m and its corresponding labour union is denoted by s. Each union (s, m) sets nominal wages $W_t^s(m)$ for its members by maximising their utility subject to labour demand. Labor union also bears quadratic adjustment cost with indexation to a weighted average of lagged inflation (weighted by ι) and steady state inflation (weighted by $1 - \iota$).

$$E_0 \sum_{t=0}^{\infty} \beta_s^t \left(U_{c_t^s(i,m)} \left[\frac{W_t^s(m)}{P_t} l_t^s(i,m) - \frac{\kappa_w}{2} \left(\frac{W_t^s(m)}{W_{t-1}^s(m)} - \pi_{t-1}^{\iota} \pi^{1-\iota} \right)^2 \frac{W_t^s}{P_t} \right] - \frac{l_t^S(i,m)^{1+\phi}}{1+\phi} \right), \tag{5.8}$$

subject to demand from labour packers

$$l_t^s(i,m) = l_t^s(m) = \left(\frac{W_t^s(m)}{W_t^s} \right)^{-\varepsilon_t^I} l_t^s \,. \tag{5.9}$$

5.3.3 Entrepreneurs

Entrepreneurs hire labors supplied by households and purchase capital from capital goods producers to produce intermediate goods. Entrepreneurs produce intermediate goods using the constant return to scale production function, given by

$$y_t^e = A_t^e [k_{t-1}^e u_t]^{\alpha} l_t^{e(1-\alpha)}, \tag{5.10}$$

where y_t^e denotes intermediate output, A_t^e denotes stochastic technology following AR(1) process, k_t^e denotes capital, l_t^e denotes labors hired and α denotes capital share. Labors hired by entrepreneurs come from both labour of patient household $l_t^p$and impatient households l_t^i. The capital inside the production function must be adjusted first by the capacity utilisation rate u_t. The term l_t^e represents the bundled labors derived by

$$l_t^e = \left(l_t^p\right)^{\eta_i} \left(l_t^i\right)^{1-\eta_i}, \tag{5.11}$$

where η_i measures labour income share of patient households. In this basic model, we still assume equal income share between patient and impatient labour. Entrepreneurs borrow loan from banks to purchase capital and maximizes its utility derived from consumption given by

$$max\, E_0 \sum_{t=0}^{\infty} \beta_e^t \, U(c_t^e) \,, \tag{5.12}$$

where its utility function is given by

$$U(c_t^e) = log(c_t^e - a^e c_{t-1}^e), \tag{5.13}$$

subject to the budget constraint

$$\begin{aligned} c_t^e + w_t\left(l_t^p + l_t^i\right) + \left(1 + r_{t-1}^{be}\right) b_{t-1}^e + q_t^k k_t^e + \psi(u_t) k_{t-1}^e \\ = q_t^e y_t^e + b_t^e + q_t^k (1 - \delta_k) k_{t-1}^e \,, \end{aligned} \tag{5.14}$$

where q_t^e and q_t^k denote the price of intermediate goods and price of capital, respectively. This budget constraint implies that at period t entrepreneurs earn income from selling intermediate goods to retailers by $q_t^e y_t^e$, selling the goods to capital goods producers by $q_t^k(1 - \delta_k)k_{t-1}^e$ and borrow loan from bank at period t by b_t^e. They use income to purchase consumption c_t^e, pay labour wages by $w_t(l_t^p(i) + l_t^i(i))$ and pay back the previous loan by $\left(1 + r_{t-1}^b\right)b_{t-1}^e$. Furthermore, u_t denotes the capacity utilisation rate of capital and $\psi(u_t)$ denotes the real cost of setting a level u_t of utilisation rate.

In borrowing funds from banks, entrepreneurs also face collateral constraint given by

$$\left(1 + r_t^b\right)b_t^e \leq LTV_t^e E_t[q_{t+1}^k \pi_{t+1}(1 - \delta_k)k_t^e]\,, \tag{5.15}$$

where δ_k is a depreciation rate for capital and LTV ratio is assumed to follow exogenous stochastic process.

5.3.4 Capital Goods Producers

Capital good producer produces capital by purchasing undepreciated capital from entrepreneurs and some final inputs from retailers and later sell the effective capital x_t back to entrepreneurs. Entrepreneurs are the owner of capital good producers. Capital good producers live in perfect competitive setting. They buy $(1 - \delta)k_{t-1}$ at price q_t^k from entrepreneurs and i_t units of final goods from retailers at price P_t to produce new capital k_t. Hence, the problem of capital good producers is to maximise the expected lifetime net effective capital subject to the law of motion of effective capital.

$$max\, E_0 \sum_{t=0}^{\infty} \beta_e^t\left(q_t^k \Delta x_t - P_t i_t\right), \tag{5.16}$$

where $\Delta x_t = k_t - (1 - \delta)k_{t-1}$ denotes the flow of effective capital. The flow of effective capital is adjusted by investment adjustment cost such that

$$x_t = x_{t-1} + \left(1 - \frac{\kappa_i}{2}\left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right)^2\right) i_t\,, \tag{5.17}$$

where q_t^k is the real price of capital. The equation above also implies that capital good producers must bear adjustment cost if they change the investment level from i_{t-1} to i_t, where the amount of investment adjustment cost is given by

$$\frac{\kappa_i}{2}\left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right)^2 i_t\,. \tag{5.18}$$

5.3.5 Retailers

Retailers play a role to buy intermediate goods from entrepreneurs, differentiate them without cost and sell the final output to households and capital good producers. Retailers are assumed to be monopolistically competitive by incorporating staggered price setting that indexed to a combination of past and steady state inflation. The past inflation is weighted by ι_p and the steady state inflation is weighted by $1 - \iota_p$. Following the Calvo pricing model, the fraction α of final goods firms are able to set the optimal price and the rest fraction by

$1 - \alpha$ of firms are unable to do so. Every time firm j adjusts its optimal price, the firm must face a quadratic adjustment cost parameterized by κ_p.

The retailers who choose $P_t(j)$ maximise profit that is derived from revenue selling

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[P_t(j) y_t(j) - P_t^w y_t(j) - \frac{\kappa_p}{2} \left(\frac{P_t(j)}{P_{t-1}(j)} - \pi_{t-1}^{\iota_P} \pi^{1-\iota_P} \right)^2 P_t y_t \right], \qquad \mathbf{(5.19)}$$

subject to

$$y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\varepsilon_t^y} y_t\,, \qquad \mathbf{(5.20)}$$

where ε_t^y is the stochastic demand price elasticity.

5.3.6 Loan and Deposit Demand

Due to monopolistic competition in banking sector, the model assumes that impatient households purchase differentiated loan products and patient households purchase differentiated deposit products from banks. In accommodating this feature, the model assumes that total loan given to impatient households is a composite constant elasticity of substitution following Dixit-Stiglitz framework. Similarly, the total deposit received from patient households is also the aggregation of differentiated deposit following a composite constant elasticity of substitution. Banks are assumed to have interest rate stickiness that represented by elasticity coefficient ε_t^{bh}, ε_t^{be} and ε_t^d. The ε_t^{bh} denotes the elasticity coefficient representing the lending rate stickiness for impatient household loan, ε_t^{be} denotes the elasticity coefficient representing the lending rate for entrepreneur, and ε_t^d denotes the elasticity coefficient representing the deposit rate for patient household. Therefore, the demand schedule for loan given to impatient households by bank j is given as follow.

$$b_t^i(j) = \left(\frac{r_t^{bh}(j)}{r_t^{bh}} \right)^{-\varepsilon_t^{bh}} b_t^i\,, \qquad \mathbf{(5.21)}$$

where the aggregated lending rate charged to impatient households follows

$$r_t^{bh} = \left[\int_0^1 r_t^{bh}(j)^{1-\varepsilon_t^{bH}}\, dj \right]^{\frac{1}{1-\varepsilon_t^{bh}}}. \qquad \mathbf{(5.22)}$$

Similarly, the aggregated loan for entrepreneur given by bank j is given by

$$b_t^e(j) = \left(\frac{r_t^{be}(j)}{r_t^{be}} \right)^{-\varepsilon_t^{be}} b_t^e, \qquad \mathbf{(5.23)}$$

where the aggregated lending rate charged to entrepreneurs follows

$$r_t^{be} = \left[\int_0^1 r_t^{be}(j)^{1-\varepsilon_t^{be}} \, dj \right]^{\frac{1}{1-\varepsilon_t^{be}}} . \qquad \mathbf{(5.24)}$$

Similarly, the demand schedule for deposit demand of bank j is given as follow

$$d_t^i(j) = \left(\frac{r_t^d(j)}{r_t^d} \right)^{-\varepsilon_t^d} d_t \, , \qquad \mathbf{(5.25)}$$

where the aggregated deposit rate given to patient households follows

$$r_t^d = \left[\int_0^1 r_t^d(j)^{1-\varepsilon_t^d} \, dj \right]^{\frac{1}{1-\varepsilon_t^d}} . \qquad \mathbf{(5.26)}$$

5.3.7 Banks

The banks are set to live in a monopolistic competitive environment where they have the market power to adjust interest rates. In doing so, we divide the banks into two categories namely wholesale banks and retail banks. The wholesale bank operates under perfect competitive environment, while retail bank operates under monopolistic competitive environment. Each bank consists of one wholesale bank and two retail banks, namely deposit retail bank and loan retail bank. Deposit retail bank plays a role to absorb deposit funds from patient households and pass the deposit on to the wholesale bank. The wholesale bank collects all deposits from the deposit retail bank as a wholesale deposit (D_t) at the wholesale deposit rate R_t^d and intermediate the funds to the loan retail bank as a wholesale loan (B_t) at the wholesale lending rate R_t^b according to the exogenous level of capital to asset ratio (CAR_t) set by the authority. Finally, the loan retail bank will give out the loan to impatient households and entrepreneurs. In absorbing the deposit and lending out the funds, retail banks can set the deposit rate and the lending rate, respectively, to maximise profit.

- **Wholesale Bank**

The main role of the wholesale bank in the extended model is to bind the balance sheet constraint. That is, the wholesale bank sets the level of net worth and the wholesale deposit on the liability side and sets the level of wholesale loan on the asset side. Thus, the balance sheet constraints ensure the accounting identity is binding.

$$B_t = K_t^b + D_t \, , \qquad \mathbf{(5.27)}$$

where the law of motion in capital accumulation is given similar to the simple model as follows

$$\pi_t k_t^b = (1-\delta^b) k_{t-1}^b + JB_t \, , \qquad \mathbf{(5.28)}$$

where k_t^b denotes bank capital, δ^b is depreciation rate of bank capital and JB_t denotes retained profit of the bank. Retained profit is derived from period $(t-1)$ profit minus dividends paid to patient household that given at period t.

Wholesale banks also bear the adjustment cost due to the deviation of the capital to asset ratio in bank from the target set by the authority. That is, the deviation of capital to asset position in period t, K_t^b/B_t, from the target level CAR_t imposes the adjustment cost by

$$\frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t}-CAR_t\right)^2 K_t^b, \tag{5.29}$$

where κ_{Kb} denotes the capital adjustment coefficient. The problem of the wholesale bank in the simple model is now improved by adding capital adjustment cost inside the maximization problem. Thus, the problem of the wholesale bank now is to choose the level of debt B_t and deposit D_t to maximise the cash flow as follow,

$$max\, R_t^B B_t - R_t^D D_t - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t}-CAR_t\right)^2 K_t^b, \tag{5.30}$$

subject to balance sheet identity and capital accumulation given above given by

$$b_t^i + b_t^e = d_t + k_t^b, \tag{5.31}$$

$$k_t^b = \frac{1}{\pi_t}[(1-\delta^{kb})k_{t-1}^b + (r_{t-1}^{bh} b_{t-1}^i + r_{t-1}^{be} b_{t-1}^e - r_{t-1}^d d_{t-1} - D_t)]. \tag{5.32}$$

- **Deposit Retail Bank**

Retail deposit bank receives deposits from patient households $d_t^P(i)$ at deposit rate r_t^d and pass the funds to the wholesale bank at rate R_t^D. In other words, the wholesale bank purchases deposit funds from the deposit retail bank at price R_t^D. Retail deposit banks also experience adjustment cost every time they change the deposit rate from r_{t-1}^d to r_t^d. The amount of adjustment cost due to the change of deposit rate is given by

$$\frac{\kappa_d}{2}\left(\frac{r_t^d}{r_{t-1}^d}-1\right)^2 r_t^d d_t\,, \tag{5.33}$$

where κ_d denotes the adjustment deposit cost coefficient. Therefore, the maximization problem of the retail deposit bank i in period t is to set the deposit rate $r_t^d(i)$ to maximise the profit, which is given by

$$max\, E_0 \sum_{t=0}^{\infty} \beta_D^t \left[R_t^D D_t - r_t^d d_t^P - \frac{\kappa_d}{2}\left(\frac{r_t^d}{r_{t-1}^d}-1\right)^2 r_t^d d_t\right], \tag{5.34}$$

where β_t^D denotes a discount factor of the deposit retail bank at period t. The maximization of profit should be solved with subject to the deposit demand at will be formulated later.

- **Loan Retail Bank**

Similar to deposit retail bank, the loan retail bank is assumed to live in a monopolistic competitive environment. Recall that the loan retail bank offers two types of loan, namely household loan and entrepreneur loan. The household loan is given out to impatient households at the lending rate r_t^{bh}, while the entrepreneur loan is given out to entrepreneurs at the lending rate r_t^{be}.

Similar to the deposit retail bank, the loan retail bank also bears adjustment cost whenever the lending rate is adjusted from r_{t-1}^{bh} to r_t^{bh} for the households loan, and from r_{t-1}^{be} to r_t^{be} for the entrepreneurs loan. Therefore, the total adjustment cost that the loan retail bank bears is given by

$$\frac{\kappa_{bh}}{2}\left(\frac{r_t^{bh}}{r_{t-1}^{bh}}-1\right)^2 r_t^{bh} b_t^i + \frac{\kappa_{be}}{2}\left(\frac{r_t^{be}}{r_{t-1}^{be}}-1\right)^2 r_t^{be} b_t^e, \qquad \mathbf{(5.35)}$$

where κ_{bh} and κ_{be} denote the adjustment coefficient for adjusting the lending rate in household loan and entrepreneur loan, respectively. While b_t^i and b_t^e denote the amount of loan given out to households and entrepreneurs, respectively.

Therefore, the problem of the loan retail bank i is to choose $r_t^{bh}(i)$ and $r_t^{be}(i)$ to maximise the profit, which is given by

$$max\, E_0 \sum_{t=0}^{\infty} \beta_L^t \left[r_t^{bh}(i) b_t^I(j) + r_t^{be}(i) b_t^E(i) - R_t^b B_t(j) - \frac{\kappa_{bh}}{2}\left(\frac{r_t^{bh}}{r_{t-1}^{bh}}-1\right)^2 r_t^{bh} b_t^i \right.$$
$$\left. - \frac{\kappa_{be}}{2}\left(\frac{r_t^{be}}{r_{t-1}^{be}}-1\right)^2 r_t^{be} b_t^e \right], \qquad \mathbf{(5.36)}$$

where β_t^L denotes the discount factor of the loan retail bank at period t. The maximisation is solved subject to the demand of loan retail bank.

- **Bank Profit**

The total profit of banking sector is the sum of the profits of the wholesale bank and the two retail banks. The profit Π_t of each type of banks in period t is given as follow.

$$\Pi_t^{Total} = \Pi_t^{wholesale\ bank} + \Pi_t^{Deposit\ retail\ bank} + \Pi_t^{Loan\ retail\ bank} \qquad \mathbf{(5.37)}$$

$$\Pi_t^{wholesale\ bank} = R_t^B B_t - R_t^D D_t - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t} - CAR_t\right)^2 K_t^b, \qquad \mathbf{(5.38)}$$

$$\Pi_t^{Deposit\ retail\ bank} = R_t^D D_t - r_t^d d_t^P - \frac{\kappa_d}{2}\left(\frac{r_t^d}{r_{t-1}^d}-1\right)^2 r_t^d d_t\,, \qquad \mathbf{(5.39)}$$

$$\Pi_t^{Loan\ retail\ bank} = r_t^{bh} b_t^i + r_t^{be} b_t^E - R_t^b B_t - \frac{\kappa_{bh}}{2}\left(\frac{r_t^{bh}}{r_{t-1}^{bh}} - 1\right)^2 r_t^{bh} b_t^i - \frac{\kappa_{be}}{2}\left(\frac{r_t^{be}}{r_{t-1}^{be}} - 1\right)^2 r_t^{be} b_t^e. \quad (\mathbf{5.40})$$

Therefore, the total profit is given by

$$\Pi_t^{Total} = r_t^{bh} b_t^i + r_t^{be} b_t^e - r_t^d d_t^p - Adjustment\ Cost, \quad (\mathbf{5.41})$$

where the adjustment cost is given by

$$Adjustment\ cost$$
$$= \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t} - CAR_t\right)^2 K_t^b + \frac{\kappa_d}{2}\left(\frac{r_t^d}{r_{t-1}^d} - 1\right)^2 r_t^d d_t + \frac{\kappa_{bh}}{2}\left(\frac{r_t^{bh}}{r_{t-1}^{bh}} - 1\right)^2 r_t^{bh} b_t^i + \frac{\kappa_{be}}{2}\left(\frac{r_t^{be}}{r_{t-1}^{be}} - 1\right)^2 r_t^{be} b_t^e. \quad (\mathbf{5.42})$$

5.3.8 The Central Bank

The central bank sets the policy rate r_t^{ib} according to the simple rule as follow

$$\left(1 + r_t^{ib}\right) = \left(1 + r^{ib}\right)^{(1-\phi_R)}\left(1 + r_{t-1}^{ib}\right)^{\phi_R}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)}\left(\frac{y_t}{y_{t-1}}\right)^{\phi_y(1-\phi_R)} \varepsilon_t^{r^{ib}}, \quad (\mathbf{5.43})$$

where ϕ_R is the weight assigned to inflation and ϕ_y to output growth, r^{ib} is the steady state policy rate, and $\varepsilon_t^{r^{ib}}$ is a monetary policy shock with standard deviation $\sigma_{r^{ib}}$. The market clearing condition in goods market is

$$y_t = c_t + q_t^k[k_t - (1-\delta)k_{t-1}] + k_{t-1}\psi(u_t) + \delta^b\left(\frac{K_{t-1}^b}{\pi_t}\right) + Adj_t, \quad (\mathbf{5.44})$$

where $c_t \equiv c_t^p + c_t^i + c_t^e$ is aggregate consumption, k_t is aggregate physical capital, and K_t^b is aggregate bank capital. The term Adj_t includes all adjustment costs. In the housing market, equilibrium is given by $\bar{h} = h_t^P + h_t^I$, where $\bar{h}$ is the fixed housing stock.

5.3.9 Exogenous Shocks

The model is equipped to accommodate eleven types of exogenous shocks. The model originally contains 13 shocks, including shock on LTV for entrepreneurs and LTV for impatient households. However, since LTV ratios in this study are not designed as a stochastic process, the two shocks are then removed. Hence, only eleven shocks are left in the model namely the technology shock, consumption shock housing demand shock, markup shock on deposit demand, markup shock on household lending rate, markup shock on entrepreneurs lending rate, investment shock, stochastic demand price elasticity, labour shock, banking capital shock, and shock on policy rate. All exogenous shocks follow autoregressive AR(1) process, in which the details are provided in appendix C.

5.3.10 Parameter Values

The parameters used in the simulation follow those from the original model Gerali et al. (2010). Some key parameters are presented in Table 5.1.

Table 5-1: Parameter Values

Parameters	Description	Value
β_P	Patient households' discount factor	0.994
β_I	Impatient households' discount factor	0.975
β_E	Entrepreneurs discount factor	0.975
β_{CG}	Capital goods discount factor	0.975
β_S	Labor union discount factor	0.975
ϕ	Inverse of Frisch elasticity	1
η_i	Share of unconstrained households	0.8
ε^h	Weight of housing in households' utility function	0.2
a^p, a^i, a^e	Degree of habit formation in consumption	0.856
α	Capital share in the production function	0.3
γ_p	Share of patient households	1
γ_i	Share of impatient households	1
δ	Depreciation rate of physical capital	0.025
κ_i	Cost for adjusting investment	10.18
ε^y	Is the markup in the goods market	6
ε^l	Is the markup in the labour market	5
κ_P	Cost for adjusting goods prices	28.65
κ_W	Cost for adjusting nominal wages	99.90
ι_P	Indexation of prices to past inflation	0.160
ι_W	Indexation of nominal wages to past inflation	0.276
ι_D	Indexation deposit rates	0.00
ι_{be}	Indexation rates on loans to firm	0.00
ι_{bh}	Indexation rates on loans to households	0.00
LTV^H	Households' LTV ratio	0.7
LTV^E	Entrepreneurs' LTV ratio	0.35
ε^{be}	$\varepsilon^{be}/(\varepsilon^{be}-1)$ is the markup on rate on loans to entrepreneurs	2.7
ε^{bh}	$\varepsilon^{bh}/(\varepsilon^{bh}-1)$ is the markup on rate on loans to households	2.7
ε^d	$\varepsilon^d/(\varepsilon^d-1)$ is the markdown on deposit rate	-1.4
κ_{bh}	Cost for adjusting rate on loans to households	10.09
κ_{be}	Cost for adjusting rate on loans to entrepreneurs	9.364
κ_d	Cost for adjusting rate on deposits	3.503
CAR	Target capital-to-loans ratio	0.09
ξ_1	Parameter of adjustment cost for capacity utilisation	0.0478
ξ_2	Parameter of adjustment cost for capacity utilisation	0.00478
ρ_H	Persistence weighting function loans to households	0.94
ρ_E	Persistence weighting function loans to entrepreneurs	0.92
ϕ_π	Taylor Rule coefficient on inflation	1.98

Parameters	Description	Value
ϕ_R	Taylor Rule coefficient on policy rate	0.77
ϕ_y	Taylor Rule coefficient on output	0.35
κ_{Kb}	Cost for adjusting capital-assets ratio	11.06
δ_b	Depreciation rate of bank capital	0.115
ρ^a	Persistence technology shock	0.97
ρ^{qk}	Persistence investment efficiency shock	0.45
ρ^k	Persistence financial shock	0.82

The discount factor across agents are set differently. Patient households have a larger discount factor by 0.994, while the discount factor for impatient households and entrepreneurs are set equally by 0.975. Furthermore, consumption habit formation across agents are set identically with degree of habit formation 0.856. In terms of macroprudential instrument, we set the steady state for CAR by 0.09, the LTV^H by 0.7 and the LTV^E by 0.35. The last two instruments, namely LTV^H and LTV^E, are set differently where impatient household's is set twice than that of the entrepreneurs. In terms of the monetary policy rule, the model rules the interest smoothing parameter by 0.77. Furthermore, the coefficient on inflation in the Taylor rule is set at 1.98 and the coefficient in the output is set to be 0.35.

5.4 Results and Analysis

5.4.1 Simulation Scenarios

The simulation in this study provides two scenarios, namely the scenario where the central bank only optimises a single macroprudential instrument and the scenario where the central bank optimises multiple macroprudential instruments. The optimisation assumes that the central bank optimises macroprudential instruments under commitment and sets the nominal interest rate based on the simple Taylor rule. All cases are simulated under the ad-hoc loss function, which will be explained in the subsequent section. Table 5.2 summarises all the simulation scenarios.

Table 5-2: The Simulation Scenarios

Scenarios	Cases	CAR	LTV^{joint}	LTV^H	LTV^E
Benchmark	Benchmark	-	-	-	-
Scenario 1: single instrument	C	Optimised	-	-	-
	L^J	-	Optimised	-	-
	L^H	-	-	Optimised	-
	L^E	-	-	-	Optimised
Scenario 2: multiple instruments	CL^J	Optimised	Optimised	-	-
	CL^H	Optimised	-	Optimised	-
	CL^E	Optimised	-	-	Optimised
	L^EL^H	-	-	Optimised	Optimised
	CL^EL^H	Optimised	-	Optimised	Optimised

There are three macroprudential instruments in the model: capital adequacy ratio (CAR), loan-to-value ratio for impatient households (LTV^H), and loan-to-value ratio for entrepreneurs (LTV^E). In addition, we also construct a joint LTV ratio (LTV^{Joint}) where the central bank equalises the log-linear of one LTV with the log-linear of another LTV. The joint LTV ratio is present to accommodate the possibility that equalising the dynamics of two LTV ratios could be more efficient than optimising two LTV ratios separately.

In the benchmark model, all macroprudential policy instruments are set as constants and not optimised (i.e., when no macroprudential policy is active in the economy). In this table, $\boldsymbol{C}$ refers to CAR; $\boldsymbol{L^J}$ refers to LTV^{joint}; $\boldsymbol{L^H}$ refers to LTV^H, and $\boldsymbol{L^E}$ refers to LTV^E. For example, $\boldsymbol{CL^E L^H}$ is the case when the central bank implements CAR, LTV^H, and LTV^E simultaneously. The simulation follows the algorithm of commitment regime from Dennis (2007) and the comparison across cases is evaluated based on the unconditional loss value.

5.4.2 Loss Function

The simulation in this study is conducted under an ad-hoc loss function. The ad-hoc loss function in the study is based on that used by Angelini et al. (2011), which is the summed quadratic deviation of inflation, output, loan-to-output ratio, and two macroprudential policy instruments from their steady states. Equation (5.45) describes the structure of the loss function. However, the main difference between our loss function from that of Angelini's is that the loss function (5.45) provided below combines both monetary policy and macroprudential policy instruments, while Angelini et al. (2011) separate the loss function into two different institutions, namely the central bank and the macroprudential authority. Our loss function is given as

$$W = E_0\left[\sum_{t=0}^{\infty} \beta^t\left(\pi_t^2 + \lambda_Y \tilde{Y}_t^2 + \lambda_\vartheta \tilde{\vartheta}_t^2 + \lambda_{Rn} \tilde{R}_{nt}^2\right)\right], \qquad \mathbf{(5.45)}$$

where β is the discount factor, and λ_Y is the weight of output relative to inflation. Moreover, $\tilde{\vartheta}_t^2$ represents variations in the loan-to-output ratio from its steady state, and λ_ϑ is the weight given for the loan-to-output ratio relative to inflation. Likewise, λ_{Rn} is the weight given to the nominal interest rate, which is the monetary policy instrument, while λ_{MP} is the weight given to the macroprudential policy instrument (MP), which can be the CAR and/or the LTV ratio (or both). The weights of λ_{Rn} is set equally to one, which expresses that the variation of the monetary instrument.

The loss function is composed of three parts. The first part is the macroeconomic objective, which is the objective when the central bank in concerned about the fluctuation of inflation and output from their steady states. The second part of the loss function is the financial stability objective, which is the part in which the central bank incorporates loan-to-output ratio into the loss function. Hence, the central bank believes that stabilising the loan-to-output ratio can foster financial stability. As quoted in Angelini et al. (2014), the inclusion of loan-to-output ratio follows the recommendation of the BCBS, which proposes that the credit-to-GDP ratio should be used as a benchmark for the countercyclical capital buffer, as introduced in Basel III. In their study, Angelini et al. (2014) also assume that the loan-to-output ratio can represent abnormal credit behaviour, as this ratio demonstrates how the credit expansion is compared to the level of economic activity.

Furthermore, as mentioned in Reinhart and Rogoff (2008) and Borio and Drehman (2009), as cited in Angelini et al. (2014), abnormal credit expansion tends to trigger financial crises. The loan-to-output ratio also represents leverage, which magnified the impact of the shock that occurred during the subprime mortgage crisis in 2008. Hence, including this ratio in the loss function can enable the central bank to penalise or dampen the variation of the ratio when it fluctuates too much.

The third part of the loss function comprises the policy instruments. The central bank aims to prevent the nominal interest rate from fluctuating too much by transforming this variable into the loss function. Although the nominal interest rate in the model follows the simple Taylor rule, this variable essential to a loss function with that aims to avoid excessive fluctuation in interest rate. Also, the minimization of interest rate, together with output and inflation, describes a typical loss function, as postulated in Woodford (2003), except that all weights in our case are set to a value of one.

Among the provided macroprudential policy instruments, the difference between loan-to output-ratio and the loan-to-value ratio should be clarified. Although they sound similar, the two ratios are different. Loan-to-output ratio is the comparison between the total loans in the economy and the total output produced in the same period. On the other hand, LTV ratio considers loans given towards the expected market collateral value. In the model of Gerali et al. (2010), the value of collateral is determined by the expected future housing value (for households) or physical capital value (for entrepreneurs). Therefore, since the two ratios are different, they can both be used in the loss function.

5.4.3 Single Macroprudential Instrument

In this scenario, the simulation assumes that the central bank only optimises one macroprudential instrument under commitment, manages other macroprudential policy instruments as constants, and manages the nominal interest rate using a simple Taylor rule. The simulation aims to demonstrate which macroprudential policy instrument is superior to the other instrument, under commitment. Additionally, we also aim to observe whether implementing two separate LTV ratios is more beneficial than implementing a joint type one. As shown in Table 5.3, this scenario provides four cases.

Table 5-3: The Simulation Result from Optimising Single Macroprudential Instrument

Cases		$LOSS$
$\boldsymbol{C}$	Optimising Capital adequacy ratio	1.2524
$\boldsymbol{L^J}$	Optimising LTV joint	0.7775
$\boldsymbol{L^H}$	Optimising LTV impatient household	0.4959
$\boldsymbol{L^E}$	Optimising LTV entrepreneurs	0.6162

The first case is case $\boldsymbol{C}$, which is a situation where the central bank only optimises CAR, while LTV^H and LTV^E are constants. The second case is $\boldsymbol{L^J}$, which is a situation where the central bank optimises a joint LTV ratio and leaves CAR as a constant[4]. The third case is where the central bank only optimises LTV^H, while CAR and LTV^E are set as constants, which is denoted as $\boldsymbol{L^H}$. The final case is $\boldsymbol{L^E}$**,** where the central bank optimises LTV^E and leaves CAR and LTV^H as constants.

Based on the policy performance, the simulation demonstrates that $\boldsymbol{L^H}$ is the best performing case with a loss value of 0.4959, which implies that optimising LTV for impatient households produces a superior policy performance than optimising the rest of macroprudential instruments. In contrast, policy performance when the central bank optimises CAR alone (i.e., case $\boldsymbol{C}$) is the worst of all the cases with a loss of 1.2524, which is almost twice worse than $\boldsymbol{L^H}$.

Table 5.3 also demonstrates that, under a single instrument optimisation, separating the LTV ratio into two types is more beneficial than having them aggregated as a joint LTV. The simulation shows that the joint LTV performs with a loss of 0.7775, which performs worse than $\boldsymbol{L^H}$ and $\boldsymbol{L^E}$ that perform with loss values of 0.6162 and 0.4959, respectively. Therefore, overall, when the central bank optimises a single macroprudential instrument, optimising LTV for impatient households is superior to optimising other macroprudential policy instruments.

5.4.4 Multiple Macroprudential Instruments

The second scenario in the simulation is where the central bank implements multiple macroprudential instruments. We present five different cases that cover all possible interactions among the instruments as shown in Table 5.4.

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[4] Under case $\boldsymbol{L^J}$, LTV^H and LTV^E do not exist since they are replaced by the joint type LTV^j.

Table 5-4: The Simulation Result from Optimising Multiple Macroprudential Instrument

Case		$LOSS$
CL^J	Optimising CAR and LTV$^{\text{joint}}$	0.4121
CL^H	Optimising CAR and LTV$^{\text{H}}$	0.4761
CL^E	Optimising CAR and LTV$^{\text{E}}$	0.6107
$L^E L^H$	Optimising LTV$^{\text{H}}$ and LTV$^{\text{E}}$	0.3825
$CL^E L^H$	Optimising CAR, LTV$^{\text{H,}}$ and LTV$^{\text{E}}$	0.3822

The first case is CL^J, which represents the case where the central bank optimises CAR and the joint LTV ratio, while leaving other macroprudential instruments as constants. Furthermore, the second case is CL^H, which is when the central bank optimises CAR and LTV for impatient households and leaves the other macroprudential instruments as constants. In a similar fashion, case CL^E is when the central bank only optimises CAR and LTV for entrepreneurs. Case $L^E L^H$ is when the central bank only optimises the LTV for impatient households and entreprenerus. Finally, $CL^E L^H$ is when the central bank optimises CAR, LTV for impatient households, and LTV for entrepreneurs.

Various findings from the simulation stand out. First, case CL^J, which is the optimisation of CAR and the joint LTV ratio, can deliver a policy performance of 0.4121, which is the best of all cases. Considering that the case L^J in Table 5.3 performs at 0.7775, this indicates that the presence of C (i.e., CAR) in the simulation of CL^J can improve the policy performance from 0.7775 to 0.4121, which is an improvement of 49.36%. Likewise, considering that case C in Table 5.3 results in policy performance of 0.4121, the policy performance of CL^J indicates that the presence of the joint LTV L^J can improve the performance significantly from 1.2524 to 0.4121, which is an improvement of 60.72%. Hence, optimising C and L^J simultaneously in the form of CL^J is better off than optimising C or L^J separately. Therefore, based on this finding, we argue that the central bank can gain more benefit when interacting multiple macroprudential instruments. The subsequent section regarding the unconditional variances will further explore through which economic variable the optimisation can significantly influence the policy performance.

Second, according to Table 5.4 above, $CL^E L^H$ is the second-best performing case with a policy performance of 0.3822. This means that optimising CAR, LTV for impatient households, and LTV for entrepreneurs can produce the second-best policy performance after CL^J. Considering that the case $L^E L^H$ performs at 0.3825, the policy performance of $CL^E L^H$ indicates that the presence of CAR in the simulation $CL^E L^H$ can improve the policy performance modestly from 0.3825 to 0.3822, which is only 0.07% of improvement. This finding shows that the contribution of CAR in miniscule and diminishes significantly when the LTV ratio is changed from being joint to being separated.

In contrast, considering the policy performance in case of $\boldsymbol{CL^H}$ is 0.4761, this implies that the presence of $\boldsymbol{L^E}$ into the simulation of $\boldsymbol{CL^E L^H}$ can improve the policy performance from 0.4761 to 0.3822, which is 18.5% of improvement. Similarly, given that the policy performance in $\boldsymbol{CL^E}$ is 0.6107, this implies that the presence of $\boldsymbol{L^H}$ into the simulation of $\boldsymbol{CL^E L^H}$ can improve the policy performance from 0.6107 to 0.3822 or 35.74% of improvement. Based on these findings, the impact of LTV for households is greater than LTV for entrepreneur and CAR, while CAR gives the smallest improvement in the simulation.

Third, recall that introducing CAR to the joint LTV ratio can improve the policy performance by 49.36%. In contrast, introducing CAR to the optimisation of the separate LTVs only improves the policy performance by 0.07%. This finding implies that equalising the dynamics of two LTV ratios as a joint LTV can result in a declining contribution of CAR. In other words, the CAR performs substantially better when the central bank equalises the LTVs, but then has almost no effect when the separation of LTV takes place. We argue this finding indicates a conflict where the interaction between macroprudential policy instruments can hinder the efficacy of another macroprudential instrument. Therefore, managing multiple macroprudential policy instruments simultaneously in the economy requires careful consideration, since the interaction of the instruments induces a conflict.

The conflict under multiple instrument optimisation is also seen from the number of instruments being optimised. For instance, as shown in Table 5.4, policy performance between $\boldsymbol{L^E L^H}$ and $\boldsymbol{CL^E L^H}$ is almost identical although the number of variables being optimised increases from two to three variables, which suggests that the impact of CAR is miniscule. In contrast, the impact of CAR is more obvious between $\boldsymbol{L^J}$ and $\boldsymbol{CL^J}$, although the number of instruments increases from one to two. Based on this finding, we argue that managing too many policy instruments can pose the central bank with risk of conflict among the instruments.

5.4.5 Performance Analysis

This section analyses the performance of all cases in comparison to the performance of the benchmark model. This part specifically investigates how much the economy can benefit from activating macroprudential policy. Therefore, in the benchmark model in this section, the central bank optimises nothing in the economy and only sets the nominal interest rate using the ordinary simple Taylor rule. Technically, in this case, all macroprudential instruments are set as constants. The benefit from optimising macroprudential instruments, which is denoted by Δ^{MP}, can be derived by following the formula (5.46)

$$\Delta^{MP} = \left(\frac{LOSS^{*} - LOSS}{LOSS^{*}}\right) x100\%\,, \tag{5.46}$$

where $LOSS^{*}$ denotes the loss value from the benchmark model, and $LOSS$ denotes the loss value from a particular case, as shown in Table 5.3 and 5.4. The notation used here is consistent with that of the previous section. Our simulation calculates that the policy performance for the benchmark model when all macroprudential policy instruments are constants is 1.4028 (i.e. $\boldsymbol{LOSS^{*}}$**=1.4028**). On the basis of this result and using equation (5.46), the benefit of activating macroprudential policy under a single policy instrument scenario can be measured and provided in Table 5.5.

Table 5-5: Benefits from Optimising Single Macroprudential Instrument

Case		Δ^{MP}
Benchmark	No optimisation	0.00%
$\boldsymbol{C}$	Optimising Capital adequacy ratio	10.72%
$\boldsymbol{L^{J}}$	Optimising LTV joint	44.57%
$\boldsymbol{L^{H}}$	Optimising LTV impatient household	64.65%
$\boldsymbol{L^{E}}$	Optimising LTV entrepreneurs	56.07%

As shown in Table 5.5, in the single instrument scenario, optimising CAR alone ($\boldsymbol{C}$) only benefits the economy by 10.72% more than the benchmark model. This achievement is tiny compared to the rest of the cases. For instance, optimising the single joint LTV ($\boldsymbol{L^{J}}$) can improve the economy by 44.57% more than the case when macroprudential policy does not exist. Furthermore, optimising only LTV for entrepreneurs ($\boldsymbol{L^{E}}$) can benefit the economy by 56.07% more than the benchmark model. Finally, the optimisation of LTV for impatient households ($\boldsymbol{L^{H}}$) delivers the highest benefit at 64.65% more than the benchmark model. Therefore, overall, optimising macroprudential policy under a single scenario can benefit the economy up to 64.65% better than the case when the macroprudential policy does not exist.

A similar result occurs when the central bank optimises multiple macroprudential policy instruments in the economy. Table 5.6 illustrates the benefit of optimising CAR and LTV simultaneously.

Table 5-6: Benefits from Optimising Multiple Macroprudential Instruments

Case		Δ^{MP}
Benchmark	No optimisation	0.00%
$\boldsymbol{CL^J}$	Optimising CAR and $\text{LTV}^{\text{joint}}$	66.01%
$\boldsymbol{CL^H}$	Optimising CAR and LTV^{H}	66.06%
$\boldsymbol{CL^E}$	Optimising CAR and LTV^{E}	55.75%
$\boldsymbol{L^E L^H}$	Optimising LTV^{H} and LTV^{E}	72.73%
$\boldsymbol{CL^E L^H}$	Optimising CAR, LTV^{H} , and LTV^{E}	72.75%

Overall, the second scenario produces a greater difference in policy performance than the first. The simulation demonstrates that optimising CAR and the joint LTV ($\boldsymbol{CL^J}$) simultaneously can improve the economy by 66.01% more efficient than not optimising any macroprudential instrument. Furthermore, if the central bank optimises CAR and LTV for impatient households simultaneously ($\boldsymbol{CL^H}$), it can improve the economy by 66.06% more than when macroprudential policy is not active. Similarly, the coordination between CAR and LTV for entrepreneurs ($\boldsymbol{CL^E}$) can only benefit the economy by 55.75% relative to the benchmark model. The coordination between LTV for impatient households and entrepreneurs ($\boldsymbol{L^E L^H}$) can benefit the economy by 72.73% more than the benchmark model. Finally, when the central bank coordinates all macroprudential instruments in the economy, case $\boldsymbol{CL^E L^H}$, the benefit that the interaction can yield is 72.75% better than the benchmark model. The results from this table informs that under the multiple instrument scenario, activating macroprudential policy can benefit the economy up to 72.75% more efficient than the case of no macroprudential policy.

Based on the finding above, we argue that optimising multiple macroprudential instruments is generally more beneficial. For instance, the benefit of optimising all the instruments simultaneously is 72.75%. In contrast, when the instrument is optimised individually, optimising LTV for entrepreneurs only benefits the economy by 56.07%; optimising LTV for impatient households only benefits by 64.65%; and optimising CAR alone only benefits the economy by 10.72%. These benefits are all smaller than most cases in multiple instrument optimisation. This finding suggests that optimising multiple macroprudential instruments is welfare-enhancing. Recall that multiple instruments optimisation can improve the economy up to 72.75%. Therefore, relative to the single instrument scenario, which benefits the economy up to 64.65%, multiple instrument optimisation can thus increase the benefit by 8.1%[5].

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[5] Which is derived from 72.75% minus 64.65%.

In conclusion, our simulation demonstrates that, generally, optimising multiple macroprudential policy instruments can benefit the economy more than optimising a single instrument. In our simulation, the benefit from a multiple instrument optimisation is 10.01% higher than the single instrument optimisation. One could argue that optimising more instruments naturally delivers a better policy performance, since this implies that the model reduces more variables in the loss function[6]. In our case, this is not entirely true. For instance, our simulation illustrates that the benefit from case $\boldsymbol{L^H}$ remains higher than $\boldsymbol{CL^E}$ although the former only optimises single policy instrument. Furthermore, although it is welfare enhancing, multiple policy instrument also has a drawback. Our simulation demonstrates that multiple macroprudential instrument interaction can generate a conflict in terms of hindering the efficacy of another policy instrument. There should be a threshold regarding how many macroprudential instruments that the central bank can manage while benefitting the economy at the same time. However, further study is required to validate this argument.

5.4.6 Unconditional Variances

This section explains the variance decomposition from the chosen case, relative to the benchmark, which is the case when all macroprudential instruments are set as constants. This section aims to explore how macroprudential policy significantly stabilizes the economy. In this section, we provide four cases. In addition to the variables in the loss function, we also provide the variance for macroprudential policy instruments being optimized. The first case is $\boldsymbol{L^J}$, which is the best performing case under the single instrument scenario. The second case is $\boldsymbol{CL^J}$, which is the best performing case under the multiple instrument senario. The third case is $\boldsymbol{L^E L^H}$, which is the case where the central bank does not involve CAR in the simulation. Finally, the last case is $\boldsymbol{CL^E L^H}$, which is the case where the central bank separates the LTV into impatient households and entrepreneurs, and optimises them simultaneously with CAR. Table 5.7 illustrates the variance decomposition of these four cases.

Table 5-7: Unconditional Variances from the Chosen Cases

Case	$\boldsymbol{\pi_t}$	$\boldsymbol{Y_t}$	$\boldsymbol{r_t}$	$\boldsymbol{\vartheta_t}$	$\boldsymbol{CAR_t}$	$\boldsymbol{LTV_t^H}$	$\boldsymbol{LTV_t^e}$	$\boldsymbol{LTV_t^j}$
Benchmark	0.1282	0.3061	0.0537	1.1961	-	-	-	-
$\boldsymbol{L^J}$	0.1162	0.4253	0.0447	0.2277	-	-	-	0.2905
$\boldsymbol{CL^J}$	0.1289	0.2321	0.0521	0.0207	0.0033	-	-	0.1209
$\boldsymbol{L^E L^H}$	0.1273	0.2022	0.0504	0.0259	-	0.0786	0.0858	-
$\boldsymbol{CL^E L^H}$	0.1273	0.2020	0.0504	0.0257	0.0008	0.0784	0.0848	-

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[6] Recall that the loss function depends on a number of policy instruments being optimised. That is, the more policy instruments optimised, a number of variables in the loss function increases.

As shown in Table 5.7, in the benchmark model, the variation of macroprudential policy instruments is absent because the central bank is not optimising any macroprudential instruments in the economy. In contrast, in other cases, all macroprudential instruments fluctuate when the central bank optimises them.

Some findings from the simulation stand out. First, the case where the central bank optimises the single joint LTV ($\boldsymbol{L^J}$) is the best when comes to the job of dampening the fluctuation of inflation. In that case, inflation fluctuation declines from 0.1282 to 0.1162, which is 9.36% more stabile than that of the benchmark model. However, once the central bank incorporates CAR into the optimisation ($\boldsymbol{CL^J}$), our simulation demonstrates that the variance of inflation worsens from 0.1282 to 0.1289, or around 0.54%, although the deterioration is minimal. However, in contrast, this case performs very well in dampening the fluctuation of the loan-to-output ratio. The variance of the loan-to-output ratio declines from 1.1961 to 0.0207, which is 98.2% more stable than that of the benchmark model.

The presence of CAR plays a significant role in reducing the loan-to-output ratio and helps in stabilising the joint LTV. The presence of CAR can stabilise the joint LTV ratio by 53.38% than the benchmark model, which is from 0.2905 to 0.1209. We argue that this is a substitution effect between macroprudential instruments, which means that the presence of one instrument can help stabilise another instrument, but at the cost of a higher fluctuation of the instrument itself. The more stabilised joint LTV indicates that the presence of CAR can decrease credit risks for the lender. However, as a consequence, CAR fluctuates more, which means that banks fluctuate their capital buffer more frequently. Therefore, we argue that although the case $\boldsymbol{CL^J}$ works impressively for financial stability, which is the ultimate objective of macroprudential policy, the case impedes monetary policy from stabilising inflation. For this reason, we argue that the central bank should not operate this policy. The substitution effect between macroprudential policy instruments is not only found in the case of $\boldsymbol{CL^J}$ but also in the case of $\boldsymbol{CL^E L^H}$. In this case, the presence of CAR causes the variance of CAR inceases but also reduces the variance of LTV for impatient households and entrepreneurs simultaneously, although the improvement is only small.

The simulation demonstrates that interacting CAR with the separated LTV ratios is not only helpful in achieving financial stability, but also helpful in stabilising inflation. That is, relative to the benchmark model, this case can stabilise the loan-to-output ratio by 97.8% of the benchmark model, which is from 1.1961 to 0.0257. Inflation is also stabilised under this case from 0.1282 to 0.1273, although the improvement is only small by 0.70%. The stabilisation of these two objectives suggests that the implementation of this case does not create a conflict with monetary policy. In terms of dampening output fluctuation, we demonstrate that case $\boldsymbol{CL^E L^H}$ is also superior. That is, the variance of output declines by 34% from 0.3061 to 0.2020, which suggests that although case $\boldsymbol{CL^E L^H}$ results in a slightly higher loss than $\boldsymbol{CL^J}$, case $\boldsymbol{CL^E L^H}$ performs better because it stabilises all economic variables in the loss function. Therefore, we argue that case $\boldsymbol{CL^E L^H}$ is the best case that the central bank can implement.

Among all variables in the loss function, the loan-to-output ratio is the variable that most contribute to reducing loss loss in the economy. Before the optimisation takes place, the unconditional variance for the loan-to-output ratio is 1.1961, which accounts for 71% of the total variance in the benchmark model. The variation then declines significantly, from 1.1961 to 0.0257 (or declines by 97.8%) once the central bank optimises all available macroprudential instruments. This improvement is the highest compared to those in other variables, which suggests that macroprudential policy is useful to dampen the fluctuation of the loan-to-output ratio. This result also confirms Basel III's recommendation to prioritise macroprudential policy to stabilise the debt-to-GDP ratio. In case $\boldsymbol{CL^E L^H}$, the simulation also found that the fluctuation between LTV for impatient households and LTV for entrepreneurs are almost similar, but the LTV for impatient households performs better with unconditional variance by 0.0784, while the fluctuation of LTV for entrepreneurs is 0.0848. Finally, relative to case $\boldsymbol{L^E L^H}$, the unconditional variance demonstrates that the role of CAR is much smaller than that of the LTV ratio.

5.4.7 Impulse Response Function

This section explains the impulse response functions when the economy experiences exogenous shocks. The optimised model in the impulse function refers to the case when the central bank optimises CAR, LTV for entrepreneurs and LTV for households simultaneously ($\boldsymbol{CL^E L^H}$). On the other hand, the benchmark model in the impulse function refers to the case when the central bank optimises no macroprudential policy and only manages the policy rate using the non-optimal simple Taylor rule. Of the eleven types of shocks in the model, this section only provides the impulse response function for five types of shocks. The shocks are consumption shock, housing demand shock, markup shock on deposit rate, markup shock on household lending rate, markup shock on entrepreneurs lending rate, and technology shock. The five shocks are considered sufficient to represent the response of key agents in the economy, namely households, firms, and banks.

- **Consumption Shock**

This section describes the response of some key economic variables when one positive standard deviation of consumption shock is present in the economy ($\sigma_0^z = 0.0144$), which is given as

$$\varepsilon_t^z = 0.394\, \varepsilon_{t-1}^z + \sigma_t^z\ . \tag{5.47}$$

For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^H , and LTV^E ($\boldsymbol{CL^E L^H}$)

The impulse presents two models, namely the benchmark model and the optimised model. The benchmark model is the case when no macroprudential policy is active in the economy. Overall, the economic response in the optimised model under positive consumption shock is more stabilised than the benchmark model. This result demonstrates that the presence of macroprudential policy can dampen the fluctuation of some economic variables.

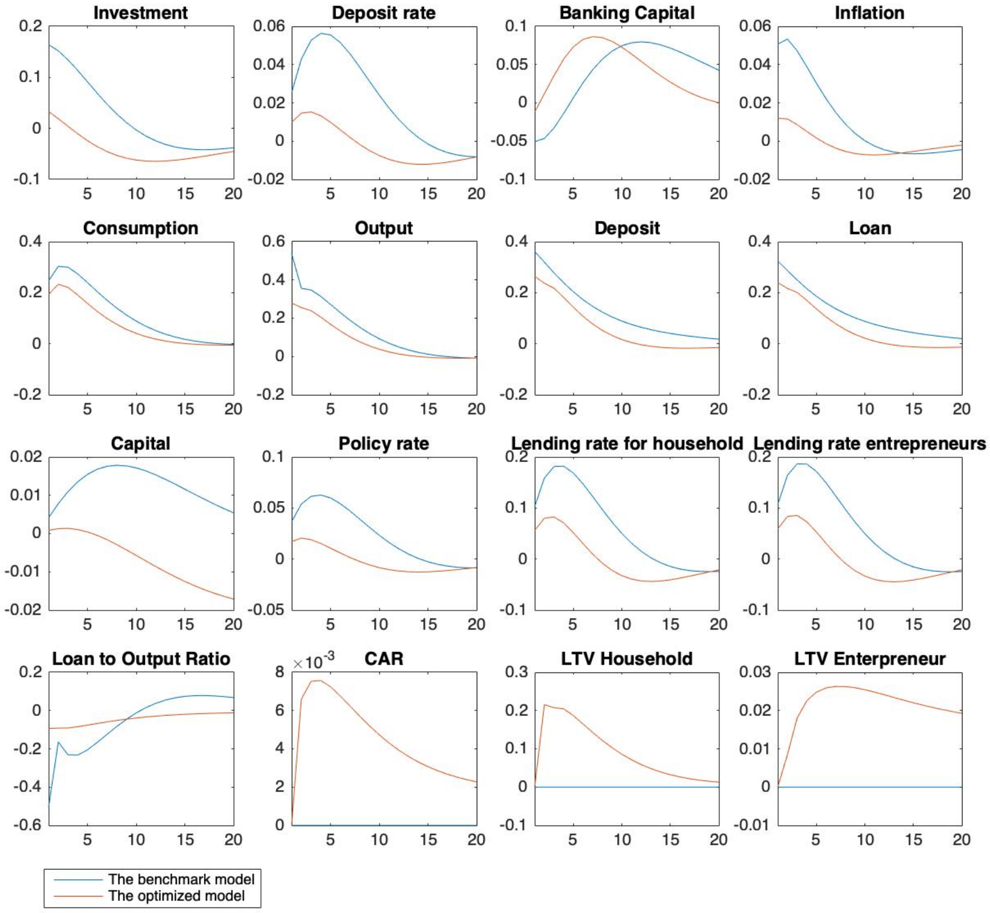

Figure 5-1: Impulse Response Function Under Consumption Shock

One standard deviation of positive consumption shock stimulates households' consumption activity. This rising consumption increases demand for goods, which then drives the price of final goods upward through the supply and demand mechanism. Everything else being equal, the accelerating consumption and higher final goods price causes inflation to rise. The rising final goods price then offers higher profits for firms and thus incentivises firms to increase production. Therefore, everything else being equal, the production of output rises in the initial period. The higher production activity also triggers firms to demand more loans from banks since now they need to produce output a larger output than usual. Also, in anticipating higher production, capital good producers accelerate investment, produce more capital stock, and hence provide more new capital in the economy for firms. As a response, the loans given from banks increase above a steady state because firms now have more collateral supporting their higher demand for loans.

The loan initially has no impact on banking capital, but it then gradually increases banking capital and profits in the subsequent periods. The increasing banking profit is ultimately driven by higher loans for households and entrepreneurs. As the demand for loans rises, banks are more tempted to gain more profit and they increase the lending rate both for households and entrepreneurs elevate. The percentage increase of lending rate from its steady state exceeds that of deposit rate, which then increases credit spread from the steady state. In the benchmark model, the loan-to-output ratio plummets because the increase of output is higher than the deviation of the loan from its steady state. This situation reflects an accelerating economy but increasing risks in the financial sector.

Initially, macroprudential policy instruments seem to have no response to the shock. However, the impulse function illustrates that LTV for impatient households and entrepreneurs start to rise in the subsequent periods. The rise of these two LTVs indicates that the positive consumption shock initially triggers macroprudential policy to allow more credit. Although the rising LTVs allow more credit for the borrower, at the same time this situation is more risky for the lender and destabilises the financial sector, which can be seen from the high response of the loan-to-output ratio from its steady state. Therefore, after some time, the LTVs are saturated and gradually return to their steady state. Also, in comparison to the case where the ratios do not exist, the presence of LTV can dampen the loan and the loan-to-output ratio more signiifficantly than in the benchmark model. In addition to macroprudential policy, the shock also leads the central bank to cut the policy rate, which is followed by a decrease in lending and deposit rates.

To prevent over lending in the economy, the central bank also regulates to elevate the CAR. However, the rise in CAR is very small. These two policy instruments can stabilise the response of the loan to the shock. In this shock, CAR and LTV work in the opposite directions. Consequently, the size of the loans that firms can receive is also smaller than in the benchmark model, which is then followed by less banking capital, less output production, and a lower inflation than those in the benchmark model. Furthermore, as not all households' demand can be met by firms, capital good producers then produce less capital than in the benchmark model, which then reduces investment and provides smaller capital stock. This macroprudential action can balance the progression of output and loans in the economy, such that it stabilises the loan-to-output ratio more than in the benchmark model.

- **Housing Demand Shock**

A positive housing demand shock by one standard deviation ($\sigma_0^j = 0.0658$) is given to the economy. Housing demand shock in the model is described related to consumers' budget constraints and is given as

$$\varepsilon_t^j = 0.921\ \varepsilon_{t-1}^j + \sigma_t^j\ . \qquad \textbf{(5.48)}$$

Figure 5.2 illustrates the impulse response function for some key economic variables.

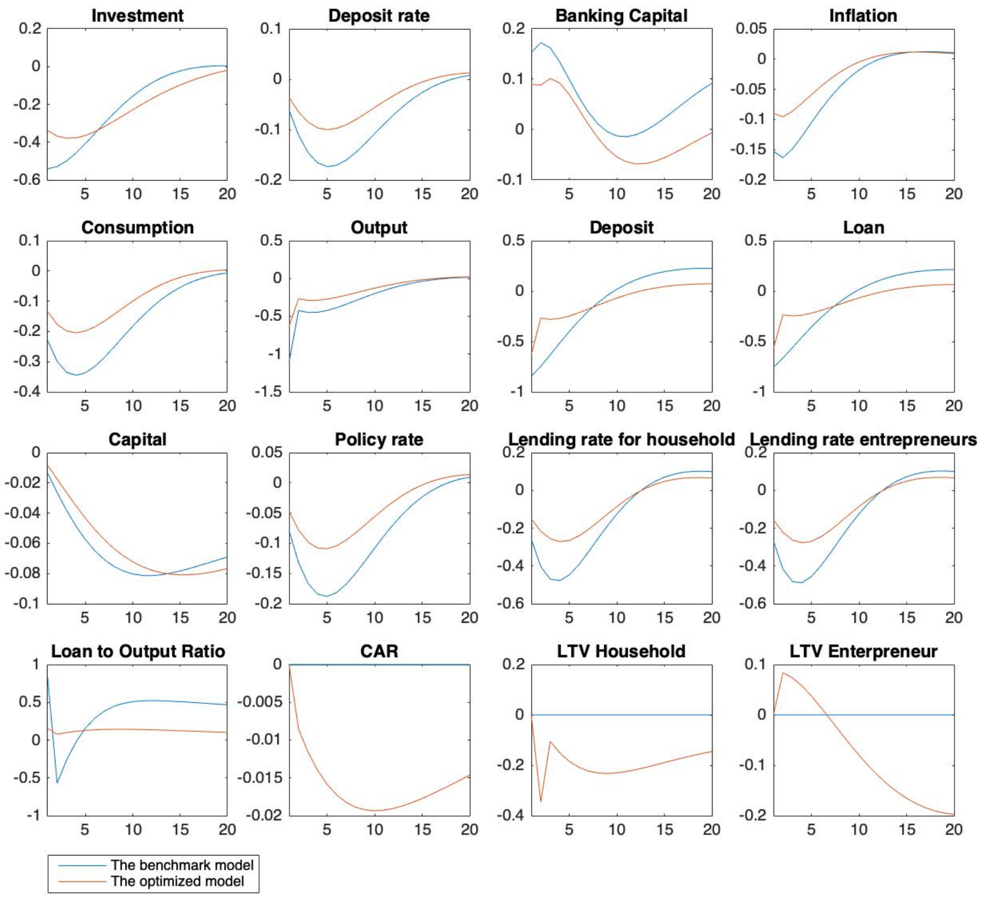

Figure 5-2: Impulse Response Function Under Housing Demand Shock

For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^H , and LTV^E ($\boldsymbol{CL^E L^H}$)

In general, the simulation illustrates that the fluctuation of real economic variables in the optimised model is smaller than those in the benchmark model. Also, the persistence of real economic variables between the two models is similar, which means that the propagation of shock to the real economy is minimal. The presence of housing demand shock comes to the economy through households' budget constraints. This positive shock reflects higher households' expenditure to purchase houses. On impact, based on the household budget constraint, higher purchase on housing will reduce private consumption. The lower consumption also corresponds to the lower demand of final goods. Through supply and demand, the impact of a smaller demand for final goods reduces equilibrium price, inflation, and diminishes firms' profitability. Smaller production also disincentivises capital goods producers from providing more new capital stock in the economy. As a result, capital stock in the economy declines and investment falls.

Furthermore, all else being equal, the lower firms' profitability will reduce labour income, which subsequently discourage patient households to save more deposits in banks . Therefore, smaller deposit in banks then influences the ability of banks to supply loans, which explains why the loan supply in the two models decreases. In the benchmark model, the impulse function illustrates that the loan increases more quickly than production, which causes the loan-to-output ratio to rise immediately in the initial period. This rising loan-to-output ratio indicates an increasing impact of systemic risk that requires macroprudential policy to manage.

As a macroprudential authority, the central bank optimises LTV for impatient households and LTV for entrepreneurs to prevent the loan-to-output ratio from soaring and increasing impact of systemic risk. The two LTVs do not fluctuate in the first period, but then gradually move in the subsequent periods. For instance, LTV for impatient households falls, which means that macroprudential policy discourages households from allocating more spending in housing purchase. In contrast, LTV for entrepreneurs temporarily rises, which indicates that macroprudential policy allows entepreneurs to receive more loans and drive higher production. However, the two LTVs tend to decline across the subsequent periods, which means that macroprudential policy tends to decrease loans for impatient households and borrowers. In preventing loans from shrinking, the CAR declines. The interaction among these three macroprudential policy instruments can stabilise loans from decreasing further than that in the benchmark model. Therefore, during this shock, CAR and LTV behave in opposite directions. Additionally, the central bank also implements a simple Taylor rule and cuts the policy rate below its steady state. In the optimised model, the fall in policy rate is more moderate than it is in the benchmark model.

In conclusion, the response of most key economic variables to the shock in the optimised model is more stabilised than that in the benchmark model. For instance, the optimisation of multiple macroprudential instruments moderates the reaction of inflation, loan, consumption, and investment. Similarly, the loan-to-output ratio is also found to be much more stable in the optimised model than in the benchmark model. The more stable loan-to-output ratio indicates that the activation of macroprudential policy under this shock is also useful to mitigate the impact of systemic risks. However, although macroprudential policy can moderate the impact of shocks and minimise the impact of systemic risks, it does not make the economy recovers more quickly than than the benchmark model does.

- **Markup Shock on Deposit Rate**

Figure 5.4 demonstrates the impulse response function when one standard deviation of positive shock on demand elasticity of deposit rate is given to the economy ($\sigma_0^D = 0.0488$). This shock in the model is constructed as follows:

$$\varepsilon_t^D = 0838\varepsilon_{t-1}^D + \sigma_t^D \, . \tag{5.49}$$

This shock explains the scenario where retail banks increase the deposit rate independently of monetary policy.

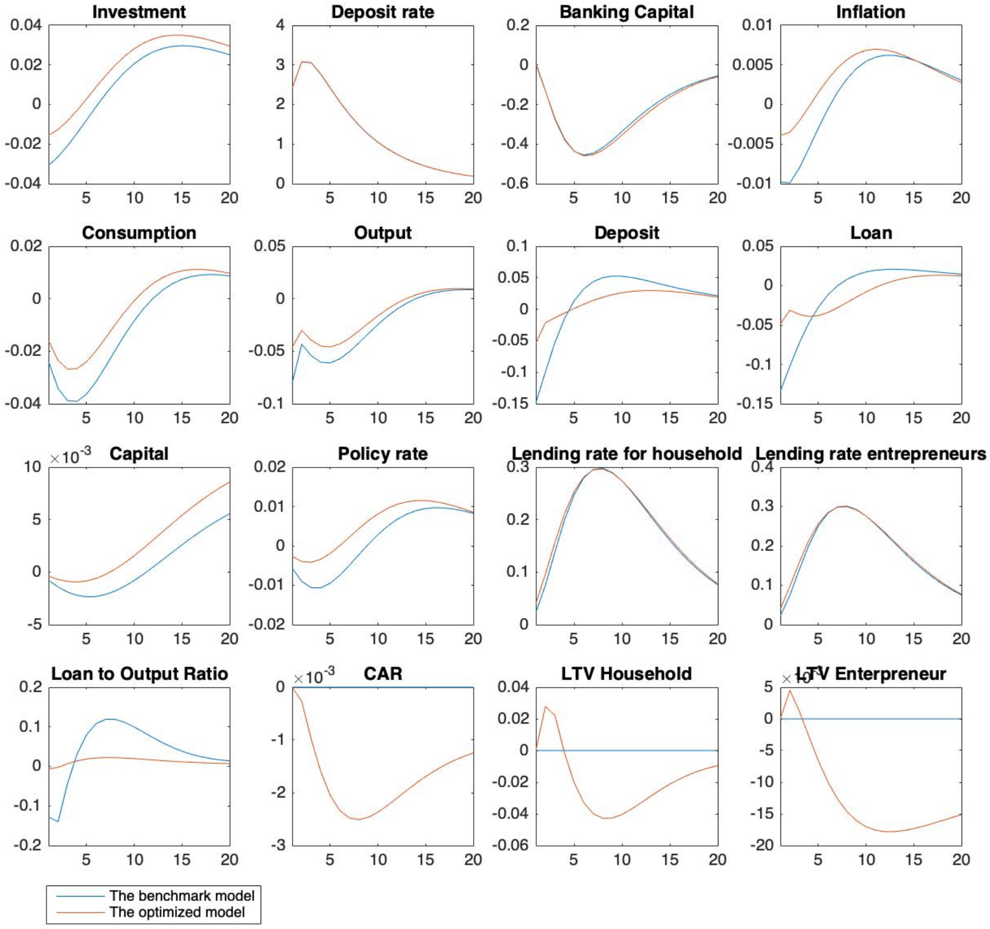

Figure 5-3: Impulse Response Function Under Markup Shock on Deposit Demand

For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^H , and LTV^E ($\boldsymbol{CL^E L^H}$)

The positive shock of demand elasticity on deposit rate, or the deposit rate shock, pushes the deposit rate upward. The increase of the deposit rate in the optimised model and in the benchmark model are identical. Increased deposit rates encourage patient households to save more deposits in banks. As a consequence, everything else being equal, the budget constraint for patient households suggests that the increase in deposits will cause consumption to go down. Therefore, consumption activity declines. The decline in consumption also means that households' demand for final goods diminishes. Therefore, everything else being equal, the decreased demand for final goods causes the equilibrium price for final goods to decline. Everything else being equal, a decline in final goods price causes the inflation rate to decline as well. In the benchmark model, the falling inflation and output automatically causes the Taylor rule to decrease the policy rate.

The lower final goods price also reduces the supply of goods, which means that firms now produce a smaller output than usual. This explains why output falls below the steady state when the shock presents. The decline in production also affects capital goods producers. That is, due to smaller profits from capital production, the capital goods producers now only create less capital in the economy, which then reduces investment. In the financial sector, a lower demand for final goods also negatively affects the supply of loans from the banking sector negatively. Although more deposits are created in banks, the banks only intermediate smaller amount of credit due to the weakening production. As a consequence, lower credit will negatively affect banking profitability and reduce banking capital. In the benchmark model, the loans decline further than the output. Therefore, the loan-to-output ratio plummets deeper than that it does in the optimised model.

The LTV for impatient households and entrepeneurs show no response to the shock in the initial period, but then increases in the subsequent period. The increasing LTV for impatient households indicates that macroprudential policy relaxes the restrictions for impatient households to access more loans and purchase more housing. Relaxing the instrument can moderate the impact of the shock on loan activity. Similarly, the LTV for entrepreneurs also increases, which indicates that macroprudential policy intends to grant more access for entrepreneurs to receive more loans. However, the two LTVs tend to decline in the long run, which means that macroprudential policy tends to decrease loans for impatient households and borrowers, which possibly intends to curb the impact of systemic risks. However, in preventing the loan from shrinking, the central bank also regulates banks to reduce CAR. The interaction among these three policy instruments then moderates the fall of the loans, which means that banks in the optimised model can supply more loans to the economy. Therefore, under this shock, CAR and LTV work in the opposite direction.

In conclusion, a higher supply of loans in the optimised model can stabilise most economic variables in the impulse. For instance, entrepreneurs can receive more loans and demand more capital, which incentivises capital good goods producers to provide more capital in the economy. Furthermore, with more capital produced, investment can rebound. Similarly, impatient households can then receive more loans to purchase houses, which improves housing prices. Finally, as production increases, firms can gain more profit and hence pay higher dividends for households. All else being equal, higher dividens can improve households' spending for consumption. In the optimised model, the pace of response of loan and output is relatively similar, such that the loan-to-output ratio can be stabilised.

- **Markup Shock on Household Lending Rate**

Figure 5.4 illlustrates the impulse response function when positive shock on demand elasticity of household lending rate by one standard deviation comes to the economy ($\sigma_0^{bh} = 0.1454$). This shock in the model is constructed as:

$$\varepsilon_t^{bh} = 0.820\varepsilon_{t-1}^{bh} + \sigma_t^{bh} \,. \qquad \textbf{(5.50)}$$

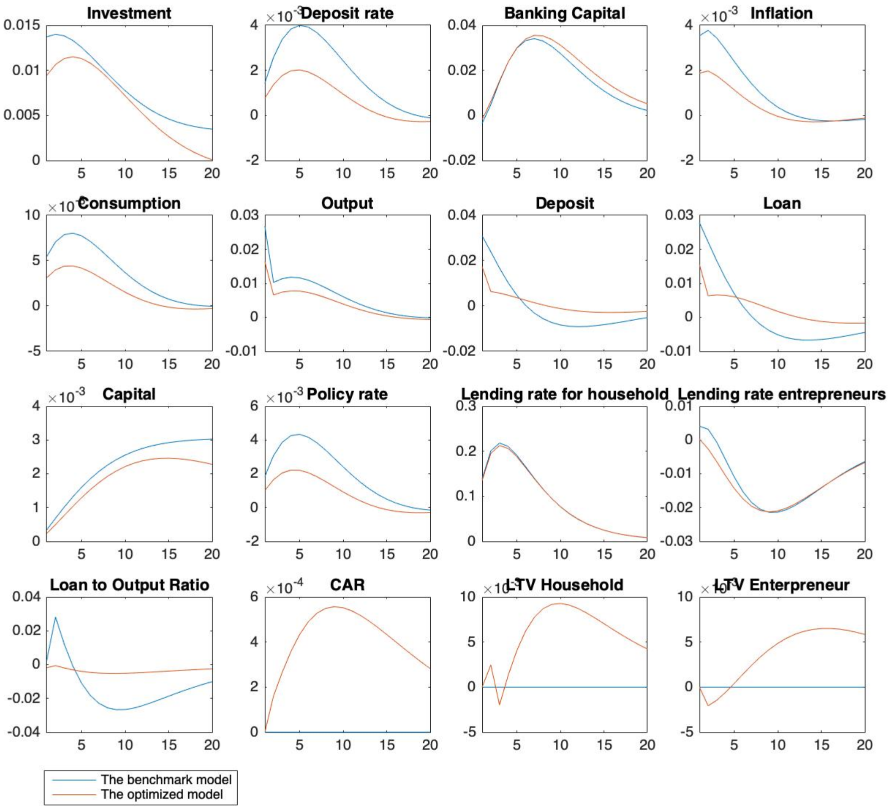

Figure 5-4: Impulse Response Function Under Markup Shock on Household Lending Rate

This shock explains the scenario where retail banks increase lending rates for households independently of monetary policy. For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^H , and LTV^E $(\boldsymbol{CL^E L^H})$

Overall, the response of economic variables in the optimised model is more stable than those in the benchmark model. The shock on the lending rate for impatient households automatically increases the lending rate for households, which causes credit for impatient households more expensive. This condition restrains households from demanding such loans and hence increases consumption instead. That is, impatient households become less attracted to purchasing new houses. The higher household spending on consumption will increase their demand for final goods and thus increases the new equilibrium price of final goods. Everything else equal, higher final goods price will raise inflation. Higher final goods price then encourage firms to produce more output in the economy, such that production goes up when the shock presents. Moreover, accelerating production activity also incentivises capital good producers to create more new capital, which causes investment and capital stock to respond positively when the shock comes. Higher production also allows firms to earn greater profits and more dividends are sent to patient households. The higher dividends sent to patient households enable them to create more deposits in the banking sector.

In the financial sector, more deposit creation from patient households enables banks to increase more credit for borrowers. Under the benchmark model, the loan rises when the shock presents. It seems that the loan accelerates more quickly than the output, which then drives the loan-to-output ratio upward. The rising loan-to-output ratio in the benchmark model indicates that the impact of systemic risk in the banking sector is rising. In managing financial stability, the central bank optimises both LTV for impatient households and entrepreneurs simultaneously. LTV for impatient households tends to increase. The increase of LTV for impatient households indicates that macroprudential policy allows impatient households to receive more loans and purchase new houses.

In contrast, the LTV for entrepreneurs decreases temporarily before it moves up after some time, which indicates that macroprudential policy intends to restrict firms from accessing more loans. However, the two LTVs tend to increase across the subsequent periods, which means that macroprudential policy tends to increase loans for impatient households and borrowers. In preventing overlending, the central bank regulates banks to elevate the CAR, although the rise in CAR is very small. These two policy instruments can stabilise the response of loans to the shock. Therefore, during this shock, CAR and LTV work in opposite directions. As shown in the impulse function, the loan in the optimised model fluctuate less than they do in the benchmark model. That means that banks in the optimised model intermediate smaller loans than that under the optimised model.

In conclusion, the decreasing loans given in the economy can stabilise the fluctuation of other economic variables. For instance, given banks can now supply less loans for entrepreneurs, output in the optimised model only increases less than it does in the benchmark model. Capital good producers will also adjust their capital production, such that investment and capital stock are more modest than those in the benchmark model. Correspondingly, the smaller output produced means less dividends for households, which then also reduces consumption. Furthermore, the declining consumption reduces demand for final goods, which then reduces equilibrium prices. Everything else being equal, inflation in the optimised model is more moderate than in the benchmark model. Finally, with smaller loans and reduced output, the loan-to-output ratio is stabilised and the impact of systemic risk is dampened.

- **Markup Shock on Entrepreneurs Lending Rate**

Figure 5.7 illustrates the impulse response function when one standard deviation of positive shock on demand elasticity of entrepreneurs' lending rate is present in the economy ($\sigma_0^{be} = 0.1454$). In the model, this shock is constructed as:

$$\varepsilon_t^{be} = 0834\varepsilon_{t-1}^{be} + \sigma_t^{be} \ . \qquad \textbf{(5.51)}$$

This shock explains the circumstance where retail banks increase the level of lending rate for entrepreneurs independently of monetary policy. For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^{H} , and LTV^{E} ($\boldsymbol{CL^{E}L^{H}}$)

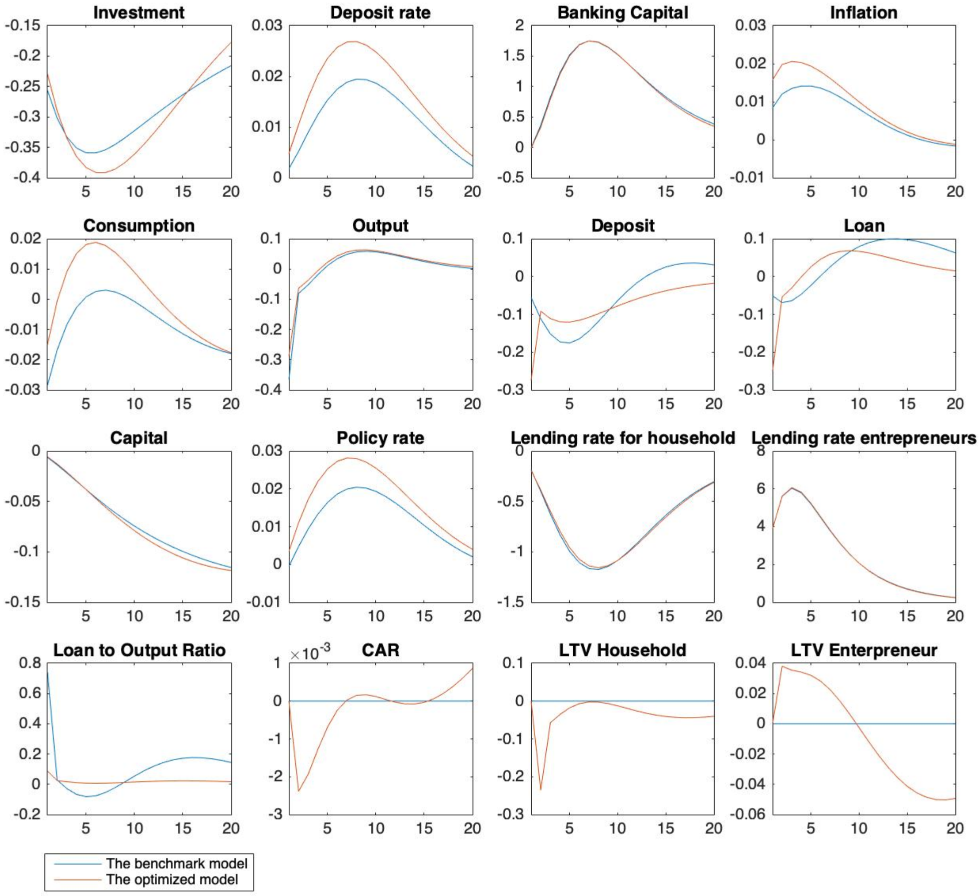

Figure 5-5: Impulse Response Function Under Markup Shock on Entrepreneurs Lending Rate

Overall, economic variables in the optimised model are more stable than those in the benchmark model. A positive shock on markup on entrepreneurs' lending rate elevates the lending rate above its steady state, which causes loans for entrepreneurs to be more expensive. Everything else being equal, this higher borrowing cost reduces the entrepreneurs' demand for loans and reduces the total loan itself. Therefore, in the benchmark model, the impulse illustrates that the loan declines below the steady state when the shock presents. The fall in loans granted for entrepreneurs negatively affects output since firms now only have less fund to purchase new capital. Therefore, output also goes down below the steady state in the initial period.

The falling output production corresponds to the falling firms' demand for new capital and causes the capital goods producers to create less new capital in the economy, reducing capital stock and investment. From the household perspective, the smaller output produced will affect firms' profitability and provides less dividends for households. As a consequence, everything else equal, less dividends received reduces consumption, which explains why consumption declines in the initial period. Overall, a weaker production corresponds reduces the supply of goods and rises the equilibrium of final good prices.

Everything else equal, higher prices for final goods increases inflation. The benchmark model demonstrates that systemic risk rises because the loan-to-output ratio soars.

In diminishing the impact of systemic risk, the central bank implements macroprudential policy. LTV for both impatient households and entrepreneurs shows no discernible response in the initial period, but then move in opposite directions in the subsequent periods. LTV for impatient households declines, while LTV for entrepreneurs increases, which mainly reduces loan from banks. Recall that higher LTV means higher credit access given by banks. Therefore, the fall of LTV for impatient households suggests that banks tend to prevent impatient households from purchasing more loans. In contrast, the increasing LTV for entrepreneurs implies that banks intend to encourage entrepreneurs to access more loans. However, the two LTVs tend to decline in the long run, which means that macroprudential policy tends to curb the loan for impatient households and borrowers.

In preventing the loan from shrinking, the central bank regulates banks to reduce CAR. These policy instruments can stabilise the response of loans to the shock. Therefore, under this shock, CAR and LTV move in opposite directions. Overall, this increased access incentivises entrepreneurs to borrow more loans and use these loans to purchase new capital from capital goods producers. The capital goods producers then use the loans to create more new capital and increases investment. With more new capital provided, firms can boost their production, gain greater profits, give more dividends to households, and eventually improve consumption.

In conclusion, some economic variables in the optimised model move more moderately than those in the benchmark model, but some of them do not. The more stabilised response of economic variables can be seen in consumption and investment, where the optimised model can moderate the impact of the shock on these two variables. Another variable that is significantly stabilised in the optimised model is the loan-to-output ratio, which indicates the efficacy of macroprudential policy under this shock. In contrast, the optimised model tends to increase inflation more than in the benchmark model. With the more stabilised response of output and inflation, the optimised model increases the policy rate more than in the benchmark model.

- **Technology Shock**

This section explains the impulse response function when one standard deviation of technology shock ($\sigma_0^A = 0.0062$) on the economy. The process of technology shock is given as follows:

$$A_t^e = 0.939 A_{t-1}^e + \sigma_t^A \,. \qquad \textbf{(5.52)}$$

Figure 5.6 illustrates the impulse response function for some key economic variables.

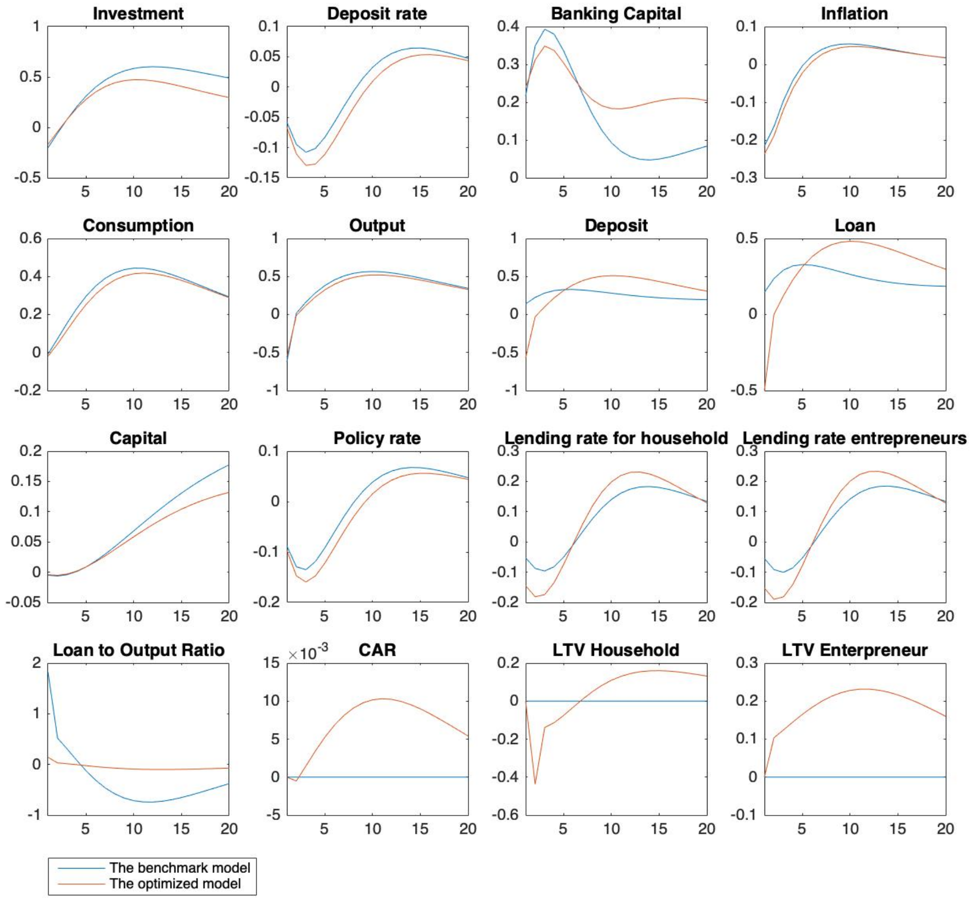

Figure 5-6: Impulse Response Function Under Technology Shock

For the sake of clarity, the benchmark model and optimized model are as follows:

- The benchmark model : No instruments are optimised.
- The optimized model : Optimising CAR, LTV^{H} , and LTV^{E} ($\boldsymbol{CL^{E}L^{H}}$)

A positive technology shock affects the economy through a production function of intermediate goods. Typically, one positive standard deviation of technology shock should have caused production activity to move upward, which then also increases the final goods, everything else equal. However, this is not a usual case to happen when macroprudential policy exists. Recall that macroprudential policy tends to increase credit when lending activity is slowing but restrain it when the lending activity is excessive. In this case, the positive shock favouring entrepeneurs triggers macroprudential policy to restrain credit for entrepreneurs rather than to enhance it. Consequently, LTV for entrepreneurs elevates above its steady state. The rise of LTV for entrepreneurs imposes increases their bankability, which increases their demand for new loans. On the other hand, LTV for impatient households declines in the initial period. This situation suggests that macroprudential policy tends to encourage entrepreneurs from accessing more loan but at the same time discourage households from purchasing more housing. As a result, loans in the optimised model increases, although it is slightly below te steady state in the beginning.

Higher LTV for entrepreneurs also incentivies capital goods producers to produce more capital in the economy, although capital and investment slightly declines in the beginning. Everything else equal, with increased production activity, a supply of goods increases, firms profitability increases, labour income increases, and eventually causes consumption spending to increase. However, the impulse function illustrates that the movement of consumption between the benchmark model and in the optimized model is relatively the same. However, higher production activity that increases supply of goods leads to lower prices, and hence reduces inflation.

In the benchmark model, the positive productivity shock encourages loan to grow above its steady state, which then increases the loan-to-output ratio. The excessive loan-to-output ratio poses higher financial risks for the economy, which calls the need for macroprudential policy intervention. Therefore, when the central bank activates macroprudential policy, the rise of LTV for entrepreneurs increases loan activity. In the long run, the two LTVs tend to increase across the subsequent periods, which means that macroprudential policy tends to increase loans for impatient households and borrowers. To prevent overlending, the central bank elevates the CAR. The interaction of these instruments can stabilise the response of loans to the shock. Therefore, under this shock, CAR and LTV work in the opposite direction. Across all variables, the loan-to-output ratio is the most stabilised variable in the optimised model, which reflects macroprudential policy efforts in achieving financial stability.

Besides macroprudential policy, the central bank also implements a conventional monetary policy by cutting the policy rate, which decreases lending and deposit rates, everything else equal. Consequently, credit spread is adjusted to decline, everything else equal. The decline in the lending rate then reduces the borrowing cost and makes it more affordable for entrepreneurs, which then gradually increases loans. The LTV of entrepreneurs will increase until it gradually declines after some time, but still stays above the steady state. On the other hand, the rising LTV for impatient households also improves impatient households' bankability to borrow more money and they can purchase more houses. The increase in the purchase of houses increases asset prices and incentivises capital goods producers to create more new capital in the economy. This rising capital production increases investment, production activity, and eventually consumption.

5.5 Concluding Remarks

Macroprudential policy is broad and still requires further development, particularly regarding its role in conjunction with the well-established monetary policy. Therefore, both the choice and design of how macroprudential policy instruments interact are crucial to ensure the policy can benefit the economy. This study focuses on the interaction between conventional monetary policy and the macroprudential policy with multiple instruments. The study demonstrates to what extent this interaction can benefit the economy compared to when the authority only focuses on the operation of a single macroprudential instrument. The result of this study is expected to contribute positively to macroprudential policy literature.

Using the model taken from Gerali et al. (2010), this study utilises two prominent types of macroprudential instruments: the CAR and LTV. Moreover, the model divides the latter into LTV for impatient households and LTV for entrepreneurs. Using the method developed by Dennis (2007), this study produces various simulations in a scenario that the central bank optimises macroprudential policy instruments under the fully optimal commitment rule. As for the monetary policy instrument, the central bank follows a simple Taylor rule, which is the one provided in the reference model.

Using the ad-hoc loss function constructed by the variation of inflation, output, loan-to-output ratio, monetary instrument, and macroprudential instrument(s), the study introduces two different scenarios in the simulation. In the first scenario, the central bank optimises only one macroprudential policy instrument and leaves other policy instruments as constants. In the second scenario, the central bank assumes to optimise multiple macroprudential policy instruments, which cover all possible pairings of instruments. The best case is determined based on how it compares to the benchmark model. The benchmark model is designed as a case in which all macroprudential instruments are constants. In other words, the benchmark model is the scenario where macroprudential policy is not active.

Our simulation demonstrates some findings. Firstly, macroprudential policy can benefit the economy more than if the policy does not exist. The ability of the policy to achieve financial stability is the main benefit. This positive contribution of macroprudential policy is similar to what has been stated in studies conducted by Boar et al. (2017), Akinci and Olmstead-Rumsey (2015), Lim et al. (2011), Dell' Ariccia et al. (2012), and Galati and Moessner (2014), among others.

Secondly, we argue that there is a mutual benefit derived from interacting with multiple macroprudential instruments, which is not the case when optimising the policy based on a single instrument. However, managing multiple macroprudential instruments simultaneously in the economy requires careful consideration, since the interaction can create a conflict between the instruments. The conflict manifests itself in such a way that the interaction can benefit some policy instruments, but also attenuates the efficacy of other policy instruments. In other words, a trade-off between variables can emerge when the central bank manages too many policy instruments. There should be a threshold regarding how many macroprudential instruments the central bank can manage while still benefitting the economy at the same time. However, further study is required to validate this argument.

Thirdly, our simulation demonstrates that there is a substitution effect between macroprudential instruments, which means that the presence of one instrument can help in stabilising the other instrument but at the cost of a higher fluctuation of the instrument itself. For this model, we argue that optimising CAR and the joint LTV can deliver the best policy performance, but it has a negative impact on inflation. At this rate, we argue that the central bank should not operate this policy. In contrast, the case when the central bank optimises CAR and the separate LTVs perform positively to inflation, although this case only gives a second-best policy performance.

This finding suggests that the implementation of this case does not cause a conflict with monetary policy. Therefore, we argue that this is the best case that the central bank can implement for our reference model. Moreover, for this model, we found that LTV is superior to CAR. The superiority of LTV ratio to CAR is understood, as mortgage market and housing prices dominate the banking activity in the models. This high impact of LTV ratio on the economy with housing market is in line with studies conducted by Ritcher, Schularick, and Shim (2018), Suh (2012), Akinci and Olmstead-Rumsey (2015), Montoro and Moreno (2011), and Lim et al. (2011), among others.

In addition, among all the variables in the loss function, the loan-to-output ratio is the variable that contributes most significantly to the total loss in the economy, which indicates that macroprudential policy is useful to stabilise this ratio. This result is in line with the recommendation made by Basel III that prioritises macroprudential policy to stabilise debt-to-GDP ratio, which also supports the studies conducted by Angelini et al. (2014), Reinhart and Rogoff (2008), and Borio and Drehman (2009). From the perspective of policy recommendation, this study supports the view that multiple macroprudential instruments can a provide better policy performance. Finally, the simulation on impulse response functions demonstrates that optimising multiple macroprudential instruments can moderate the fluctuation of credit and, at the same time, accelerate the economy to return to its steady states.

CHAPTER 6

CONCLUDING REMARKS

6.1 Main Results and Contribution to The Literature

This thesis presents essays on unconventional monetary policy and macroprudential policy, and explores the ways in which they interact with traditional monetary policy. The credit injection ratio is the focused instrument of the unconventional monetary policy, and the capital adequacy ratio and loan-to-value ratio are the focus in terms of the macroprudential policy.

The thesis consists of three core chapters. In the first chapter, we investigate the optimal strategic interaction between the conventional monetary policy and the quantitative easing policy. The second chapter examines whether the optimal simple rule for quantitative easing policy can be optimally constructed based on the endogenous variables in the economy. Finally, the final chapter interacts conventional monetary policy with macroprudential policy to understand to the extent to which macroprudential policy with multiple policy instruments can benefit the economy. The reference model for the first and second chapters is that of Gertler and Karadi (2011), while the reference for the third chapter is the model from Gerali et al. (2010). All the simulations are conducted following the algorithm developed by Dennis (2004; 2007), and Dennis and Ilbas (2016).

The first core chapter reveals that simultaneous interaction under fully optimal commitment regime between the conventional monetary policy and the quantitative easing policy offers the best policy performance compared to other policy regimes. In this case, the central bank's commitment in quantitative easing plays an important role in the policy performance. Our finding regarding the positive impact of commitment in quantitative easing is similar to arguments proposed by Ugai (2007); Beriel and Mendes (2015), Khrisnamurthy and Vissing-Jorgensen (2011), and Oda and Ueda (2007), among others, who argue that commitment is an essential factor in the operation of quantitative easing policy.

In contrast, a discretionary policy regime delivers the lowest policy performance, with a level similar to that when the two policies interact using the leadership scenario. The study also found that the quantitative easing policy is best performing when it leads the interaction (i.e., the central bank optimises the quantitative easing policy before the conventional monetary policy), which is in line with the argument from Cui and Sterk (2018). Finally, the findings of this chapter demonstrate that the combination of the non-optimal simple monetary rule and the simple quantitative easing rule is still better than discretionary or leadership regimes, which suggests a possibility of using an optimal simple rule in managing quantitative easing policy. However, performance of the simple policy rule regime is conditional on the level of the central bank's aggressiveness, in terms of combatting the crisis. The simulation reveals that the simple policy rule regime outperforms the discretionary policy regime if the credit parameter in the simple quantitative easing rule is below 15.

Most policy performances produced indicate that the traditional monetary policy remains superior to the quantitative easing policy, except for the independent leadership regime where quantitative easing leads the interaction. This result contributes to the literature by indicating that the quantitative easing policy cannot replace the traditional monetary policy, which is noted in studies by Curdia and Woodford (2018); Cui and Sterk (2018); Sheedy (2016); and Kiley (2018), among others. Furthermore, by using the simulation on the simple policy rule regime, this study also reinforces that the central bank's excessive aggressiveness, in terms of injecting credit into the economy, can benefit the fluctuation of some macroeconomic variables. However, this also contributes to the deterioration of policy performance, which is a similar notion to ideas expounded by Cui and Sterk (2018); Kiley (2008); Sheedy (2016) and Fernandez, Bortz, and Zeolla (2018), among others.

We also found that, although the commitment regime offers the smallest loss value, its ability to stabilise inflation performs worse than the simple policy rule regime. That is to say, the simple policy rule regime outperforms the commitment and discretionary policy regimes, in terms of the role of inflation stabilisation. In contrast, the job of stabilising output, credit spread, and nominal interest rate are best in the commitment regime. Finally, simulations of impulse response functions under various shocks demonstrate that central bank injects the largest liquidity under the simple policy rule regime.

The second core chapter formulates the optimal simple quantitative easing rule when the central bank manages both monetary and quantitative easing policies. This chapter works on the assumption that the central bank only optimises quantitative easing policy to minimise loss function, while the monetary policy rule is maintained in order to follow the non-optimal simple Taylor rule, as provided in the original model.

The study demonstrates that the best performing optimal simple quantitative easing rule is under the past time horizon, using information from lagged deviation of leverage, capital price, and credit spread from their steady states. However, incorporating inflation and output in the optimal simple rule only returns minor improvements to the policy performance. Similarly, when the central bank utilises non-zero interest rate smoothing parameters, the structure of the optimal simple quantitative easing rule remain unchanged, which is still constructed by the past leverage, capital price, and credit spread. The superiority of information from financial sector in quantitative easing is similar with argument from Borio and Zabai (2016).

Our investigation on unconditional variances shows that the optimal simple quantitative easing rule results in the lower fluctuation of credit injection than that in the fully optimal commitment rule. This implies that the optimal simple quantitative easing rule can prompt the central bank to inject less credit than they would under full commitment. However, this lower credit injection leads to higher fluctuations in output and credit spread, than in the fully optimal commitment rule. Across all variables in the loss function, output has been shown to be the most fluctuating variable.

This second core chapter contributes to the recent evolving literature that focuses on developing the quantitative easing policy rule and conventionalising the unconventional monetary policy, such as Sheedy (2016), Curdia and Woodford (2010), and Quint and Rabanal (2017). It is shown that the quantitative easing positively contributes to the economy, compared to when quantitative easing is not active. Although this is not an empirical finding based on econometric studies, this favourable impact finding is similar to studies from Chen et al. (2016); Gagnon et al. (2011); Khrisnamurty and Vissing-Jorgensen (2011); Chung et al. (2012); Giannone, Lenza, Pill, and Reichlin (2012); Quint and Rabanal (2017); Meaning and Zhu (2011), and Kapetianos et al. (2012), among others.

This chapter also reinforces that the central bank should mainly derive its information from the banking sector when implementing the quantitative easing policy. Among all banking variables provided in the reference model, credit spread is the most affecting variable in the simple quantitative easing rule. Hence, the chapter argues that targeting credit spread in the quantitative easing policy can improve the efficacy of the optimal simple quantitative easing rule in the economy. The importance of credit spread in the operation of quantitative easing policy subsequently supports studies from Gertler and Karadi (2011); Quint and Rabanal (2017); Christensen and Gillan (2018); Pang and Siklos (2010), and Paesani and Bruno (2014), among others.

Furthermore, the findings in this chapter also highlight that past time endogenous variables can provide the central bank with useful information to determine the level of quantitative easing in the financial sector at present time. This is an interesting result because the quantitative easing policy rule usually incorporates either a contemporaneous or future time horizon, such as shown in Gertler and Karadi (2011); Sheedy (2016); Cui and Sterk (2018), and Curdia and Woodford (2010), among others.

Finally, the study also found that the central bank's aggressiveness can create a trade-off between optimality and stability in the economy. The central bank's aggressiveness can unbind the optimality of the simple quantitative easing rule. This occurs because the credit parameter changes the feedback coefficients in the optimal simple rule, which consequently leads to a higher credit injection into the economy and, thus higher loss. However, although aggressiveness can reduce the fluctuation of other variables in the loss function, which generally benefit the macroeconomy, it deteriorates policy performance, which is similarly noted by Cui and Sterk (2018); Kiley (2008); Sheedy (2016) and Fernandez, Bortz, and Zeolla (2018). Therefore, the credit injection ratio, as the quantitative easing instrument, should not be used with excessive aggressiveness.

The third core chapter incorporates both conventional monetary policy and macroprudential policy, in order to investigate the effect of macroprudential policy on the economy under the commitment regime. A number of conclusion are drawn from our simulations. First, the presence of macroprudential policy can benefit the economy compared to a situation in which macroprudential policy does not exist. Our finding regarding macroprudential policy's positive contribution is similar to that noted in the studies of Boar et al. (2017); Akinci and Olmstead-Rumsey (2015); Lim et al. (2011); Dell' Ariccia et al. (2012); Galati and Moessner (2014); Quint and Rabbanal (2013); Angelini, Neri and Panetta (2012); Kannan and Rabanal (2012); Rubio and Carrasco-Gallego (2016); Basto, Gomes, and Lima (2018), and Lambertini, Mendicino, and Punzi (2013), among others. This chapter outlines the mutual benefit that is possible when multiple macroprudential policy instruments interact, compared to only optimising the policy based on a single instrument.

However, managing multiple macroprudential instruments simultaneously in the economy requires careful consideration, since the interaction can create conflict between the instruments. This conflict is manifested in the fact that this interaction can benefit some policy instruments but can also attenuate the efficacy of another policy instrument. That is to say, a trade-off between variables emerges when the central bank manages too many policy instruments. Thus, there should be a threshold regarding how many macroprudential instruments a central bank can manage, while benefitting the economy at the same time. However, further study is required to validate this argument. Finally, the efficacy of the LTV ratio in the economy is similar for both LTV for households and LTV for entrepreneurs. The significant impact of the LTV ratio can be understood in an economy with extensive housing market, which is also articulated in the studies by Ritcher, Schularick, and Shim (2018); Suh

(2012); Akinci and Olmstead-Rumsey (2015); Montoro and Moreno (2011), and Lim et al. (2011), among others.

Our simulations on unconditional variances demonstrate that there is a substitution effect between macroprudential policy instruments, which means that the presence of one policy instrument can help stabilise the other policy instrument, but at the cost of higher fluctuation for the instrument itself. This model demonstrates that optimising the CAR and the joint LTV ratio can deliver the best policy performance, but this also returns a negative impact on inflation. Consequently, we argue that the central bank should not operate this policy. In contrast, when the central bank optimises CAR and the separate LTV ratios, it can reduce the fluctuation of inflation, despite only returning the second-best policy performance. This finding suggests that this situation does not cause a conflict with monetary policy. Hence, we argue that this scenario provides the best performance and suggest the central bank to implement this model.

We found that LTV is superior to CAR in our reference model. The superiority of LTV ratio over CAR is understood, as the mortgage market and housing prices dominate economic activities in the reference model. The efficacy of LTV ratio as a policy instrument of macroprudential policy in this study is in line with studies from Rubio and Carrasco-Gallego (2014); Mendicino and Punzi (2014); Basto, Gomes, and Lima (2018), and Lambertini, Mendicino, and Punzi (2013).

Furthermore, among all the variables in the loss function, the loan-to-output ratio is the variable that contributes most significantly to the benefit of macroprudential policy in the economy. This finding indicates that macroprudential policy is a useful tool to create financial stability by dampening the fluctuation of the loan-to-output ratio. This result supports the recommendation from Basel III that prioritises macroprudential policy to stabilise the debt-to-GDP ratio, which in turn supports the work of Angelini et al. (2014); Reinhart and Rogoff (2008), and Borio and Drehman (2009). Finally, we also found that, although optimising multiple numbers of macroprudential policy instruments is better than relying solely on the single macroprudential instrument optimisation, the results of the unconditional variance demonstrate that the capital adequacy ratio does not fluctuate significantly.

6.2 Policy Implications of The Research

Less research is being conducted into unconventional monetary policies, particularly quantitative easing policy, compared to conventional monetary policy or fiscal policy. This is understood as quantitative easing is considered to only active during an economic crisis, which makes it unconventional, compared to policies that work during regular economic activities. However, quantitative easing is not entirely unconventional, as the central bank actually has been operating the policy in government bonds market for the last 200 years (Goldman Sachs, 2019). Hence, conventionalising quantitative easing policy is something logical for policymakers to think about, considering its narrow scope of literature today. Martin and Milas (2012) argue that the literature on quantitative easing policy is limited and too narrow, which means exploration of alternative approaches to quantitative easing are required. For instance, most studies in this area refer to a global financial crisis as a starting point, which is a time in which massive credit injection into the economy are made. They then expand this perspective to elaborate on the effectiveness of the policy in terms of dampening the impact of the crisis.

Unfortunately, other possibilities to expand the research area of quantitative easing policy are overlooked and underexplored. For instance, to our best knowledge, the topics related to conventionalising the quantitative easing policy, how this policy should interact with traditional monetary policy, and how the central bank should govern this policy, are all rarely examined in the literature. Hence, this study as an effort towards expanding the literature on quantitative easing policy. That is to say, this thesis expands quantitative easing policy beyond the current narrow focus on its effectiveness in the economy. From a policy perspective, as the economy is growing more sophisticatedly, it is most likely that this type of policy will play a significant future role, rather than being assumed to only be active during times of financial distress.

The results of the first two chapters in this thesis present a picture for policymakers and researchers, which urges them to view the quantitative easing policy as a more strategic policy, rather than as simply an emergency asset purchase. For example, the first chapter reveals that the non-optimal simple rule can perform better than the discretionary or the leadership policy regime, provides policymakers a broader insight to elaborate an appropriate simple rule to set the size of quantitative easing in the economy. Furthermore, one finding from the second chapter regarding the optimal simple rule for quantitative easing also provides information for policymakers regarding the critical financial variables that can help direct the path of quantitative easing in the economy. Furthermore, the importance of the past time horizon for financial variables also indicates the crucial nature of the degree of access or transparency between the central bank and the historical information in the private sector. These examples have favourable implications for the development of quantitative easing policy specifically, as well as for other macro-stabilisation policies in general.

Macroprudential policy is similar to quantitative easing policy in that it is also a relatively new policy that is growing in popularity, and whose name has become popular since the global financial crisis. However, macroprudential policy differs from quantitative easing policy in that macroprudential policy is naturally broad due to various sources of systemic risk. To our best knowledge, current macroprudential policy studies focus on two areas: namely those that assess the effectiveness of the policy and those that examine its interactions with monetary policy. This study contributes to both areas by exploring the interactions between monetary and macroprudential policy, when the latter implements more than one policy instrument.

For instance, one finding from our study is that the substantial magnitude of impact from the presence of macroprudential policy can improve policy performance up to 72.75% than the case without its presence. This indicates the interesting policy implication of whether this policy could have replaced the conventional monetary policy in practice or not. Further research should elaborate on this, in order to answer this research question. Another significant finding from the last chapter is that the interaction of multiple policy instruments can induce conflict, but it can also trigger a substitution effect between the instruments. Our finding also demonstrates that LTV is more impactful than CAR. These two findings suggest policymakers that the choice of macroprudential instrument is also dependent on the structure of the instrument and the type of dominant market in the economy. For instance, in our case, when mortgages dominant the banking sector, the loan to value ratio might have a more powerful impact on the economy than other macroprudential instruments.

6.3 Limitation of The Study and Direction for Further Research

In an effort to present a new perspective within this research area, this thesis contains assumptions and has limitations that call for further research. From a methodological perspective, the construction of the loss function is one of the limitations in this research. All three chapters implement ad-hoc loss functions, rather than the optimal welfare function that is derived from a utility function. The ad-hoc loss function contains some limitations, such as the rationale behind the choice of variables or the weights assigned to each variable in the loss function. Hence, future research is necessary to establish whether the results of this thesis change when these two types of loss functions are switched. Furthermore, this study is limited by its lack of examination of the intertemporal impact of the quantitative easing policy, which is asserted in similar studies.

Another assumption of this study lies in its traditional monetary policy. In practice, quantitative easing policy is usually present when the traditional interest rate monetary policy is poorly functioning, or when the overnight short-term interest rate is extremely low. In contrast, our simulation presents a circumstance when monetary policy can work normally using the ordinary simple Taylor rule, which does not reflect the malfunctioning of monetary policy. This fundamental assumption probably explains the superiority of the traditional monetary policy over the quantitative easing policy across most regimes in the first chapter. Unfortunately, this thesis does not provide further analysis regarding the interaction between the two policies under a zero lower bound constraint, which highlights another limitation. Hence, further research should elaborate whether the superiority of monetary policy is maintained, even when the zero lower bound constraint is applied.

Regarding macroprudential policy study in this thesis, further research could be continued to explore the interaction between monetary policy and macroprudential policy when both the capital adequacy ratio and loan-to-value ratio are expressed in the simple policy rule, rather than in the optimal policy rule. Another further study can also focus on the interaction between independent monetary policy and macroprudential policy pursuing different loss functions, rather than a single loss function, which can contribute to answer whether macroprudential policy and monetary policy should be mandated under single or separate institutions. Finally, further research can also explore the role of macroprudential policy in recovering the economy after an economic crisis.

GLOSSARY

BCBS : Basel Committee on Banking Supervision

BIS : Bank of International Settlement

CAR : Capital Adequacy Ratio

FED : Federal Reserve

GDP : Gross Domestic Product

LDR : Loan-to-Deposit Ratio

LGD : Loan-Given-Defaut

LTV : Loan-to-Value Ratio

MEP : Maturity Extensive Program

MP : Monetary Policy

QE : Quantitative Easing

UK : United Kingdom

US : United States

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APPENDIX A

Solving Dynamic Optimization in Rational Expectation Model

This section explains the methodology used in this thesis. The first step from the simulation is to replicate the reference model using the undetermined coefficient approach from Uhlig (1999), which classifies endogenous variables into pre-determined and non-predetermined variables. Given the model replication has been established, the equation system is then rearranged into a structural form rather than in a state space model. Specifically, we produce matrix $\boldsymbol{A}$ to satisfy the algorithm from Dennis (2007), which is given by

$$\boldsymbol{A}_0\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_2E_t\boldsymbol{y}_{t+1} + \boldsymbol{A}_3\boldsymbol{x}_t + \boldsymbol{A}_4E_t\boldsymbol{x}_{t+1} + \boldsymbol{A}_5\boldsymbol{v}_t, \qquad \textbf{(A.1)}$$

where matrices $\boldsymbol{A}_0, \boldsymbol{A}_1, \boldsymbol{A}_2, \boldsymbol{A}_3, \boldsymbol{A}_4$ and $\boldsymbol{A}_5$ contain the model of structural parameters, $\boldsymbol{y}_t$ is the vector of endogenous variables, $\boldsymbol{x}_t$ denotes the vector of policy instrument, $\boldsymbol{v}_t$ is the vector of stochastic disturbances where $\boldsymbol{v}_t \sim i.i.d.[\boldsymbol{0}, \boldsymbol{\Omega}]$ and $\boldsymbol{\Omega}$ is the variance-covariance matrix of structural shocks. In case of simultaneous interaxtion, the vector $\boldsymbol{x}_t$ is decomposed into two. Accordingly, following Dennis and Ilbas (2016), the setting of two independent policies will expand the structural form of the model into the following

$$\boldsymbol{A}_0\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_2E_t\boldsymbol{y}_{t+1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_4E_t\boldsymbol{x}_{t+1} + \widetilde{\boldsymbol{A}}_4E_t\widetilde{\boldsymbol{x}}_{t+1} + \boldsymbol{A}_5\boldsymbol{v}_t, \qquad \textbf{(A.2)}$$

where $\boldsymbol{x}_t$ denotes the vector of policy instrument for the first policy and $\widetilde{\boldsymbol{x}}_t$ denotes the policy instrument for the second policy. The main difference between the former structural form with the latter is that matrix $\boldsymbol{A}_3$ is split into $\boldsymbol{A}_3$ and $\widetilde{\boldsymbol{A}}_3$, which represent the matrix of structural parameter of the first and second policy instrument at period t, respectively. Similarly, matrix $\boldsymbol{A}_4$ is also split into $\boldsymbol{A}_4$ and $\widetilde{\boldsymbol{A}}_4$, which represent the matrix of structural parameter for the first and second policy instrument at period $t+1$, respectively.

- **Fully Optimal Commitment Regime**

In the fully optimal commitment regime, it is assumed that the central bank implements two policies simultaneously. Under commitment, the policymaker adheres to its chosen policy rules from the beginning, apply the rules to all subsequent periods, and never reoptimises. Every period, the authority sets policy instruments to minimise the loss function given by

$$Loss = E_0\sum_{t=0}^{\infty}\beta^t[\boldsymbol{y}_t'\boldsymbol{W}\boldsymbol{y}_t + \boldsymbol{x}_t'\boldsymbol{Q}\boldsymbol{x}_t], \qquad (\mathbf{A.3})$$

where β is the discount factor, $\boldsymbol{y}_t$ is an $(n\,x\,1)$ vector of endogenous variables, $\boldsymbol{x}_t$ is a $(p\,x\,1)$ vector of policy instruments, $\boldsymbol{W}$ is a welfare matrix, which is the square matrix $(n\,x\,n)$ representing the weights assigned to variables in the loss function, and $\boldsymbol{Q}$ is the square matrix $(p\ x\ p)$ representing the weights of policy instruments in the loss function. Vectors $\boldsymbol{y}_t$ and $\boldsymbol{x}_t$ represent deviations from the nonstochastic steady state values. The sign E_0 denotes the mathematical expectations operator conditional on period 0 information. The policymaker determie $\boldsymbol{x}_t$ to minimise the the loss function (A.3) subject to the constraints:

$$\boldsymbol{A}_0\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_2\boldsymbol{y}_{t+1} + \boldsymbol{A}_3\boldsymbol{x}_t + \boldsymbol{A}_4\boldsymbol{x}_{t+1} + \boldsymbol{\rho}_t \tag{A.4}$$

$$\boldsymbol{\rho}_t = \boldsymbol{A}_5\boldsymbol{v}_t - \boldsymbol{A}_2\eta_{t+1} - \boldsymbol{A}_2\boldsymbol{\mu}_{t+1}, \tag{A.5}$$

where $\boldsymbol{\eta}_{t+1}$ and $\boldsymbol{\mu}_{t+1}$ are the expectation errors and are martingale difference sequences, which are defined as

$$\boldsymbol{\eta}_{t+1} = \boldsymbol{y}_{t+1} - E_t\boldsymbol{y}_{t+1}, \tag{A.6}$$

$$\boldsymbol{\mu}_{t+1} = \boldsymbol{x}_{t+1} - E_t\boldsymbol{x}_{t+1}. \tag{A.7}$$

The solution in the commitment regime is to solve the optimisation problem above using the Lagrangian is as follows

$$L = E_0 \sum_{t=0}^{\infty} \beta^t [\boldsymbol{y}_t'\boldsymbol{W}\boldsymbol{y}_t + \boldsymbol{x}_t'\boldsymbol{Q}\boldsymbol{x}_t + 2\boldsymbol{\lambda}_t'(A_0\boldsymbol{y}_t - \boldsymbol{A}_1\boldsymbol{y}_{t-1} - \boldsymbol{A}_2\boldsymbol{y}_{t+1} - \boldsymbol{A}_3\boldsymbol{x}_t - \boldsymbol{A}_4\boldsymbol{x}_{t+1} - \boldsymbol{\rho}_t)] \tag{A.8}$$

then taking derivatives of L with respect to $\boldsymbol{\lambda}_t$, $\boldsymbol{y}_t$ and $\boldsymbol{x}_t$, gives the following results

$$\frac{\partial Loss}{\partial \lambda_t} = \boldsymbol{A}_0\boldsymbol{y}_t - \boldsymbol{A}_1\boldsymbol{y}_{t-1} - \boldsymbol{A}_2E_t\boldsymbol{y}_{t+1} - \boldsymbol{A}_3\boldsymbol{x}_t - \boldsymbol{A}_4E_t\boldsymbol{x}_{t+1} - \boldsymbol{A}_5\boldsymbol{v}_t = \boldsymbol{0} \tag{A.9}$$

$$\frac{\partial Loss}{\partial y_t} = \boldsymbol{W}\boldsymbol{y}_t + \boldsymbol{A}_0'\boldsymbol{\lambda}_t - \beta^{-1}\boldsymbol{A}_2'\boldsymbol{\lambda}_{t-1} - \beta\boldsymbol{A}_1'E_t\boldsymbol{\lambda}_{t+1} = \boldsymbol{0} \tag{A.10}$$

$$\frac{\partial Loss}{\partial x_t} = \boldsymbol{Q}\boldsymbol{x}_t - \boldsymbol{A}_3'\boldsymbol{\lambda}_t - \beta^{-1}\boldsymbol{A}_4'\boldsymbol{\lambda}_{t-1} = 0. \tag{A.11}$$

One possibility to solve the derivative equations (A.9) – (A.11) above is to express them in the second-order form as follows:

$$\begin{bmatrix} \boldsymbol{0} & \boldsymbol{A}_0 & -\boldsymbol{A}_3 \\ \boldsymbol{A}_0' & \boldsymbol{W} & \boldsymbol{0} \\ -\boldsymbol{A}_3' & \boldsymbol{0} & \boldsymbol{Q} \end{bmatrix} \begin{bmatrix} \boldsymbol{\lambda}_t \\ \boldsymbol{y}_t \\ \boldsymbol{x}_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{0} & \boldsymbol{A}_1 & \boldsymbol{0} \\ \beta^{-1}\boldsymbol{A}_2' & \boldsymbol{0} & \boldsymbol{0} \\ \beta^{-1}\boldsymbol{A}_4' & \boldsymbol{0} & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{\lambda}_{t-1} \\ \boldsymbol{y}_{t-1} \\ \boldsymbol{x}_{t-1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{0} & \boldsymbol{A}_2 & \boldsymbol{A}_4 \\ \beta\boldsymbol{A}_1' & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \end{bmatrix} E_t \begin{bmatrix} \boldsymbol{\lambda}_{t+1} \\ \boldsymbol{y}_{t+1} \\ \boldsymbol{x}_{t+1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{A}_5 \\ \boldsymbol{0} \\ \boldsymbol{0} \end{bmatrix} [\boldsymbol{v}_t], \tag{A.12}$$

given $\boldsymbol{y}_{-1} = \bar{\boldsymbol{y}}$ and $\boldsymbol{\lambda}_{-1} = \boldsymbol{0}$, where $\boldsymbol{\lambda}$ represents Lagrange Multipliers from the optimisation problem. Implementing the undetermined-coefficient method returns the solutions in the form

$$\begin{bmatrix} \boldsymbol{\lambda}_t \\ \boldsymbol{y}_t \\ \boldsymbol{x}_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{\theta}_{11} & \boldsymbol{\theta}_{12} & \boldsymbol{0} \\ \boldsymbol{\theta}_{21} & \boldsymbol{\theta}_{22} & \boldsymbol{0} \\ \boldsymbol{\varphi}_1 & \boldsymbol{\varphi}_2 & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{\lambda}_{t-1} \\ \boldsymbol{y}_{t-1} \\ \boldsymbol{x}_{t-1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{\theta}_{13} \\ \boldsymbol{\theta}_{23} \\ \boldsymbol{\varphi}_3 \end{bmatrix} [\boldsymbol{v}_t], \tag{A.13}$$

where the optimal solution above depends on the vector of the lagged Lagrange multipliers. Suppose $\boldsymbol{z}_t = [\boldsymbol{\lambda}_t{}'\ \boldsymbol{y}_t{}'\ \boldsymbol{x}_t{}']'$, then we can rearrange the solution as $\boldsymbol{z}_t = \boldsymbol{H}\boldsymbol{z}_{t-1} + \boldsymbol{G}\boldsymbol{v}_t$. Accordingly, the loss function can be written as

$$Loss = [\boldsymbol{z}_{t-1}'\boldsymbol{H}'\widehat{\boldsymbol{P}}\boldsymbol{H}\boldsymbol{z}_{t-1} + \boldsymbol{v}_t'\boldsymbol{G}'\widehat{\boldsymbol{P}}\boldsymbol{G}\boldsymbol{v}_t + \frac{\beta}{1-\beta}tr(\boldsymbol{G}'\widehat{\boldsymbol{P}}\boldsymbol{G}\boldsymbol{\Omega})\ ], \qquad \textbf{(A.14)}$$

where $\boldsymbol{z_t}$ denotes the deviation of vector $\boldsymbol{z}_t$ from its steady states and $\boldsymbol{v_t}$ denotes the deviation of vector $\boldsymbol{v}_t$ from its steady state. The matrix $\widehat{\boldsymbol{P}}$ is defined as a fixed point from

$$\widehat{\boldsymbol{P}} \equiv \widehat{\boldsymbol{K}} + \beta\boldsymbol{H}'\widehat{\boldsymbol{P}}\boldsymbol{H}, \qquad \textbf{(A.15)}$$

where

$$\widehat{\boldsymbol{K}} \equiv \begin{bmatrix} \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{W} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{Q} \end{bmatrix}. \qquad \textbf{(A.16)}$$

- **Discretionary Policy Regime**

In discretionary policy regime, it is assumed that the central bank always reoptimises in every period. Under discretion, we assume the central bank that optimises policy instrument today is the Stackelberg leader, while the private sector agents and future policymakers are assumed as Stackelberg followers. This discretion optimisation method also employs the algorithm developed by Dennis (2007) where we allow expected future instruments to enter the optimisation constraints and that we base the algorithm on a framework in which the optimisation constraints are written in a structural form (A.1), not in a state-space form (Dennis, 2007).

Considering that the state variables are $\boldsymbol{y}_{t-1}$ and $\boldsymbol{v}_t$, we expect that the solution derived under discretion regime will also be functions of these variables. Hence, there are matrices $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$ and $\boldsymbol{F}_2$ that build solutions in the following process

$$\boldsymbol{y}_t = \boldsymbol{H}_1\boldsymbol{y}_{t-1} + \boldsymbol{H}_2\boldsymbol{v}_t \qquad \textbf{(A.17)}$$

$$\boldsymbol{x}_t = \boldsymbol{F}_1\boldsymbol{y}_{t-1} + \boldsymbol{F}_2\boldsymbol{v}_t. \qquad \textbf{(A.18)}$$

Substituting equations (A.17) and (A.18) to structural form (A.1) gives

$$\boldsymbol{D}\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \boldsymbol{A}_5\boldsymbol{v}_t, \qquad \textbf{(A.19)}$$

where

$$\boldsymbol{D} = \boldsymbol{A}_0 - \boldsymbol{A}_2\boldsymbol{H}_1 - \boldsymbol{A}_4\boldsymbol{F}_1. \qquad \textbf{(A.20)}$$

Furthermore, substituting equation (A.17) and (A.18) to the loss function (A.3) gives the loss function that expressed in terms of $\boldsymbol{y}_t, \boldsymbol{x}_t, \boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$ and $\boldsymbol{F}_2$, as follows

$$Loss = \boldsymbol{y}_t'\boldsymbol{P}\boldsymbol{y}_t + \boldsymbol{x}_t'\boldsymbol{Q}\boldsymbol{x}_t + \frac{\beta}{1-\beta}tr[(\boldsymbol{F}_2'\boldsymbol{Q}\boldsymbol{F}_2 + \boldsymbol{H}_2'\boldsymbol{P}\boldsymbol{H}_2)\boldsymbol{\Omega}], \qquad \textbf{(A.21)}$$

where

$$\boldsymbol{P} = \boldsymbol{W} + \beta(\boldsymbol{F}_1'\boldsymbol{Q}\boldsymbol{F}_1 + \boldsymbol{H}_1'\boldsymbol{P}\boldsymbol{H}_1). \qquad \textbf{(A.22)}$$

Next, replacing $\boldsymbol{y}_t$ in equation (A.21) using equation (A.19) produces the loss function as follows

$$Loss = (\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \boldsymbol{A}_5\boldsymbol{v}_t)'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \boldsymbol{A}_5\boldsymbol{v}_t)$$

$$+\boldsymbol{x}_t'\boldsymbol{Q}\boldsymbol{x}_t + \frac{\beta}{1-\beta}tr[(\boldsymbol{F}_2'\boldsymbol{Q}\boldsymbol{F}_2 + \boldsymbol{H}_2'\boldsymbol{P}\boldsymbol{H}_2)\boldsymbol{\Omega}]. \quad \textbf{(A.23)}$$

Furthermore, when policymaker optimiess a policy instrument to minimise a loss function, this is equal to differentiating equation (A.23) with respect to $\boldsymbol{x}_t$, which gives

$$\frac{\partial Loss}{\partial x_t} = \boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_5\boldsymbol{v}_t) + (\boldsymbol{Q} + \boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)\boldsymbol{x}_t = \boldsymbol{0}. \quad \textbf{(A.24)}$$

Rearranging equation (A.24) in terms of $\boldsymbol{x}_t$ gives

$$\boldsymbol{x}_t = -(\boldsymbol{Q} + \boldsymbol{A}_3'\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)^{-1}\boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_5\boldsymbol{v}_t). \quad \textbf{(A.25)}$$

Comparing equation (A.25) to equation (A.18) yield the evolutions for $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ as follows

$$\boldsymbol{F}_1 = -(\boldsymbol{Q} + \boldsymbol{A}_3'\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)^{-1}\boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_1 \quad \textbf{(A.26)}$$

$$\boldsymbol{F}_2 = -(\boldsymbol{Q} + \boldsymbol{A}_3'\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)^{-1}\boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_5. \quad \textbf{(A.27)}$$

Finally, substituting equation (A.22) to the solution equation (A.17) gives a new evolution for $\boldsymbol{y}_t$ as follows

$$\boldsymbol{y}_t = \boldsymbol{D}^{-1}(\boldsymbol{A}_1 + \boldsymbol{A}_3\boldsymbol{F}_1)\boldsymbol{y}_{t-1} + \boldsymbol{D}^{-1}(A_5 + \boldsymbol{A}_3\boldsymbol{F}_2)\boldsymbol{v}_t. \quad \textbf{(A.28)}$$

Comparing equation (A.28) to which is compared to (A.21) gives equations as follow

$$\boldsymbol{H}_1 = \boldsymbol{D}^{-1}(\boldsymbol{A}_1 + \boldsymbol{A}_3\boldsymbol{F}_1) \quad \textbf{(A.29)}$$

$$\boldsymbol{H}_2 = \boldsymbol{D}^{-1}(\boldsymbol{A}_5 + \boldsymbol{A}_3\boldsymbol{F}_2). \quad \textbf{(A.30)}$$

Finally, since $\boldsymbol{P}$ and $\boldsymbol{D}$ are implicit functions of $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$ and $\boldsymbol{F}_2$, the final solution (A.26), (A.27), (A.29), and (A.30) can be solved using an iterative procedure to find the fixed point between the matrices until converges. Finally, using the known $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2$ and $\boldsymbol{P}$, the evaluation of loss value under discretionary regime can be computed using equation (A.21). The iteration procedure taken can be executed in the following order:

Step 1. Initialise $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$ and $\boldsymbol{F}_2$.

Step 2. Solve $\boldsymbol{D}$ according to equation (A.20) and $\boldsymbol{P}$ according to equation (A.22).

Step 3. Update $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$ and $\boldsymbol{F}_2$ according to equation (A.26), (A.27), (A.29), and (A.30), respectively.

Step 4. Iterate over Steps 2 and 3 until convergence.

- **Simple Policy Rule Regime**

In the simple policy rule regime, the central bank is assumed to operate a simple policy rule in managing the policy instrument. Hence, no optimisation of policy instrument takes place in this regime. The system of equations is an ordinary rational expectation model with a simple policy rule that present within the system. The solution of this regime is matrices $\boldsymbol{H}_1$ and $\boldsymbol{H}_2$ that constructs the evolution of $\boldsymbol{z}_t$ as follows

$$\boldsymbol{z}_t = \boldsymbol{H}_1 \boldsymbol{z}_{t-1} + \boldsymbol{H}_2 \boldsymbol{v}_t, \tag{A.31}$$

where $\boldsymbol{z}_t = [\,\boldsymbol{y}_t{}' \;\; \boldsymbol{x}_t{}']'$, is a vector that contains all endogenous variables and policy instrument. Finally, the loss value for this regime is evaluated using

$$Loss = \sum_{t=0}^{\infty} \beta^t \, \boldsymbol{z}_t' \boldsymbol{W} \boldsymbol{z}_t \tag{A.32}$$

where $\boldsymbol{W}$ is a welfare matrix.

- **Independent Simultaneous Regime**

This regime explains a situation when the central bank optimises two policy instruments simultaneously where each policy pursues different objective functions. Suppose there are two macro policies: monetary policy ($P1$) and quantitative easing policy ($P2$). The central bank is assumed to minimise loss function $Loss^{P1}$ for monetary policy, and $Loss^{P2}$ for quantitative easing policy with their formulas as follow

$$Loss^{P1} = E_0 \textstyle\sum_{t=0}^{\infty} \beta^t (\boldsymbol{y}_t' \boldsymbol{W} \boldsymbol{y}_t + \boldsymbol{x}_t' \boldsymbol{Q}_1 \boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t' \boldsymbol{Q}_2 \widetilde{\boldsymbol{x}}_t) \tag{A.33}$$

$$Loss^{P2} = E_0 \textstyle\sum_{t=0}^{\infty} \widetilde{\beta}^t (\boldsymbol{y}_t' \widetilde{\boldsymbol{W}} \boldsymbol{y}_t + \boldsymbol{x}_t' \widetilde{\boldsymbol{Q}}_1 \boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t' \widetilde{\boldsymbol{Q}}_2 \widetilde{\boldsymbol{x}}_t) \tag{A.34}$$

where $\boldsymbol{W}$ denotes the welfare matrix, $\boldsymbol{Q}_1$ denotes the weight for monetary policy instrument, and $\boldsymbol{Q}_2$ denotes the weight for quantitative easing policy instrument[7].

Under simultaneous movement, the solution method is to find matrix $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1$ and $\widetilde{\boldsymbol{F}}_2$ such that

$$\boldsymbol{y}_t = \boldsymbol{H}_1 \boldsymbol{y}_{t-1} + \boldsymbol{H}_2 \boldsymbol{v}_t \tag{A.35}$$

$$\boldsymbol{x}_t = \boldsymbol{F}_1 \boldsymbol{y}_{t-1} + \boldsymbol{F}_2 \boldsymbol{v}_t \tag{A.36}$$

$$\widetilde{\boldsymbol{x}}_t = \widetilde{\boldsymbol{F}}_1 y_{t-1} + \widetilde{\boldsymbol{F}}_2 v_t. \tag{A.37}$$

Substituting equations (A.35) – (A.37) into the structural model form (A.2) gives a relationship as follow

$$\boldsymbol{D} \boldsymbol{y}_t = \boldsymbol{A}_1 \boldsymbol{y}_{t-1} + \boldsymbol{A}_3 \boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3 \widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5 \boldsymbol{v}_t, \tag{A.38}$$

where

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[7] $\widetilde{\boldsymbol{W}}$ is the welfare matrix that quantitative easing pursues; $\widetilde{\boldsymbol{Q}}_1$ is the weight on monetary policy instrument that quantitative easing policy assign on its loss function; $\widetilde{\boldsymbol{Q}}_2$ is the wright on quantitative easing instrument that quantitative easing policy sets on its own loss function. If the two authorities cooperate then $W = \widetilde{W}$, $Q_1 = \widetilde{Q}_1$ and $Q_2 = \widetilde{Q}_2$.

$$\boldsymbol{D} = \boldsymbol{A}_0 - \boldsymbol{A}_2\boldsymbol{H}_1 - \boldsymbol{A}_4\boldsymbol{F}_1 - \widetilde{\boldsymbol{A}}_4\widetilde{\boldsymbol{F}}_1. \tag{A.39}$$

Further, expressing the loss function (A.33) and (A.34) in terms of $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1$ and $\widetilde{\boldsymbol{F}}_2$ using the equations (A.35) - (A.37) gives the equation of loss function as follow

$$Loss^{P1} = (\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t)'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t) + \boldsymbol{x}_t'\boldsymbol{Q}_1\boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t'\boldsymbol{Q}_2\widetilde{\boldsymbol{x}}_t + \frac{\beta}{1-\beta}tr\left[\left(\boldsymbol{F}_2'\boldsymbol{Q}_1\boldsymbol{F}_2 + \widetilde{\boldsymbol{F}}_2'\boldsymbol{Q}_2\widetilde{\boldsymbol{F}}_2 + \boldsymbol{H}_2\boldsymbol{P}\boldsymbol{H}_2\right)\boldsymbol{\Omega}\right] \tag{A.40}$$

$$Loss^{P2} = (\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t)'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t) + \boldsymbol{x}_t'\widetilde{\boldsymbol{Q}}_1\boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t'\widetilde{\boldsymbol{Q}}_2\widetilde{\boldsymbol{x}}_t + \frac{\beta}{1-\beta}tr\left[\left(\boldsymbol{F}_2'\widetilde{\boldsymbol{Q}}_1\boldsymbol{F}_2 + \widetilde{\boldsymbol{F}}_2'\widetilde{\boldsymbol{Q}}_2\widetilde{\boldsymbol{F}}_2 + \boldsymbol{H}_2\widetilde{\boldsymbol{P}}\boldsymbol{H}_2\right)\boldsymbol{\Omega}\right]. \tag{A.41}$$

where

$$\boldsymbol{P} = \boldsymbol{W} + \beta(\boldsymbol{F}_1'\boldsymbol{Q}_1\boldsymbol{F}_1 + \widetilde{\boldsymbol{F}}_1'\boldsymbol{Q}_2\widetilde{\boldsymbol{F}}_1 + \boldsymbol{H}_1'\boldsymbol{P}\boldsymbol{H}_1) \tag{A.42}$$

$$\widetilde{\boldsymbol{P}} = \widetilde{\boldsymbol{W}} + \beta\left(\boldsymbol{F}_1'\widetilde{\boldsymbol{Q}}_1\boldsymbol{F}_1 + \widetilde{\boldsymbol{F}}_1'\widetilde{\boldsymbol{Q}}_2\widetilde{\boldsymbol{F}}_1 + \boldsymbol{H}_1'\widetilde{\boldsymbol{P}}\boldsymbol{H}_1\right). \tag{A.43}$$

Differentiating the two loss functions above with respect to $\boldsymbol{x}_t$ will result

$$\frac{\partial Loss^{P1}}{\partial \boldsymbol{x}_t} = \boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t) + \boldsymbol{Q}_1\boldsymbol{x}_t = 0 \tag{A.44}$$

$$\frac{\partial Loss^{P2}}{\partial \widetilde{\boldsymbol{x}}_t} = \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t) + \widetilde{\boldsymbol{Q}}_2\boldsymbol{x}_t = 0 \tag{A.45}$$

Comparing (A.35) and (A.36) to the solution (A.44) and (A.45) gives solutions for F_1, $F_2, \tilde{F}_1, \tilde{F}_2$ as follow

$$\boldsymbol{F}_1 = -(\boldsymbol{Q}_1 + \boldsymbol{A}_3'\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)^{-1}\boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_1) \tag{A.46}$$

$$\boldsymbol{F}_2 = -(\boldsymbol{Q}_1 + \boldsymbol{A}_3'\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\boldsymbol{A}_3)^{-1}\boldsymbol{A}_3'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_5 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_2) \tag{A.47}$$

$$\widetilde{\boldsymbol{F}}_1 = -\left(\widetilde{\boldsymbol{Q}}_2 + \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\widetilde{\boldsymbol{A}}_3\right)^{-1}\widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\boldsymbol{A}_1 \tag{A.48}$$

$$\widetilde{\boldsymbol{F}}_2 = -\left(\widetilde{\boldsymbol{Q}}_2 + \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\widetilde{\boldsymbol{A}}_3\right)^{-1}\widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\boldsymbol{A}_5 \tag{A.49}$$

Furthermore, substituting (A.48) and (A.49) back to equation (A.38), respectively, gives the solution as follow

$$\boldsymbol{H}_1 = \boldsymbol{D}^{-1}\left(\boldsymbol{A}_1 + \boldsymbol{A}_3\boldsymbol{F}_1 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_1\right) \tag{A.50}$$

$$\boldsymbol{H}_2 = \boldsymbol{D}^{-1}\left(\boldsymbol{A}_5 + \boldsymbol{A}_3\boldsymbol{F}_2 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_2\right) \tag{A.51}$$

Given that the matrices $\boldsymbol{F}$ contains $\boldsymbol{P}$, and vice versa, the iterative procedure can be taken to derive the converged solution. The iterative procedure can be taken using the following steps:

Step 1. Initialise $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1$ and $\widetilde{\boldsymbol{F}}_2$.

Step 2. Solve $\boldsymbol{D}$ according to equation (A.39), $\boldsymbol{P}$ according to equation (A.42), and $\widetilde{\boldsymbol{P}}$ according to equation (A.43)

Step 3. Update $\boldsymbol{H}_1$ according to (A.50); $\boldsymbol{H}_2$ according to (A.51); $\boldsymbol{F}_1$ according to (A.46); $\boldsymbol{F}_2$ according to (A.47) ; $\widetilde{\boldsymbol{F}}_1$ according to (A.48); $\widetilde{\boldsymbol{F}}_2$ according to (A.49)

Step 4. Iterate over Steps 2 – 4 until convergence.

Finally, given the known $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1$ and $\widetilde{\boldsymbol{F}}_2$, the evaluaton of loss value is conducted by substituting the known matrices into equations (A.57) and (A.58).

- **Independent Leadership Regime**

In this regime, the central bank assumes to optimise two different policy instruments sequentially. That is, one policy moves first after the other. The policy that moves earlier is called as a leader, while the policy moves after is called as a follower. The follower optimises by taking information on the policy instrument of the first mover. The loss function that the two policies pursue are not alike. Suppose the first policy pursues loss function (A.33) while the second policy pursues to minimise loss function (A.34). Suppose the leader's policy instrument is $\boldsymbol{x}_t$ and the follower's policy instrument movement is $\widetilde{\boldsymbol{x}}_t$. Thus, the solution under this regime is the evolution of endogenous variables $\boldsymbol{y}_t$ and policy instruments, $\boldsymbol{x}_t$ and $\widetilde{\boldsymbol{x}}_t$, such that

$$\boldsymbol{y}_t = \boldsymbol{H}_1\boldsymbol{y}_{t-1} + \boldsymbol{H}_2\boldsymbol{v}_t \tag{A.52}$$

$$\boldsymbol{x}_t = \boldsymbol{F}_1\boldsymbol{y}_{t-1} + \boldsymbol{F}_2\boldsymbol{v}_t \tag{A.53}$$

$$\widetilde{\boldsymbol{x}}_t = \widetilde{\boldsymbol{F}}_1\boldsymbol{y}_{t-1} + \widetilde{\boldsymbol{F}}_2\boldsymbol{v}_t + \boldsymbol{L}\boldsymbol{x}_t \tag{A.54}$$

where, as shown in equation (2.54), the policy instrument of the follower $\widetilde{\boldsymbol{x}}_t$ is now defined as the function of the policy instrument of the leader $\boldsymbol{x}_t$. The matrix $\boldsymbol{L}$ in equation (A.54) indicates a relationship between the two policy instruments. Substituting equation (A.52) – (A.54) into the structural form equation (A.2) gives the equation as follows:

$$\boldsymbol{D}\boldsymbol{y}_t = \boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3\boldsymbol{x}_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t, \tag{A.55}$$

where

$$\boldsymbol{D} = \boldsymbol{A}_0 - \boldsymbol{A}_2\boldsymbol{H}_1 - \boldsymbol{A}_4\boldsymbol{F}_1 - \widetilde{\boldsymbol{A}}_4\widetilde{\boldsymbol{F}}_1 - \widetilde{\boldsymbol{A}}_4\boldsymbol{L}\boldsymbol{F}_1. \tag{A.56}$$

Furthermore, substituting the solution (A.52) – (A.54) to the loss functions (A.33) and (A.34) provides the loss functions expressed in terms of $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1, \widetilde{\boldsymbol{F}}_2$ and $\boldsymbol{L}$ as follows:

$$Loss^{P1} = \boldsymbol{y}_t'\boldsymbol{P}\boldsymbol{y}_t + \boldsymbol{x}_t'\boldsymbol{Q}_1\boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t'\boldsymbol{Q}_2\widetilde{\boldsymbol{x}}_t + \frac{\beta}{1-\beta}tr\big[\big(\boldsymbol{F}_2'\boldsymbol{Q}_1\boldsymbol{F}_2 + (\widetilde{\boldsymbol{F}}_2' + \boldsymbol{L}\boldsymbol{F}_2)'\boldsymbol{Q}_2\big(\widetilde{\boldsymbol{F}}_2 + \boldsymbol{L}\boldsymbol{F}_2\big) + \boldsymbol{H}_2'\boldsymbol{P}\boldsymbol{H}_2\big)\boldsymbol{\Omega}\big] \tag{A.57}$$

$$Loss^{P2} = \boldsymbol{y}_t'\widetilde{\boldsymbol{P}}\boldsymbol{y}_t + \boldsymbol{x}_t'\widetilde{\boldsymbol{Q}}_1\boldsymbol{x}_t + \widetilde{\boldsymbol{x}}_t'\widetilde{\boldsymbol{Q}}_2\widetilde{\boldsymbol{x}}_t + \frac{\widetilde{\beta}}{1-\widetilde{\beta}}tr\big[\big(\boldsymbol{F}_2'\widetilde{\boldsymbol{Q}}_1F_2 + (\widetilde{\boldsymbol{F}}_2' + \boldsymbol{L}\boldsymbol{F}_2)'\widetilde{\boldsymbol{Q}}_2\big(\widetilde{\boldsymbol{F}}_2 + \boldsymbol{L}\boldsymbol{F}_2\big) + \boldsymbol{H}_2'\widetilde{\boldsymbol{P}}\boldsymbol{H}_2\big)\boldsymbol{\Omega}\big], \tag{A.58}$$

where

$$\boldsymbol{P} = \boldsymbol{W} + \beta\big(\boldsymbol{F}_1'\boldsymbol{Q}_1\boldsymbol{F}_1 + \widetilde{\boldsymbol{F}}_1'\boldsymbol{Q}_2\widetilde{\boldsymbol{F}}_1 + \boldsymbol{H}_1'\boldsymbol{P}\boldsymbol{H}_1\big), \qquad \textbf{(A.59)}$$

$$\widetilde{\boldsymbol{P}} = \widetilde{\boldsymbol{W}} + \tilde{\beta}\big(\boldsymbol{F}_1'\widetilde{\boldsymbol{Q}}_1\boldsymbol{F}_1 + (\widetilde{\boldsymbol{F}}_1' + \boldsymbol{L}\boldsymbol{F}_1)\widetilde{\boldsymbol{Q}}_2(\widetilde{\boldsymbol{F}}_1' + \boldsymbol{L}\boldsymbol{F}_1) + \boldsymbol{H}_1'\widetilde{\boldsymbol{P}}\boldsymbol{H}_1\big). \qquad \textbf{(A.60)}$$

Furthermore, differentiating equations (A.57) and (A.58) with respect to $\boldsymbol{x}_t$ and $\widetilde{\boldsymbol{x}}_t$, respectively, gives

$$\frac{\partial Loss^{P1}}{\partial \boldsymbol{x}_t} = (\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}((\boldsymbol{A}_1 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_1)\,\boldsymbol{y}_{t-1} + (\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})\boldsymbol{x}_t + (\boldsymbol{A}_5 +$$

$$\widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_2)\boldsymbol{v}_t) + \boldsymbol{Q}_1\boldsymbol{x}_t + \boldsymbol{L}'\boldsymbol{Q}_2(\widetilde{\boldsymbol{F}}_1\boldsymbol{y}_{t-1} + \widetilde{\boldsymbol{F}}_2\boldsymbol{v}_t + \boldsymbol{L}\boldsymbol{x}_t) = \boldsymbol{0}, \qquad \textbf{(A.61)}$$

$$\frac{\partial Loss^{P2}}{\partial \widetilde{\boldsymbol{x}}_t} = \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}(\boldsymbol{A}_1\boldsymbol{y}_{t-1} + \boldsymbol{A}_3 x_t + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{x}}_t + \boldsymbol{A}_5\boldsymbol{v}_t) + \widetilde{\boldsymbol{Q}}_2\boldsymbol{x}_t = \boldsymbol{0}. \qquad \textbf{(A.62)}$$

Next, comparing equation (A.61) to the solution equation (A.53) results in the specification for $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ as follows:

$$\boldsymbol{F}_1 = -\big(\boldsymbol{Q}_1 + \boldsymbol{L}'\boldsymbol{Q}_2\boldsymbol{L} + (\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\,\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}((\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\big)^{-1}$$

$$\times\ (\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}(\boldsymbol{A}_1 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_1) + \boldsymbol{L}'\boldsymbol{Q}_2\widetilde{\boldsymbol{F}}_1 \qquad \textbf{(A.63)}$$

$$\boldsymbol{F}_2 = -\big(\boldsymbol{Q}_1 + \boldsymbol{L}'\boldsymbol{Q}_2\boldsymbol{L} + (\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\,\boldsymbol{D}^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}((\boldsymbol{A}_3 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\big)^{-1}$$

$$\times (\boldsymbol{A}_1 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L})'\boldsymbol{D}'^{-1}\boldsymbol{P}\boldsymbol{D}^{-1}\big(\boldsymbol{A}_5 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_2\big) + \boldsymbol{L}'\boldsymbol{Q}_2\widetilde{\boldsymbol{F}}_2\,. \qquad \textbf{(A.64)}$$

Furthermore, comparing equation (A.62) to the solution equation (A.54) results in the equations for $\widetilde{\boldsymbol{F}}_1$, $\widetilde{\boldsymbol{F}}_2$ and $\boldsymbol{L}$ as follows:

$$\widetilde{\boldsymbol{F}}_1 = -\big(\widetilde{\boldsymbol{Q}}_2 + \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\widetilde{\boldsymbol{A}}_3\big)^{-1}\widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\boldsymbol{A}_1, \qquad \textbf{(A.65)}$$

$$\widetilde{\boldsymbol{F}}_2 = -\big(\widetilde{\boldsymbol{Q}}_2 + \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\widetilde{\boldsymbol{A}}_3\big)^{-1}\widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\boldsymbol{A}_5, \qquad \textbf{(A.66)}$$

$$\boldsymbol{L} = -\big(\widetilde{\boldsymbol{Q}}_2 + \widetilde{\boldsymbol{A}}_3'\boldsymbol{D}^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\widetilde{\boldsymbol{A}}_3\big)^{-1}\widetilde{\boldsymbol{A}}_3'\boldsymbol{D}'^{-1}\widetilde{\boldsymbol{P}}\boldsymbol{D}^{-1}\boldsymbol{A}_3. \qquad \textbf{(A.67)}$$

Finally, substituting the equations (A.65) and (A.66) back to equation (A.55) will produce the equations of $\boldsymbol{H}_1$ and $\boldsymbol{H}_2$ as follows:

$$\boldsymbol{H}_1 = \boldsymbol{D}^{-1}\big(\boldsymbol{A}_1 + \boldsymbol{A}_3\boldsymbol{F}_1 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_1 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L}\boldsymbol{F}_1\big), \qquad \textbf{(A.68)}$$

$$\boldsymbol{H}_2 = \boldsymbol{D}^{-1}\big(\boldsymbol{A}_5 + \boldsymbol{A}_3\boldsymbol{F}_2 + \widetilde{\boldsymbol{A}}_3\widetilde{\boldsymbol{F}}_2 + \widetilde{\boldsymbol{A}}_3\boldsymbol{L}\boldsymbol{F}_2\big). \qquad \textbf{(A.69)}$$

Given that the matrices $\boldsymbol{F}$ contains $\boldsymbol{P}$, and vice versa, the iterative procedure can be taken to derive the converged solution. The iterative procedure can be taken in the following steps:

Step 1. Initialise $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1, \boldsymbol{F}_2, \widetilde{\boldsymbol{F}}_1, \widetilde{\boldsymbol{F}}_2$ and $\boldsymbol{L}$.

Step 2. Solve $\boldsymbol{D}$ according to equation (A.56), $\boldsymbol{P}$ according to equation (A.59), and $\widetilde{\boldsymbol{P}}$ according to equation (A.60)

Step 3. Update $\boldsymbol{H}_1$ according to (A.68); $\boldsymbol{H}_2$ according to (A.69); $\boldsymbol{F}_1$ according to (A.63); $\boldsymbol{F}_2$ according to (A.64) ; $\widetilde{\boldsymbol{F}}_1$ according to (A.65); $\widetilde{\boldsymbol{F}}_2$ according to (A.66), and $\boldsymbol{L}$ according to (A.67).

Step 4. Iterate over steps 2 – 4 until convergence.

Finally, given the known $\boldsymbol{H}_1, \boldsymbol{H}_2, \boldsymbol{F}_1$, $\boldsymbol{F}_2$, $\widetilde{\boldsymbol{F}}_1$, $\widetilde{\boldsymbol{F}}_2$ and $\boldsymbol{L}$, the evaluaton of loss value is conducted by substituting the known matrices into equations (A.57) and (A.58).

- **Cooperating Leadership Regime**

This regime explains a situation when a central bank implements two policies that pursue the identical objective function but one policy is optimized before the other. The algorithm in solving this regime is similar to that of the independent leadership regime, except now the loss function between the two policies is identical. Precisely, suppose the first policy minimizes loss function (A.33) and the second policy minimizes the loss function (A.34), the cooperation exists when $\boldsymbol{W} = \widetilde{\boldsymbol{W}}$, $\boldsymbol{Q}_1 = \widetilde{\boldsymbol{Q}}_1$, and $\boldsymbol{Q}_2 = \widetilde{\boldsymbol{Q}}_2$. Accordingly, equation (A.52) to (A.69) are employed to derive the optimal solution for this regime.

Solving the Optimal Simple Policy Rule Under Commitment

The solution method used in this study follows the method to find the optimal simple policy rules in rational expectation model from Dennis (2004). The method introduces the algorithm to derive the optimal simple policy rule under two regimes: commitment and discretion regime. In commitment regime, the policymaker is assumed committed to the optimised simple rule in the first period and implement it in all subsequent periods. Hence, the policymaker never re-optimises the feedback coefficient in the rule throughout periods. On the contrary, under discretionary regime the policymaker is assumed to always optimise the rule period-by-period by assuming that the subsequent policymakers will also behave the same. This study only focuses on building the optimal simple rule under commitment.

The algorithm on finding optimal simple rule is applied under the structural form of economy given by

$$\boldsymbol{A}_0 y_t = \boldsymbol{A}_1 y_{t-1} + \boldsymbol{A}_2 E_t \boldsymbol{y}_{t+1} + \boldsymbol{A}_3 \boldsymbol{x}_t + \boldsymbol{A}_4 E_t \boldsymbol{x}_{t+1} + \boldsymbol{A}_5 \boldsymbol{v}_t \,, \qquad (\mathbf{A.70})$$

where matrix $\boldsymbol{A}_0, \boldsymbol{A}_1, \boldsymbol{A}_2, \boldsymbol{A}_3, \boldsymbol{A}_4$ and $\boldsymbol{A}_5$ contains the model structural parameters, $\boldsymbol{y}_t$ is the vector of endogenous variables, $\boldsymbol{x}_t$ denotes the vector of policy instrument, v_t is the vector of stochastic disturbances where $\boldsymbol{v}_t \sim i.i.d.[0, \boldsymbol{\Omega}]$ and $\boldsymbol{\Omega}$ is the variance covariance matrix of structural shock. Ideally, if there are two policy instruments, the vector $\boldsymbol{x}_t$ should contain two policy instruments. However, the development of simple rule in this study is only conducted for macroprudential policy instrument, such that only one policy instrument, i.e.

the credit injection ratio, lies in vector $\boldsymbol{x}_t$ and $\boldsymbol{x}_{t+1}$. Suppose the simple rule is considered to be given in the following form

$$\boldsymbol{x}_t = \boldsymbol{\varphi}_1 \boldsymbol{y}_{t-1} + \boldsymbol{\varphi}_2 \boldsymbol{y}_t + \boldsymbol{\varphi}_3 E_t \boldsymbol{y}_{t+1} + \varphi_4 \boldsymbol{v}_t, \qquad \textbf{(A.71)}$$

where $\boldsymbol{x}_t$ denotes the policy instrument at period t, which is the the credit injection ratio in this study. Furthermore, $\boldsymbol{\varphi}_1$- $\boldsymbol{\varphi}_4$ are the feedback coefficient in the simple rule which can be expressed as the set of free parameters $\boldsymbol{\varphi} = [\boldsymbol{\varphi}_1\ \boldsymbol{\varphi}_2\ \boldsymbol{\varphi}_3\ \boldsymbol{\varphi}_4]$.

Under the commitment regime, the loss function is constructed in the following way

$$Loss^{pc} = \sum_{t=0}^{\infty} \beta^t [\boldsymbol{y}_t' \boldsymbol{W} \boldsymbol{y}_t + \boldsymbol{x}_t' \boldsymbol{Q} \boldsymbol{x}_t], \qquad \textbf{(A.72)}$$

where $\boldsymbol{W}$ is the welfare matrix and $\boldsymbol{Q}$ is the weight matrix given to the policy instrument. Under this study, the welfare matrix is an ad-hoc loss function which contains the deviation of inflation, output and credit spread from their steady state. On the other hand, $\boldsymbol{Q}$ is the weight given to the the credit injection ratio. Solving the pre-commitment regime involves combining the equation **(A.70)** and **(A.71)** into the form as follows

$$\begin{bmatrix} \boldsymbol{A}_0 & -\boldsymbol{A}_3 \\ -\boldsymbol{\varphi}_2 & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \boldsymbol{y}_t \\ \boldsymbol{x}_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{A}_1 & \boldsymbol{0} \\ \boldsymbol{\varphi}_1 & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{y}_{t-1} \\ \boldsymbol{x}_{t-1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{A}_2 & \boldsymbol{A}_4 \\ \boldsymbol{\varphi}_3 & \boldsymbol{0} \end{bmatrix} E_t \begin{bmatrix} \boldsymbol{y}_{t+1} \\ \boldsymbol{x}_{t+1} \end{bmatrix} + \begin{bmatrix} \boldsymbol{A}_5 & 0 \\ \boldsymbol{\varphi}_4 & 0 \end{bmatrix} \begin{bmatrix} \boldsymbol{v}_t \\ 0 \end{bmatrix}, \qquad \textbf{(A.73)}$$

which can be simplified into

$$\boldsymbol{B}_0 \boldsymbol{z}_t = \boldsymbol{B}_1 \boldsymbol{z}_{t-1} + \boldsymbol{B}_2 E_t \boldsymbol{z}_{t+1} + \boldsymbol{B}_4 \boldsymbol{\eta}_t, \qquad \textbf{(A.74)}$$

where $\boldsymbol{\eta}_t = [\boldsymbol{v}_t\ \boldsymbol{0}]'$ has variance-covariance matrix $\boldsymbol{\Omega}$. Solving equation (A.73) using the standard rational expectation solution method produces the solution as follow

$$\boldsymbol{z}_t = \boldsymbol{\theta}_1 \boldsymbol{z}_{t-1} + \boldsymbol{\theta}_2 \boldsymbol{\eta}_t, \qquad \textbf{(A.75)}$$

where $\boldsymbol{\theta}_1$ and $\boldsymbol{\theta}_2$ contain the cross-equation restrictions implied by rational expectations. The simplification of $\boldsymbol{z}_t = [\boldsymbol{y}_t'\ \ \boldsymbol{x}_t']'$ also affects the loss function, which now can be given as

$$Loss^{pc} = \sum_{t=0}^{\infty} \beta^t\, \boldsymbol{z}_{t-1}' \widetilde{\boldsymbol{W}} \boldsymbol{z}_{t-1}, \qquad \textbf{(A.76)}$$

where

$$\widetilde{\boldsymbol{W}} = \begin{bmatrix} \boldsymbol{W} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{Q} \end{bmatrix}. \qquad \textbf{(A.77)}$$

Furthermore, combining equation (A.75) and (A.76) gives the formula of loss function in terms of the set of free parameters $\boldsymbol{\varphi}$, which is given by

$$Loss^{pc}(\boldsymbol{\varphi}) = \sum_{j=0}^{\infty} \left[\beta^j \boldsymbol{z}_{t-1}' \boldsymbol{\theta}_1'^{j} \widetilde{W} \boldsymbol{\theta}_1^j \boldsymbol{z}_{t-1} + \sum_{k=j}^{\infty} \beta^{k+1} tr\left(\boldsymbol{\theta}_2' \boldsymbol{\theta}_1'^{j} \widetilde{\boldsymbol{W}} \boldsymbol{\theta}_1^j \boldsymbol{\theta}_2 \boldsymbol{\Omega}\right) \right], \qquad \textbf{(A.78)}$$

where for β lies between 0 and 1, it ensures the geometric sums in equation (A.78) converges and the recursive equilibrium law motion equation (A.80) is stable. Next, equation (A.78) can be further simplified into

$$Loss^{pc}(\boldsymbol{\varphi}) = \boldsymbol{z}'_{t-1}\boldsymbol{P}\boldsymbol{z}_{t-1} + \frac{\beta}{(1-\beta)} tr[\boldsymbol{\theta}'_2\boldsymbol{P}\boldsymbol{\theta}_2\boldsymbol{\Omega}], \qquad \textbf{(A.79)}$$

where P is the fix point of

$$\boldsymbol{P} = \widetilde{\boldsymbol{W}} + \beta\boldsymbol{\theta}'_1\boldsymbol{P}\boldsymbol{\theta}_1 \qquad \textbf{(A.80)}$$

and $\boldsymbol{z}_t$ is the initial state of the economy, where it is assumed as the deviation of endogenous variables from their steady states. The computation steps to solve for optimal simple pre-commitment rules can be arranged as follows:

Step 1. The initial values for the free parameters in $\boldsymbol{\varphi} = [\boldsymbol{\varphi}_1\ \boldsymbol{\varphi}_2\ \boldsymbol{\varphi}_3\ \boldsymbol{\varphi}_4]$ are chosen.

Step 2. Given $\boldsymbol{\varphi}$, the $\boldsymbol{\theta}_1$ and $\boldsymbol{\theta}_2$ are solved using the standard rational expectation solution method.

Step 3. Given $\boldsymbol{\theta}_1$ and $\boldsymbol{\theta}_2$, the loss function $Loss^{pc}(\boldsymbol{\varphi})$ is then evaluated according to equation (2.78).

Step 4. The values of free parameters φ are then searched numerically to find the smallest possible loss $Loss^{pc}(\boldsymbol{\varphi})$.

APPENDIX B

This appendix provides the complete set of equation used for the simulation in chapter 3 and chapter 4. This set of equations is adopted from the original dynare code of the reference model Gertler and Karadi (2011).

HOUSEHOLD

1. Marginal utility of consumption (ϱ_t)

$$\varrho_t = (C_t - hC_{t-1})^{-1} - \beta h E_t (C_{t+1} - hC_t)^{-1}, \qquad \textbf{(B.1)}$$

2. Real interest rate on deposit (R_t)

$$R_t = \frac{1}{\beta \Lambda_{t,t+1}} \qquad \textbf{(B.2)}$$

3. Stochastic discount rate ($\Lambda_{t,\mathrm{t}+1}$)

$$\Lambda_{t,t+1} \equiv \frac{E(\varrho_{t+1})}{\varrho_t} \qquad \textbf{(B.3)}$$

4. Labor market equilibrium (L_t)

$$L_t^{\varphi} = \frac{(1-\alpha)\varrho_t P_{mt} Y_t}{\chi} \qquad \textbf{(B.4)}$$

FINANCIAL INTERMEDIARIES

5. Value of banks' capital (v_t)

$$v_t = E_t\{(1-\theta)\beta\Lambda_{t,t+1}E(R_{kt+1} - R_t) + \theta\beta\Lambda_{t,t+1}x_{t,t+1}E(v_{t+1})\} \qquad \textbf{(B.5)}$$

6. Value of banks' net wealth (η_t)

$$\eta_t = (1-\theta) + \beta\Lambda_{t,t+1}\theta z_{t+1}E(\eta_{t+1}) \qquad \textbf{(B.6)}$$

7. Optimal Leverage (ϕ_t)

$$\phi_t = \frac{\eta_t}{(\lambda - v_t)(1-\psi_t)} \qquad \textbf{(B.7)}$$

8. Growth rate of banks' capital ($z_{t,t+1}$)

$$z_{t,t+1} = E(R_{kt+1} - R_t)(1-\psi_t)\phi_t + R_t \qquad \textbf{(B.8)}$$

9. Growth of banks’ net wealth ($x_{t,t+1}$)

$$x_{t,t+1} = \frac{E(Q_{t+1}S_{t+1})}{Q_tS_t} = \left(\frac{E(\phi_{t+1})}{\phi_t}\right) z_{t,t+1} \tag{B.9}$$

10. Aggregate capital (Credit) (K_t)

$$K_t = \frac{\phi_t N_t}{Q_t} \tag{B.10}$$

11. Bank Net worth (N_t)

$$N_t = N_t^e + N_t^n \tag{B.11}$$

12. Existing banks net worth accumulation (N_t^e)

$$N_t^e = \theta z_t N_t \varepsilon_t^N \tag{B.12}$$

13. New banks’ net worth (N_t^n)

$$N_t^n = \omega(1-\psi_{t-1})Q_t\xi_t K_{t-1} \tag{B.13}$$

INTERMEDIATE GOOD PRODUCERS

14. Return to Capital (R_{kt})

$$R_{kt} = \frac{P_{mt}\alpha Y_{mt}}{K_{t-1}Q_{t-1}} + \frac{\xi_t}{Q_{t-1}}\left(Q_t - \delta(U_t)\right) \tag{B.14}$$

15. Production function (Y_{mt})

$$Y_{mt} = A_t(U_t\xi_t K_{t-1})^{\alpha} L_t^{1-\alpha} \tag{B.15}$$

CAPITAL GOODS PRODUCER

16. Capital price (Q_t)

$$Q_t = 1 + \frac{\eta_i}{2}\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}} - 1\right)^2 + \eta_i\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}} - 1\right)\left(\frac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}}\right)$$

$$-E_t\left[\beta\Lambda_{t,t+1}\eta_i\left(\frac{E(I_{nt+1})+I_{ss}}{I_{nt}+I_{ss}} - 1\right)\left(\frac{E(I_{nt+1})+I_{ss}}{I_{nt}+I_{ss}}\right)^2\right] \tag{B.16}$$

17. Depreciation rate ($\delta(U_t)$)

$$\delta(U_t) = \delta_c + \frac{\partial_\delta}{1+\zeta}U_t^{(1+\zeta)} \tag{B.17}$$

18. Optimal capacity utilization rate (U_t)

$$U_t^{(1+\eta)} = \frac{P_{mt}\alpha Y_{mt}}{\partial_\delta \xi_t K_{t-1}} \tag{B.18}$$

19. Net investment (I_{nt})

$$I_{nt} \equiv I_t - \delta(U_t)\xi_t K_{t-1} \tag{B.19}$$

20. Investment (I_t)

$$I_t = K_t - K_{t-1}\xi_t(1 - \delta(U_t)). \tag{B.20}$$

GOVERNMENT

21. Government consumption (G_t)

$$G_t = G_{ss} \tag{B.21}$$

EQUILIBRIUM

22. Total output (Y_t)

$$Y_t = C_t + I_t + G_t + \tau\psi_t Q_t K_t + (\tfrac{I_{nt}+I_{ss}}{I_{nt-1}+I_{ss}} - 1)^2(I_{nt} + I_{ss}) \tag{B.22}$$

24. Price dispersion (D_t)

$$D_t = \frac{Y_{mt}}{Y_t} \tag{B.23}$$

25. Intermediate goods price (P_{mt})

$$P_{mt} = \frac{1}{MC_t} \tag{B.24}$$

26. Optimal price choice I (F_t)

$$F_t = Y_t P_{mt} + \beta\gamma\Lambda_{t,t+1}E(\pi_{t+1}^{\varepsilon})\pi_t^{-\varepsilon\gamma_p}E(F_{t+1}) \tag{B.25}$$

27. Optimal price choice II (Z_t)

$$Z_t = Y_t + \beta\gamma\Lambda_{t,t+1}E\left(\pi_{t+1}^{(\varepsilon-1)}\right)\pi_t^{\gamma_p(1-\varepsilon)}E(Z_{t+1}) \tag{B.26}$$

28. Optimal price choice III (π_t^*)

$$\pi_t^* = \left(\tfrac{\varepsilon}{\varepsilon-1}\right)\left(\tfrac{F_t}{Z_t}\right)\pi_t \tag{B.27}$$

29. Price Index (π_t)

$$\pi_t^{(1-\varepsilon)} = \gamma\pi_{t-1}^{\gamma_p(1-\varepsilon)} + (1-\gamma)\pi_t^{*(1-\varepsilon)} \tag{B.28}$$

30. Nominal interest rate (R_{nt})

$$R_{nt} = R_t E_t(\pi_{t+1}) \tag{B.29}$$

31. Marginal cost (MC_t)

$$\left(\frac{MC_t}{\left(\frac{\varepsilon}{\varepsilon-1}\right)}\right)^{\kappa_y} = \left(\frac{\beta}{\pi_t^{\kappa_\pi}}\right)\left(\frac{R_{nt}}{R_{nt-1}^{\rho}}\right)^{\frac{1}{1-\rho}} \qquad (\mathbf{B.30})$$

32. Credit injection ratio (ψ_t)

$$\psi_t = \psi + \kappa\big(log(R_{kt+1}) - log(R_t) - (logR_k - logR)\big) + \varepsilon_t^S , \qquad \textbf{(B.31)}$$

EXOGENOUS SHOCK

33. TFP Shock (A_t)

$$A_t = 0.95A_{t-1} + e_t^A \qquad \textbf{(B.32)}$$

34. Capital quality shock (ξ_t)

$$\xi_t = 0.66\xi_{t-1} + e_t^K, \qquad \textbf{(B.33)}$$

35. Government expenditure shock (ε_t^G)

$$\varepsilon_t^G = 0.66\varepsilon_{t-1}^G + e_t^G \qquad (\mathbf{B.34})$$

35. Monetary policy shock (ε_t^i)

$$\varepsilon_t^i = e_t^i \qquad \textbf{(B.35)}$$

36. Credit policy shock (ε_t^S)

$$\varepsilon_t^S = 0.66\varepsilon_{t-1}^S + e_t^S \qquad \textbf{(B.36)}$$

APPENDIX C

This appendix provides the complete set of equation used for the simulation in chapter 3. The reference model used in these two chapters is the one from Gerali, Nerri, Panetta, and Signoretti (2010). This set of equations is derived from the original dynare code of the reference model.

PATIENT HOUSEHOLDS

1. Patient household's consumption (c_t^p)

$$\lambda_t^p\left(c_t^p - a^p c_{t-1}^p\right) = (1 - a^p)\varepsilon_t^z \qquad \mathbf{(C.1)}$$

2. Housing demand from patient household $\left(h_t^p\right)$

$$h_t^p = \frac{j\varepsilon_t^h}{\lambda_t^p q_t^h + \beta_p E_t(\lambda_{t+1}^p q_{t+1}^h)} \qquad (\mathbf{C.2})$$

3. First order condition of patient household's deposit (λ_t^p)

$$\lambda_t^p = \beta_p E_t\left(\lambda_{t+1}^p\right)\frac{(1 + r_t^d)}{E_t(\pi_{t+1})} \qquad (\mathbf{C.3})$$

4. Patient households' labor supply (l_t^p)

$$\begin{aligned}\left(1 - \varepsilon_t^l\right)l_t^p = &- \frac{l_t^{p(1+\phi)}\varepsilon_t^l}{w_t^p\lambda_t^p} + \kappa_W\left(\pi_t^{wp} - \pi_{t-1}^{iw}\pi^{(1-iw)}\right)\pi_t^{wp} \\ &- \beta_p\frac{E\left(\lambda_{t+1}^p\right)}{\lambda_t^p}\kappa_W\Big(E_t\left(\pi_{t+1}^{wp}\right) \\ &- \pi_t^{iw}\pi^{(1-iw)}\Big)\frac{E_t\left(\pi_{t+1}^{wp}\right)^2}{E_t(\pi_{t+1})}\end{aligned} \qquad (\mathbf{C.4})$$

5. Patient household's wage inflation (π_t^{WP})

$$\pi_t^{wp} = \frac{w_t^p}{w_{t-1}^p}\pi_t \qquad (\mathbf{C.5})$$

6. Dividend (JR_t)

$$\frac{JR_t}{\gamma_p} = c_t^p + q_t^h\left(h_t^p - h_{t-1}^p\right) + d_t^p - w_t^p l_t^p - \left(1 + r_{t-1}^d\right)\frac{d_{t-1}^p}{\pi_t} \qquad (\mathbf{C.6})$$

IMPATIENT HOUSEHOLDS

7. Impatient households' consumption (c_t^i)

$$\lambda_t^i\left(c_t^i - a^i c_{t-1}^i\right) = \left(1 - a^i\right)\varepsilon_t^z \tag{C.7}$$

8. First order condition of impatient household's borrowing (λ_t^i)

$$\lambda_t^i = s_{it}\left(1 + r_t^{bh}\right) + \beta_i E_t \lambda_{t+1}^i \frac{\left(1 + r_t^{bh}\right)}{E_t \pi_{t+1}} \tag{C.8}$$

9. Impatient households' labor supply (l_t^i)

$$\begin{aligned}\left(1 - \varepsilon_t^l\right)l_t^i = &- \frac{l_t^{i(1+\phi)}\varepsilon_t^l}{w_t^i \lambda_t^i} + \kappa_W\left(\pi_t^{wi} - \pi_{t-1}^{\iota_W}\pi^{(1-\iota_W)}\right)\pi_t^{wi} \\ &- \beta_p \frac{E_t\left(\lambda_{t+1}^i\right)}{\lambda_t^i}\kappa_W\left(E_t\left(\pi_{t+1}^{wi}\right)\right. \\ &\left. - \pi_t^{\iota_W}\pi^{(1-\iota_W)}\right)\frac{E_t\left(\pi_{t+1}^{wi}\right)^2}{E_t\left(\pi_{t+1}\right)}\end{aligned} \tag{C.9}$$

10. Impatient household's wage inflation (π_t^{wi})

$$\pi_t^{wi} = \frac{w_t^i}{w_{t-1}^i}\pi_t \tag{C.10}$$

11. Housing demand by impatient households (h_t^i)

$$q_t^h\left(h_t^i - h_{t-1}^i\right) = b_t^i + w_t^i l_t^i - c_t^i - \left(1 + r_{t-1}^b\right)\frac{b_{t-1}^i}{\pi_t} \tag{C.11}$$

12. Demand for loan by impatient households (b_t^i)

$$\left(1 + r_t^{bh}\right)b_t^i = LTV_t^H E_t\left(q_{t+1}^h\right)h_t^i E_t\left(\pi_{t+1}\right) \tag{C.12}$$

13. Impatient household multiplier on borrowing constant (s_{it})

$$s_{it} LTV_t^H E_t q_{t+1}^h \pi_{t+1} = \lambda_t^i q_t^h - \beta_i E_t \lambda_{t+1}^i q_{t+1}^h - j\frac{\varepsilon_t^h}{h_t^i} \tag{C.13}$$

CAPITAL PRODUCERS

14. Capital accumulation (K_t)

$$K_t = (1 - \delta_K)K_{t-1} + \left(1 - \frac{\kappa_i}{2}\left(\frac{I_t \varepsilon_t^{qk}}{I_{t-1}} - 1\right)^2\right)I_t \tag{C.14}$$

15. Investment (I_t)

$$\left(1-\frac{\kappa_i}{2}\left(\frac{I_t\varepsilon_t^{qk}}{I_{t-1}}-1\right)^2-\kappa_i\left(\frac{I_t\varepsilon_t^{qk}}{I_{t-1}}-1\right)\left(\frac{I_t\varepsilon_t^{qk}}{I_{t-1}}\right)\right)$$

$$+\beta_e\left(\frac{E(\lambda_{t+1})}{\lambda_t}\right)\left(\frac{E(q_{t+1}^k)}{q_t^k}\right)\kappa_i\left(\frac{I_{t+1}(E(\varepsilon_{t+1}^{qk}))}{I_t}-1\right)E_t(\varepsilon_{t+1}^{qk})\left(\frac{E(I_{t+1})}{I_t}\right)^2$$

$$=\frac{1}{q_t^k} \qquad (\mathbf{C.15})$$

ENTREPRENEURS

16. Consumption for entrepreneurs (c_t^e)

$$\lambda_t^e\left(c_t^e-a^i c_{t-1}^e\right)=\left(1-a^i\right) \qquad (\mathbf{C.16})$$

17. First order condition: (s_{et})

$$s_{et}LTV_t^eE_t\left(q_{t+1}^k\pi_{t+1}\right)(1-\delta_k)$$

$$=-\beta_eE_t(\lambda_{t+1}^e)\Bigg(E_t(q_{t+1}^k)(1-\delta_k)+E_t(r_{t+1}^k)E(u_{t+1})$$

$$+\left(\varepsilon_1(E_t(u_{t+1})-1)+\frac{\varepsilon_2}{2}(E_t(u_{t+1})-1)^2\right)\Bigg)+\lambda_t^e$$

$$+q_t^k \qquad (\mathbf{C.17})$$

18. Wage of patient households (w_t^p)

$$w_t^p=\eta_i(1-\alpha)\frac{y_t^e}{\left(l_t^{pd}u_t\right)} \qquad (\mathbf{C.18})$$

19. Wage of impatient households (w_t^i)

$$w_t^i=(1-\eta_i)(1-\alpha)\frac{y_t^e}{\left(l_t^{id}x_t\right)} \qquad (\mathbf{C.19})$$

20. First order condition of entrepreneur's borrowing (λ_t^e)

$$\lambda_t^e=\beta_eE_t(\lambda_{t+1}^e)\frac{\left(1+r_t^{be}\right)}{E_t(\pi_{t+1})}+s_{et}\left(1+r_t^{be}\right) \qquad (\mathbf{C.20})$$

21. Utilization rate (u_t)

$$\varepsilon_2(u_t-1)=\left(r_t^k-\varepsilon_1\right) \qquad (\mathbf{C.21})$$

22. Effective capital (x_t)

$$\begin{aligned}\frac{y_t^e}{x_t} = c_t^e + \left(1 + r_{t-1}^{be}\right)\frac{b_{t-1}^{ee}}{\pi_t} + w_t^p l_t^{pd} + w_t^i l_t^{id} + \left(\varepsilon_1(u_t - 1) + \frac{\varepsilon_2}{2}(u_t - 1)^2\right)k_{t-1}^e - b_t^{ee} \\ - q_t^k\left((1 - \delta_k)k_{t-1}^e\right. \\ \left. - k_t^e\right) \qquad \textbf{(C.22)}\end{aligned}$$

23. Production technology (y_t^e)

$$y_t^e = A_t^e(u_t k_{t-1}^e)^\alpha \left(\left(l_t^p\right)^{\eta_i}\left(l_t^i\right)^{(1-\eta_i)}\right)^{1-\alpha} \qquad \textbf{(C.23)}$$

24. Entrepreneur borrowing in branch (b_t^{ee})

$$\left(1 + r_{t-1}^{be}\right)b_t^{ee} = LTV_{et}E_t(q_{t+1}^k \pi_{t+1})k_t^e(1 - \delta_k) \qquad \textbf{(C.24)}$$

25. Return on capital (r_t^k)

$$r_t^k = \alpha A_t^e u_t^{(\alpha-1)} k_t^{e(\alpha-1)} k_{t-1}^{e(\alpha-1)} \left(\frac{\left(l_t^p\right)^{\eta_i}\left(l_t^i\right)^{1-\eta_i}}{x_t}\right)^{(1-\alpha)} \qquad \textbf{(C.25)}$$

26. Capital price $\left(q_t^k\right)$

$$\begin{aligned}q_t^k = \frac{1}{(k_t - (1 - \delta_k)k_{t-1})}\Bigg(Y_t - C_t \\ - \Bigg(\left(\varepsilon_1(u_t - 1) + \frac{\varepsilon_2}{2}(E_t(u_{t+1}) - 1)^2\right) + \frac{\kappa_p}{2}\left(\pi_t - \pi_{t-1}^{IP}\bar{\bar{\pi}}^{(1-\iota_P)}\right)^2 Y_t \\ + \frac{\kappa_d}{2}\left(\frac{r_{t-1}^d}{r_{t-2}^d} - 1\right)^2 r_{t-1}^d d_{t-1}^b + \frac{\kappa_{be}}{2}\left(\frac{r_{t-1}^{be}}{r_{t-2}^{be}} - 1\right)^2 r_{t-1}^{be} b_{t-1}^e \\ + \frac{\kappa_{bh}}{2}\left(\frac{r_{t-1}^{bh}}{r_{t-2}^{bh}}\right. \\ \left. - 1\right)^2 r_{t-1}^{bh} b_{t-1}^h\Bigg)\Bigg) \qquad \textbf{(C.26)}\end{aligned}$$

BANKS

26. Wholesale banking interest rate (R_t^b)

$$R_t^b = -\kappa^{K_b}\left(\frac{K_t^b}{B_t} - CAR_t\right)\left(\frac{K_t^b}{B_t}\right)^2 + r_t^{ib} \qquad \textbf{(C.27)}$$

27. Accumulation of bank capital (${K_t}^b$)

$$ {K_t}^b \pi_t = (1-\delta^{K_b}) \frac{K_{t-1}^b}{\varepsilon_t^{K_b}} + JB_{t-1} \qquad (\mathbf{C.28}) $$

28. Deposit of patient household $\left(d_t^p\right)$

$$ \gamma_p d_t^P = \gamma_b d_t^b \qquad (\mathbf{C.29}) $$

29. Loan for impatient households in branch $\left(b_t^h\right)$

$$ \gamma_b b_t^h = \gamma_i b_t^i \qquad (\mathbf{C.30}) $$

30. Aggregate loan for entrepreneurs (b_t^e)

$$ \gamma_b b_t^e = \gamma_e b_t^{ee} \qquad (\mathbf{C.31}) $$

31. Aggregate deposit in banking system $\left(d_t^b\right)$

$$ d^b d_t^b + K^b K_t^b = b^h b_t^h + b^e b_t^e \qquad (\mathbf{C.32}) $$

32. FOC deposit branch: deposit interest rate (r_t^d)

$$ \begin{aligned} -1 &+ \left(\frac{\varepsilon_t^D}{\varepsilon_{t-1}^D - 1}\right) - \left(\frac{\varepsilon_t^D}{\varepsilon_{t-1}^D - 1}\right)\left(\frac{r_t^{ib}}{r_t^d}\right) - \kappa^d \left(\frac{r_t^d}{r_{t-1}^d} - \left(\frac{r_{t-1}^d}{r_{t-2}^d}\right)^{\iota_D}\right)\left(\frac{r_t^d}{r_{t-1}^d}\right) \\ &+ \beta_p E_t \left(\frac{\lambda_{t+1}^p}{\lambda_t^p}\right) \kappa^d \left(\frac{r_{t+1}^d}{r_t^d} - \left(\frac{r_t^d}{r_{t-1}^d}\right)^{\iota_D}\right)\left(\frac{r_{t+1}^d}{r_t^d}\right)^2 \left(\frac{d_{t+1}^b}{d_t^b}\right) \\ &= 0 \qquad (\mathbf{C.33}) \end{aligned} $$

33. FOC loan branch: loan interest rate for entrepreneurs (r_t^{be})

$$ \begin{aligned} 1 &+ \left(\frac{\varepsilon_t^{be}}{\varepsilon_{t-1}^{be} - 1}\right) - \left(\frac{\varepsilon_t^{be}}{\varepsilon_{t-1}^{be} - 1}\right)\left(\frac{R_t^b}{r_t^{be}}\right) - \kappa^{be} \left(\frac{r_t^{be}}{r_{t-1}^{be}} - \left(\frac{r_{t-1}^{be}}{r_{t-2}^{be}}\right)^{\iota_{be}}\right)\left(\frac{r_t^{be}}{r_{t-1}^{be}}\right) \\ &+ \beta_p E_t \left(\frac{\lambda_{t+1}^p}{\lambda_t^p}\right) \kappa^{be} \left(\frac{r_{t+1}^{be}}{r_t^{be}} - \left(\frac{r_t^{be}}{r_{t-1}^{be}}\right)^{\iota_{be}}\right)\left(\frac{r_{t+1}^{be}}{r_t^{be}}\right)^2 \left(\frac{b_{t+1}^e}{b_t^e}\right) \\ &= 0 \qquad (\mathbf{C.34}) \end{aligned} $$

34. FOC loan branch: loan interest rate for impatient households (r_t^{bh})

$$ \begin{aligned} 1 &+ \left(\frac{\varepsilon_t^{bh}}{\varepsilon_{t-1}^{bh} - 1}\right) - \left(\frac{\varepsilon_t^{bh}}{\varepsilon_{t-1}^{bh} - 1}\right)\left(\frac{R_t^b}{r_t^{bh}}\right) - \kappa^{be} \left(\frac{r_t^{bh}}{r_{t-1}^{bh}} - \left(\frac{r_{t-1}^{bh}}{r_{t-2}^{bh}}\right)^{\iota_{bh}}\right)\left(\frac{r_t^{bh}}{r_{t-1}^{bh}}\right) \\ &+ \beta_p E_t \left(\frac{\lambda_{t+1}^p}{\lambda_t^p}\right) \kappa^{bh} \left(\frac{r_{t+1}^{bh}}{r_t^{bh}} - \left(\frac{r_t^{bh}}{r_{t-1}^{bh}}\right)^{\iota_{bh}}\right)\left(\frac{r_{t+1}^{bh}}{r_t^{bh}}\right)^2 \left(\frac{b_{t+1}^h}{b_t^h}\right) \\ &= 0 \qquad (\mathbf{C.35}) \end{aligned} $$

35. Overall bank profits (JB_t)

$$\begin{aligned}JB_t = r_t^{bh} b_t^h + r_t^{be} b_t^e - r_t^d d_t^b - \frac{\kappa^d}{2}\left(\frac{r_t^d}{r_{t-1}^d} - 1\right)^2 r_t^d d_t^b - \frac{\kappa^{be}}{2}\left(\frac{r_t^{be}}{r_{t-1}^{be}} - 1\right)^2 r_t^{be} b_t^e \\ - \frac{\kappa^{bh}}{2}\left(\frac{r_t^{bh}}{r_{t-1}^{bh}} - 1\right)^2 r_t^{bh} b_t^h \\ - \frac{\kappa^{kb}}{2}\left(\frac{K_t^b}{B_t} - CAR_t\right)^2 K_t^b \qquad \mathbf{(C.36)}\end{aligned}$$

RETAILERS

36. Aggregate retail profits (JR_t)

$$JR_t = Y_t\left(1 - \frac{1}{x_t} - \frac{\kappa_p}{2}\pi_t - \pi_{t-1}^{\iota_P}\pi^{\iota_P}\right)^2 \qquad \mathbf{(C.37)}$$

37. New Keynesian Phillips curve (π_t)

$$\begin{aligned}\kappa_p\left(\pi_t - \pi_{t-1}^{\iota_P}\bar{\pi}^{(1-\iota_P)}\right)\pi_t \\ = 1 - \varepsilon_t^y + \frac{\varepsilon_t^y}{x_t} \\ - \beta_P E_t\left(\frac{(\lambda_{t+1}^P)}{\lambda_t^P}\kappa_p\left(\pi_{t+1}\right.\right. \\ \left.\left. - \pi_{t-1}^{\iota_P}\bar{\pi}^{(1-\iota_P)}\right)\pi_{t+1}\frac{(y_{t+1})}{y_t}\right) \qquad \mathbf{(C.38)}\end{aligned}$$

AGGREGATION AND EQUILIBRIUM

38. Aggregate consumption (C_t)

$$C_t = \gamma_p c_t^p + \gamma_i c_t^i + \gamma_e c_t^e \qquad \mathbf{(C.39)}$$

39. Aggregate loan for households (B_t^H)

$$B_t^H = \gamma_b b_t^h \qquad \mathbf{(C.40)}$$

40. Aggregate loan for entrepreneurs (B_t^E)

$$B_t^E = \gamma_b b_t^e \qquad \mathbf{(C.41)}$$

41. Aggregate loan (B_t)

$$B_t = B_t^H + B_t^E \qquad \mathbf{(C.42)}$$

42. Aggregate deposit (D_t)

$$D_t = \gamma_p d_t^p \qquad \mathbf{(C.43)}$$

43. Aggregate output (Y_t)

$$Y_t = \gamma_e y_t^e \qquad \mathbf{(C.44)}$$

44. Individual bank's profit (jb_t)

$$\gamma_b jb_t = JB_t \qquad \mathbf{(C.45)}$$

45. Aggregate labor from patient households by labor union (L_t^{PD})

$$\gamma_e l_t^{PD} = \gamma_p l_t^p \qquad \mathbf{(C.46)}$$

46. Aggregate labor from impatient households by labor union (L_t^{ID})

$$\gamma_e l_t^{ID} = \gamma_i l_t^i \qquad \mathbf{(C.47)}$$

47. Total housing purchased (h_t)

$$h_t = \gamma_p h_t^p + \gamma_i h_t^i \qquad \mathbf{(C.48)}$$

48. Entrepreneurs' capital purchased (k_t^e)

$$\gamma_e k_t^e = K_t \qquad \mathbf{(C.49)}$$

49. Output gap $\left(\hat{Y}_t\right)$

$$\hat{Y}_t = C_t + (K_t - (1 - \delta_k))K_{t-1} \qquad \mathbf{(C.50)}$$

50. Aggregate wage inflation (π_t^W)

$$\pi_t^W = \left(\frac{\left(w_t^P + w_t^i\right)}{\left(w_{t-1}^P + w_{t-1}^i\right)}\right)\pi_t \qquad \mathbf{(C.51)}$$

TAYLOR RULE

51. Taylor rule, nominal interest rate $\left(r_t^{ib}\right)$

$$\left(1 + r_t^{ib}\right) = \left(1 + r_{ss}^{ib}\right)^{1-\rho_{ib}}\left(1 + r_{t-1}^{ib}\right)^{\rho_{ib}}\left(\left(\frac{\pi_t}{\pi_{ss}}\right)^{\phi_\pi}\left(\frac{\hat{Y}_t}{\hat{Y}_{t-1}}\right)^{\phi_Y}\right)^{1-\rho_{ib}}\left(1 + \varepsilon_t^{r_{ib}}\right) \quad \mathbf{(C.52)}$$

52. Interest rate for loan of entrepreneurs (r_t^e)

$$r_t^e = \lambda_t^e - \beta_e \lambda_{t+1}^e \frac{\left(1 + r_t^{be}\right)}{E_t(\pi_{t+1})} \qquad \mathbf{(C.53)}$$

53. Loan to output ratio (ϑ_t)

$$\vartheta_t = \frac{B_t}{Y_t} \tag{C.54}$$

54. Margin rate of the wholesale bank (b_t^m)

$$b_t^m = \left(\frac{b_{t-1}^h}{b_{t-1}^h + b_{t-1}^e}\right) r_{t-1}^{bh} + \left(\frac{b_{t-1}^e}{b_{t-1}^h + b_{t-1}^e}\right) r_{t-1}^{be} - r_{t-1}^d \tag{C.55}$$

55. Interest rate spread $\left(SPR_t^b\right)$

$$SPR_t^b = \frac{1}{2}\left(r_t^{bh} + r_t^{be}\right) - r_t^d \tag{C.56}$$

EXOGENOUS PROCESSES

56. Shock on consumption (ε_t^z)

$$\varepsilon_t^z = \rho_{\varepsilon^z} \varepsilon_{t-1}^z + \sigma_t^z \tag{C.57}$$

57. Shock on technology (A_t^e)

$$A_t^e = \rho_{A^e} A_{t-1}^e + \sigma_t^A \tag{C.58}$$

58. Shock on housing demand $\left(\varepsilon_t^h\right)$

$$\varepsilon_t^h = \rho_{\varepsilon^h} \varepsilon_{t-1}^h + \sigma_t^{\varepsilon^h} \tag{C.59}$$

59. Shock on markup on deposit rate $\left(mk_t^d\right)$

$$\varepsilon_t^D = \rho_{\varepsilon^h} \varepsilon_{t-1}^D + \sigma_t^D \tag{C.60}$$

60. Shock on markup on lending rate for entrepreneurs $\left(mk_t^{be}\right)$

$$\varepsilon_t^{be} = \rho_{\varepsilon^{be}} \varepsilon_{t-1}^{be} + \sigma_t^{be} \tag{C.61}$$

61. Shock on markup on lending rate for impatient households $\left(\varepsilon_t^{bh}\right)$

$$\varepsilon_t^{bh} = \rho_{\varepsilon^{bh}} \varepsilon_{t-1}^{bh} + \sigma_t^{bh} \tag{C.62}$$

62. Shock on capital price $\left(\varepsilon_t^{qk}\right)$

$$\varepsilon_t^{qk} = \rho_{\varepsilon^{qk}} \varepsilon_{t-1}^{qk} + e^{\varepsilon^{qk}} \tag{C.63}$$

63. Shock on output $\left(\varepsilon_t^y\right)$

$$\varepsilon_t^y = \rho_{\varepsilon^y} \varepsilon_{t-1}^y + e^{\varepsilon^y} \tag{C.64}$$

64. Shock on labor demand $\left(\varepsilon_t^l\right)$

$$\varepsilon_t^l = \rho_{\varepsilon^l}\varepsilon_{t-1}^l + e^{\varepsilon^l} \qquad (\mathbf{C.65})$$

65. Shock on banking capital $\left(\varepsilon_t^{K^b}\right)$

$$\varepsilon_t^{K^b} = \rho_{\varepsilon^{K^b}}\varepsilon_t^{K^b} + e^{\varepsilon^{K^b}} \qquad (\mathbf{C.66})$$