HOUSING, BANKING CREDIT AND MONETARY POLICY:
A NK-DSGE ANALYSIS

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ABSTRACT

HOUSING, BANKING CREDIT AND MONETARY POLICY : A NK-DSGE ANALYSIS

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This dissertation consists of two papers that study monetary policy transmission regarding the role of housing and banking credit. The key idea is that housing serves as collateral for loans and loans affect economic activities. We, therefore, employ a New Keynesian DSGE model with credit constraint in the credit market to investigate the responses of key macroeconomic variables to the structural shocks.

The first paper elucidates the role of housing in monetary policy effect on household consumption by developing a two-sector NK-DSGE model with credit constraint and applying Bayesian technique to estimate the model. The results emphasize the following: (1) The household consumption movement is the consequence of house price change. An increase in house price reinforces consumption by increasing the opportunity to access the credit to finance consumption. (2) The role of housing in monetary policy is transmitted by : (i) *the wealth effect on spending*; an increase in interest rate causes real house price to fall and further alleviates consumption, (ii) *the balance sheet effect on borrowing*: households

who are borrowers suffer more when interest rate increases because of the combination of wealth decline and credit tightening, and (iii) *the amplification effect on borrowing:* housing collateral amplifies the effect of interest rate shock and housing demand shock under high credit relaxation, meaning that the higher loan-to-value (LTV) ratio, the larger impact on consumption.

The second paper analyzes the effect of bank lending through housing collateral on the economy. We extend a previous two-sector NK-DSGE model by incorporating the banking sector and determining an endogenous LTV ratio in the credit constraint deviated from a fixed ratio in the first model. Our attempt in the second model is to emphasize the contribution of financial shocks emerging from the credit supply and the credit risk shock to capture the linkage between the banking sector and the real economy. The findings show that; (1) a reduction in the LTV ratio (credit crunch) causes household consumption to fall substantially, (2) higher credit risk affects banks, which reduce the loan supply and increase the loan–deposit spread to compensate for the loss in profit and capital, (3) The endogenous LTV ratio amplifies the effect of a monetary policy shock but mutes the effect of a banking credit risk shock, and (4) the existence of banks attenuates the impact of contractionary monetary policy by reducing banking credit risk.

In summary, the dissertation emphasizes the importance of banking activities. Banking credit tied to the value of housing collateral establishes a link between the financial and the real sector in the manner of the propagation of economic impacts.

To my dearest parents.

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Finally, I take full responsibilities for any mistakes and deficiencies in this dissertation.

CHAPTER 1
INTRODUCTION

Since the global financial crisis in 2008-2009, interaction between the financial and real sectors has become more alert. The events of the crisis are a reminder that the real estate sector played a key role in generating a severe and long-lasting harmful impact on the economy in many countries. In Thailand, the real estate sector accounted for 6 percent of GDP in 2017-2018. It consists of three principal segments; residential (housing), commercial, and industrial. The majority of real estate value comes from housing sector, therefore the macroeconomic point of view, housing demand and supply are the main indicators that a considerable amount of capital is circulating within the sector, generating an increasing level of income and employment. From the microeconomic view, housing is the largest component of household assets, accounting for 76 percent of total assets (National Statistical Office of Thailand, 2015). In addition, housing loans contributes a considerable share, 15 percent, of bank lending. In that light, an adverse impact on the housing market causes severe problems for the household financial position, the soundness of the banking system, and the broader economy, as experienced in Thailand’s 1997 housing market bubble and financial crisis. This suggests the policymaker that financial stability of the housing market should be protected.

The Bank of Thailand (BOT) has conducted monetary policy under a flexible inflation targeting framework since 2000 to maintain price stability and to keep economic activity consistent with the potential. Nevertheless, due to the flexible inflation targeting framework which allows for balancing multiple objectives, the BOT explicitly addresses additional macroprudential policy mandate to preserve financial stability. This objective does, indeed, attempt to mitigate risks that carry the possibility of undermining the financial system, and passes spillover effect on the economy such as bank runs and bankruptcy that could ruin the economic system. In particular, one of macroprudential policy applies loan-to-value (LTV) ratio as a measure on mortgage loans to prevent banks from over-lending, and restricts the build-up of excessive risk in housing sector.

With the above in mind, this dissertation studies monetary policy transmission with regard to the role of housing and banking credit. The key idea is that housing not only provides services on consumption, but also serves as collateral for loans. Loans allow households to smooth their consumption, create demand and stimulate economic activities.

In the first study, we elucidate how housing plays a role in monetary policy effects on household consumption. Although empirical studies have examined the effect of monetary policy on housing and consumption, the impact of interest rate on households is heterogeneous, depending on net worth and financial position. We then employ the New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model, which has been recognized as a technical tool for economic analysis. We develop a two-sector NK-DSGE model with credit constraint. As in Kiyotaki and Moore (1997), loans must be backed by collateral to guarantee borrowers' debts. We allow housing to be used as collateral for credit accessibility (borrowing). We use Bayesian estimation to investigate the effect of interest rate shock, housing demand shock, inflation shock and productivity shock on the economic variables.

Nevertheless, the first paper is an exploratory work that brings the implication of credit constraint tied to housing value (collateral) in monetary policy effect. In reality, banks appear as an intermediary, providing credit in the economy. The expansion or contraction of credit supply specifically affects consumption, investment and aggregate output as a stimulus or deterrent in the economy. Moreover, shocks that deteriorate credit market conditions and disruptions in financial intermediation can induce a crisis causing bankruptcy and spread on business activities. For that reason, the stability of banks and financial institutions through supervisory measures, are essential for the provision of prudent management and a decent risk management system.

The issues mentioned above constitute the motivation for the second study, where we incorporate the banking sector to examine the effect of bank lending through housing collateral. The second paper has three contributions. First, we extend the two-sector NK-DSGE model with credit constraint used in the previous study by including banking sector. To capture the role of macroprudential policy, banks are regulated under central bank's supervision by maintaining the minimum capital adequacy ratio (capital against risk-weighted assets). Moreover, we focus on financial shocks emerging from credit supply shock and credit risk shock to elucidate these effects on economic activities. Second, we feature LTV ratio as endogenous variable whereas most of the literature on NK-DSGE designates LTV ratio as an exogenous ratio. Our model attempts to fill a gap in the literature by proposing endogenous LTV ratio to illustrate the response of banking activities after the emergence of economic shocks. Third, we consider the limitation from the previous model. We resolve the comovement problem originating in unpleasantly negative comovement between outputs in two sectors after a monetary policy shock, by enriching wage rigidity in the extended model.

This dissertation is structured as follows. The introduction is presented in *Chapter 1*. *Chapter 2* describes the background of the housing market, mortgage loans and current LTV measures in Thailand. The first study is presented in *Chapter 3*, with analysis of the role of housing in NK-DSGE model based on Bayesian estimation results. The extended model, integrating the banking sector, – the second study is presented in *Chapter 4*. Finally, *Chapter 5* gives a conclusion that emphasizes the key findings, limitations and direction for future research.

CHAPTER 2
HOUSING MARKET, MORTGAGE LOANS AND LTV MEASURE IN THAILAND

This chapter brings a background of housing market and current situation in mortgage loans which lead to the policy challenge and macroprudential tool—current LTV measure to stabilize the overheating of demand and supply.

1. Stylized facts in housing market and mortgage loans

Lesson learned from the crisis of 1997

During 1995-1997, all asset prices including land, property, and securities were appreciating. Economic growth was in an upward trend and created a rise in demand on housing which encouraged rising in housing prices and production. Market players had the opportunity to invest, to speculate and to make more profits. Many of them relied on housing loans, besides, the new policy of capital accounts flexibility, namely Bangkok International Banking Facilities (BIBF)[1] resulted in a high inflow of foreign capital for business. Foreign

[1] Bangkok International Banking Facilities (BIBF) was established in 1992 which entitled the international funds, primarily in the term of short term loans to easily enter into the domestic financial market. BIBF granted

loans were available at a low-interest rate. Therefore, the real estate sector was overheated and convinced market players to be highly optimistic. This contributed a period of housing market bubbles. However, the maturity between loans and housing projects were incompatible. Most of the short- or medium-term loans were funding long term projects which took a long time to get returns and faced with uncertainty from, e.g. housing price, interest rate, and capital value in the future. The investments were not driven by yields, or sustainable gains while the low borrowing rate on funding from foreign loans led to an increase in external debts. Moreover, the failure of exchange rate policy pegging Baht to currencies' basket caused international hedge funds and speculators attacked Baht and eventually necessitated the floating of Baht. Meanwhile, excessive lending and imprudent credit extension engendered too much risk-taking and deteriorated housing asset quality. The massive capital outflow, sharp currency depreciation, falling housing prices, and economic downturn exacerbated financial institution's outstanding debt and non-performing loans (NPLs) severely increased. The profit loss in real estate companies propagated widespread bankruptcy towards financial institution's insolvency.

The financial crisis in 1997 triggered the housing market to be reversed from over demand to being increasingly oversupplied. Housing price dramatically collapsed. A slump of consumer's purchasing power depressed a number of units sold during for 5 years. The post-crisis annual average units sold sank to only 10,000 units from the previous sale at 148,000 units per year (Figure 2-1). What we learned from this crisis is in what manner in

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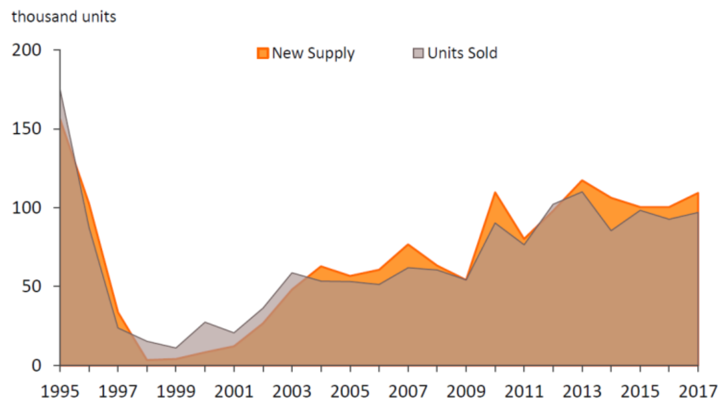
some privileges, e.g. tax exemption, borrowing cost reduction, loosing obligation for opening new commercial banks' branches (See Watanagase, 2001) the real estate boom could become the structural weakness and a contributor to financial fragility.

Figure 2-1: New supply and units sold in housing market



Source: Krungsri Research (2018)

A new chapter of recovering

The housing market started to recover in 2003. Government expenditure in the infrastructure sector strengthened market sentiment. In 2003-2004, significant investments were made in low-rise housing, especially on the western Bangkok Outer Ring Road. In 2006, the mega-projects were launched the rapid mass transportation in the Bangkok metropolitan area. This encouraged a corresponding increase in investment of high-rise building and condominiums.

However, the subprime mortgage crisis started in 2007 had widespread effects not only on the stability of the global financial system but also on the spilling systemic shock over into the real economy across the world; Thailand was no exception. The crisis affected the domestic property market slugged. Both supply and units sold, in 2009, was 59,000 units

(Figure 2-1), dropped approximately 10 percent from the previous year but market rebounded the following year because of improving economy.

Although the real estate industry suffered from severe flooding in Bangkok in 2011, the housing market was improved by the stimulus of the First home scheme of 2011-2012. Property market became overheating during 2012. The demand for residential properties increased. The high-rise residential properties, especially condominiums, was expanding significantly. Condominiums have become a favorite of the housing market due to four factors: (a) the extension of mass transit network lines in Bangkok and increasing connections within the communications network, which is making its use more convenient; (b) changing consumers preference, particularly working-age population driven by a desire to save money and to reduce commuting time that is causing a switch in preferences from low-rise housing in the suburbs to high-rise accommodation in the city center; (c) changing social structures to single-person families and (d) the declining availability of land and subsequent rising costs. These factors resulted in the developers being increasingly turned to condominiums to meet consumer demand for housing. Meanwhile, the low-rise residential properties simultaneously registered some growth after a considerable slowdown due to the great flood.

During 2013, the real estate market kept growing. Many entrepreneurs profited as a surge in domestic demand, both residential and commercial purposes. Noticeably, average annual growth in Return of Assets (ROA) of real estate companies registered in the stock exchange market was significantly improving. A rise in profit attracted both existing and new entry companies competitively to create more supply in the market. Moreover, the low-interest rate had been an incentive to increase financing under low borrowing cost. Then, the market share of each company had to be undoubtedly diminished. It was because the market had become full competitive, entrepreneurs retained properties' project or otherwise, they tend to lose market share and profits. While the demand was not able to absorb all units produced, the stocks of houses, therefore, started rising over the years.

Prolonged oversupply

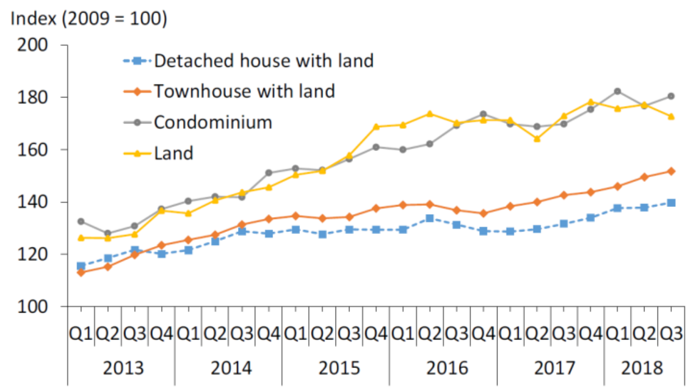
In 2014, real estate sector activities slowed down in the first half of the year as a result of domestic political conflict and economic slowdown. However, housing markets started to register steady improvement both in terms of demand and supply after the political situation subsided. Meanwhile, the search for yield behavior was observed in 2015. Signs of investment from short-term speculative purposes also started to emerge. As demand for property softened, while companies continued launching new projects, the number of cumulative housing stocks climbed significantly.

Despite some temporary positive effect from the government's economic stimulus measure[2] on the real estate market, the economic recovery was sluggish and ability to borrow of households were deteriorated by high debt burden. Commercial banks became more cautious about issuing mortgage loans and tighten regulations on lending from awareness of non-performing loans (NPLs). Hence, the housing market experienced an oversupply period.

Although the market during 2014-2016 grew at a slow pace, prices of all property types in Bangkok and its vicinities, especially condominium still edged up in line with the cost of land and construction materials which continued upward trend (Figure 2-2).

[2] Measure on discounted fees of registration and transfer of ownership between October 29, 2015 and April 28, 2016.

Figure 2-2: Real estate price indices



Source: BOT (2018)

During 2014-2016, the housing market showed a moderate improvement due to structural change in the market itself, which both demand and supply became sluggish. In 2017, however, housing demand partly supported by the progress in several train line extension projects and residential units approved mortgage loans. Housing supply gradually rose in tandem with housing demand. Developers had an adjustment in their behavior; they delayed launching new projects, and rather, focused on selling the already constructed units. This situation continued until 2018; housing demand grew slightly while new residential units for sale seemed to stabilize. Precisely, there was no sign of widespread house price bubble because it rose from fundamental value e.g. land price. Furthermore, given that the rise in house prices has been slow and on a gradual path, a sharp correction in house prices is unlikely deemed.

Mortgage loan and LTV measure

As a means of financing, the commercial banks' loan, namely mortgage loan is used to fund the investment projects. There are two types of mortgage loans; 1) loan to companies or developers (Pre-finance) and 2) loan to private consumers (Post-finance)

In practice, Loan-to-value (LTV) ratio is one of measurement of lending risk that financial institutions or lenders examine before approving credit. LTV is determined by the amount of loan provided to borrowers against the value of the collateral, i.e. mortgage. Typically, mortgage loan with higher LTV imply a higher risk for lenders. Lenders apply the LTV ratio to access the level of exposure taken on. If borrowers request a loan for an amount that is at or close to the collateral value (high LTV), therefore banks perceive that there is a greater risk of loss in case of mortgage loan going into default. Nevertheless, LTV is applied in macroprudential tools to restrict the excessive build-up of risk in the real estate sector, for instance, mortgage lending.

In Thailand, LTV implementation is evident with a degree of restraints and target groups. The first LTV measures were implemented in 2003 which a cap on LTV ratio of 70 percent was imposed on high-valued mortgages (at and above 10 million baht) as a pre-emptive measure against potential risk in the high-end property market. Later in 2009, the BOT increased the LTV limit of high-value mortgages to 80 percent and, instead of a strict limit, introduced higher risk-weighted capital charge on high-value mortgages. This measure was intended to provide a further boost to the property market following the global financial crisis after the concern over the property market had already subsided. Following a sign of potential speculative activities in the low-value property segment, risk-weighted capital charge on low-value mortgages (below 10 million baht) was implemented in 2011 for high-rise property (e.g. apartment buildings) and 2013 for the low-rise property (e.g. houses). The tightening LTV on the low-rise property was initially aimed for January 2012 but later postponed to January 2013 due to the severe flood in 2011. In 2019, the BOT has revised and regulated the LTV scheme which is given a detail in the next section.

Table 2-1: Implementation of LTV measures in Thailand

Year	Details	Targeted mortgage	Objective
2003	Imposing a 70% of LTV strict limit	High-valued mortgages (greater than or equal to 10 million baht)	To prevent speculation which leads to housing bubbles during credit expansion
2009	- Increasing the LTV limit from 70% to 80% - Imposing risk-weighted capital charge (RW) of 75% for loans with LTV greater than 80% (risk-weighted capital charge of 35% for loans with LTV below or equal to the 80% limit)	High-valued mortgages (greater than or equal to 10 million baht)	To stimulate property market in the time of global economic slowdown
2011	Imposing risk-weighted capital charge of 75% for loans with LTV greater than 90% (risk-weighted capital charge of 35% otherwise)	High-rise property with value below or equal to 10 million baht	To ensure credit standards regarding risk associated with costs
2013	Imposing risk-weighted capital charge of 75% for loans with LTV greater than 95% (risk-weighted capital charge of 35% otherwise)	Low-rise property with value below or equal to 10 million baht	To ensure credit standards regarding risk associated with costs

Source: BOT (2018)

2. Policy challenges in the current situation

In 2018, while overall financial stability stayed sound, some risks, which have caused the policy challenges and could undermine financial stability in the future, persist. Policy challenges are originated from the market itself and the financial institution's competition.

Demand-Supply's behaviors

(1) The significance of foreign demand from China; in recent years, low-cost funding has become more accessible for developers, making it easier to start or expand new projects. But this could potentially lead to underpricing of risks, as reflected in situations where new supply exceeds actual demand, especially for the projects targeted at foreign buyers. Indeed, demand from China (including Hong Kong) now accounts for about 40 percent of foreign purchases of condominiums. This group of buyers also stands to face the negative impact of US trade measures in the future. The possible slowdown in foreign demand, notably from China could happen. This, in turn, could pressure the excess supply problem to intensify.

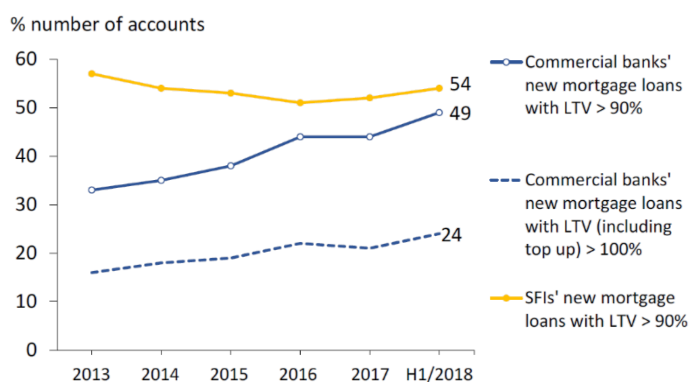
(2) Companies' marketing strategies; developers' strategies include facilitating buyers to obtain loans in excess of the actual selling price (i.e. cash-back loans) and guaranteeing rental yields. These could prompt households to take out more loans than necessary or purchase housing mainly for investment purposes. Going forward, these strategies may contribute to the build-up of higher default risks in the household sector and the real estate market due to underpricing risks.

Financial institutions' behaviors

The higher competition in the mortgage loan market has led to more lenient credit underwriting standards among financial institutions.

(1) An increase in new mortgage loans with an LTV ratio exceeding 90 percent; the proportion of new mortgage accounts with a high LTV ratio has increased steadily over the years (Figure 2-3). Moreover, top-up[3] loans both from new and refinancing loans are included. There seems to be a widespread practice among commercial banks of lending with LTV greater than 100 percent which means that the value of loan exceeds the value of the collateral. Besides, the mortgage loans are taken out for the second time or more and are being paid at the same time.

Figure 2-3: Proportion of new mortgage loan accounts with high LTV ratio

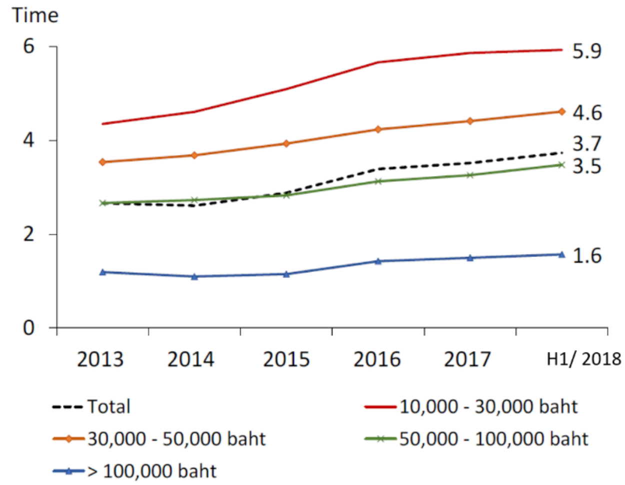


Source: BOT (2018)

[3] Top-up loans are loans which financial institutions grant to borrowers at the same time when mortgage loans are approved, or during the installment period for other purposes, e.g. personal loans, loans for mortgage-reducing term assurances, home for cash loans. This type of loan against the same collaterals used for mortgages and not included under the BOT's regulation on mortgage loans.

(2) A rise in Loan-to-income (LTI) of mortgage loans from low-income borrowers; the lending practices are more flexible though the borrowers do not have a strong financial position. Hence, the LTI of every income groups of borrowers has been increasing (Figure 2-4). This could fuel the risk tolerance of households that can be seen in the mortgage debt service ratio (M-DSR)[4]. Although the repayment periods for mortgage loans have been extended, borrowers M-DSGR stayed elevated (Figure 2-5).

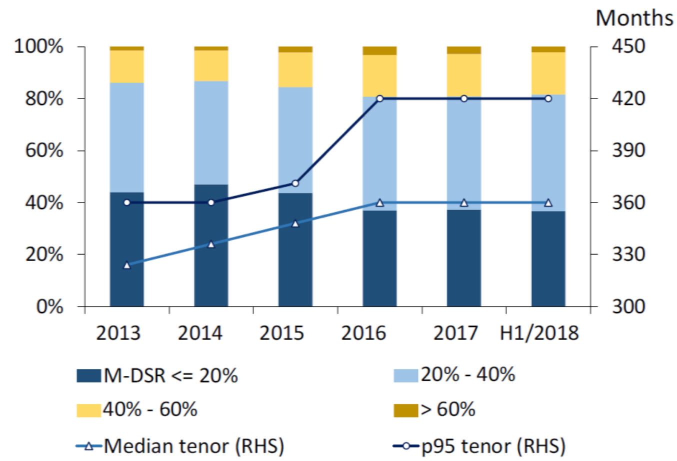
Figure 2-4: LTI ratio of borrowers by income level



Source: BOT (2018)

[4] Mortgage debt service ratio (M-DSR) is the proportion of gross income that is spent on housing-related payment.

Figure 2-5: Proportion of loan accounts by M-DSR and tenor of borrowers in banking system



Source: BOT (2018)

Furthermore, top-up loans which accompany mortgage loans (including all cases; coming with new and refinancing loans, granting afterward) have grown significantly, which in turn cause higher debt burden of borrowers. Offering more attractive interest rates compared to uncollateralized personal loans, these top-up loans prompt households to over-borrow to finance their consumption spending.

(3) A widespread search-for-yield behavior; the search-for-yield behavior continues to persist amid the low-interest-rate environment from mortgage loans facilitating. Homebuyers make a profit from rental yields or capital gains. The number of mortgage loans, especially for residential properties valued at 10 million baht or more are given for the second contract or more rise steadily with LTV ratio as high as the first contract. These mortgage loans approved provide liquidity that keeps housing prices afloat, under the market conditions that is prone to risks from speculation. Should new demand turn out weaker than expected, a

sharp price correction could occur which could threaten the aggregate economic and financial stability.

From mentioned above, only the interest rate may not be an appropriate instrument to reduce the competition in the mortgage loan market and prevent the accumulated debt from future borrowing. The effectiveness and side effects have to be concerned. Moreover, consideration of the source of imbalances in housing market could reduce unnecessary cost from implementing interest rate policy.

3. The latest LTV measure

The competition in the mortgage loan market which is prone to risk implies that macroprudential policy should work as a complement to, not substitute for monetary policy stance and the existing regulations on mortgage credit might be inadequate. If preventive measures are abandoned, the intense competition in housing's lending could accumulate fragilities which lead to the build-up of systemic risk and the disability to resist the financial shocks. As experienced in many countries, propagation in the housing market crash is often one of the main causes of an economic and financial crisis.

This concerns in mind, it is suggested that regulators should improve financial institution supervision in practice, i.e. macroprudential policy for settling the foundation of prudent credit culture. Accordingly, the BOT has revised and launched the LTV regulation which will be applied to loan contracts signed from 1 April 2019 onwards. The key points of LTV measure can be summarized as the following (Table 2-2);

(1) For the first mortgage contract, LTV limits are set to 100 percent of the collateral value with top-up loans included in the loan value.

(2) For a mortgage contract to buy a property valued at 10 million baht or above, both the first and second contract is subject to an LTV limit of 80 percent.

(3) For a mortgage contract to buy a property valued below 10 million baht, the second contract is subject to an LTV limit of 90 percent if the first contract has been paid for 3 years or longer, and LTV limit of 80 percent if the first contract has been paid for less than 3 years.

(4) For the third and subsequent mortgage contract, the LTV limits are set to 70 percent for any property price.

(5) The LTV calculation excludes loans for mortgage-reducing term assurances (MRTA) and non-life insurance, which help to mitigate risks for both borrowers and financial institutions. The calculation also exceeds the loan given to SMEs, which support funding access for small business.

Table 2-2: LTV measure (effectively started on 1 April 2019)

Property price	Mortgage contract	Collateral	LTV ratio	Type of measure
< 10 million baht	1st contract	Low-rise	95%**	RW
		High-rise	90%**	RW
	2nd contract	Low-rise and high-rise (case 1: the 1st outstanding contract having been paid for ≥ 3 years)	90%	Limit
		Low-rise and high-rise (case 2: the 1st outstanding	80%	Limit

		contract having been paid for < 3 years)		
≥ 10 million baht	1st and 2nd contract	Low-rise and high-rise	80%	Limit
Any	3rd contract and above	Low-rise and high-rise	70%	Limit

Remark: * As an example of how contracts are counted, the borrowers are said to have a "second contract" when they are currently paying for the first outstanding mortgage loan and, on top of that, are going to service the second mortgage at the same time. ** The total value of loans must not exceed that of the collaterals.

Source: BOT (2018)

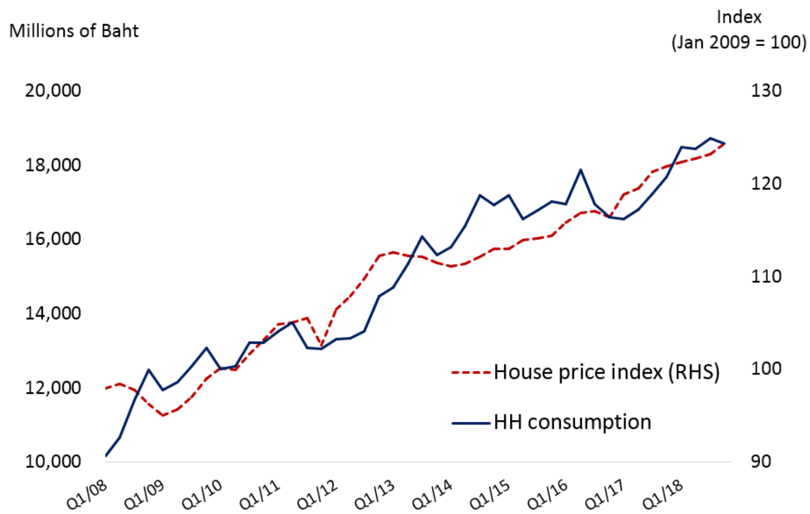
Nevertheless, the success of this macroprudential policy mainly come from cooperation with financial institutions. Most importantly, the financial institutions should maintain proper credit standards for mortgage loans and target a priority on real-demand homebuyers. Besides, they should refrain providing loan exceeded the value of the collateral which could stimulate over-borrowing and speculation in the housing market. These efforts can prevent accumulated systemic risks from taking place and foster the resilience of the overall financial system.

CHAPTER 3
THE ROLE OF HOUSING IN MONETARY POLICY EFFECT ON HOUSEHOLD CONSUMPTION

1. Introduction

The lesson learned from Thailand's housing market crash in 1997 has emphasized the linkage between house price and domestic consumption. After house prices collapsed, a slump in households' purchasing power depressed the housing market's activities for 5 years following the crisis. However, there was not only a housing spending decline, but also a widespread decrease in non-housing spending. For the majority of Thai households, occupied houses, land and buildings represent a major component and account for 76 percent of total assets (National Statistical Office of Thailand, 2015). These housing-related assets are mainly financed in the credit market and tied to long-term interest rate payments. Moreover, the evidence suggests that the movement of consumption is in line with house prices over the years (Figure 3-1). Housing financed by commercial banks is an important factor in explaining the relationship among house price, interest rate and household consumption.

Figure 3-1: Thailand's house price and household consumption (real terms)



Remark: Household consumption excludes housing expenditure and maintenance.
Source: BOT, National Economic and Social Development Board

Theoretically, house price is considered into monetary policy transmission through at least six channels: through the direct effects of interest rate on (1) the user cost of capital, (2) expectations of future house price movement, (3) housing supply, and the indirect effects through (4) the standard wealth effect, (5) the balance sheet effect on consumer spending, and (6) the balance sheet effect on housing demand. (Mishkin, 2007). To analyze the role of house price in household consumption inevitably involves both the wealth effect and balance sheet effect. For the wealth effect, housing is one of the assets whose price changes according to interest rate changes. The reallocation towards non-interest-bearing assets causes a demand for housing, which results in changes in price and accumulated wealth. The positive change in total wealth will then stimulate household expenditure. However, the effect of an interest rate change is not only on expenditure through housing wealth. A new view of the policy transmission emphasizes that the balance sheet of private agents is also affected because the interest rate changes net worth or cash flow, the so-called balance sheet effect. The effect of interest rate arises when household consumption depends on credit accessibility in the credit market. This credit accessibility is determined by the balance sheet's position and the collateral value. Housing serves as collateral for borrowing and relaxing the credit constraint. A change in house price makes the collateral value either appreciate or depreciate, which may improve or depress both the amount and term of credit. Therefore, housing provides the additional opportunity to finance consumer spending.

From the theoretical view and empirical evidence, this paper aims to elucidate how housing plays a role in monetary policy effect on household consumption. Firstly, we develop a two-sector New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model that allows housing to be used as collateral for credit accessibility (borrowing).

The model specification closely follows Monacelli (2009) which features demand, supply and monetary policy conducted by central bank in the economy. On the demand side, there are two type of households: impatient and patient with heterogeneous preference. Impatient households are financially constrained and borrow against their housing collateral constraint. On the supply side, there are two sectors (housing and non-housing) running by intermediate goods and final goods producers. However, we embody labor supply coming from all households, whereas only impatient households supply labor in Monacelli (2009). We consider labor supply assumption from the realistic reason and the benefit of capturing the redistribution of wealth and labor working hours responding to housing demand shock.

Secondly, to allow the NK-DSGE model to capture the empirical performance, we apply Bayesian techniques in parameter estimation using the Thai data ranging from 2000:Q2 to 2017:Q4. We find that the aspect of the Thai housing is well aligned with the assumption made in the model. Moreover, this model is applicable to Thailand as well as the U.S., perhaps with different parameter values, e.g. the loan-to-value (LTV) ratio and the fraction of impatient households. We choose these parameters regarding the fact that how much the degree of credit relaxation is and how many credit-constrained households there are relative to total population in the country. For the Bayesian estimation, we investigate the contribution of structural shocks, e.g. monetary policy, housing demand, productivity, and inflation shock on macroeconomic variables. Finally, we explore the implication of LTV ratio on the responses of consumption and economic variables regarding to the shocks. This exercise reveals the policy implications of stimulating an economy through housing credit regarding the relationship between house price and consumption.

The results are structured as follows: (1) The household consumption movement affected by monetary policy, housing demand, inflation and productivity shock is the consequence of house price change. An increase in house prices reinforces household consumption by increasing the opportunity to access the credit needed to finance consumption (2) The role of housing in monetary policy is transmitted by: (i) *the wealth effect on spending*; an increase in interest rate causes real house price to fall and further alleviates consumption, (ii) *the balance sheet effect on borrowing*: households who are borrowers suffer more when the interest rate increases. The combination of wealth decline and credit tightening severely affects consumption in a downturn. Finally, (iii) *the* *amplification effect on borrowing:* housing collateral amplifies the effect of interest rate shock and housing demand shock under high credit relaxation, meaning that the higher LTV ratio, the larger impact on consumption. Regarding the results, they reveal the policy implication that it is possible to stimulate an economy by means of credit relaxation. However, a high LTV ratio amplifies the impact when contractionary monetary policy is implemented.

2. Literature review

In empirical studies such as Elbourne (2008) and Jarocinski and Smets (2008), house price is related to economic activities. A change in consumption and investment is fundamentally caused by interest rates through a change in house price. Aoki, Proudman and Vlieghe (2002) explained that housing is used as collateral to reduce the agency costs associated with borrowing. Therefore, an increase in house price means more collateral is available and encourages to finance housing investment and consumption. Furthermore, the evidence found by Mian, Rao and Sufi (2013) provides an insight into the business cycle corresponding to house price changes. The study emphasizes that if the financial market requires consumers to have a sufficient net worth as collateral for borrowing, households with a lower net worth show a higher marginal propensity to consume out of wealth shock. For a given decline in house price, households respond differently based on their net worth and level of existing debt. Low net worth and highly leveraged households sharply cut their spending and the total impact of an economic downturn is more severe. Consequently, when asset prices collapse and high debts emerge, the situation becomes more challenging for monetary policy reactions to recover the economy. Aladangady (2014)'s findings indicated that there are unequal effects of monetary policy. The relationship between house price and spending is explained by a combination of wealth and collateral effects. For homeowners, collateral effects arise as household borrowing constraints are loosened by rising home values. Homeowners then increase their consumption due to rising home values after interest rate increase, whereas there no significant effect on spending for renters. Unlike homeowners, renters have only the pure wealth effect and the wealth effect is disregarded in their spending response. Subsequently, the effect of monetary policy is not significant for renters.

Empirical studies can only show how the average households react when asset price or interest rate changes. However, it is not a given that households will always react in the same way. The impact of interest rate on households is heterogeneous depending on net worth and debt (leverage). How households choose to react to a change in the balance sheet, therefore, may play an influential role in evaluating the impact on the real economy.

However, in the analysis of aggregate macroeconomics, the new methodological approach of DSGE has become more accepted because it explains aggregate economic phenomena derived from micro-foundations, particularly based on the preferences of the decision-makers. To investigate monetary policy effect and other shocks, the NK-DSGE model is widely established. It is a rigidity-based general equilibrium model measured along the lines of many well-known papers, e.g. Rotemberg and Woodford (1999); Smets and Wouters (2003); Christiano, Eichenbaum and Evans (CEE hereafter, 2005); and Gali (2008). Smets and Wouters (2003) in particular is a fully-fledged New Keynesian model in the analysis of stochastic shocks and their contributions to business fluctuations. However, they have not concentrated on the heterogeneity of households and the existing credit friction.

The standard monetary DSGE model has been augmented by including housing collateral and credit constraint. The augmented model includes the theoretical concept of credit market imperfection originally proposed by Bernanke and Gertler (BG hereafter, 1989); Kiyotaki and Moore (KM hereafter, 1997); Carlstrom and Fuerst (1997); and Bernanke, Gertler and Gilchrist (BGG hereafter, 1999), among others.

BG (1989) and BGG (1999) analyzed the role of borrowers' balance sheet in the business cycle, in which asymmetric information between borrowers and lenders always exists. These papers assume costly state verification (CSV)[5], as in Townsend (1979), and focus on credit market friction by a link between the net worth of borrowers and the agency problem associated with external finance premiums. Borrowers' net worth inversely affects the expected agency cost and external finance premiums. Importantly, fluctuations in borrowers' net worth can amplify and propagate exogenous shocks. Another remarkable study which reveals how credit constraint interacts with aggregate economic activity over the business cycle is the dynamic model of KM (1997). As in KM (1997), credit constraint arises naturally because lenders cannot force borrowers to repay their debts unless the debts are secured, so loans must be backed by collateral. In their model, durable assets such as land, housing and machinery play roles not only as factors in production, but they also serve as collateral for loans. Their model has become influential as it illustrates that small shocks might be enough to explain business cycle fluctuations if credit markets are imperfect.

[5] CSV in contract theory considers the contract design problem in which lenders must pay a fixed "auditing cost" in order to observe an individual borrowers' realized return.

Iacoviello (2005) embedded the KM mechanism inside a standard NK-DSGE setup in which collateral constraint depends on real estate values for firms and for a subset of households who confront with nominal debt. This study constitutes the interaction between asset prices and economic activities through the role of the collateral effect and the debt deflation effect. A rise in asset prices increases the borrowing capacity of debtors as it allows them to spend and invest more (collateral effect). On the other hand, a rise in consumer price reduces the real value of outstanding debt obligations, positively affecting their net worth (debt deflation effect). The net effect on consumer demand is positive and acts as a powerful amplification mechanism. On the other hand, Aoki, Proudman and Vlieghe (2004) proposed a general equilibrium model based on the financial accelerator model of BGG (1999). The model focuses on the macro effects of imperfections in credit markets because such imperfections generate a premium on the external costs of raising funds which in turn affects borrowing decisions. A rise in house price and so an increase in homeowners' net worth decreases the external finance premium, which leads to a further rise in housing demand and spills over into overall consumption. The reasons why houses have been focused on in the study of credit market imperfections are (i) houses provide a housing service to consumers which is directly affected by economic shocks, (ii) houses serve as collateral to lower borrowing costs being by far the easiest asset to borrow against. Nevertheless, Monacelli (2009) pointed to the prominent role played by not only housing but also durable assets by proposing a two-sector DSGE model incorporating durable goods into credit constraint. The distinctive feature of durable goods is that it has a shadow value, which now links to a shadow value of borrowing when it is applied as collateral in borrowing limit. Corresponding to the same implication of the role of assets or housing to consumption, the asset price movement reinforces the collateral constraint channel; when monetary policy is contracting, it lowers the relative price of durables and collateral value, thereby affecting the borrowing capacity. This effect works when durable goods prices are assumed to be relatively more flexible than non-durable prices. These results allow us to model a two-sector DSGE model in this study.

The importance of housing is emphasized by Iacoviello and Neri (2010) since housing market developments are not just a reflection of the economy, but may also be one of the sources driving the business cycle. As in this study, the movement of house prices generates the feedback effect to borrowing capacity and the expenditure of households, and to the relative profitability of firms. Therefore, the fluctuations in the housing market have a spillover from the housing market to consumption and investment. This raises a following question whether house price movement during expansion and contraction creates similar impacts on economic activities. Recently, this issue has been clarified by Guerrieri and Iacoviello (2017); this study included the asymmetric effects of housing booms and busts depending on collateral constraints which are occasionally binding in the NK-DSGE model. The results emphasize the macroeconomic asymmetries. During a housing boom, collateral constraints become slack and the expansion of housing wealth makes a small contribution to consumption. By contrast, the subsequent housing collapse tightens the constraints and sharply exacerbates the recession. Economic activities are more sensitive to house prices when housing prices are low than when they are high.

3. Two-sector NK-DSGE model

There are 5 agents in the economy: impatient households, patient households, wholesalers, retailers and central bank. As in Monacelli (2009), two types of households have heterogeneity in discount rates. Impatient households who are borrowers are subject to credit constraint, with the borrowing limit determined by the expected future value of housing collateral. Within each group, households maximize utility by choosing consumption goods, holding housing and hours worked for firms.

There are two production sectors; consumption goods and housing sector. Wholesalers combine labors to produce intermediate goods with monopolistic power in price setting. Retailers are the final goods producers under perfectly competitive markets. Following Iacoviello and Neri (2010), we allow price rigidity in consumption goods sector but let the price in housing sector flexible. There are several reasons why housing might have flexible prices. (See Iacoviello and Neri (2010); Carlstrom and Fuerst (2010)) Additionally, our analytical reason is to observe the response of relative price of housing, so we allow house price to move freely and impose only consumption goods price to be sticky. If both are equal in stickiness, there is a flat response of relative price.

This model closely follows Monacelli (2009). We choose to build on Monacelli (2009)'s model because it is well suited to capture the implications of housing collateral under a two-sector NK-DSGE model. Our modifications in terms of modeling have two aspects. First, we embody supply of labor coming from both groups of households, whereas only impatient households supply labor in Monacelli (2009). Second, we introduce four exogenous shocks which are monetary policy, housing demand, productivity and inflation shock to apply Bayesian estimation.

3.1 Impatient households

The impatient households (denoted with a prime), with the fraction, τ, of the population maximize consumption goods $\left(C_t'\right)$, holding housing $\left(H_t'\right)$ and work for firm $\left(N_t'\right)$ that lifetime utility function is given by

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t' + \varepsilon_t^H \log H_t' - \chi \frac{{N_t'}^{1+\phi}}{1+\phi} \right) \tag{3.1}$$

where E_0 is the expectation operator, β is the discount factor, χ is the disutility of supplying labor and ϕ is the inverse elasticity of labor supply. As in Iacoviello (2005), there is a housing demand shock, ε_t^H, that affects the utility from housing services H_t'. Impatient households maximize the utility function in (3.1) with the budget constraint (in real terms) as

$$C_t' + q_t \left(H_t' - \left(1-\delta^h\right) H_{t-1}' \right) + \frac{R_{t-1}}{\pi_{c,t}} b_{t-1}' = b_t' + w_t N_t' \tag{3.2}$$

where $q_t = P_{h,t} / P_{c,t}$ is real house price, $b_t' = B_t' / P_{c,t}$ is the amount of loans, $w_t = W_t / P_{c,t}$ is real wage, δ^h is housing depreciation rate, R_{t-1} is the gross nominal interest rate of loans between t-1 and t and $\pi_{c,t}$ is gross inflation rate capturing the price change from t-1 to t.

Since impatient households prefer current consumption and hold less financial wealth, they are net borrowers. As in KM (1997), durable assets such as housing and land serve as collateral for loans, and borrowers' credit constraint is affected by the future price of collateralized assets. Thus credit constraint is endogenously determined as

$$R_t b'_t \leq m\mathrm{E}_t\left(q_{t+1} H'_t \pi_{c,t+1}\right) \tag{3.3}$$

where m is the fraction of the housing value that can be used as collateral; in general, this is the loan-to-value (LTV) ratio. In the neighborhood of the steady state, borrowers prefer to borrow up to the maximum so credit constraint (3.3) is always binding in the equilibrium (see more below). Define λ'_t and $\lambda'_t \psi_t$ as the multiplier on constraints (3.2) and (3.3), respectively. λ'_t implies a shadow price of budget constraint and ψ_t implies a shadow price of housing. The first-order conditions for optimum C'_t, H'_t, b'_t and N'_t are the following.

$$\lambda'_t = \frac{1}{C'_t} \tag{3.4}$$

$$\frac{\varepsilon_t^H}{H'_t} + \frac{1}{C'_t} m\psi_t \mathrm{E}_t\left(q_{t+1}\pi_{c,t+1}\right) + \beta\left(1-\delta^h\right)\mathrm{E}_t\left(\frac{q_{t+1}}{C'_{t+1}}\right) = \frac{q_t}{C'_t} \tag{3.5}$$

$$\psi_t R_t = 1 - \beta R_t \mathrm{E}_t\left(\frac{C'_t}{C'_{t+1}\pi_{c,t+1}}\right) \tag{3.6}$$

$$w_t = \chi C' N_t'^{\phi} \tag{3.7}$$

Importantly, if the credit constraint is binding, $\psi_t > 0$, the marginal utility of current consumption is greater than the marginal gain of shifting one unit of consumption for impatient households. Given R_t, a higher ψ_t means a higher marginal benefit of using housing to extend consumption by borrowing. This implies that a rise in ψ_t is a tightening of the credit constraint.

3.2 Patient households

The difference between the two groups is that patient households have ownership in the monopolistic firms in each sector and they are more patient, implying that the discount factor, defined as γ, is higher than β (put simply, the impatient households discount the future consumption more heavily than patient households). They maximize lifetime utility (3.8) subject to the budget constraint, in real terms (3.9).

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \gamma^t \left(\log C_t'' + \varepsilon_t^H \log H_t'' - \nu \frac{{N_t''}^{1+\phi}}{1+\phi} \right) \tag{3.8}$$

$$C_t'' + q_t \left(H_t'' - \left(1-\delta^h\right) H_{t-1}'' \right) + \frac{R_{t-1}}{\pi_{c,t}} b_{t-1}'' = b_t'' + w_t N_t'' + \Gamma_{c,t} + \Gamma_{h,t} \tag{3.9}$$

where $\Gamma_{c,t}, \Gamma_{h,t}$ are real profits from holding monopolistic firms. Note that patient households lend the same amount as impatient households borrow, $-b_t''$, and receive back the same amount as debt payments, represented by $-b_t'' R_{t-1} / \pi_{c,t}$.

Define λ_t'' as the multiplier on constraint (3.9) then the first-order conditions for the real values of C_t'', H_t'', b_t'' and N_t'' result in the following equations.

$$\lambda_t'' = \frac{1}{C_t''} \tag{3.10}$$

$$\frac{\varepsilon_t^H}{H_t''} + \gamma\left(1-\delta^h\right)\mathrm{E}_t\left(\frac{q_{t+1}}{C_{t+1}''}\right) = \frac{q_t}{C_t''} \tag{3.11}$$

$$\gamma R_t \mathrm{E}_t\left(\frac{C_t''}{C_{t+1}''}\pi_{c,t+1}\right) = 1 \tag{3.12}$$

$$w_t = \nu C_t'' N_t''^{\phi} \tag{3.13}$$

Under the assumption of zero inflation at the steady state[6], equations (3.6) and (3.12) pin down the steady state as

$$\psi = \gamma - \beta \tag{3.14}$$

Due to the different households' discount rate whereby $\gamma > \beta$, this results in $\psi > 0$ at the steady state. The positive value of the shadow price of housing guarantees that (i) the credit constraint is always binding; impatient households are financially constrained and borrow at the maximum of their limit. (ii) Borrowers always choose to hold a positive amount of debt, i.e., no voluntary deleveraging.

3.3 Wholesalers

Typical wholesalers produce intermediate goods in two sectors: c (consumption goods/ non-housing) and h (housing). Assume a continuum of firms indexed by $i \in [0,1]$.

[6] In a log-linear model, the zero inflation steady state assumption yields an analytical convenience and an elimination of effects, e.g. price dispersion, marginal markup. (Ascari and Sbordone, 2014)

They differentiate goods and set their own price. For the production, wholesalers use identical technology and hire labor from two groups of households, disregarding the type thereof. The production function is represented by

$$Y_{n,t}(i) = \varepsilon_t^A N_{n,t}(i)^{1-\alpha} \tag{3.15}$$

where n = *c*, *h*. ε_t^A is a productivity shock assumed to be identical in the two sector. $1-\alpha$ is labor income share.

Optimal price setting

Consumption goods sector (c)

By assuming price stickiness, the price setting follows Calvo (1983). Each firm resets its price with probability $1-\theta$ in any particular period such that the firm chooses the selling price; $P_{c,t}(i)$ where $P_{c,t}^*$ denotes the optimal price set by the representative firm, while θ does not allow the firm to reset the price according to $P_{c,t}(i) = P_{c,t-1}(i)$. Hence, θ represents price stickiness.

Following the basic NK model of Gali (2008), the representative firm optimizes $P_{c,t}^*$ in period *t* from the maximization problem defined as

$$\max_{P_{c,t}^*} \sum_{k=0}^{\infty} \theta^k \mathrm{E}_t \left(Q_{c,t,t+k} \left(P_{c,t}^* Y_{c,t+k|t}(i) - \varepsilon_t^u \Psi_{c,t+k}\left(Y_{c,t+k|t} \right) \right) \right) \tag{3.16}$$

subject to the demand constraint

$$Y_{c,t+k|t}(i) = \left(\frac{P_{c,t}^*}{P_{c,t+k}} \right)^{-\varepsilon} Y_{c,t+k} \tag{3.17}$$

For $k = 0,1,2, \ldots$ where $Q_{c,t,t+k} = \gamma^k \lambda''_{t+1} / \lambda''_t = \gamma^k C''_t / C''_{t+1}$ is the stochastic discount factor, which is the same as patient households since they have ownership in firm, $\Psi_{c,t+k}\left(Y_{c,t+k|t}\right)$ is the cost function and ε is the elasticity of substitution across differentiated inputs. We introduce ε_t^u to capture an inflation shock derived by cost-push.

Let $\Psi'_{c,t+k|t} / P_{c,t+k} = MC^r_{c,t+k|t}$ be the real marginal cost in period $t+k$, $\Theta = \varepsilon / \varepsilon - 1$ is the mark-up price in monopolistic competition and $\pi_{c,t,t+k} = P_{c,t+k} / P_{c,t}$ is the gross inflation from price changing in period $t+k$. Thus, the first-order condition can be written as

$$\sum_{k=0}^{\infty} \theta^k \mathrm{E}_t \left(Q_{c,t,t+k} Y_{c,t+k|t} \left(\frac{P^*_{c,t}}{P^*_{c,t-1}} - \Theta \varepsilon_t^u MC^r_{c,t+k|t} \pi_{c,t-1,t+k} \right) \right) = 0 \tag{3.18}$$

In the zero inflation steady state, $P^*_{c,t} / P_{c,t-1} = 1$ and $\pi_{c,t-1,t+k} = 1$. It follows that $Y_{c,t+k|t} = Y_c$ and $MC^r_{c,t+k|t} = MC^r_c$ because all firms will be producing at the same quantity. In addition, $MC^r_c = 1/\Theta, Q_{c,t,t+k} = \gamma^k$. The first-order Taylor expansion around steady state yields

$$p^*_{c,t} - p_{c,t-1} = \left(1 - \gamma\theta\right) \sum_{k=0}^{\infty} \left(\gamma\theta\right)^k \mathrm{E}_t \left(\hat{\varepsilon}_t^u + \overset{r}{mc}_{c,t+k|t} + \left(p_{c,t+k|t} - p_{c,t-1} \right) \right) \tag{3.19}$$

where $\overset{r}{mc}_{c,t+k|t} = mc^r_{c,t+k|t} - mc^r_c$ denotes the log deviation of real marginal cost from steady state value.

Housing sector (h)

By assuming price is flexible, the representative intermediate firm chooses $P_{h,t}\left(i\right)$ to maximize

$$P_{h,t}\left(i\right)Y_{h,t}\left(i\right)-W_t N_{h,t}\left(i\right) \tag{3.20}$$

subject to the production function in (3.15) and the demand function for housing product

$$Y_{h,t}\left(i\right)=\left(\frac{P_{h,t}\left(i\right)}{P_{h,t}}\right)^{-\varepsilon}Y_{h,t} \tag{3.21}$$

Each firm *i* takes the nominal wage W_t as a given due to the assumption of a perfectly competitive labor market. Substituting for $Y_{h,t}\left(i\right)$ and $N_{h,t}\left(i\right)$, the firm problem in (3.20) becomes one of choosing $P_{h,t}\left(i\right)$ to maximize

$$\max_{P_{h,t}} P_{h,t}\left(i\right)\left(\frac{P_{h,t}\left(i\right)}{P_{h,t}}\right)^{-\varepsilon}Y_{h,t}-W_t\left(\frac{Y_{h,t}}{\varepsilon_t}\right)^{\frac{1}{1-\alpha}}\left(\frac{P_{h,t}\left(i\right)}{P_{h,t}}\right)^{\frac{-\varepsilon}{1-\alpha}} \tag{3.22}$$

The resulting first-order condition is

$$\left(1-\varepsilon\right)\left(\frac{P_{h,t}\left(i\right)}{P_{h,t}}\right)^{-\varepsilon}Y_{h,t}+\frac{\varepsilon}{1-\alpha}W_t\left(\frac{Y_{h,t}}{\varepsilon_t^A}\right)^{\frac{1}{1-\alpha}}\left(\frac{P_{h,t}\left(i\right)}{P_{h,t}}\right)^{\frac{-\varepsilon}{1-\alpha}}P_{h,t}\left(i\right)^{-1}=0 \tag{3.23}$$

which simplifies to

$$P_{h,t}\left(i\right)=\frac{\varepsilon}{\varepsilon-1}MC_{h,t}=\Theta MC_{h,t} \tag{3.24}$$

We again note that $MC_{h,t}$ is nominal marginal cost and denote $P_{h,t}(i) = P^*_{h,t}$ as the optimal price set by representative firm. Next, it is useful to rewrite the optimal pricing condition under log form as

$$P^*_{h,t} = \mu + mc_{h,t} \tag{3.25}$$

where $P^*_{h,t} = \log P_{h,t}(i), \mu = \log \Theta$ and $mc_{h,t} = \log MC_{h,t}$. Furthermore, we can write the (log) real marginal cost of production as

$$mc^r_{h,t} = \log MC^r_{h,t} = -\mu \tag{3.26}$$

3.4 Retailers

The retailers buy differentiated intermediate goods and transform to homogenous final goods produced by identical and perfectly competitive producers. By taking price $P_{n,t}$ as a given (n = *c*, *h*), $Y_{n,t}(i)$ is the quantity demanded of intermediate goods $i \in [0,1]$. The final goods production function is expressed by

$$Y_{n,t} = \left(\int_0^1 Y_{n,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.27}$$

Firms choose $Y_{n,t}(i), Y_{n,t}$ in order to maximize their profits

$$\max P_{n,t} Y_{n,t} - \int_0^1 P_{n,t}(i) Y_{n,t}(i) di \tag{3.28}$$

from the first-order condition gives the individual demand curve for each retailer as

$$Y_{n,t}(i)=\left(\frac{P_{n,t}(i)}{P_{n,t}}\right)^{-\varepsilon}Y_t \tag{3.29}$$

Aggregate price dynamics

Since each firm is in a competitive market, the profit of final good producers must be zero in equilibrium. It must be held as

$$P_{n,t}Y_{n,t}=\int_0^1 P_{n,t}(i)Y_{n,t}(i)di \tag{3.30}$$

Combined with (3.29), we obtain the price index

$$P_{n,t}=\left(\int_0^1 P_{n,t}(i)^{1-\varepsilon}di\right)^{\frac{1}{1-\varepsilon}} \tag{3.31}$$

Consumption goods sector (c)

From Calvo's pricing, let $s(t)\subset[0,1]$ represent firms not optimizing price in *t*, each firm may reset their price only with probability $1-\theta$. We can, therefore, rewrite the dynamic of the aggregate price level as

$$P_{c,t}=\left[\int_{s(t)} P_{c,t}(i)^{1-\varepsilon}di+(1-\theta)\left(P_{c,t}^{*}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{3.32}$$

Since the distribution of prices among firms does not adjust at *t*, it corresponds to the distribution of effective prices at *t-1*. Hence, we can state

$$P_{c,t}=\left[\theta P_{c,t-1}{}^{1-\varepsilon}+(1-\theta)\left(P_{c,t}^{*}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{3.33}$$

Housing sector (h)

Corresponding to (3.31), the aggregate price dynamic is shown as

$$P_{h,t} = \left(\int_0^1 P_{h,t}(i)^{1-\varepsilon}\, di\right)^{\frac{1}{1-\varepsilon}} \tag{3.34}$$

From the price setting above, in the consumption goods sector (c), we combine the optimal price setting (3.19) and aggregate price dynamic (3.33). The new Keynesian Phillip curve (NKPC) yields

$$\hat{\pi}_{c,t} = \gamma E_t\left(\hat{\pi}_{c,t+1}\right) + \kappa\left(\frac{1+\phi}{1-\alpha}\right)\left(\hat{Y}_{c,t} - \hat{\varepsilon}_t^A\right) + \kappa\hat{\varepsilon}_t^u \tag{3.35}$$

where $\kappa = \dfrac{(1-\theta)(1-\gamma\theta)}{\theta}$

3.5 Central bank

The monetary policy implementation is followed by the standard Taylor principle which responds to inflation and output deviated from the steady state level. The rule operates the nominal interest rate and allows for monetary policy shock.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\Omega_R}\left(\left(\frac{\pi_{c,t}}{\pi_c}\right)^{\Omega_\pi}\left(\frac{Y_{c,t}}{Y_c}\right)^{\Omega_Y}\right)^{1-\Omega_R}\varepsilon_t^R \tag{3.36}$$

where R, π_c and Y_c are the steady state value of the gross interest rate, inflation and output in the consumption goods sector, respectively. Ω_R, Ω_π and Ω_Y are policy weighted and chosen by the central bank. ε_t^R is an exogenous monetary policy shock.

$Y_{c,t}$ is different from the aggregate output (GDP); however, the output in consumption goods accounts for 95 percent of the total GDP of Thailand. It is approximately equal to GDP within a local region of the steady state (see, for example, Iacoviello (2005) and Guerrieri and Iacoviello (2017)).

3.6 Equilibrium

The equilibrium is an allocation $\left\{Y_{c,t}, Y_{h,t}, C_t', C_t'', H_t', H_t'', b_t', N_t', N_t'', N_{c,t}, N_{h,t}, \psi_t\right\}_{t=0}^{\infty}$ together with the sequence of prices $\left\{\pi_{c,t}, q_t, R_t\right\}_{t=0}^{\infty}$ satisfying the first-order conditions, budget constraint, credit constraint, resource constraint, and the following market clearing conditions:

goods market: $$Y_{c,t} = C_t = \tau C_t' + (1-\tau) C_t'' \quad (3.37)$$

housing market: $$Y_{h,t} = \tau\left(H_t' - \left(1-\delta^h\right) H_{t-1}'\right) + (1-\tau)\left(H_t'' - \left(1-\delta^h\right) H_{t-1}''\right) \quad (3.38)$$

labor market: $$\tau N_t' + (1-\tau) N_t'' = \sum_n N_{n,t} \ , \ n = c, h \quad (3.39)$$

loans market: $$b_t' + b_t'' = 0 \quad (3.40)$$

The set of shock variables is assumed to follow the first-order autoregressive stochastic process with an independently and identically distributed (i.i.d.) normal error term.

monetary policy shock: $$\log\varepsilon_t^R = \rho_R \log\varepsilon_{t-1}^R + \eta_t^R \quad (3.41)$$

housing demand shock: $$\log\varepsilon_t^H = \rho_H \log\varepsilon_{t-1}^H + \eta_t^H \quad (3.42)$$

productivity shock: $$\log\varepsilon_t^A = \rho_A \log\varepsilon_{t-1}^A + \eta_t^A \quad (3.43)$$

inflation shock: $$\log\varepsilon_t^U = \rho_U \log\varepsilon_{t-1}^U + \eta_t^U \quad (3.44)$$

3.7 Steady state

After defining the economy's equilibrium, the DSGE model needs to define the steady state value to ensure that there is a value for the variables that is maintained over time. Note that in a steady state with zero inflation $P_{c,t} = P_{c,t-1}$ for all *t*, so $\pi_{c,t} = P_{c,t}/P_{c,t-1} = \pi_c = 1$. The steady state values are presented in Table 3-1.

Table 3-1: Steady state

Steady state	
$R = \frac{1}{\gamma}$	(s1)
$\psi = \gamma - \beta$	(s2)
$\frac{C'}{Y_c} = \frac{1}{\left(\tau + (1-\tau)\frac{\chi}{\nu}\right)}$	(s3)
$\frac{C''}{Y_c} = \frac{\chi}{\tau\nu + (1-\tau)\chi}$	(s4)

$$\frac{qH'}{Y_c}=\frac{1}{\left(1-m\psi-\beta\left(1-\delta^h\right)\right)\left(\tau+\left(1-\tau\right)\frac{\chi}{v}\right)}$$	(s5)
$$\frac{qH''}{Y_c}=\frac{\chi}{\left(1-\gamma\left(1-\delta^h\right)\right)\left(\tau v+\left(1-\tau\right)\chi\right)}$$	(s6)
$$\frac{b'}{Y_c}=\frac{m\gamma}{\left(1-m\psi-\beta\left(1-\delta^h\right)\right)\left(\tau+\left(1-\tau\right)\frac{\chi}{v}\right)}$$	(s7)
$$\frac{H'}{H''}=\frac{qH'/Y_c}{qH''/Y_c}$$	(s8)
$$\frac{Y_h}{H''}=\tau\delta^h\left(\frac{H'}{H''}\right)+\left(1-\tau\right)\delta^h$$	(s9)
$$N'=\left[\frac{1}{\chi}\left(1+\frac{\delta^h}{\left(1-m\psi-\beta\left(1-\delta^h\right)\right)}+\frac{m\left(1-\gamma\right)}{\left(1-m\gamma-\beta\left(1-\delta^h\right)\right)}\right)\right]^{\frac{1}{1+\phi}}$$	(s10)
$$N''=\left[\frac{\left(C'/Y_c\right)}{vN'\left(C''/Y_c\right)}+\left(1+\frac{\delta^h}{\left(1-m\psi-\beta\left(1-\delta^h\right)\right)}+\frac{m\left(1-\gamma\right)}{\left(1-m\gamma-\beta\left(1-\delta^h\right)\right)}\right)\right]^{\frac{1}{\phi}}$$	(s11)

Source: Author's calculation

3.8 Linearized model

Solving the DSGE model in linear form is easier than doing so in its non-linear form, thus non-linear equations can be approximated linearly by a procedure of log-linearizing the model around its steady state (Uhlig's method).

The steady state values are denoted by variables with subscript *ss*. Simply replacing a variable X_t with $X_{ss}e^{\hat{X}_t}$, where $\hat{X}_t=\log X-\log X_{ss}$ represents the log of the variable's deviation from its steady state, and subsequently using the properties of the following:

$$e^{\left(\hat{X}_t + a\hat{Y}_t\right)} \approx 1 + \hat{X}_t + a\hat{Y}_t \tag{a}$$

$$\hat{X}_t \hat{Y}_t \approx 0 \tag{b}$$

$$\mathrm{E}_t\left[ae^{\hat{X}_{t+1}}\right] \approx a + a\mathrm{E}_t\left[\hat{X}_{t+1}\right] \tag{c}$$

A collection of the first order and equilibrium condition is linearized around the steady state. The final specification of all equations is shown in Table 3-2.

Table 3-2: Model block in linearized form

Equation	
$\frac{Y_c}{qH'}\left(\hat{\varepsilon}_t^H - \hat{H}_t'\right) + m\psi\frac{Y_c}{C'}\left(\hat{\psi}_t + \hat{\pi}_{c,t+1} + \hat{q}_{t+1} - \hat{C}_t'\right) + \beta\left(1-\delta^h\right)\frac{Y_c}{C'}\left(\hat{q}_{t+1} - \hat{C}_{t+1}'\right) = \frac{Y_c}{C'}\left(\hat{q}_t - \hat{C}_t'\right)$	(L1)
$\hat{C}_t' = -\left(\frac{\gamma-\beta}{\beta}\right)\hat{\psi}_t - \left(\frac{\gamma}{\beta}\right)\hat{R}_t + \hat{C}_{t+1}' + \hat{\pi}_{c,t+1}$	(L2)
$\frac{Y_c}{qH''}\left(\hat{\varepsilon}_t^H - \hat{H}_t''\right) + \gamma\left(1-\delta^h\right)\frac{Y_c}{C''}\left(\hat{q}_{t+1} - \hat{C}_t''\right) = \frac{Y_c}{C''}\left(\hat{q}_t - \hat{C}_t''\right)$	(L3)
$\hat{C}_t'' = \hat{C}_{t+1}'' - \hat{R}_t + \hat{\pi}_{c,t+1}$	(L4)
$\hat{C}_t' + \phi\hat{N}_t' = \hat{C}_t'' + \phi\hat{N}_t''$	(L5)
$\hat{b}_t'' = \hat{H}_t'' + \hat{q}_{t+1} + \hat{\pi}_{c,t+1} - \hat{R}_t$	(L6)
$\hat{\pi}_{c,t} = \gamma E_t\left(\hat{\pi}_{c,t+1}\right) + \kappa\left(\frac{1+\phi}{1-\alpha}\right)\left(\hat{Y}_{c,t} - \hat{\varepsilon}_t^A\right) + \kappa\hat{\varepsilon}_t^u\ ,\ \kappa = \frac{(1-\theta)(1-\gamma\theta)}{\theta}$	(L7)
$\hat{Y}_{c,t} = \left(\tau\frac{C'}{Y_c}\right)\hat{C}_t' + \left((1-\tau)\frac{C''}{Y_c}\right)\hat{C}_t''$	(L8)

$\left(\dfrac{Y_h}{H''}\right)\hat{Y}_{h,t}=\tau\dfrac{H'}{H''}\left(\hat{H}'_t-\left(1-\delta^h\right)\hat{H}'_{t-1}\right)+\left(1-\tau\right)\left(\hat{H}'_t-\left(1-\delta^h\right)\hat{H}'_{t-1}\right)$	(L9)
$\hat{R}_t=\Omega_R\hat{R}_{t-1}+\left(1-\Omega_R\right)\left[\Omega_\pi\hat{\pi}_{c,t}+\Omega_Y\hat{Y}_{c,t}\right]+\hat{\varepsilon}_t^R$	(L10)
$\hat{Y}_{c,t}=\left(1-\alpha\right)\hat{N}_{c,t}+\hat{\varepsilon}_t^A$	(L11)
$\hat{Y}_{h,t}=\left(1-\alpha\right)\hat{N}_{h,t}+\hat{\varepsilon}_t^A$	(L12)
$\tau\hat{N}'_t+\left(1-\tau\right)\hat{N}''_t=\hat{N}_{c,t}+\hat{N}_{h,t}$	(L13)
$\left(\dfrac{C'}{Y_c}\right)\hat{C}'_t+\left(\dfrac{qH'}{Y_c}\right)\left(\hat{q}_t+\hat{H}'_t-\left(1-\delta^h\right)\hat{q}_t-\left(1-\delta^h\right)\hat{H}'_{t-1}\right)+\left(\dfrac{b'}{\gamma Y_c}\right)\left(\hat{b}'_{t-1}+\hat{R}_{t-1}-\hat{\pi}_{c,t}\right)$ $=\left(\dfrac{b'}{Y_c}\right)\hat{b}'_t+\left(\chi\left(1+\phi\right)\dfrac{C'}{Y_c}\left(N'\right)^{1+\phi}\right)\hat{N}'_t+\left(\chi\dfrac{C'}{Y_c}\left(N'\right)^{1+\phi}\right)\hat{C}'_t$	(L14)
$\left(\dfrac{C'}{Y_c}\right)\hat{C}'_t+\left(\dfrac{qH'}{Y_c}\right)\left(\hat{q}_t+\hat{H}'_t-\left(1-\delta^h\right)\hat{q}_t-\left(1-\delta^h\right)\hat{H}'_{t-1}\right)+\left(\dfrac{b'}{\gamma Y_c}\right)\left(\hat{b}'_{t-1}+\hat{R}_{t-1}-\hat{\pi}_{c,t}\right)$ $=\left(\dfrac{b'}{Y_c}\right)\hat{b}'_t+\left(\nu\dfrac{C''}{Y_c}N'N''^{\phi}\right)\left(\hat{N}'_t+\hat{C}''_t\right)+\left(\nu\phi\dfrac{C''}{Y_c}N'N''^{\phi}\right)\hat{N}''_t$	(L15)

Source: Author's derivation

4. Bayesian estimation

4.1 Methodology

The Bayesian analysis formally incorporates prior beliefs and uncertainty regarding the parameterization of the model. In other words, in Bayesian analysis, the parameters of the model are regarded as random variables which take a certain value with some probability. It combines likelihood with prior information. By introducing prior information in the form of probability densities, the likelihood function is reweighed by the prior density. The degree of uncertainty about the prior information can thereby be expressed by the standard deviation of the prior density. Therefore, the Bayesian approach is explicitly take account of all uncertainty surrounding parameter estimates. The Bayesian estimation connects prior beliefs and data, in which prior distributions are used to describe the state of knowledge about the parameter vector $\boldsymbol{\theta}$ before observing the sample $\mathbf{Y}$. So, the priors act as an initial guide and the maximum likelihood approach enters through the estimation process by confronting the model with data. Technically, priors and likelihood functions are explained by Bayes' rule.

First, a density function of priors is denoted by $p\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathrm{A}\right)$ where A stands for a specific model, $\boldsymbol{\theta}_{\mathrm{A}}$ represents the parameters of model A. Second, the density of the observed data given the model and its parameters, called the likelihood function, is described by $L\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathbf{Y}_{\mathrm{T}},\mathrm{A}\right) \equiv p\left(\mathbf{Y}_{\mathrm{T}} \mid \boldsymbol{\theta}_{\mathrm{A}},\mathrm{A}\right)$ where $\mathbf{Y}_{\mathrm{T}}$ are the observations until period T. Third, from Bayes' theorem $p\left(\boldsymbol{\theta} \mid \mathbf{Y}_{\mathrm{T}}\right) = \dfrac{p\left(\boldsymbol{\theta};\mathbf{Y}_{\mathrm{T}}\right)}{p\left(\mathbf{Y}_{\mathrm{T}}\right)}$, we know that $p\left(\boldsymbol{\theta};\mathbf{Y}_{\mathrm{T}}\right) = p\left(\mathbf{Y}_{\mathrm{T}} \mid \boldsymbol{\theta}\right) \times p\left(\boldsymbol{\theta}\right)$. We can subsequently use this to combine prior density and likelihood function. Fourth, posterior density can be expressed by $p\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathbf{Y}_{\mathrm{T}},\mathrm{A}\right) = \dfrac{p\left(\mathbf{Y}_{\mathrm{T}} \mid \boldsymbol{\theta}_{\mathrm{A}},\mathrm{A}\right) \times p\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathrm{A}\right)}{p\left(\mathbf{Y}_{\mathrm{T}} \mid \mathrm{A}\right)}$ where $p\left(\mathbf{Y}_{\mathrm{T}} \mid \mathrm{A}\right) = \int_{\boldsymbol{\theta}_{\mathrm{A}}} p\left(\boldsymbol{\theta}_{\mathrm{A}};\mathbf{Y}_{\mathrm{T}} \mid \mathrm{A}\right) d\boldsymbol{\theta}_{\mathrm{A}}$ is the marginal density of the data conditional on the model. Finally, the posterior kernel is represented by the numerator of posterior density, i.e. $p\left(\mathbf{Y}_{\mathrm{T}} \mid \boldsymbol{\theta}_{\mathrm{A}},\mathrm{A}\right) \times p\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathrm{A}\right) \equiv \kappa\left(\boldsymbol{\theta}_{\mathrm{A}} \mid \mathbf{Y}_{\mathrm{T}},\mathrm{A}\right)$. The kernel equation can construct the posterior moments of interest by using an algorithm such as the Kalman filter to estimate likelihood function. Then, the Metropolis-Hasting algorithm is used to simulate the parameter values and the accepted values are kept to construct a histogram of posterior distribution.

From the computational point of view, solving the DSGE model and algorithms for Bayesian estimation can be done by using the DYNARE program:

Step 1: Rewrite the solution of the DSGE model in state-space representation;

Step 2: Specify the prior distribution of the parameters to estimate;

Step 3: Estimate the likelihood of the DSGE solution with the algorithm of the Kalman filter. After deriving the log-likelihood[7], $\ln L(\boldsymbol{\theta} \mid \mathbf{Y}_{\mathrm{T}})$ and specifying prior, $\ln p(\boldsymbol{\theta})$, the log posterior kernel can be expressed as $\ln \kappa(\boldsymbol{\theta} \mid \mathbf{Y}_{\mathrm{T}}) = \ln L(\boldsymbol{\theta} \mid \mathbf{Y}_{\mathrm{T}}) + \ln p(\boldsymbol{\theta})$;

Step 4: Find the mode of posterior distribution by maximizing the log posterior kernel with respect to parameter vector $\boldsymbol{\theta}$;

Step 5: Simulate the posterior distribution by using the Metropolis-Hasting algorithm.

As in Griffoli (2013), the Metropolis-Hastings algorithm comprises the following steps:

1) Choose a starting point $\boldsymbol{\theta}^0$, where this is typically the posterior mode, and run a loop over Steps 2, 3 and 4;

2) Draw new candidate values $\boldsymbol{\theta}^*$ from a jumping distribution $J(\boldsymbol{\theta}^* \mid \boldsymbol{\theta}^{t-1}) = \mathrm{N}(\boldsymbol{\theta}^{t-1}, c\Sigma_m)$ where Σ_m is the inverse of the Hessian computed at the posterior mode;

[7] See Griffoli (2013)

3) Compare the acceptance ratio $r = \frac{p\left(\boldsymbol{\theta}^{*} \mid \mathbf{Y}_{T}\right)}{p\left(\boldsymbol{\theta}^{t-1} \mid \mathbf{Y}_{T}\right)} = \frac{\kappa\left(\boldsymbol{\theta}^{*} \mid \mathbf{Y}_{T}\right)}{\kappa\left(\boldsymbol{\theta}^{t-1} \mid \mathbf{Y}_{T}\right)}$;

4) Accept or discard $\boldsymbol{\theta}^{*}$ according to the following rule and update the jumping distribution. If $r > 1; \boldsymbol{\theta}^{t} = \boldsymbol{\theta}^{*}$, the candidate is accepted. Otherwise, use the candidate of the last period $\boldsymbol{\theta}^{t} = \boldsymbol{\theta}^{t-1}$;

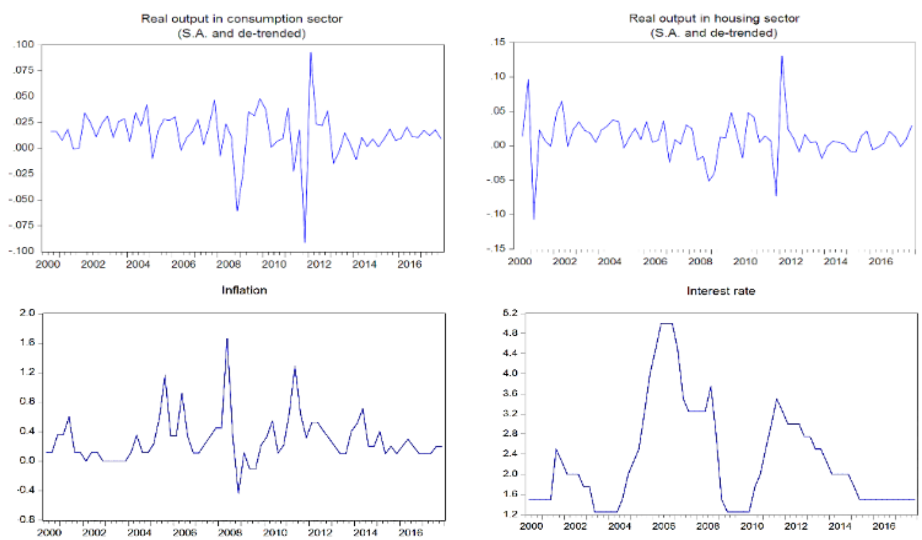
5) Update the mean drawing distribution and note the value of the parameters accepted. After having repeated these steps often enough, build a histogram of these retained values. The smooth histogram will eventually be the posterior distribution.

In this study, we simulate the posterior distribution by using Metropolis-Hastings (MHs) algorithm with 500,000 replications for two Markov chains of MHs. We disregard 25 percent of the initially generated parameters because of an unrepresentative equilibrium distribution.

4.2 Data

The samples are compiled from the quarterly data from Thailand, starting from 2000:Q2 to 2017:Q4, during which the inflation targeting regime has been implemented. The observable data consists of four macroeconomic series. First, *output in the consumption goods sector*; $Y_{c,t}$ is measured by GDP excluding the real estate sector. Second, *output in the housing sector*; $Y_{h,t}$ is the real estate value in the GDP component. The series is transformed in real terms, seasonally adjusted and de-trended by the first difference of log transformation of the original data which is published by the National Economic and Social Development Board (NESDB). Third, *inflation*; $\pi_{c,t}$ is obtained by the percentage change in the consumer price index (CPI) from the Bureau of Trade and Economic Indices, Ministry of Commerce. Fourth, *interest rate*; R_t which is the policy rate, namely RP 1 day from the Bank of Thailand (BOT). All observations are stationary and are plotted in Figure 3-2.

Figure 3-2: Observed data



Source: Author

4.3 Prior specifications

Two parameters are calibrated. First, the LTV ratio, *m*, is set at 0.8. This parameter is difficult to identify. Due to the BOT have introduced risk-weighted capital charge (RW) for mortgage loans with LTV greater than 80 percent since 2009, the competition in mortgage loans market among financial institutions is high. For instance, in the first half of 2018, 49 percent of new mortgage loan accounts took LTV ratio that exceeds 90 percent[8]. We then select LTV ratio at 80 percent which is slightly different from the literature (70 percent in Monacelli (2009) and 85 percent in Iacoviello and Neri (2010)). Second, the share of impatient households is set at 0.2. We average the share of the number of borrowers from the Thai Credit Bureau in total population in 2009-2016. This value is in line with the U.S. data in Iacoviello and Neri (2010). The rest of the parameters are given prior information in Table 3-3. Overall, the standard parameters are consistent with the previous studies. Some parameters are chosen based on the Thai data.

The discount factor for patient households (γ) is set at 0.99, whereas that for the impatient households (β) is set at 0.96. The heterogeneity guarantees a well-defined steady state from the positive value of credit constraint (ψ). As in Monacelli (2009) and Iacoviello and Neri (2010), the inverse elasticity of the labor supply (ϕ) is assumed to be 1. However, the patient households tend to be more sensitive to the disutility of supplying labor (ν) because of the income effect. We, therefore, allow for 1.1; this is slightly greater than impatient households (χ). We follow Monacelli (2009) by selecting depreciation rate for housing at 0.01. This yields the steady-state value of annual depreciation rate of 4 percent which is corresponding to the Thai housing depreciation rate.[9] The elasticity of inputs

[8] See figure 2-3 in chapter 2

[9] For calculation, the Revenue Department, Ministry of Finance suggests annual depreciation rate for buildings at 5 percent at the maximum. It is approximated around 0.1 in a quarter.

substitution (ε) is assumed to be 5, which implies a steady-state mark-up of 25 percent. Recently, Apaitan, Disyatat and Manopimoke (2018) found that Thailand's price rigidity is high; the mean duration that price does not change is approximately 4 to 7 months. This study suggests the degree of price stickiness (θ) is 0.75.[10] For monetary policy implementation, we follow the Taylor rule's parameters in Thailand from Phrommin (2016). The interest rate smoothing (Ω_R) is at 0.8, while the policy response's coefficients are at 1.7 and 0.125 in inflation weighted (Ω_π) and output growth weighted (Ω_Y), respectively. The shock persistence values $(\rho_H, \rho_A, \rho_U, \rho_R)$ are chosen by the computational reason to facilitate the convergence diagnosis. We select the prior mean for $\rho_H, \rho_A, \rho_U, \rho_R$ to be 0.9, 0.6, 0.1 and 0.2 with a standard deviation of 0.01 (see more below). Finally, the standard deviation of structural shocks $(\sigma_H, \sigma_A, \sigma_U, \sigma_R)$ is assumed in an inverse gamma distribution with a mean of 0.1 and an informative standard error of 2.0.

Table 3-3: Prior information

Parameters	Description	Distribution	Mean	Std.dev
γ	Patient hhs' discount factor	Beta	0.99	0.001
β	Impatient hhs' discount factor	Beta	0.96	0.01
ϕ	Inverse elasticity of labor supply	Normal	1	0.5
ε	Elasticity of substitution across inputs	Normal	5.0	0.01
α	Non-labor income share on output	Beta	0.36	0.01
θ	Degree of price stickiness	Beta	0.75	0.01
χ	Labor disutility of impatient hhs	Normal	1.0	0.01
ν				

[10] See Dixon and Kara (2006) for calculation

δ^h	Labor disutility of patient hhs	Normal	1.1	0.01
Ω_R	Housing depreciation rate	Beta	0.01	0.001
Ω_π	Central bank's interest rate smoothing	Beta	0.8	0.01
Ω_Y	Central bank's inflation response	Normal	1.7	0.01
ρ_H	Central bank's output gap response	Beta	0.125	0.01
ρ_A	Housing demand shock persistence	Beta	0.9	0.01
ρ_U	Productivity shock persistence	Beta	0.2	0.01
ρ_R	Inflation shock persistence	Beta	0.6	0.01
σ_H	Monetary policy shock persistence	Beta	0.1	0.01
σ_A	Std. of housing demand shock	Inv. gamma	0.1	2.0
σ_U	Std. of productivity shock	Inv. gamma	0.1	2.0
σ_R	Std. of inflation shock	Inv. gamma	0.1	2.0
	Std. of monetary policy shock	Inv. gamma	0.1	2.0

Source: Author

5. Results and analysis

5.1 Posterior estimates

Table 3-4 reports the posterior mean and 90 percent interval distribution of all parameters, together with the mean and standard deviation of prior distribution.

The behavior of households described by parameters γ and β shows that patient households have a discount rate of 0.9906, which is more than impatient households at 0.8817. Even if the estimated discount factors differ from the calibrated values of previous studies, e.g. Iacoviello (2005) and Monacelli (2009), the result suggests that the model lines up well with the data in the given priors. The inverse elasticity of labor supply (ϕ) is 3.7573, indicating a slight elasticity of the labor supply with respect to real wages at 1/3.7573 = 0.2661. The elasticity of substitution across inputs (ε) is the same as stated previously at 5. In the production function, labor contributes approximately to 63 percent of the total output $(1-\alpha)$. The labor disutility for households in both groups are not different from prior information. The labor disutility of patient households (ν) is estimated to be 1.1, whereas it is estimated to be 1 for impatient ones (χ). These values of labor disutility are common in many literature.

Focusing on the parameters in the interest rate reaction function, the monetary authority gives more weight to inflation, backward interest rate and output growth. This satisfies the so-called Taylor principle, meaning that the response of interest rate to inflation (Ω_{π}) is greater than one, at 1.7016. The interest rate also positively responds to output growth (Ω_{Y}) at 0.1272. In addition, there is evidence of a high degree of interest rate smoothing (Ω_{R}) at 0.7898.

The stochastic processes of housing demand shock (ρ_{H}) has a high dependence on its own lag, as indicated by the posterior persistence parameters of 0.9383. The inflation shock is moderate persistent with autocorrelation coefficient (ρ_{U}) of 0.5982. Noticeably, the model suggests a low degree of shock persistence in monetary policy (ρ_{R}) and productivity (ρ_{A}), at 0.0967 and 0.2091 respectively. In particular, interest rate persistence is quite low but we cannot simply ignore it because it does not imply that there is no impact on interest rate movement. Since the prior and posterior mean of shock processes are different from common values in the literature, we performed sensitivity analysis with respect to these parameters and found that the values of parameter obtained above deliver the convergence of MHs in the parameter moments.

Other parameters of the standard deviation of shocks explain that housing demand shock (σ_H) exhibits larger size than other shocks with 28.8464. This value is in the range that is consistent with Iacoviello (2005)'s model.[11] We also find that the model incorporating housing demand shock seems to produce a larger standard deviation of housing demand shock than other shocks in the model. This indicates a role of housing demand shock in explaining a variance decomposition.

Table 3-4: Posterior mean and 90% interval distribution

Parameters	Prior distribution (mean, std.)	Posterior mean	90% Interval
γ	Beta (0.99, 0.001)	0.9906	[0.9891, 0.9922]
β	Beta (0.96, 0.01)	0.8817	[0.8650, 0,8946]
ϕ	Normal (1, 0.5)	3.7573	[3.4112, 4.1806]
ε	Normal (5, 0.01)	5.0001	[4.9836, 5.0163]
α	Beta (0.36, 0.01)	0.3668	[0.3502, 0.3834]
θ	Beta (0.75, 0.01)	0.7501	[0.7339, 0.7668]
χ	Normal (1, 0.01)	1.0000	[0.9834, 1.0163]
ν	Normal (1.1, 0.01)	1.1000	[1.0838, 1.1167]
δ^h	Beta (0.1, 0.001)	0.0096	[0.0080, 0.0112]
Ω_R	Beta (0.8, 0.01)	0.7898	[0.7746, 0.8055]
Ω_π			

[11] We apply Bayesian estimation of Iacoviello (2005)'s model using Thai data to compare the posterior standard deviation of housing demand shock.

Ω_Y	Beta (1.7, 0.01)	1.7016	[1.6854, 1.7180]
ρ_H	Beta (0.125, 0.01)	0.1272	[0.1103, 0.1435]
ρ_A	Beta (0.9, 0.01)	0.9383	[0.9283, 0.9485]
ρ_U	Beta (0.2, 0.01)	0.2091	[0.1923, 0.2264]
ρ_R	Beta (0.6, 0.01)	0.5982	[0.5819, 0.6148]
σ_H	Beta (0.1, 0.01)	0.0967	[0.0809, 0.1125]
σ_A	Inv. gamma (0.1, 2.0)	28.8464	[21.9778, 35.4690]
σ_U	Inv. gamma (0.1, 2.0)	0.2364	[0.2001, 0.2703]
σ_R	Inv. gamma (0.1, 2.0)	2.5044	[2.1567, 2.8464]
	Inv. gamma (0.1, 2.0)	0.1104	[0.0940, 0.1262]

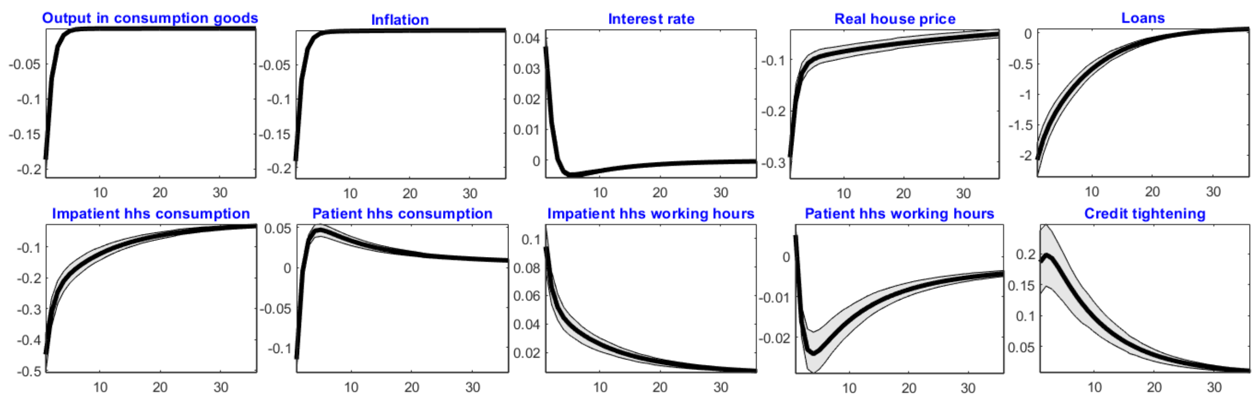
Source: Author's estimation

5.2 Impulse response analysis

Monetary policy shock

Figure 3-3 illustrates the responses of macroeconomic variables to a monetary policy shock. A positive monetary policy shock of one standard deviation immediately raises interest rate approximately by 0.04 percentage points. Following this shock, real house price reduces by 0.3 percent. As the value of housing used as collateral reduces, the amount of loans that impatient households can borrow decreases by 2 percent. This implies that credit constraint is tighter; credit tightening, expressed by ψ_t, increases approximately by 0.2 percent. Impatient households' consumption falls by 0.45 percent. At the same time, an increase in interest rate causes patient households' consumption to fall by 0.1 percent but it drops in a short-lived period before slightly increases in the later periods. The explanation is that since patient households are lenders and better-off from an increase in interest rate. Crucially, impatient households are affected more by the consumption decline. This is because impatient households confront the higher cost of debt repayments, negative collateral value together with negative income effect. The combination of wealth decline and credit tightening affects their consumption in a downturn. Overall, output in consumption goods sector (aggregate consumption) decreases approximately 0.2 percent after a positive monetary policy shock.

Figure 3-3: Impulse response to positive monetary policy shock

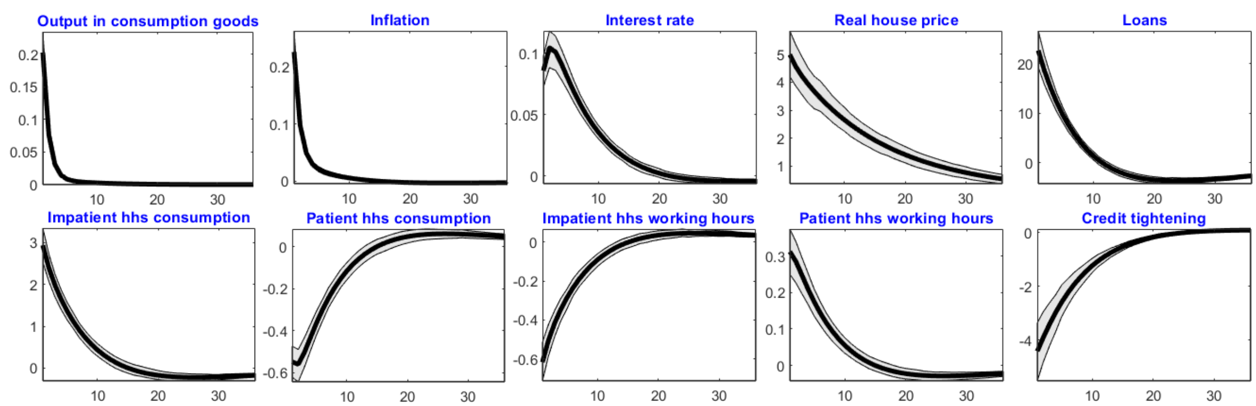


Source: Author

Housing demand shock

Figure 3-4 demonstrates the estimated impulse response to a housing demand shock. A positive housing demand shock of one standard deviation generates a long-lasting 5 percent increase in real house price. The aggregate output in the consumption goods sector increases by 0.2 percent; however, the consumption responses are heterogeneous among two groups. A rise in real house price expands the borrowing capacity of impatient households, as seen by credit constraint loosening by 4 percent. This induces impatient households to borrow more by 20 percent to finance their consumption. Prominently, impatient households' consumption is boosted by 3 percent, while patient households' consumption falls by 0.5 percent. A rise in consumption is substituted by a drop in working hours. We find that impatient households work less whereas patient households work more. This is a result of the model feature, an increase in one group has to be offset by the other because resources are shifted away from one sector to the other. Since impatient households have a high marginal propensity to consume and sensitive to housing wealth, an increase in housing wealth and consumption induces impatient households to reduce working hours. This is consistent with Daly et al. (2009); the large increase in housing wealth causes labor force participation to fall as individuals return to school, focus on home production or enjoy time away from work. Therefore, labor supply also responds to wealth shock.

Figure 3-4: Impulse response to positive housing demand shock

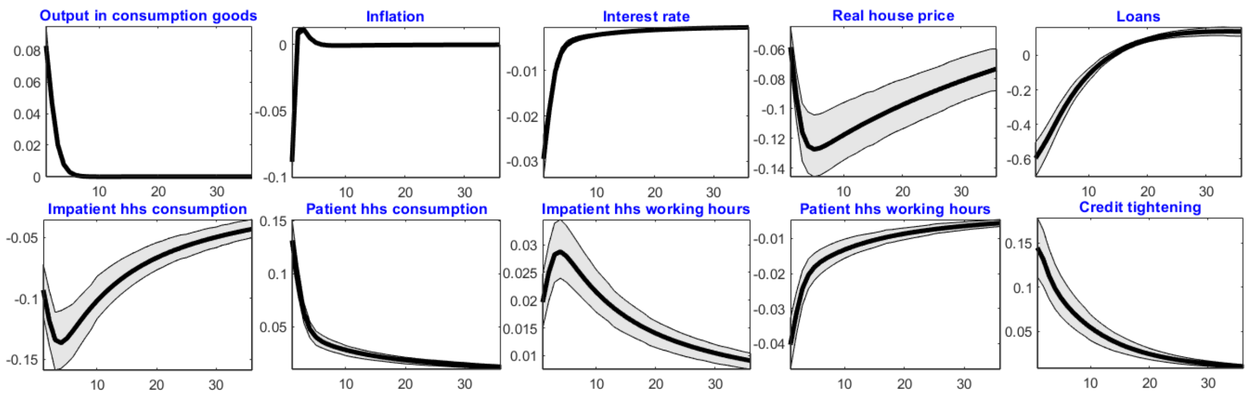


Source: Author

Productivity shock

Figure 3-5 illustrates the effect of productivity shock on real variables. A positive productivity shock of one standard deviation has a positive impact on output in both consumption goods and housing. In particular, a rise in productivity decreases the marginal cost of production, therefore, price drops. The productivity shock causes immediate decreases in inflation and interest rate approximately by 0.1 and 0.03 percentage points, respectively. In this model, we see that the monetary policy slightly reacts to the declined inflationary pressure, which corresponds to Smets and Wouters (2003); Gali (2008); and Hilberg and Hollmayr (2013). Noticeably, a rise in productivity causes the price in consumption goods and housing to fall and since house price is assumed to be flexible, real house price falls by 0.06 percent before reaching the trough at 0.12 percent. A decrease in real house price reduces the amount of loans by 0.6 percent and impatient households' consumption by 0.1 percent. However, patient households' consumption increases about 0.15 percent as a result of lower inflation. Overall, we find that the positive productivity shock stimulates aggregate consumption by 0.08 percent.

Figure 3-5: Impulse response to positive productivity shock

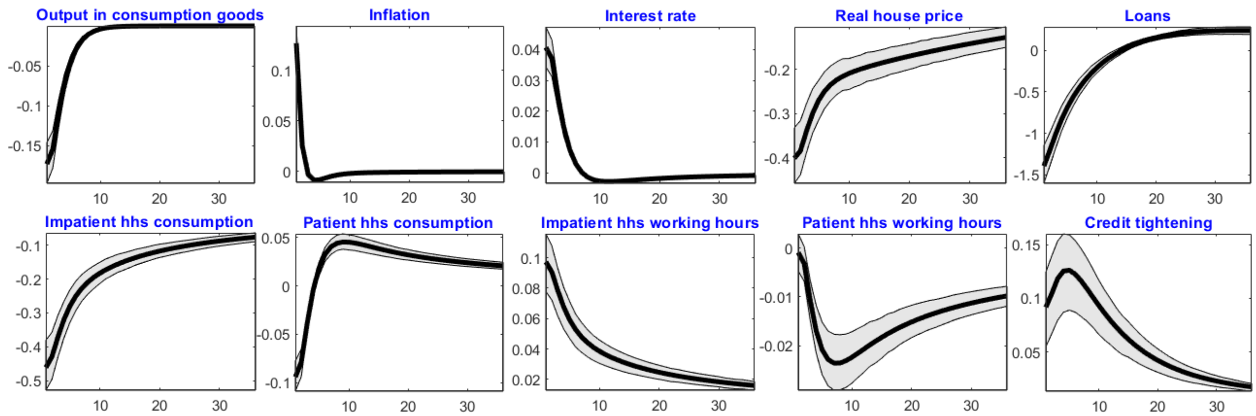


Source: Author

Inflation shock

Finally, Figure 3-6 reveals the impulse response to a positive inflation shock of one standard deviation. In this model, inflation shock represents temporary cost-push shock. This leads to an increase in marginal cost and price. The persistence in inflation shock thus causes an inflation to rise by 0.15 percentage points. Higher inflation dampens real house price by 0.4 percent. Since the borrowing opportunity relies on the collateral value, impatient households have more difficulty in financing their consumption. The consumption of impatient households reduces by approximately 0.45 percent. Similarly, patient households cut their expenditure by 0.1 percent from higher inflation. Consequently, the negative impact on household consumption and output in consumption goods suggests the monetary authority increase the interest rate by 0.04 percentage points to assist the economy in recovering from the adverse shock.

Figure 3-6: Impulse response to positive inflation shock



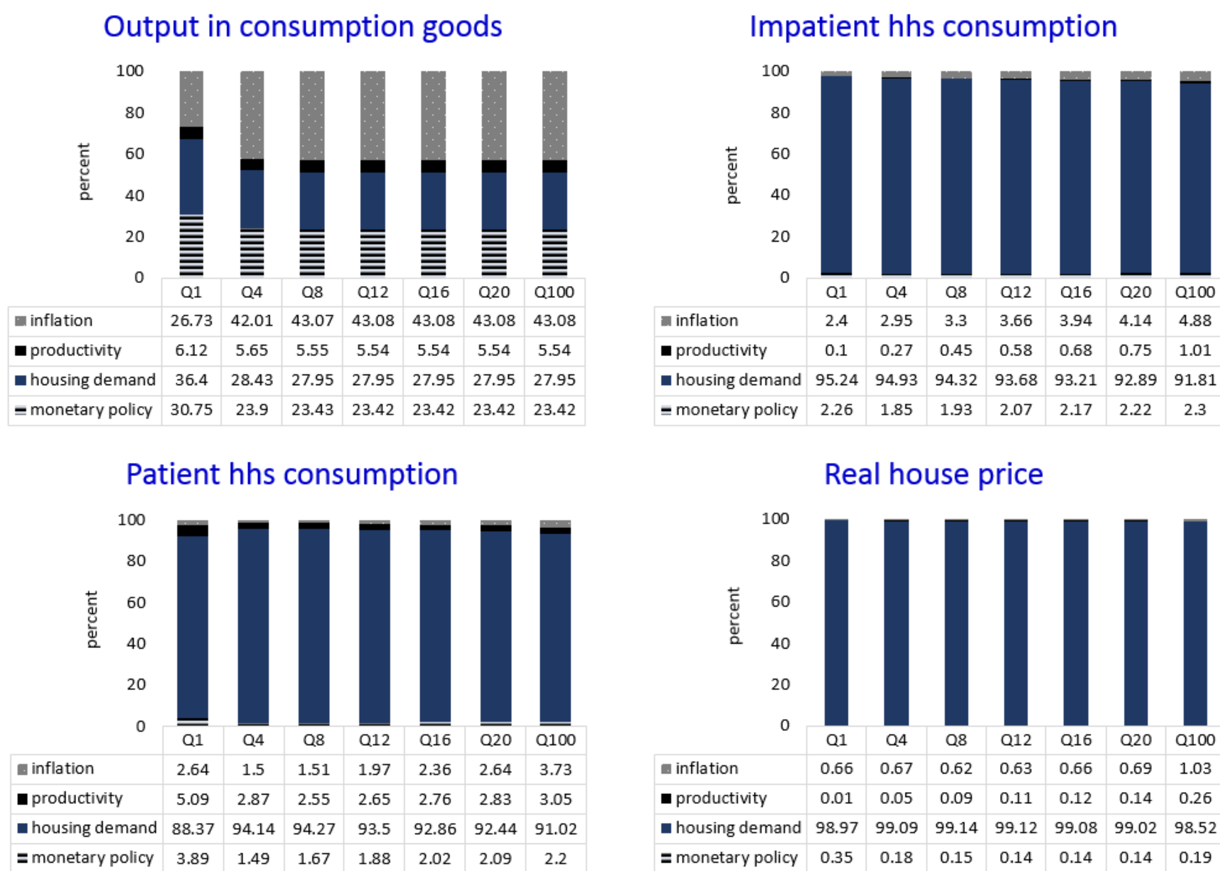
Source: Author

5.3 Variance decomposition

Variance decomposition measures the proposition of movement in a sequence due to various shocks. We label the variance decomposition to visually represent the contribution of each shock to the variation of selected variables under the time horizon. As shown in Figure 3-7, there are several points to mention regarding the decomposition. First, the variation of the total output in consumption goods is largely composed of housing demand shock, followed by monetary policy, inflation and productivity shock. Although housing demand shock makes a greater contribution in the first quarter, inflation shock begins to dominate after that. Second, productivity shock is the least important factor in the movement of real variables, especially real house price and consumption. Third, housing demand shock contributes to a change in consumption of both impatient and patient households whereas monetary policy shock seems to have a small impact. This implies that monetary policy transmission significantly works through house price to affect household consumption.

Fourth, shock decomposition for real house prices mostly varies with housing demand shock, which accounts for more than 90 percent of the variation. This confirms the theory that, other things being equal, there is a positive relationship between demand and price.

Figure 3-7: Variance decomposition of selected variables



Output in consumption goods

	Q1	Q4	Q8	Q12	Q16	Q20	Q100
inflation	26.73	42.01	43.07	43.08	43.08	43.08	43.08
productivity	6.12	5.65	5.55	5.54	5.54	5.54	5.54
housing demand	36.4	28.43	27.95	27.95	27.95	27.95	27.95
monetary policy	30.75	23.9	23.43	23.42	23.42	23.42	23.42

Impatient hhs consumption

	Q1	Q4	Q8	Q12	Q16	Q20	Q100
inflation	2.4	2.95	3.3	3.66	3.94	4.14	4.88
productivity	0.1	0.27	0.45	0.58	0.68	0.75	1.01
housing demand	95.24	94.93	94.32	93.68	93.21	92.89	91.81
monetary policy	2.26	1.85	1.93	2.07	2.17	2.22	2.3

Patient hhs consumption

	Q1	Q4	Q8	Q12	Q16	Q20	Q100
inflation	2.64	1.5	1.51	1.97	2.36	2.64	3.73
productivity	5.09	2.87	2.55	2.65	2.76	2.83	3.05
housing demand	88.37	94.14	94.27	93.5	92.86	92.44	91.02
monetary policy	3.89	1.49	1.67	1.88	2.02	2.09	2.2

Real house price

	Q1	Q4	Q8	Q12	Q16	Q20	Q100
inflation	0.66	0.67	0.62	0.63	0.66	0.69	1.03
productivity	0.01	0.05	0.09	0.11	0.12	0.14	0.26
housing demand	98.97	99.09	99.14	99.12	99.08	99.02	98.52
monetary policy	0.35	0.18	0.15	0.14	0.14	0.14	0.19

Source: Author

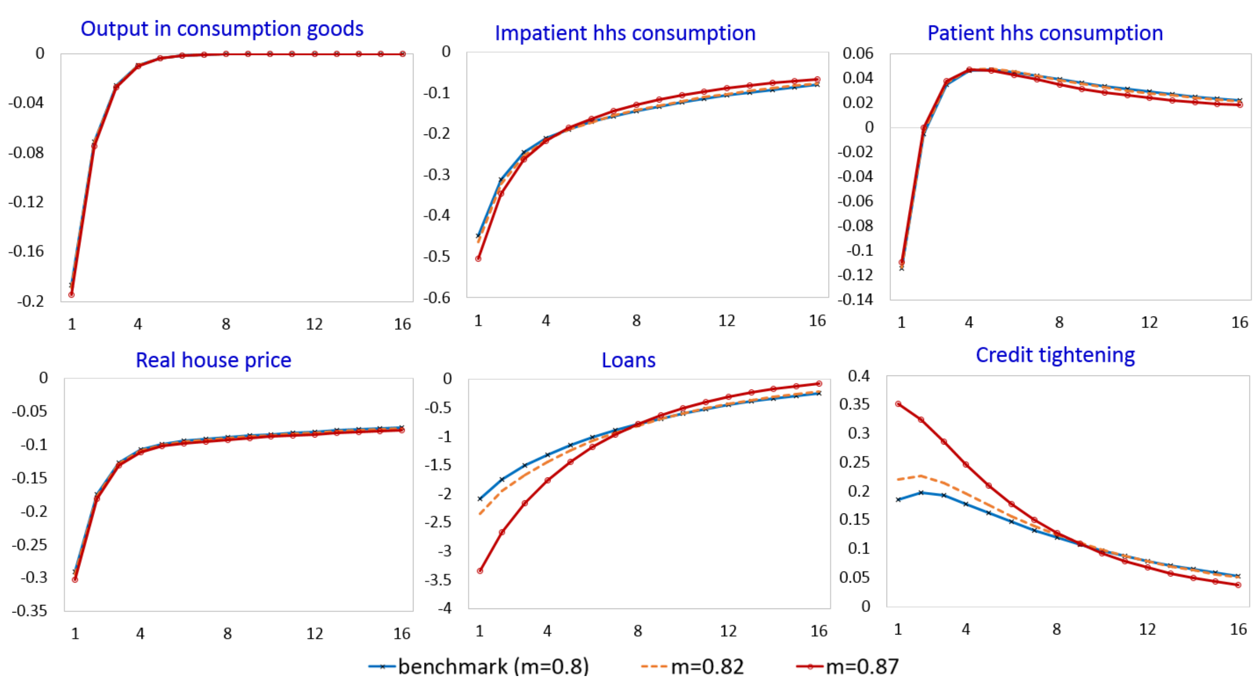
5.4 The role of credit relaxation

Although the literature on credit market imperfection extensively focuses on the net worth of business firms, e.g. BG (1989); Gertler and Gilchrist (1993); and BGG (1999), credit market imperfection also applies to consumer lending. Asymmetric information problems and limited commitment force lenders to engage default risks and apply screening. Some examples of screening include offering different types of funds with different interest rates and asking for different amounts of collateral to reveal information about the type of borrower. The amount of collateral endorsed by lenders determines credit size. When borrowers are required to provide more collateral value to receive the same amount of credit, or obtain less credit over collateral value, it means that lenders are less willing to supply loans, i.e., the credit market is tightening. For the economy in which household consumption relies on credit size, credit constraint tightening or loosening also differentiates the impacts on real expenditure and output.

To investigate the role of credit size in consumption response, we vary the LTV ratio (*m*) in the model; this indicates how much credit constraints can be relaxed and identifies the amount of loans as a fraction of the collateral value (or credit size). In the benchmark model, the LTV ratio is set at 80 percent ($m = 0.8$) and increases due to credit relaxation. When *m* is larger, it implies stronger credit relaxing as opposed to credit tightening.

The impulse response to positive monetary policy shock (of one standard deviation) among various *m*-levels is presented in Figure 3-8. After interest rate increases, household consumption responds to changes in the interest rate. However, impatient households respond strongly to monetary policy when credit is more relaxed. The higher *m* creates a larger impact on consumption. What is the intuitive explanation of this? The LTV ratio is a measure of leverage – the debt (or borrowing) to finance the equity (or asset). For impatient households who are borrowers, the leverage is higher when the interest rate goes up. A higher debt burden and deteriorated financial position force them to reduce consumption. Interestingly, patient households who are lenders are relatively better off under high LTV, though consumption still falls in the first quarter (the higher the LTV, the smaller the impact on decreased consumption). It could be argued that patient households will deduct their lending as a result of higher riskiness when higher LTV exists. Overall, aggregate consumption, as well as real house price, is affected more when LTV is higher. Therefore, credit relaxation amplifies the effect of a positive monetary policy shock.

Figure 3-8: Impulse response to monetary policy shock of credit relaxation

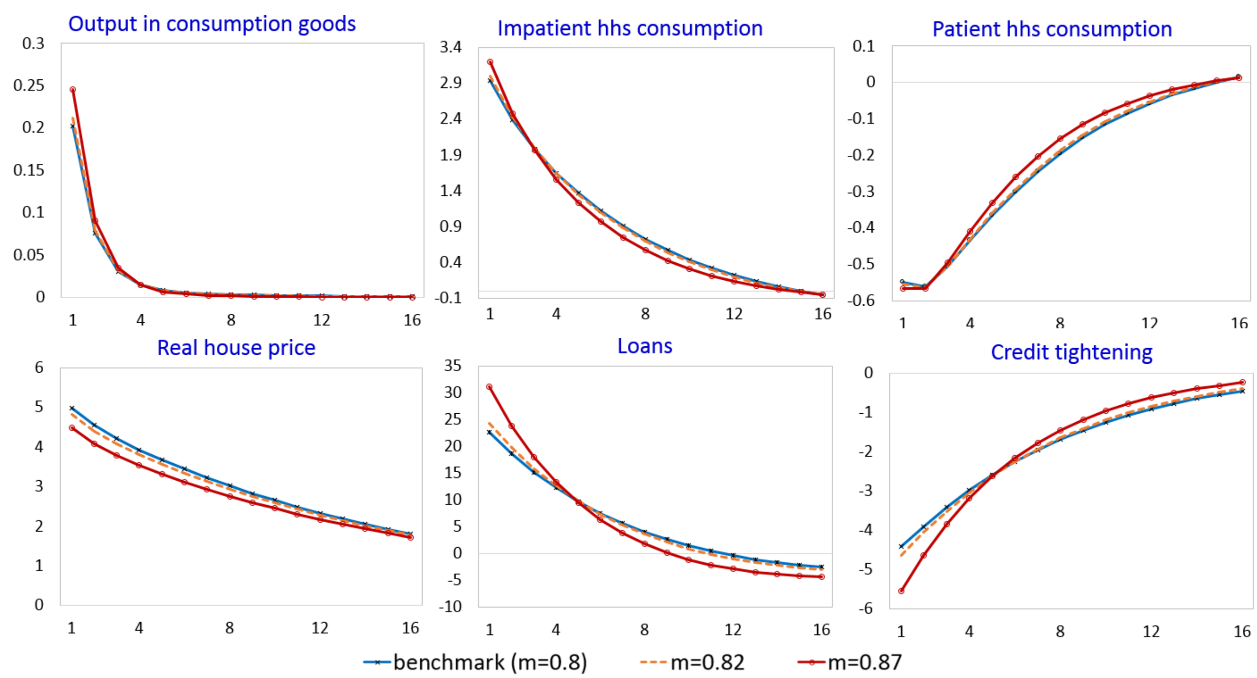


Source: Author

Meanwhile, the impulse response to positive housing demand shock (of one standard deviation) is presented in Figure 3-9. Overall, a positive housing demand shock reinforces an increase in output in the consumption goods sector. Impatient households increase their consumption more in the case of a higher LTV. However, for patient households, the consumption reduces as they reallocate resources to supply credit to impatient households.

In comparison to the effect of housing demand shock under various LTV ratios, a higher LTV significantly amplifies the response of household consumption. In fact, the LTV level implies housing market liquidity associated with liquidation cost in the case of a default. A rise in housing demand makes the housing market more liquid, i.e. households can sell their homes faster and at a higher price (Hedlund et al., 2016). Moreover, liquidation cost depends on the cost of carrying and the transaction margin when housing is resold (Christoph and Ungerer, 2015). During a period of high LTV, the liquidation cost is low and so credit constraint is loosened. This gives more opportunity to households to finance their consumption.

Figure 3-9: Impulse response to housing demand shock of credit relaxation



Source: Author

6. Concluding remarks

This chapter aims to elucidate the role of housing in monetary policy effect on household consumption. For the analysis, we develop a two-sector NK-DSGE model based on Monacelli (2009) that allows housing to be used as collateral for credit accessibility. In addition, we apply a Bayesian approach in the estimation of parameters and explore the role of LTV in the responses of economic variables.

Our estimated model, using the Thai data from 2000:Q2 to 2017:Q4, explains the empirical relationship between housing and consumption. The results from the impulse response function and variance decomposition seemingly conclude that housing is the main determinant of household consumption movement: an increase in house price reinforces household consumption by increasing the opportunity to access the credit to finance consumption. In addition, the role of housing in monetary policy effect on household consumption is transmitted by: (i) *the wealth effect on spending*; an increase in interest rate causes real house price to fall and further alleviates consumption, (ii) *the balance sheet effect on borrowing*: households, who are borrowers suffer more when interest rate increases. The combination of wealth decline and credit tightening severely affect consumption in a downturn. Finally, (iii) *the amplification effect on borrowing:* housing collateral amplifies the effect of interest rate shock and housing demand shock under high credit relaxation, which means that the higher the LTV ratio, the larger the impact on consumption. Regarding these results, we give the policy implication that it is possible to stimulate an economy by means of credit relaxation. It should be considered that a high LTV ratio amplifies the impacts when contractionary monetary policy is implemented.

As was found in the two-sector DSGE model literature, this model faces some limitations concerning the specification and numerical data. The first limitation comes from the "comovement puzzle" that the incorporation of long-lived durable goods in sticky-price models fundamentally changes their nature in a way that has not yet been fully appreciated (Barsky et al., 2007). With a flexibly-priced durable goods sector, in particular, a contractionary monetary policy shock leads to a decrease in the purchase of non-durable goods but not in durable goods, since a fall in the relative price of durable goods after a contractionary policy shock induces an increase in durable goods spending. Our results concerning the output in the housing sector, therefore, are unpleasant in their response to positive monetary policy shock. However, regardless of this issue, our estimated model is inherently capable of capturing the effects of monetary policy on consumption and output in the economy.

A second limitation of the study is the lack of similar empirical works in a two-sector NK-DSGE model for the Thai economy, although we realize the importance of the comparison of such results with earlier works. Besides, the lack of NK-DSGE studies using the Thai data causes difficulties in evaluating the prior information of some parameters that may not fully reflect the behavior of the Thai economy.

Nevertheless, this study is a primary work in a two-sector NK-DSGE model, which includes housing in the credit constraint using the Thai data; it paves the way for future research. For instance, financial intermediaries plays a prominent role in the business cycle. The incorporation of the financial sector can emanate shocks originating from this sector in order to explain the interaction between financial and real activities. In addition, an extension of the estimated NK-DSGE model to an open-economy DSGE model will allow us to explore the role of the exchange rate plays in response to structural shocks. Finally, the effort of solving the comovement problem is worth its comprehensive explanation of the response of durable goods after a monetary policy shock. Several papers have addressed this issue using a variety of specifications (see Dey and Tsai, 2017). Concerning this issue, we feature the additional rigidity in wages, which is encapsulated in the extended NK-DSGE model in the next chapter.

CHAPTER 4
BANK LENDING AND HOUSING COLLATERAL IN BUSINESS CYCLE

1. Introduction

The connection between financial intermediation and business cycle fluctuation has been emphasized since the financial crisis that occurred in many countries. As shown in many studies (e.g. Gerali et al., 2010; Gertler and Kiyotaki, 2010; Meh and Moran, 2010), disruption in the banking sector spreads widely to real activities through the credit market. In particular, the credit constraint, which works through the financial accelerator effect, is the crucial determinant of cyclical fluctuation.

Since banks are primary credit providers in the economy, their balance sheet represents the soundness of both the financial and the economic system. The mechanism starts with banking activities. The spread between lending and saving rates allows banks to make profits. Lending is the major source of banks' activities to make a profit and be sustainable in the market. After distributing the dividends to shareholders, the remaining profits are used to cover the operating cost and to accumulate further bank capital. However, to protect against credit risks and maintain stability, banks are required to hold the minimum capital ratio, which is regulated under the prudential policy. Holding capital limits the ability to supply credit; in the meantime, lenders need collateral to secure their lending. As a consequence, the expansion or contraction of the credit supply, namely the credit cycle provided by banks, affects consumption, investment, and aggregate output. Of course, if the contraction of the credit supply is not prolonged and recovers by itself after being hit by economic shocks, there should be no concerns. On the other hand, a deteriorating credit market condition—a sharp increase in insolvency and bankruptcy, rising debt burdens, collapsing asset prices, and bank failure—is not only a passive reflection of a declining economy but also a significant factor depressing economic activity (BGG, 1999).

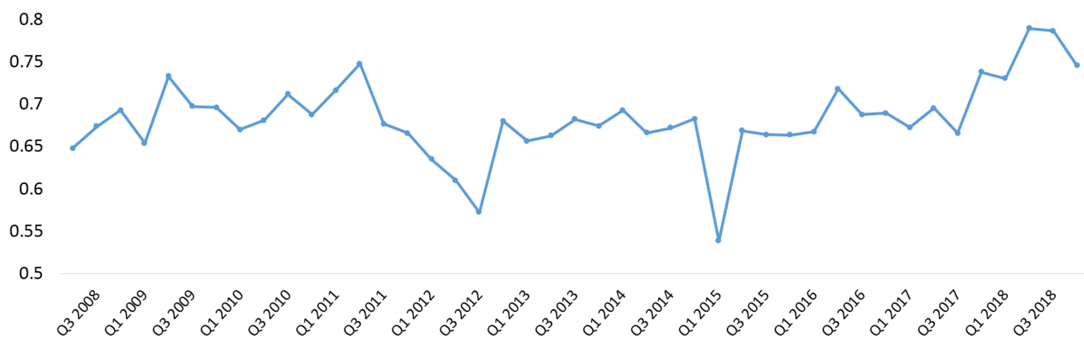
Moreover, the lesson learned, for instance, from the subprime crisis that happened in the U.S. or the credit bubble in the Asian financial crisis induced an awareness of credit market competition, overheated credit growth, and further non-performing loans (NPLs). The macroprudential policy has therefore become strongly necessary to limit systemic risks and spillover effects from the financial to the real sector. In Thailand, the intense competition in mortgage loans has been a policy concern since 2017. The regulator applies the LTV measure as a pre-emptive measure to refrain banks from providing loans that exceed the value of collateral and to guard against the excessive build-up of risk from over-borrowing and speculating in the housing market. Besides, resulting in considerably resilient financial institutions, banks are supervised under the Basel III[12] framework to maintain an adequate

[12] Basel III is an internationally agreed framework developed by the Basel Committee on Banking Supervision, which applies the regulatory framework on bank capital adequacy, stress testing, and the risk management of banks.

quantity of high-quality capital to absorb loss under normal circumstances and during periods of stress as well as to maintain the stability of the financial system. During the past crisis, the quality of borrowers was highly correlated with the systemic risk, so this Basel framework incorporates risk weighting into loans to reflect the risk-weighted assets of banks.

From a theoretical view, the LTV ratio is mentioned in the credit cycle theory based on credit market imperfection. Assets serve as collateral for loans. Creditors never allow the size of debt to exceed the future value of collateral at the fixed ratio, namely the LTV ratio. Simply put, the LTV is constant and exogenously determined. However, the credit cycle theory's view misses the dramatic change in leverage, which creates a striking change in asset prices. Leverage is the reciprocal of the margin—the ratio of the asset value to the down-payment. These ratios—LTV and leverage—are synonymous. As in the leverage cycle theory proposed by Geanakoplos (2010)**,** when the economy has high leverage, it means that people can extend their borrowing. If they have a higher marginal propensity to consume (MPC) in relation to the house price, it will increase the demand for housing and thus provoke an increase in the house price. This theory suggests that leverage is time varying and is determined by uncertainty about the future collateral price, since lenders are worried about default. Uncertainty involves many factors, for example the collateral value, source of default risk, and economic condition. Consistent with the leverage cycle theory's view, there is evidence of Thailand's LTV ratio changing over time and varying depending on the mortgage values, as shown in Figure 4-1.

Figure 4-1: Loan-to-value (LTV) ratio of mortgage loans



Remark: The LTV ratio is calculated using the ratio of new mortgage loans and the expected value of collateral.
Source: Author's calculation, based on the Thai new mortgage loans database.

Although the literature has addressed the role of financial intermediation, the endogenous LTV ratio is not widely formulated in the DSGE model. This paper thus attempts to fill the gap in the DSGE literature. The objective is to examine the effect of bank lending through housing collateral on the economy. We augment the two-sector NK-DSGE model with housing and credit constraints in chapter 3 with three additional contributions.

First, we incorporate the banking sector, which operates financial activities under the central bank's supervision. We model the credit constraint from access lending facilities and the balance sheet constraint from maintaining the capital requirement under the financial regulatory framework (Basel III). These modeling choices allow us to introduce financial shocks emerging from the credit supply and the credit risk shock to capture the linkage between the banking sector and the real economy. Second, we feature the LTV ratio, which is endogenously determined by the dynamics of the model, whereas it is fixed in the previous model. Third, we introduce wage rigidity, which represents some imperfections in the labor market. We follow the formulation of wage rigidity in a two-sector DSGE model invented by Iacoviello and Neri (2010). Accordingly, the model, including both sticky wages and price assumptions, solves the comovement puzzle of the previous model.

The features of the banking sector and the endogenous LTV ratio follow Falagiarda and Saia (2017); however, we make some distinctions in the model assumptions that reflect Thai-specific features. In particular, (i) lending facilities are considered under the BOT's regulation and (ii) the LTV ratio is significantly determined by the future value of housing collateral and economic fluctuation, not labor income. This LTV determination is explained through empirical studies using a set of Thai mortgage loans data during the period 2008–2018.

The main findings are as follows. (1) Credit crunches influence household consumption—a reduction in the LTV ratio causes household consumption to fall substantially. (2) Higher credit risk affects banks, which reduce the loan supply and increase the loan–deposit spread to compensate for the loss in profit and capital. (3) The endogenous LTV ratio amplifies the effect of a monetary policy shock—worsened economic activities after interest rate increases force banks to reduce the LTV ratio and this magnifies the negative effect on household consumption and the output in consumption goods. However, the endogenous LTV ratio mutes the effect of a banking credit risk shock. Finally, (4) the existence of banks attenuates the impact of a contractionary monetary policy since a reduction in banks' leverage lowers the risk perception regarding housing credit. Thus, the effect of an interest rate shock is moderate.

2. Literature review

Beginning of the NK-DSGE model

Following the influential paper by Kydland and Prescott (1982), which introduced the "real business cycle" (RBC) model, the theoretical foundation was augmented by incorporating the idea of market imperfection, for example monopolistic competition, establishing the "New Keynesian" framework. The inclusion of New Keynesian ideas has been structured into the dynamic stochastic general equilibrium (DSGE) model in a version called the new Keynesian dynamic stochastic general equilibrium (NK-DGSE). The term DSGE is used because it allows the economy to grow over time (dynamic), be affected by shocks (stochastic), and be based on general equilibrium principles. The NK-DSGE model is therefore a macroeconomic approach that attempts to explain the business cycle based on rigorous micro-foundations. In contrast to the RBC model, the NK-DSGE model embeds nominal rigidities into the price and wage, which are the key elements of market imperfection for understanding the real world. The early works on staggered contracts developed by Calvo (1983) and Taylor (1979) and the quadratic price adjustment cost model of Rotemberg (1982) have influenced the literature on the NK-DSGE model (e.g. King and Watson, 1996; Chari, Kehoe, and McGrattan, 2000; Erceg, Henderson, and Levin, 2000; CEE, 2001; Gali, 2002, 2008; Ireland, 2004; Smets and Wouters, 2003).

The role of nominal rigidities has been remarkably highlighted by CEE (2001), who constructed the US estimated DSGE model. The model characterizes Calvo-style nominal price and wage contracts and determines specific departures, for example habit information, adjustment costs, and capital utilization. The key finding is that stickiness in nominal wages is crucial for the estimated response of the U.S. economy to a policy shock. The model of CEE (2001) inspired the direction of future research to incorporate additional shocks into the analysis. Smets and Wouters (2003) followed the rigidity-based DSGE model to introduce a full set of structural shocks that was subsequently accepted as a fully-fledged model to analyze the effect of shocks on business fluctuations. In contrast to CEE (2001), Smets and Wouters (2003) discovered that a considerable degree of price stickiness is essential to the persistence of euro area inflation. These models show the importance of modeling nominal rigidities using the Calvo framework in the structured manner of the NK-DSGE model. Moreover, the NK-DSGE model requires the money growth rule to benefit monetary policy analysis, as developed by Gali (2002). The basic model setting represents three key components: the dynamic IS curve derived from a welfare-maximizing decision of consumers, the new Keynesian Phillips curve based on monopolistic producers with sticky prices; and the monetary policy schedule. Therefore, the NK-DSGE model has become a workhorse for the assessment of macroeconomic fluctuation, as it can explain the short-run evolution of an economy subject to additional assumptions that favorably mimic the reality.

Two-sector NK-DSGE model

One aspect of the NK-DSGE model is developed by structuring a two-sector nominal rigidities model with durable goods. When there are two sectors in rigidities model, it inherits issues that are challenging to the researchers. One issue is how to justify the degrees of stickiness in each sector. The other is how to depict the comovement of outputs in two sectors in response to a monetary policy shock.

Using a standard sticky-price general equilibrium model, Barsky (2007) demonstrated that if durable goods are flexibly priced and non-durable goods are sticky, then a monetary contraction leads to a decline in non-durable goods production but an increase in durable goods production which creates the "comovement puzzle". This is because a contractionary monetary shock will directly affect only the sector with sticky nominal prices (non-durable goods). The other sector (durable goods) is only affected indirectly as a decline in demand for inputs in non-durable sector leads to an increase in demand for inputs in durable sector, and an expansion of durable goods production. Also, a fall in relative price of durable goods after a contractionary monetary policy shock induces an increase in durable goods spending.

The attempt to solve comovement problem is pointed out by several studies and it initiates a discussion in the degree of price stickiness in each sector. Monacelli (2009) stressed the role of credit market imperfection (credit constraint) in generating the comovement. The study suggested that non-durable goods price should be stickier than durable goods price, so that the relative price of durables tends to move in the right direction in response to a monetary policy tightening. However, Sterk (2010) argued that the credit constraint in Monacelli (2009) is unable to generate comovement when the price of durable goods are perfectly flexible, which is also highlighted by Barsky (2007).

Carlstrom and Fuerst (2010) suggested that the price of durable goods and housing are more flexible than those of non-durables. House price can be assumed to be flexible in line with the empirical evidence. Importantly, the comovement puzzle does not arise if the model includes three features: sticky nominal wages, housing construction adjustment costs and habit persistence in consumption. In particular, wage rigidity assumption is able to solve the problem because labor is the primary factor in housing construction, nominal wage stickiness induces the stickiness in house price even if house price is flexible. This is consistent with what is found in Dey and Tsai (2017). The paper explained that under the setting of wage stickiness in a two-sector DSGE model, there is a monopoly distortion in labor supply, which falls after a contractionary monetary policy shock, and thus induces a fall in aggregate labor hours. Stickiness in nominal wages induces stickiness in durable goods prices, and dampens a fall in relative price of durable goods. This mitigates the incentive to purchase durable goods. Another two-sector NK-DSGE model with sticky wages is presented by Iacoviello and Neri (2010) which highlighted the spillover of housing market to broader economy. In the model feature of wage rigidities in housing and non-housing sector, housing investment is sensitive to interest rate only when wage rigidity exists. The results support the finding that sticky wages can eliminate the comovement puzzle.

Similar to the literature mentioned above, a few other studies have characterized a two-sector model with some modifications and succeeded in solving that comovement problem. For example, Kim and Katayama (2013) incorporated non-separable preferences between composite consumption and labor supply. Tsai (2016) introduced working capital and habit formation.

The NK-DSGE model with banking sector

The development of the NK-DSGE framework has continued. In particular, during the 2007 financial crisis, the interaction between the credit market and the rest of the economy became the center of attention in economic modeling. Since banks are represented as being the primary funding source for households and firms in many countries, banks' financial position inevitably affects economic fluctuations through the credit market. Most works in the literature have identified shocks originating from the supply of credit as playing a crucial role in business fluctuations. In particular, during a prolonged financial crisis, events generate a "credit crunch" in which banks cut back on lending and agents confront the difficulty of obtaining external financing. The adverse financial condition will continue to undermine the economy during its recovery. For example, Gerali et al. (2010) sought to understand the role of financial frictions and banking intermediation in shaping the business cycle in the euro area. This study extends the model of Iacoviello (2005) by introducing a stylized banking sector. The banking sector features some monopolistic market power in the loan and deposit market, in which its accumulated capital is subject to a capital adequacy requirement. Banking capital is concentrated as it captures banks' performance and is motivated by exogenous regulatory requirements. A sudden fall in bank capital triggers an increase in the lending margin and a contraction of credit volumes. Therefore, the restriction on the credit supply severely affects firms' investment and aggregate consumption. The results are consistent with those of Meh and Moran (2010), who emphasized the role of bank capital as a channel of transmission. The framework relies on Holmstrom and Tirole (1997) and Chen (2001), who proposed the double moral hazard problem between bankers and creditors. In the model, bank capital emerges endogenously to solve the asymmetric information problem between bankers and creditors. When the bank capital channel is active, an economy with more bank capital is better able to absorb negative shocks than an economy with less bank capital. The presence of an active bank capital channel amplifies and propagates the effect of shocks on output, investment, and inflation.

At the same time, the contraction of the real economy reduces asset values throughout, further weakens banks' balance sheet, and thus exacerbates the downturn. As a result of this turmoil, the central bank tries to solve the problem by embarking on direct lending programs. A new stream of literature that builds on the earlier work is rapidly emerging to address this issue. Gertler and Karadi (2011), for instance, developed a model of unconventional monetary policy to evaluate its impact to combat a simulated financial crisis in the U.S. This study indicated that either an actual decline in asset quality or the expectation of a future decline can trigger a crisis and that the central bank's credit intervention could moderate the downturn. The stabilization benefits of a credit policy exist even if the interest rate has not reached the zero lower bound (ZLB).[13] In addition, the net benefits from various credit market interventions increase with the severity of the crisis, as shown by Gertler and Kiyotaki (2010). They suggested, however, that the instrumental policy is employed only in a crisis situation.

A remarkable work by Iacoviello (2015) enabled the comprehension of financial shocks causing fluctuations in the business cycle, specifically the financial business cycle. The movement in output and investment appears to have been driven by the financial shock after 2007. In particular, during a recession, a decline in output and investment mainly comes from the effect of the default shock, housing demand shock, and LTV shock. The LTV shock,

[13] ZLB is the economic situation that occurs when the nominal interest rate falls to almost zero or zero. This means that the central bank can no longer use the interest rate to stimulate the economy, referred to as a liquidity trap.

which is related to banks' deleveraging, played a more important role in 2010. Among the scholarly works capturing financial shocks in the DSGE model, the research by Falagiarda and Saia (2017) proposed the LTV ratio as an endogenous variable, while most of the existing general equilibrium studies have modeled the LTV ratio as constant. Inspired by the earlier work of Lambertini, Mendicino, and Punzi (2013), the LTV ratio is endogenized by expressing it as a function of systemic and idiosyncratic risk at the level of both households and banks in the credit market. Moreover, in their model, the role of prudential policy has been introduced to strengthen the study of the interactions between financial institutions and the business cycle. The new formulation of capital adequacy, in which assets are risk weighted by cyclical risk sensitivity measures, is an attempt to include prudential regulatory regimes, like Basel I, II, and III, in the framework.

3. Extended two-sector NK-DSGE model

The economy consists of seven agents: impatient households, patient households, wholesalers, retailers, banks, the central bank, and the government. Households are distinguished into two groups (impatient households are denoted by a prime with a fraction ϕ , and patient households are denoted by a double prime with a fraction $1-\phi$) by the difference in time preference for consumption. Patient households work, consume, and accumulate their wealth, for example deposits, government bonds, and capital stock. On the other hand, impatient households work, consume, and borrow a positive amount of loans against their collateral from banks. Both of them supply labor through unions to intermediate firms in each sector: consumption goods (non-housing) and the housing sector. Wholesalers monopolistically produce intermediate goods and sell to retailers, who transfer final products in perfectly competitive markets. This model includes price rigidity in the consumption goods sector and wage rigidity in both sectors. Banks facing perfect competition operate financial activities by receiving deposits, providing loans, and investing in government bonds. Under the central bank's supervision, banks are allowed to access lending facilities and need to maintain the minimum capital against risk-weighted assets. The central bank conducts monetary policy following the Taylor principle and imposes the target capital requirement following the Basel III regulatory framework. The government issues bonds, collects lump-sum taxes from households, and spends on expenditure.

The extended model has three distinctive features. First, as impatient household are borrowers, the credit constraint is applied in the same way as in the previous model. However, as in Falagiarda and Saia (2017), the LTV ratio is endogenously determined by the model. We model the LTV ratio depending on the future value of housing collateral and the economic condition. The characteristic of LTV determination is explained by empirical studies on the Thai mortgage loan data. Second, in modeling the banking sector, we follow Falagiarda and Saia (2017) with a specific structure. (i) Banks have a credit constraint, as accessing lending facilities requires eligible collateral. The credit constraint depends on the future value of collateral assets and the dynamic of the LTV ratio (considered as a haircut). (ii) Banks are supervised under the financial regulatory framework (Basel III). When banks extend lending to households, they also accumulate capital out of retained earnings and need to keep their capital-to-assets ratio as close as possible to an exogenous target. The assets are weighted by two different risks, that is, risk-weighted assets in accordance with the Basel III framework. (iii) Banks face the cost of managing loans and the cost of holding the capital requirement at the target. This feature allows us to capture the adjustment to react to monetary policy and financial shocks. Third, we include the wage rigidity assumption in both sectors. We follow the formulation of the wage inflation dynamic in a two-sector DSGE model of Iacoviello and Neri (2010). In particular, we assume that households have some monopoly power that allows them to set the wages for the differentiated labor services that they supply.

3.1 Impatient households

The representative impatient households maximize their lifetime utility by choosing consumption goods $\left(C'_t\right)$, housing services $\left(H'_t\right)$, and hours worked in the consumption goods $\left(N'_{c,t}\right)$ and housing $\left(N'_{h,t}\right)$ sectors. The expected lifetime utility function is given by

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C'_t + \varepsilon_t^H \log H'_t - \frac{\chi}{1+\varphi'} \left\{ \tau_1^{-\eta'} \left(N'_{c,t}\right)^{1+\eta'} + \left(1-\tau_1\right)^{-\eta'} \left(N'_{h,t}\right)^{1+\eta'} \right\}^{\frac{1+\varphi'}{1+\eta'}} \right] \quad (4.1)$$

where β is the discount factor, χ is labor disutility, and φ' is the inverse elasticity of the labor supply. η' represents the elasticity of labor substitution between two sectors, and τ_1 measures the fraction of impatient households working in the consumption goods sector. The working hours of impatient households are represented by $N'_t = \left[\tau_1^{-\eta'} \left(N'_{c,t}\right)^{1+\eta'} + \left(1-\tau_1\right)^{-\eta'} \left(N'_{h,t}\right)^{1+\eta'} \right]^{1/1+\eta'}$. The utility is disturbed by a housing demand shock $\left(\varepsilon_t^H\right)$ in the first-order autoregressive stochastic process with an i.i.d. normal error term, which affects the housing price. Impatient households maximize their utility subject to the (real-term) budget constraint

$$C_t' + q_t\left\{H_t' - \left(1-\delta^h\right)H_{t-1}'\right\} + \frac{R_{t-1}^c}{\pi_{c,t}}L_{t-1}^c + T_t' = L_t^c + w_{c,t}N_{c,t}' + w_{h,t}N_{h,t}' \quad (4.2)$$

in which labor income is spent on consumption goods, housing, and lump-sum tax $\left(T_t'\right)$. Impatient households are financed with an amount of loans $\left(L_t^c\right)$ from banks and need to repay their loans with interest $\left(R_{t-1}^c L_{t-1}^c / \pi_{c,t}\right)$. $q_t = P_{h,t}/P_{c,t}$ denotes the real house price and $\pi_{c,t}$ is inflation, capturing the price change from t-1 to t. R_t^c is the gross lending rate, δ^h is the housing depreciation rate, and $w_{c,t} = W_{c,t}/P_{c,t}$ and $w_{h,t} = W_{h,t}/P_{c,t}$ are the real wage in the consumption goods and the housing sector, respectively.

In addition, impatient households face the credit constraint

$$R_t^c L_t^c \le LTV_t H_t' \mathrm{E}_t\left(q_{t+1}\pi_{c,t+1}\right) \quad (4.3)$$

which shows that the expected value of their housing stock as collateral must guarantee the repayment of borrowing with interest. LTV_t is the loan-to-value ratio for mortgages. It can be interpreted as proportional credit against the collateral value that banks can provide to households. To guarantee the equality of the credit constraint, impatient households cannot quickly accumulate enough wealth and are less patient with a lower discount factor, and there are small shocks around the steady state. They prefer to borrow at the maximum amount of the limit and always choose to hold a positive amount of debt in all periods.

Different from Falagiarda and Saia (2017), the LTV ratio is endogenously determined by the previous value and two variations of the value of housing collateral and the economic condition measured by the output fluctuation.[14] We disregard labor income in the LTV determination, since the labor income of Thai households seems to be insignificant in the empirical analysis over the sample period from 2008 to 2018.

$$\left(\frac{LTV_t}{LTV}\right)=\left(\frac{LTV_{t-1}}{LTV}\right)^{\phi_{LTV}}\left(\frac{q_t H'_t}{qH'}\right)^{\varphi_{1H}}\left(\frac{Y_{c,t}}{Y_c}\right)^{\varphi_{2H}}\exp\left(\varepsilon_t^{LTV}\right) \tag{4.4}$$

Here, $\varphi_{1H},\varphi_{2H}>0$ implies that increases in the real value of housing and an economy's output level result in an increase in the LTV ratio, which allows impatient households to expand their borrowing capacity. ϕ_{LTV} is a persistent parameter in the dynamic of the LTV, and ε_t^{LTV} is the LTV shock or credit supply shock in the first-order autoregressive stochastic process with an i.i.d. normal error term.

The first-order conditions with respect to consumption goods, housing services, loans, and hours worked are

[14] Output is measured using the consumption goods sector, $Y_{c,t}$, which is different from the aggregate output (GDP); however, the output in consumption goods accounts for 95 percent of the total GDP. It is approximately equal to the GDP within a local region of the steady state (see e.g. Iacoviello, 2005; Guerrieri and Iacoviello, 2017). Therefore, in this paper, the output in consumption goods represents the aggregate output or GDP in the economy.

$$\lambda_t' = \frac{1}{C_t'} \tag{4.5}$$

$$\frac{\varepsilon_t^H}{H_t'} + \frac{(1+\varphi_{1H})}{C_t'}\psi_t LTV_t \mathrm{E}_t\left(q_{t+1}\pi_{c,t+1}\right) + \beta\left(1-\delta^h\right)\mathrm{E}_t\left(\frac{q_{t+1}}{C_{t+1}'}\right) = \frac{q_t}{C_t'} \tag{4.6}$$

$$\psi_t R_t^c = 1 - \beta R_t^c \mathrm{E}_t\left(\frac{C_t'}{C_{t+1}'\pi_{c,t+1}}\right) \tag{4.7}$$

$$w_{c,t} = \chi \tau_1^{-\eta'}\left(N_t'\right)^{\varphi'}\left(\frac{N_{c,t}'}{N_t'}\right)^{\eta'} C_t' \tag{4.8}$$

$$w_{h,t} = \chi\left(1-\tau_1\right)^{-\eta'}\left(N_t'\right)^{\varphi'}\left(\frac{N_{h,t}'}{N_t'}\right)^{\eta'} C_t' \tag{4.9}$$

3.2 Patient households

The representative patient households similarly maximize their lifetime utility, given by

$$\mathrm{E}_0\sum_{t=0}^{\infty}\gamma^t\left[\log C_t'' + \varepsilon_t^H \log H_t'' - \frac{v}{1+\varphi''}\left\{\tau_2^{-\eta''}\left(N_{c,t}''\right)^{1+\eta''} + \left(1-\tau_2\right)^{-\eta''}\left(N_{h,t}''\right)^{1+\eta''}\right\}^{\frac{1+\varphi''}{1+\eta''}}\right] \tag{4.10}$$

where γ is the discount factor, $\gamma > \beta$, and v is labor disutility. The working hours of patient households are represented by $N_t'' = \left[\tau_2^{-\eta''}\left(N_{c,t}''\right)^{1+\eta''} + \left(1-\tau_2\right)^{-\eta''}\left(N_{h,t}''\right)^{1+\eta''}\right]^{1/1+\eta''}$. The different discount factors guarantee a well-defined steady state. Patient households with higher discount rates are savers, while impatient households are borrowers in the equilibrium. The maximization of utility is subject to the (real-term) budget constraint

$$C_t'' + q_t \left\{ H_t'' - \left(1-\delta^h\right) H_{t-1}'' \right\} + D_t + \frac{B_t^h}{R_t^g} + I_t + T_t'' = \frac{D_{t-1} R_{t-1}^d}{\pi_{c,t}} + \frac{B_{t-1}^h}{\pi_{c,t}} + r_t^k K_{t-1} + w_{c,t} N_{c,t}'' + w_{h,t} N_{h,t}'' \tag{4.11}$$

where patient households allocate savings to deposits $\left(D_t\right)$, holding government bonds $\left(B_t^h\right)$ and the accumulation of capital stock $\left(K_t\right)$. The returns paid on savings to deposits, government bonds, and capital stock are the deposit rate $\left(R_t^d\right)$, interest rate on government bonds $\left(R_t^g\right)$, and real rental rate $\left(r_t^k\right)$, respectively. The law of motion of capital is expressed by

$$K_t = \left(1-\delta\right) K_{t-1} + I_t \tag{4.12}$$

where I_t is investment in capital with a depreciation rate of δ.

The first-order conditions with respect to consumption goods, housing services, deposits, bonds, capital, and hours worked are

$$\lambda_t'' = \frac{1}{C_t''} \tag{4.13}$$

$$\frac{\varepsilon_t^h}{H_t''} + \gamma\left(1-\delta^h\right) \mathrm{E_t}\left(\frac{q_{t+1}}{C_{t+1}''}\right) = \frac{q_t}{C_t''} \tag{4.14}$$

$$1 = \gamma R_t^d \mathrm{E_t}\left(\frac{C_t''}{C_{t+1}''\pi_{c,t+1}}\right) \tag{4.15}$$

$$1=\gamma R_t^g \mathrm{E}_t\left(\frac{C_t''}{C_{t+1}''\pi_{c,t+1}}\right) \tag{4.16}$$

$$C_{t+1}''=\gamma C_t''\left(r_{t+1}^k+\left(1-\delta\right)\right) \tag{4.17}$$

$$w_{c,t}=v\tau_2^{-\eta''}\left(N_t''\right)^{\varphi''}\left(\frac{N_{c,t}''}{N_t''}\right)^{\eta''}C_t'' \tag{4.18}$$

$$w_{h,t}=v\left(1-\tau_2\right)^{-\eta''}\left(N_t''\right)^{\varphi''}\left(\frac{N_{h,t}''}{N_t''}\right)^{\eta''}C_t'' \tag{4.19}$$

Labor supply decision and optimal wage setting

We model wage setting in a way that is consistent with Iacoviello and Neri (2010). The formulation of wage rigidity is invented in a two-sector extension by introducing some imperfections in the labor market. In particular, impatient and patient households are monopoly suppliers of differentiated labor services. Both households combine in unions to set wages subject to Calvo's scheme and offer labor packages[15] in each sector: *c* (consumption goods sector) and *h* (housing sector). As it is analogous to price setting, a union is allowed to set wages optimally in a given period with probability θ_w. Partial indexation to past inflation is applied to the remaining $\left(1-\theta_w\right)$ fraction of nominal wages.

Consider households resetting their wages in period t. They will choose nominal wages (denoted by the tilde symbol) $\tilde{W}_{c,t}^*, \tilde{W}_{h,t}^*$ to maximize

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[15] For the consumption goods sector $N_{c,t}=\left\{N_{c,t}', N_{c,t}''\right\}$ and for the housing sector $N_{h,t}=\left\{N_{h,t}', N_{h,t}''\right\}$, which are assumed to be homogeneous among households in the composites.

$$\max_{\tilde{W}^*_{c,t},\tilde{W}^*_{h,t}} \mathrm{E}_t\left[\sum_{k=o}^{\infty}(\gamma\theta_w)^k U\left(C_{t+k|t}, H_{t+k|t}, N_{t+k|t}\right)\right] \tag{4.20}$$

The period utility function is given by

$$U\left(C_{t+k|t}, H_{t+k|t}, N_{t+k|t}\right) = \log C_{t+k|t} + \varepsilon_t^h \log H_{t+k|t} - \frac{\xi}{1+\varphi} N_{t+k|t}{}^{1+\varphi} \tag{4.21}$$

where $C_{t+k|t}$, $H_{t+k|t}$, and $N_{t+k|t}$ denote the consumption, housing, and hours worked in period $t+k$ of households that last reset their wages in period t. ξ is the labor disutility and φ is the inverse elasticity of the labor supply. $N_{t+k|t} \equiv N_{c,t+k|t} + N_{h,t+k|t}$ denotes the total hours worked. Equation (4.20) can be interpreted as the expected discounted sum of utilities generated over the (uncertain) period during which the wage remains unchanged at the level $\tilde{W}^*_{c,t}, \tilde{W}^*_{h,t}$ set in the current period.

The maximization is subject to the budget constraint and the labor demand in two sectors:

sector *c*:
$$N_{c,t+k|t} = \left(\frac{\tilde{W}^*_{c,t}}{\tilde{W}_{c,t+k}}\right)^{-\varepsilon_w} N_{c,t+k} \tag{4.22}$$

sector *h*:
$$N_{h,t+k|t} = \left(\frac{\tilde{W}^*_{h,t}}{\tilde{W}_{h,t+k}}\right)^{-\varepsilon_w} N_{h,t+k} \tag{4.23}$$

where ε_w is the elasticity of substitution across labor varieties and is assumed to be equal in the two sectors.

The first-order conditions associated with the above problem in sector *c* and sector *h* are respectively shown as

$$\sum_{\mathrm{k}=0}^{\infty}(\beta\theta_w)^{\mathrm{k}}\,\mathrm{E}_{\mathrm{t}}\left[N_{c,t+k|t}U_C\,\frac{\tilde{W}_{c,t}^{*}}{P_{c,t+k}}+\Phi N_{c,t+k|t}U_N\right]=0 \tag{4.24}$$

$$\sum_{\mathrm{k}=0}^{\infty}(\beta\theta_w)^{\mathrm{k}}\,\mathrm{E}_{\mathrm{t}}\left[N_{h,t+k|t}U_H\,\frac{\tilde{W}_{h,t}^{*}}{P_{c,t+k}}+\Phi N_{h,t+k|t}U_N\right]=0 \tag{4.25}$$

where $\Phi=\varepsilon_w/(\varepsilon_w-1)$ is the desired gross wage mark-up. $MRS_{c,t+k|t}=-U_N/U_C$ denotes the marginal rate of substitution between consumption goods and hours worked in period *t+k* for households resetting the wage in period *t*. Similarly, $MRS_{h,t+k|t}=-U_N/U_H$ is the marginal rate of substitution between housing services and hours worked. Then, the above optimality conditions can be rewritten as

$$\sum_{\mathrm{k}=0}^{\infty}(\beta\theta_w)^{\mathrm{k}}\,\mathrm{E}_{\mathrm{t}}\left[N_{c,t+k|t}U_C\left(C_{t+k|t},H_{t+k|t},N_{t+k|t}\right)\left(\frac{\tilde{W}_{c,t}^{*}}{P_{c,t+k}}-\Phi MRS_{c,t+k|t}\right)\right]=0 \tag{4.26}$$

$$\sum_{\mathrm{k}=0}^{\infty}(\beta\theta_w)^{\mathrm{k}}\,\mathrm{E}_{\mathrm{t}}\left[N_{h,t+k|t}U_H\left(C_{t+k|t},H_{t+k|t},N_{t+k|t}\right)\left(\frac{\tilde{W}_{h,t}^{*}}{P_{c,t+k}}-\Phi MRS_{h,t+k|t}\right)\right]=0 \tag{4.27}$$

Log-linearized around the steady state, denoted by small letters, the wage-setting rules are defined as

$$\tilde{w}_{c,t}^{*}=\mu_{c}^{w}+\left(1-\beta\theta_{w}\right)\sum_{\mathrm{k}=0}^{\infty}\left(\beta\theta_{w}\right)^{\mathrm{k}}\mathrm{E}_{\mathrm{t}}\left(mrs_{c,t+k|t}+p_{c,t+k}\right) \tag{4.28}$$

$$\tilde{w}_{h,t}^{*}=\mu^{w}+\left(1-\beta\theta_{w}\right)\sum_{\mathrm{k}=0}^{\infty}\left(\beta\theta_{w}\right)^{\mathrm{k}}\mathrm{E}_{\mathrm{t}}\left(mrs_{h,t+k|t}+p_{c,t+k}\right) \tag{4.29}$$

where $\mu^{w}=\log\Phi$. $\tilde{w}_{c,t}^{*},\tilde{w}_{h,t}^{*}$ are nominal wages in log form. We can rewrite the wage-setting rule as

$$\tilde{w}_{c,t}^{*}=\beta\theta_{w}\mathrm{E}_{\mathrm{t}}\left(\tilde{w}_{c,t+1}^{*}\right)+\left(1-\beta\theta_{w}\right)\left\{\tilde{w}_{c,t}-\left(1+\varepsilon_{w}\varphi^{'}\right)^{-1}\hat{\mu}_{c,t}^{w}\right\} \tag{4.30}$$

$$\tilde{w}_{h,t}^{*}=\beta\theta_{w}\mathrm{E}_{\mathrm{t}}\left(\tilde{w}_{h,t+1}^{*}\right)+\left(1-\beta\theta_{w}\right)\left\{\tilde{w}_{h,t}-\left(1+\varepsilon_{w}\varphi^{'}\right)^{-1}\hat{\mu}_{h,t}^{w}\right\} \tag{4.31}$$

where $\hat{\mu}_{c,t}^{w}=\mu_{c,t}^{w}-\mu_{c}^{w}$ and $\hat{\mu}_{h,t}^{w}=\mu_{h,t}^{w}-\mu_{h}^{w}$ denotes the deviation of the economy's (log) average wage makeup as $\mu_{c,t}^{w}=\left(\tilde{w}_{c,t}-p_{c,t}\right)-mrs_{c,t}$ and $\mu_{c,t}^{w}=\left(\tilde{w}_{c,t}-p_{c,t}\right)-mrs_{c,t}$ from its steady-state level μ_{c}^{w} and μ_{h}^{w}, respectively.

Given the wage-setting structure, the aggregate wage dynamics in log-linearized form around the steady state yield

$$\tilde{w}_{c,t}=\theta_{w}\tilde{w}_{c,t-1}+\left(1-\theta_{w}\right)\tilde{w}_{c,t}^{*} \tag{4.32}$$

$$\tilde{w}_{h,t}=\theta_{w}\tilde{w}_{h,t-1}+\left(1-\theta_{w}\right)\tilde{w}_{h,t}^{*} \tag{4.33}$$

After combining the optimal wage setting and wage dynamics, the wage inflation in the two sectors is expressed as

$$\hat{\pi}_{c,t}^{w}=\beta\mathrm{E}_{\mathrm{t}}\left(\hat{\pi}_{c,t+1}^{w}\right)-\lambda_{w}\hat{\mu}_{c,t}^{w}=\beta\mathrm{E}_{\mathrm{t}}\left(\hat{\pi}_{c,t+1}^{w}\right)-\lambda_{w}\left(\hat{w}_{c,t}-mrs_{c,t}\right) \tag{4.34}$$

$$\hat{\pi}^{w}_{h,t} = \beta \mathrm{E}_{\mathrm{t}}\left(\hat{\pi}^{w}_{h,t+1}\right) - \lambda_{w}\hat{\mu}^{w}_{h,t} = \beta \mathrm{E}_{\mathrm{t}}\left(\hat{\pi}^{w}_{h,t+1}\right) - \lambda_{w}\left(\hat{w}_{h,t} - mrs_{h,t}\right) \tag{4.35}$$

where $\hat{\pi}^{w}_{c,t} = \tilde{w}_{c,t} - \tilde{w}_{c,t-1}$, $\hat{\pi}^{w}_{h,t} = \tilde{w}_{h,t} - \tilde{w}_{h,t-1}$, $\lambda_{w} = \left(1-\theta_{w}\right)\left(1-\beta\theta_{w}\right)/\theta_{w}\left(1+\varepsilon_{w}\varphi'\right)$.

The intuition behind this is that the imperfect adjustment of nominal wages will generally drive a difference between the real wage and the marginal rate of substation of households and leads to variations in the average wage markup and, as a result, in wage inflation.

3.3 Wholesalers

Wholesalers, indexed by $i = [0,1]$, produce intermediate goods in two sectors. Under monopolistic power, firms assemble capital, hire labors disregarding the type of households, differentiate goods, and set their own price. The production function, which is identical in the two sectors, is represented by

$$Y_{n,t}(i) = \varepsilon^{A}_{t} K^{\alpha}_{n,t-1} N_{n,t}(i)^{1-\alpha} \tag{4.36}$$

where $n = c, h$. α is the capital income share and ε^{A}_{t} is the productivity shock in the first-order autoregressive stochastic process with an i.i.d. normal error term. The labor inputs *j* e mployed by firm *i* are

$$N_{n,t}(i) = \left[\int_{0}^{1} N_{n,t}(i,j)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj\right]^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \tag{4.37}$$

Assume that the price is sticky in the consumption goods sector while it is flexible in the housing sector.

Optimal price setting

From price rigidity in Calvo (1983), a fraction $1-\theta$ of firms can set prices $P_{c,t}^{*}$ in period t and optimize their profit by

$$\max_{P_{c,t}^{*}} \mathrm{E}_{\mathrm{t}}\left[\sum_{k=0}^{\infty}\theta^{k}\left(Q_{c,t,t+k}\left(P_{c,t}^{*}Y_{c,t+k|t}\left(i\right)-\Psi_{c,t+k}\left(Y_{c,t+k|t}\right)\right)\right)\right] \tag{4.38}$$

subject to the demand constraint

$$Y_{c,t+k|t}\left(i\right)=\left(\frac{P_{c,t}^{*}}{P_{c,t+k}}\right)^{-\varepsilon}Y_{c,t+k} \tag{4.39}$$

for $k=0,1,2,\ldots$, where $Q_{c,t,t+k}=\gamma^{k}\,\lambda_{t+1}''/\lambda''=\gamma^{k}\,C''/C_{t+1}''$ is the stochastic discount factor. $\Psi_{c,t+k}\left(Y_{c,t+k|t}\right)$ is the cost function and ε is the elasticity of substitution across differentiated inputs.

Let $\Psi'_{c,t+k}/P_{c,t+k}=MC_{c,t+k|t}^{r}$ be the real marginal cost in period t+k, $\Theta=\varepsilon/\varepsilon-1$ be the mark-up price in monopolistic competition, and $\pi_{c,t,t+k}=P_{c,t+k}/P_{c,t}$ be the gross inflation from the price change in period t+k. Thus, the first-order condition can be written as

$$\sum_{\mathrm{k}=0}^{\infty}\theta^{\mathrm{k}}\mathrm{E}_{\mathrm{t}}\left(Q_{c,t,t+k}Y_{c,t+k|t}\left(\frac{P_{c,t}^{*}}{P_{c,t=1}^{*}}-\Theta MC_{c,t+k|t}^{r}\pi_{c,t-1,t+k}\right)\right)=0 \tag{4.40}$$

3.4 Retailers

Retailers buy differentiated intermediate goods and sell final goods in a perfectly competitive market. Taking a given price, the final goods production function is

$$Y_{n,t} = \left[\int_0^1 Y_{n,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{4.41}$$

Firms choose $Y_{n,t}(i), Y_{n,t}$ to maximize their profits

$$\max P_{n,t} Y_{n,t} - \int_0^1 P_{n,t}(i) Y_{n,t}(i) di \tag{4.42}$$

The first-order condition gives the individual demand curve for each retailer:

$$Y_{n,t}(i) = \left(\frac{P_{n,t}(i)}{P_{n,t}} \right)^{-\varepsilon} Y_{n,t} \tag{4.43}$$

Aggregate price dynamic

The profits of final producers must be zero. After combining them with the demand curve, we obtain the price dynamic as

$$P_{c,t} = \left[\theta_p P_{c,t-1}{}^{1-\varepsilon} + (1-\theta_p)\left(P_{c,t}^{*}\right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \tag{4.44}$$

$$P_{h,t} = \left[\int_0^1 P_{h,t}(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}} \tag{4.45}$$

3.5 Banks

The modeling banks in this paper is different from that in the mainstream literature, for example Gerali et al. (2010),[16] in which financial activities operate under perfect competition and are characterized by a continuum of banks as one unit. We follow the key modeling of the banking sector characterized in the study by Falagiarda and Saia (2017). Banks collect deposits $\left(D_t\right)$ remunerated at the deposit rate $\left(R_t^d\right)$ to patient households (savers) and provide loans $\left(L_t^c\right)$ charged at the lending rate $\left(R_t^c\right)$ to impatient households (borrowers). The spread between the two rates allows banks to make profits that are partly accumulated in banking capital $\left(Z_t\right)$. Banks also invest in government bonds $\left(B_t^b\right)$, which pay an interest rate $\left(R_t^g\right)$ as an asset. Banks can access lending facilities $\left(L_t^{cb}\right)$ and are required to maintain the capital requirement at the minimum target under the financial regulatory regime supervised by the central bank. The balance sheet is given by

$$B_t^b + L_t^c = Z_t + D_t + L_t^{cb} \tag{4.46}$$

As in Gerali et al. (2010), banking capital is accumulated out of retained earnings. The law of motion of equity stock is given by

$$Z_t = \left(1-\delta^b\right) Z_{t-1} + \phi^b \Omega_{t-1}^b \tag{4.47}$$

[16] Gerali et al. (2010) distinguished banks as being composed of two retail branches (for deposits and loans) and one wholesale branch with some monopolistic competition in retail branches. However, as mentioned, an alternative setup would produce identical results.

where δ^b is the cost of managing bank capital and Ω_{t-1}^b is the real profit after paying the dividend policy at the rate $1-\phi^b$.

Following Falagiarda and Saia (2017), banks maximize the discounted sum of real profit:

$$\mathrm{E}_t \sum_{t=o}^{\infty} \beta_b^t \left[R_t^c L_t^c + R_t^g B_t^b - R_t^d D_t - R_t^{cb} L_t^{cb} - Z_t - \frac{e}{2}\left(\frac{\omega_t^c L_t^c + \omega_t^g B_t^b}{Z_t} - v^b \right)^2 Z_t - \frac{\gamma^c}{2}\left(L_t^c\right)^2 \right] \tag{4.48}$$

where β_b is the discount factor for banks.

The last term captures the cost of managing loans to impatient households. The second-last term implies a quadratic cost in terms of bank capital that banks pay when deviating from the exogenous target of the capital requirement $\left(v^b\right)$, that is, the capital-to-assets ratio (or the inverse of leverage) and the capital adequacy ratio, imposed by the regulator.

The presence of the capital requirement incorporates two different risk weights, which are loans to households $\left(\omega_t^c\right)$ and government bonds $\left(\omega_t^g\right)$. Therefore, assets are weighted, that is, risk-weighted assets according to the financial regulatory framework (Basel III), as $\omega_t^c L_t^c + \omega_t^g B_t^b$. These two risk perceptions are formulated by

$$\left(\frac{\omega_t^c}{\omega^c}\right) = \left(\frac{\omega_{t-1}^c}{\omega^c}\right)^{\phi_{\omega^c}} \left(\frac{R_t^c L_t^c}{q_t H_t'}\kappa_L\right)^{\varphi_{1\omega^c}} \left(\frac{L_t^c}{Z_t}\kappa_Z\right)^{\varphi_{2\omega^c}} \left(\frac{Y_{c,t}}{Y_c}\right)^{\varphi_{3\omega^c}} \exp\left(\varepsilon_t^{\omega^c}\right) \tag{4.49}$$

$$\left(\frac{\omega_t^g}{\omega^g}\right)=\left(\frac{\omega_{t-1}^g}{\omega^g}\right)^{\phi_{\omega^g}}\left(\frac{B_t}{Y_{c,t}}\kappa_B\right)^{\varphi_{1\omega^g}}\left(\frac{Y_{c,t}}{Y_c}\right)^{\varphi_{2\omega^g}}\exp\left(\varepsilon_t^{\omega^g}\right) \tag{4.50}$$

where $\kappa_L = qH'/R^cL^c, \kappa_Z = Z/L^c, \kappa_B = Y_c/B$, $\varphi_{1\omega^c}, \varphi_{2\omega^c}, \varphi_{1\omega^g} > 0$, $\varphi_{3\omega^c}, \varphi_{2\omega^g} < 0$ and $\phi_{\omega^c}, \phi_{\omega^g}$ is a persistent parameter in risk perception. The risk associated with loans in equation (4.49) represents the leverage position of impatient households (debt over assets) and the exposure of banks (loans provided over the bank's equity). The risk associated with government debt in equation (4.50) is explained by the total debt exposure of the government. Lately, both risk perceptions have featured components related to the economic condition captured by the output over the steady-state level.

Banks maximize their real profits in (4.48) subject to the balance sheet identity in (4.46) and the credit constraint

$$R_t^{cb}L_t^{cb} \leq LTV_t^b \mathrm{E}_t\left(\frac{B_t^b}{R_{t+1}^g}\right) \tag{4.51}$$

which represents another source of financing, namely lending facilities to provide liquidity reflecting the central bank as the lender of last resort. We depart from this credit constraint of Falagiarda and Saia (2017) to match the standard lending facilities in Thailand. Only highly secured and safe assets[17] are usually eligible for collateral. In this model, collateralized lending is guaranteed by the expected value of government bonds.

[17] For example government bonds and bills, central bank bonds and bills, and state-owned enterprise bonds guaranteed by the government with the AAA rating.

LTV_t^b is considered as a haircut and endogenously determined using the same logic behind (4.4). Although the central bank's haircut is generally fixed, we allow it to be endogenous to reflect that a change in the collateral value may reduce the eligible haircut. Therefore, the LTV ratio for the central bank's loan is determined by the risk associated with the government's total debt exposure and economic condition.

$$\left(\frac{LTV_t^b}{LTV^b}\right) = \left(\frac{LTV_{t-1}^b}{LTV^b}\right)^{\phi_{LTV^b}} \left(\frac{B_t}{Y_c}\kappa_B\right)^{\varphi_{1B}} \left(\frac{Y_{c,t}}{Y_c}\right)^{\varphi_{2B}} \exp\left(\varepsilon_t^{LTV^b}\right) \tag{4.52}$$

where $\kappa_B = Y_c / B, \varphi_{1B} < 0, \varphi_{2B} > 0$ and ϕ_{LTV^b} is the persistent parameter. $\varphi_{1B} < 0$ implies that, when the risk of government bonds is higher due to a higher value of debt exposure, the central bank is less willing to accept collateral and will lower the amount of lending to banks. The last term, $\varepsilon_t^{LTV^b}$, is the LTV ratio for a central bank loan shock in the first-order autoregressive stochastic process with an i.i.d. normal error term.

Assuming that the credit constraint (4.52) is binding, the first-order conditions with respect to deposits, loans, bank capital, and bond holding are the following:

$$R_t^g - R_t^d - e\omega_t^g\left(\frac{\omega_t^c L_t^c + \omega_t^g\left(Z_t + D_t + L_t^{cb} - L_t^c\right)}{Z_t} - v^b\right) + \frac{\lambda_t^b LTV_t^b}{R_{t+1}^g} = 0 \tag{4.53}$$

$$R_t^c - R_t^g - e\left(\frac{\omega_t^c L_t^c + \omega_t^g\left(Z_t + D_t + L_t^{cb} - L_t^c\right)}{Z_t} - v^b\right)\left(\omega_t^c\left(1 + \varphi_{1\omega^c} + \varphi_{2\omega^c}\right) - \omega_t^g\right)$$
$$-\gamma^c L_t^c - \frac{\lambda_t^b LTV_t^b}{R_{t+1}^g} = 0$$

(4.54)

$$R_t^g - 1 + \frac{e}{2}\left(\frac{\omega_t^c L_t^c + \omega_t^g\left(Z_t + D_t + L_t^{cb} - L_t^c\right)}{Z_t} - v^b\right) + \frac{\lambda_t^b LTV_t^b}{R_{t+1}^g}$$

$$+eZ_t\left(\frac{\omega_t^c L_t^c + \omega_t^g\left(Z_t + D_t + L_t^{cb} - L_t^c\right)}{Z_t} - v^b\right)\left[\frac{\left(-1-\varphi_{2\omega^c}\right)\omega_t^c L_t^c - \omega_t^g\left(D_t + L_t^{cb} - L_t^c\right)}{\left(Z_t\right)^2}\right] = 0$$

(4.55)

$$R_t^g - R_t^{cb}\left(1+\lambda_t^b\right) - e\omega_t^g\left(\frac{\omega_t^c L_t^c + \omega_t^g\left(Z_t + D_t + L_t^{cb} - L_t^c\right)}{Z_t} - v^b\right) + \frac{\lambda_t^b LTV_t^b}{R_{t+1}^g} = 0$$

(4.56)

Equation (4.53) can be simplified as an interest rate spread:

$$R_t^c - R_t^d = e\omega_t^c\left(1+\varphi_{1\omega^c} + \varphi_{2\omega^c}\right)\left(\frac{\omega_t^c L_t^c + \omega_t^g B_t^b}{Z_t} - v^b\right) + \gamma^c L_t^c \qquad (4.57)$$

which means that banks choose the optimal loans such that the marginal cost of lending activities equals the loan–deposit spread. The first term, represented by $e\omega_t^c\left(1+\varphi_{1\omega^c} + \varphi_{2\omega^c}\right)\left(\left(\omega_t^c L_t^c + \omega_t^g B_t^b / Z_t\right) - v^b\right)$, is the cost of maintaining the leverage position or capital requirement, while the last term, $\gamma^c L_t^c$, is the cost of managing loans.

3.6 Central bank

The central bank implements the policy rate according to a Taylor principle, which responds to the expected inflation and output growth.

$$\frac{R_t^{cb}}{R^{cb}} = \left(\frac{R_{t-1}^{cb}}{R^{cb}}\right)^{\Omega_R} \left(\left(\frac{\mathrm{E}_t\left(\pi_{c,t+1}\right)}{\pi_c}\right)^{\Omega_\pi} \left(\frac{Y_{c,t}}{Y_c}\right)^{\Omega_Y}\right)^{1-\Omega_R} \varepsilon_t^R \tag{4.58}$$

where $\Omega_R, \Omega_\pi, \Omega_Y$ are weights assigned to the lagged policy rate, expected inflation, and output, respectively. ε_t^R is the monetary policy shock in the first-order autoregressive stochastic process with an i.i.d. normal error term. Note that output is measured as the output in consumption goods, mainly comprising the GDP. Thus, the policy rate is determined by the expected inflation and output in the consumption goods sector deviating from the steady-state level; π_c, Y_c is the interest rate smoothing component.

Additionally, the central bank supervises banks by imposing the target capital requirement $\left(v^b\right)$ following the Basel III regulatory framework.

3.7 Government

The government's decision is under the budget balance

$$\frac{B_t}{R_t^g} + T_t = B_{t-1} + G_t \tag{4.59}$$

where the left-hand side is the revenue, the stock of government bonds issued $\left(B_t\right)$, and tax collection $\left(T_t\right)$ and the right-hand side is the expenditure, debt payment $\left(B_{t-1}\right)$, and spending $\left(G_t\right)$. Government spending follows the first-order autoregressive stochastic process with an i.i.d. normal error term.

$$\log G_t = \rho_G \log G_{t-1} + e_t \tag{4.60}$$

From the passive fiscal policy suggested by Leeper (1991), the fiscal authority adjusts direct lump-sum taxes to the response level of the real government debt outstanding.

$$T_t = \psi_0 + \psi_1 \left(\frac{B_{t-1}}{\pi_{c,t}} - \frac{B}{\pi_c} \right) \tag{4.61}$$

3.8 Market equilibrium and aggregation

Aggregate consumption:
$$C_t = \phi C_t' + (1-\phi) C_t'' \tag{4.62}$$

The aggregate consumption expresses the value of consumption goods consumed by impatient and patient households, respectively.

Consumption goods market:

$$Y_{c,t} = C_t + I_t + G_t + \frac{e}{2} \left(\frac{\omega_t^c L_t^c + \omega_t^g B_t^b}{Z_t} \right)^2 Z_t + \frac{\gamma^c}{2} \left(L_t^c \right)^2 \tag{4.63}$$

Equilibrium in the consumption goods market requires the total supply (output) to be equal to the demand from private agents, the government, and the resource adjustment costs in banking activities.

Housing market:

$$Y_{h,t} = \phi \left(H_t' - \left(1-\delta^h\right) H_{t-1}' \right) + (1-\phi) \left(H_t'' - \left(1-\delta^h\right) H_{t-1}'' \right) \tag{4.64}$$

Equilibrium in the housing market represents the allocation of housing (after depreciation) held by impatient and patient households.

Tax collection: $$T_t = \phi T_t' + (1-\phi) T_t'' \tag{4.65}$$

Tax collection shows the lump-sum tax paid by impatient and patient households.

Government bond holding: $$B_t = B_t^h + B_t^b \tag{4.66}$$

Government bond holding consists of the bonds held by patient households and banks.

Capital aggregation: $$K_t = K_{c,t} + K_{h,t} \tag{4.67}$$

The aggregate capital is obtained by combining the capital used in the two sectors.

Labor market in the consumption goods sector: $$N_{c,t} = \phi N_{c,t}' + (1-\phi) N_{c,t}'' \tag{4.68}$$

Labor market in the housing sector: $$N_{h,t} = \phi N_{h,t}' + (1-\phi) N_{h,t}'' \tag{4.69}$$

Equilibrium in the labor market in sector c (4.68) and sector h (4.69) represents the labor demand being equal to the supply provided by patient and impatient households.

Labor aggregation: $$\phi N_t' + (1-\phi) N_t'' = N_{c,t} + N_{h,t} \tag{4.70}$$

Labor aggregation requires hours worked by households (supply) to be equal to the labor demand in the two sectors.

4. Calibrated parameters

The parameters in this model are calibrated based on three anchors. First, we select the parameter values corresponding to the quarterly data moments in Thailand or calibrate them from the empirical samples. Second, some values are chosen following previous studies, which are commonly used for standard parameters since some parameters do not have a reference from the prior literature in Thailand. Third, we loosely experiment with values to accommodate the model in line with reasonable implications for impulse response analysis.

Table 4-1 summarizes the standard parameters describing the behavior of economic agents. The discount factor of impatient households is set at 0.9943, corresponding to Gerali et al. (2010), to match the steady-state quarterly policy rate of slightly above 2 percent in Thailand. As for a well-defined steady state, discussed for example by Iacoviello (2005) and Monacelli (2009), the discount factor of impatient households is slightly reduced at 0.9920. Labor disutility of impatient and patient households is differently set at 1.5 and 2, respectively, as patient households are assumed to be more sensitive to working hours because of the income effect. We weigh 80 percent of the labor supply working in the consumption goods sector as consumption goods, mainly comprising the gross domestic product. Since the elasticity of labor substitution between the two sectors implies imperfect labor mobility across sectors, we allow the values of the parameters for impatient and patient households to be moderate at 3, which is between the value found by Iacoviello and Neri (2010) and that found by Walentin (2014). The Frisch elasticity of the labor supply for both households is set equal to 1.5, slightly different from that in the literature. The share of impatient households is calibrated at 0.2[18] from the Credit Bureau data in Thailand.

For firms' parameterization, the capital share in aggregate production is set at 0.36, following Falagiarda and Saia (2017), which has no significant difference from that in other works of literature. Based on the evidence in Thailand, the period during which the price does not change is approximately 7 months, which implies Calvo's price stickiness at 0.75.

[18] The shares of the number of borrowers from the Credit Bureau in the total population in 2009–2016.

As there is no empirical work on wage stickiness, we select 0.67, which is close to the value in Dey and Tsai (2017) and Iacoviello and Nero (2010). Together with the elasticity of substitution between labor and inputs, it is somewhat problematic to select parameter values. This model suggests the value of 1.5, which may deviate significantly from the standard values commonly used in the literature. These parameters are calibrated based on an attempt to reconcile and smooth the response function to shocks. The depreciation rates in housing and capital are 0.01 and 0.025, respectively, which are standard values used in the DSGE literature.

The parameters of banks are mostly those employed by Falagiarda and Saia (2017) and Gerali et al. (2010). The cost of managing bank capital is 0.021, while the cost of managing the capital requirement is 0.1. The cost of resources used in managing loans is 0.01. By assuming that banks' dividend is 10 percent, the fraction of profit reinvested in bank capital is thus 0.9. As the committed capital adequacy ratio of Basel III is 8.5 percent, we correspondingly measure the parameter of targeted risk-weighted assets per capital in this model as 11.76.

For the monetary policy, the parameters in the Taylor rules were suggested by Phrommin (2016), who introduced the inflation-targeting period into the data estimation. The interest rate persistence is 0.8, while the inflation and output response's coefficients are 1.7 and 0.125, respectively. For the fiscal authority, the parameters are chosen from Falagiarda and Saia (2017), who suggested that the steady-state level of tax is 0.1972, the response of tax to public debt is 0.3, and the autoregressive parameter in spending is 0.8.

Table 4-1: Standard parameters

Parameters		Description	Value
Households	β	Discount factor of impatient HHs	0.9920
	γ	Discount factor of patient HHs	0.9943
	χ	Labor disutility of impatient HHs	1.5
	ν	Labor disutility of patient HHs	2
	τ_1	Share of impatient HHs working in sector c	0.8
	τ_2	Share of patient HHs working in sector c	0.8
	η'	Impatient HHs' elasticity of labor substitution between 2 sectors	3
	η''	Patient HHs' elasticity of labor substitution between 2 sectors	3
	φ'	Inverse elasticity of impatient HHs' labor supply	1.5
	φ''	Inverse elasticity of patient HHs' labor supply	1.5
	ϕ	Share of impatient HHs	0.2
Firms	α	Share of capital used in production	0.36
	θ_w	Wage stickiness	0.67
	θ	Price stickiness	0.75
	ε_w	Elasticity of substitution between varieties of labor	1.5
	ε	Elasticity of substitution between varieties of inputs	1.5
	δ^h	Depreciation rate in housing	0.01
	δ	Depreciation rate in capital	0.025
Banks	δ^b	Cost of managing bank capital	0.021
	e	Cost of managing capital requirement	0.1
	γ^c	Cost of managing loans	0.01
	ϕ^b	Profit reinvested in bank capital	0.9
	ν^b	Targeted risk-weighted assets per capital	11.76
Central bank	Ω_R	Central bank's interest rate smoothing	0.8
	Ω_π	Central bank's inflation response	1.7
	Ω_Y	Central bank's output response	0.125
Government	ψ_0	Steady-state level of tax	0.1972
	ψ_1	Response of tax to outstanding public debt	0.3
	ρ_G	Persistent parameter in government spending	0.8

Source: Author

Table 4-2 shows the parameters of the LTV ratio and the risk-weighted parameters. We compute the LTV determination by performing linear regression on a set of MGL data[19] from 2008 to 2018. We regress the observed LTV ratio—a fraction of the mortgage loans approved against the housing value (collateral) on the persistent term, collateral value, and output in consumption goods. The results from the empirical work give the persistent parameter of 0.56, and the coefficients of housing collateral and output fluctuation are 0.27 and 0.07, respectively. The rest of the parameter values in risk determination are challenging to evaluate. As there is little guidance in the reference literature, we apply the values from Falagiarda and Saia (2017), who suggested the values in the following.

Table 4-2: Parameters of LTV determination and risk perception

Parameters		Description	Value
LTV	ϕ_{LTV}	Persistent parameter in LTV for HHs	0.56
	φ_{1H}	Coefficient of housing collateral in LTV for HHs	0.27
	φ_{2H}	Coefficient of output fluctuation in LTV for HHs	0.07
	ϕ_{LTV^b}	Persistent parameter in LTV for banks	0.8
	φ_{1B}	Coefficient of public debt in LTV for banks	-0.1
	φ_{2B}	Coefficient of output fluctuation in LTV for banks	0.2
Risk perception	ϕ_{ω^c}	Persistent parameter in housing credit risk	0.8
	ϕ_{ω^g}	Persistent parameter in government bond risk	0.2
	$\varphi_{1\omega^c}$	Coefficient of HHs leverage in housing credit risk	0.01
	$\varphi_{2\omega^c}$	Coefficient of banks' exposure in housing credit risk	0.01
	$\varphi_{3\omega^c}$	Coefficient of output fluctuation in housing credit risk	-2
	$\varphi_{1\omega^g}$	Coefficient of public debt in government bond risk	0.25

[19] The mortgage loan database (MGL) contains contract-level new mortgage loans issued by all Thai commercial banks. The data are reported with a monthly frequency.

	$\varphi_{2\omega^g}$	Coefficient of output fluctuation in government bond risk	-0.5

Source: Author

Table 4-3 provides the parameters of the shock process. The first-order autoregressive parameters are arbitrarily selected to produce the impulse response function to structural shocks intuitively. The model requires a low level of the AR coefficient in a monetary policy shock but a high level of housing credit risk shock. The standard deviation of shocks is set equal to 1 to observe the apparent impact after the shocks emerge.

Table 4-3: Parameters of the shock process

Parameters		Description	Value
AR persistence	ρ_H	Housing demand shock	0.3
	ρ_A	Productivity shock	0.4
	ρ_U	Inflation shock	0.5
	ρ_R	Monetary policy shock	0.1
	ρ_{LTV}	LTV shock	0.6
	ρ_{LTV^b}	LTV for lending facilities shock	0.5
	ρ_{ω^c}	Housing credit risk shock	0.8
	ρ_{ω^g}	Government bond risk shock	0.4
Std of shocks	σ_H	Std of housing demand shock	1
	σ_A	Std of productivity shock	1
	σ_U	Std of inflation shock	1
	σ_R	Std of monetary policy shock	1
	σ_{LTV}	Std of LTV shock	1
	σ_{LTV^b}	Std of LTV for lending facilities shock	1
	σ_{ω^c}	Std of housing credit risk shock	1
	σ_{ω^g}	Std of government bond risk shock	1

Source: Author

Table 4-4 gives the steady-state values, which are consistent with the Thai data. The output in the consumption goods sector is predetermined at 1, similar to the output in the housing sector. Although the government expenditure is observed as approximately 18 percent of the GDP in Thailand, this study refers to the output in consumption goods. We therefore adjust the government purchase to 0.2. The lending rate is calibrated from quarterly the Thai commercial banks' loan rate of the minimum retail rate (MRR) during the period 2000–2018, which is averaged at 7.5 percent, so it is 1.01875 in the model, while the policy rate is 1.005, which implies the rate at 2 percent. The LTV ratio is observed from the MGL at 0.67 and the LTV ratio for lending facilities to banks is set at 0.99 from the BOT's haircut rate on eligible collateral.

Table 4-4: Steady state value

Variables	Description	Value
Y_c	Output in sector c	1
Y_h	Output in sector h	1
G	Government expenditure	0.2
R^c	Lending rate	1.01875
R^{cb}	Policy rate	1.005
LTV	LTV ratio for housing loans to HHs	0.67
LTV^b	LTV ratio for lending facilities to banks	0.99

Source: Author

5. Results and discussion

This section presents the impulse response functions (IRFs) to monetary policy shocks and financial shocks from the LTV ratio and banking credit risk. To focus on the contribution of specific features incorporated into the model, we examine the IRFs from different model specifications that characterize the existence of banks and the determination of the LTV ratio as an endogenous or fixed ratio. The benchmark specification is characterized by the model with banks and an endogenous LTV ratio. The model without banks features patient households as providers of credit (lenders) to impatient households and applies the policy rate instead of the bank lending rate charging on loans.

5.1 The impacts of the endogenous LTV ratio

5.1.1 The effect of a monetary policy shock

Figure 4-2 shows the IRFs to an increase in the interest rate shock (of one standard deviation), comparing two models: one with the endogenous LTV ratio (benchmark) and one with the fixed LTV ratio. The upward movement of the policy rate induces lending rate increases. The higher cost of borrowing dampens loans to households, although a fall in the real house price does not exist in this model.[20] Intuitively, the real house price is expected to decrease, resulting in a reduction in credit for impatient households. The household

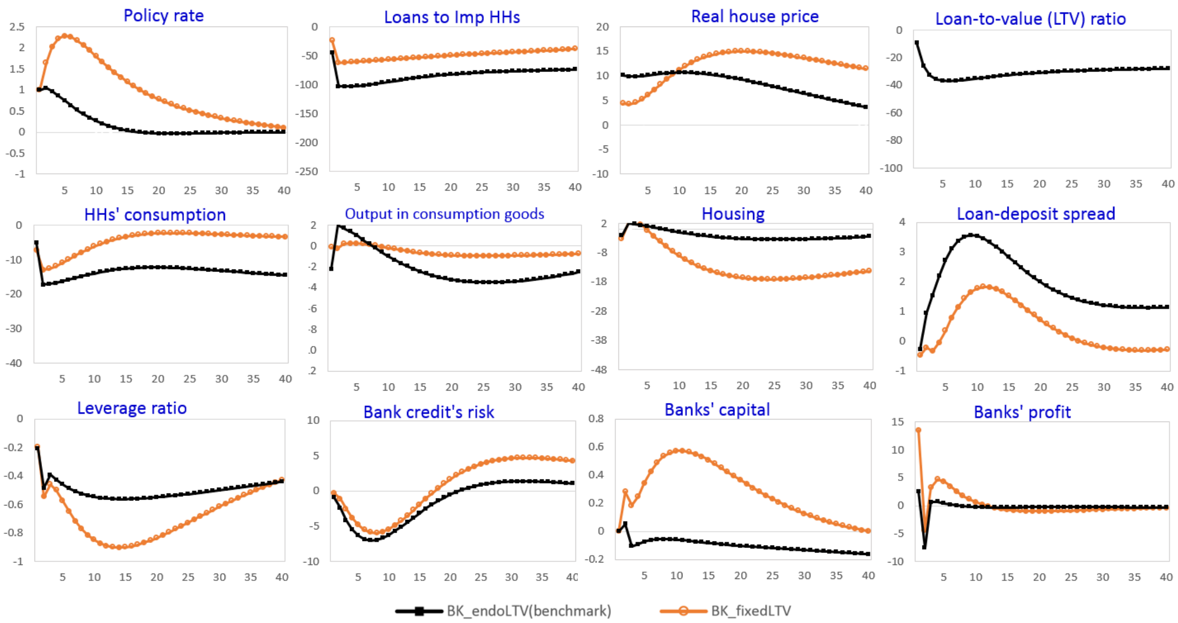
[20] This deviates from the standard result in other studies. The possible reasons for the puzzling result are that a sharp reduction in supply causes the house price to increase and/or households shift their portfolio from deposits to accumulate in housing, which they expect to utilize for financing future consumption.

consumption and output in the two sectors (consumption goods and housing) fall. Simultaneously, the worsened economic activities force banks to reduce the LTV ratio because of the fear of default risk, reflecting a tightening in the credit supply.

Because of a decline in loans to households, the bank profit sharply decreases. A reduction in lending activities offsets the previous loan–deposit spread. The bank capital, which coincides with retained earnings and profits, also falls. Since bank loans decrease more than capital, the leverage ratio (total assets per capital) falls. A slowdown in bank loans reduces the credit risk.

In the model comparison, the endogenous determination of the LTV ratio amplifies the effect of the contractionary monetary policy. When the interest rate increases, a decline in consumption and output reduces the amount of credit against collateral. Thus, the LTV ratio decreases and exacerbates the drop in bank lending. The worsened credit market condition ratio magnifies the negative effect of the increasing interest rate on household consumption and the output in consumption goods, whereas the housing sector has a mild effect. For banks' activities, banks' profit declines after a substantial contraction of bank lending. This influences banks to increase the loan–deposit spread. However, the effects on bank capital of the two models are different. When the LTV ratio is fixed, the magnitude of a reduction in loans is smaller. Banks need to accumulate capital to buffer the amount of risk-based loans; thus, bank capital increases. On the other hand, in the case of an endogenous LTV ratio, there is a large effect on loan reduction, and banks can delay raising capital. Bank capital can decrease to meet the minimum capital ratio. This is the reason for using the LTV ratio as a measure to reduce the amount of loans during adverse economic conditions to limit credit risk from bank lending.

Figure 4-2: Response to a positive monetary policy shock: endogenous vs fixed LTV ratio



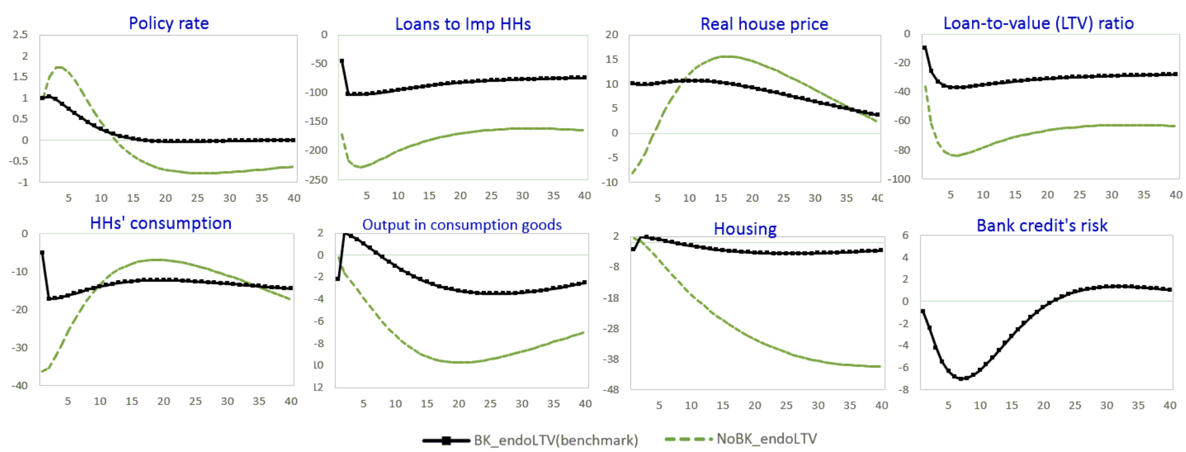
Source: Author

5.2 The role of banks in the business cycle

5.2.1 <u>The effect of a monetary policy shock</u>

Figure 4-3 compares the IRFs with an increase in the interest rate shock (of one standard deviation) between the model with banks and the model without banks, which both incorporate the endogenous LTV ratio. More precisely, the model without banks produces the negative effect of increasing the policy rate in the real house price. The combined effects of a higher lending rate and lower collateral value reduce the borrowing capacity of impatient households. A decline in loans immediately leads to a contraction in household consumption and output in both sectors. Importantly, in the model with banks, a decrease in loans to households triggers a fall in the leverage position of households and banks. A reduction in leverage can lower the risk perception of housing credit. The LTV reduction is not as severe as in the model without banks. The impacts of decreased consumption and output are then limited. Therefore, the existence of banks attenuates the impacts of a contractionary monetary policy whereby it causes lower banking credit risk and LTV reduction. Our findings of an attenuating effect of the existence of banks in a monetary policy shock are consistent with Gerali et al. (2010), who explained the stem of an attenuating effect as a result of an imperfect pass-through on bank loan rates due to stickiness and the adjustment cost.

Figure 4-3: Response to a positive monetary policy shock: banks vs no banks

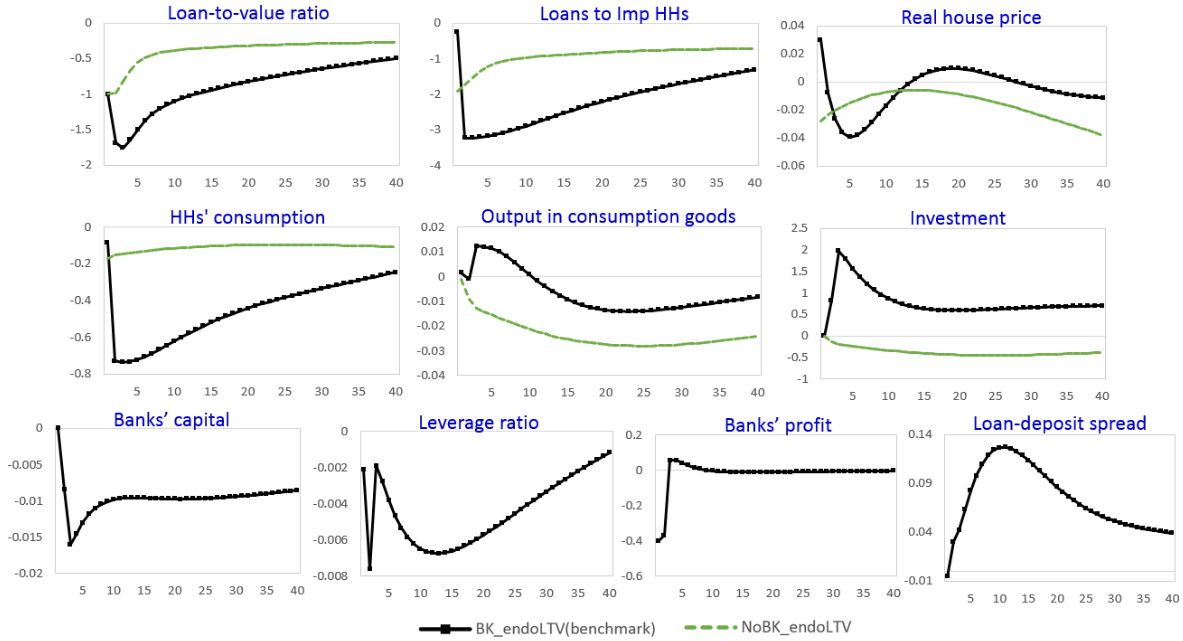


Source: Author

5.2.2 The effect of a credit crunch

Figure 4-4 presents the IRFs to a negative LTV shock (of one standard deviation) from the models with banks and without banks. This comparison is a useful instrument to analyze the mechanism of the bank lending channel through the credit crunch's effect on economic activities. A negative shock to the LTV ratio implies a reduction in the credit supply (credit crunch) and the borrowing opportunity that impatient households can receive from banks. A decline in the LTV ratio can also reflect a decrease in the housing collateral value. When banks decrease the LTV ratio, it induces a slowdown in banking activities. The bank profit immediately falls and leads to a reduction in bank capital. The leverage position decreases because of a sharp decline in bank loans. To rebalance the profit, banks raise the lending rate. The adverse financial sector affects the real sector by depressing the overall consumption and output in consumption goods. This finding indicates that a credit crunch influences household consumption. A shock to the credit supply (LTV shock) amplifies the effect on consumption since impatient households are dependently financed by bank loans. However, the impact on output is smaller and slower because a rise in investment redeems some parts of the decreasing output in consumption goods.

Figure 4-4: Response to a negative LTV shock: banks vs no banks



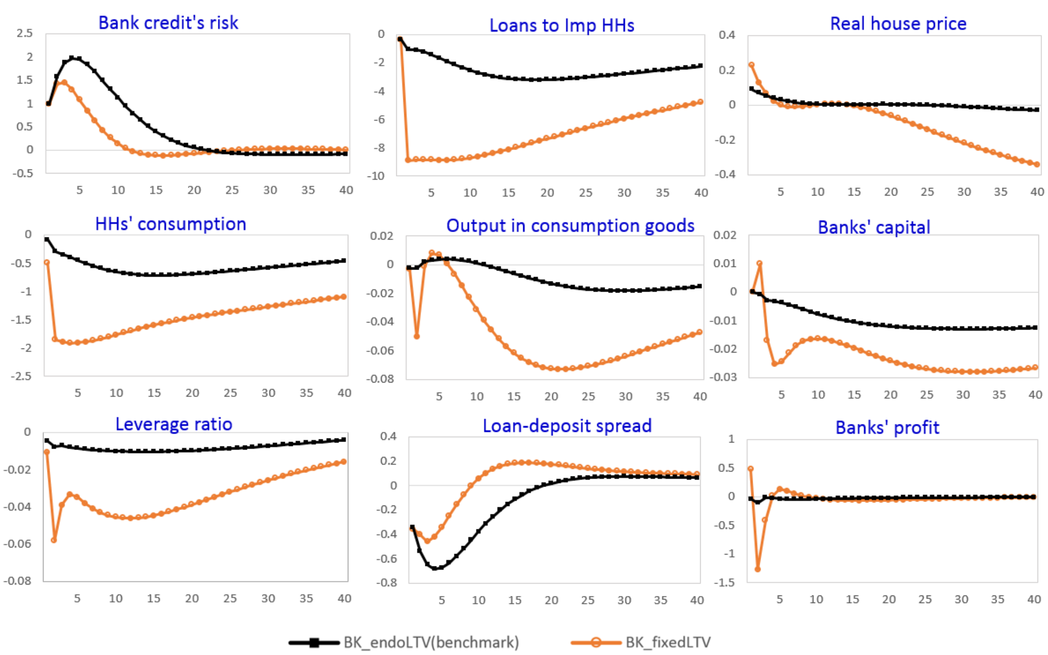
Source: Author

5.2.3 The effect of banking credit risk

Figure 4-5 presents the IRFs to a positive shock (of one standard deviation) of banking credit risk, comparing the endogenous and fixed LTV ratios. An increase in credit risk affects banks through a higher cost of maintaining capital requirements. If banks are risk taking, they need to increase their capital holding more to prevent the risk-weighted assets per capital from deviating from the target. However, banks generally reduce the loan supply by decreasing the LTV ratio and the amount of total loans. Thus, when the LTV ratio is fixed, it causes a severe contraction of bank loans to avoid loss and it generates negative profit in banking activities in a short period. The loss in profit forces banks to increase the loan–deposit spread; in particular, the loan rate will increase to compensate for the riskier credit.

Due to the fact that the interest rate spread may not adjust quickly, profits are not accumulated enough to compensate for a reduction in bank lending. This causes the bank capital and leverage ratio to fall. A downturn in the banking sector spills over to the real sector, and household consumption and output reduce. Importantly, when the LTV ratio is fixed, banks need to increase their loan–deposit spread substantially. That causes the impacts on the real and financial sectors to become stronger. Therefore, when the banking credit is riskier, a decrease in the LTV ratio can mitigate the impact of declining loans on economic contraction.

Figure 4-5: Response to a positive banking credit risk shock: endogenous vs fixed LTV ratio



Source: Author

6. Concluding remarks

In this chapter, we examine the effect of bank lending through housing collateral on the economy. The model is enriched by incorporating the banking sector with financial friction, that is, the credit constraint and balance sheet constraint. Regarding the comovement puzzle in a standard two-sector NK-DSGE model, we embody the wage rigidities suggested by Carlstrom and Fuerst (2010). We find that the model with wage rigidities enables us to resolve the comovement problem. We analyze the impacts of a monetary policy shock as well as financial shocks from the LTV ratio and banking credit risk. In addition, to focus on the contribution of specific features incorporated into the model, we compare the results from different specifications; the model with the LTV ratio vs the model with the fixed ratio and the model with banks vs the model without banks.

The extended model produces several findings. (1) A credit crunch influences household consumption—a reduction in the LTV ratio causes household consumption to fall substantially. (2) Higher credit risk affects banks by reducing the loan supply and increasing the loan–deposit spread to compensate for the loss in profit and capital. (3) The endogenous LTV ratio amplifies the effect of a monetary policy shock—worsened economic activities after interest rate increases force banks to reduce the LTV ratio and magnify the negative effect on household consumption and output in consumption goods. However, the endogenous LTV ratio mutes the effect of a banking credit risk shock. Finally, (4) the existence of banks attenuates the impact of a contractionary monetary policy since a reduction in banks' leverage lowers the risk perception of housing credit. Thus, the effect of an interest rate shock is moderate.

Given these results, the study has some limitations for developing future research. First, the puzzling response of the house price to the interest rate poses a challenge. As shown by the model comparison, the model incorporating the banking sector does not give a fall in the real house price after the interest rate increases, but the model without banks does. Regardless of this concern, however, the model can explain the role of banks and the endogenous LTV ratio from the dynamic of key macroeconomic variables that respond to the shock. We believe that this limitation of this model could be developed by further study. Second, there are structural breaks in the Thai economy in the economic crisis in 1997 and when the BOT adopted inflation targeting as an anchor in 2000. The structural breaks prevent us from using longer time series. The small size of the samples is not compatible with a large number of parameters. This limits the availability of Bayesian inference and may cause the identification problem of the estimated DSGE model. We find that employing Bayesian estimation is difficult for our model. We employ calibration instead and believe that there is somehow potential to develop it in future research. The last limitation is that we do not have much of an empirical foundation from the DSGE literature using Thailand's data. Instead, we choose the value of parameters based on the existing literature, though we are concerned that some parameters may not fully reflect the behavior of the Thai economy.

This model attempts to include banks that are constrained under the prudential regulatory framework, that is, Basel III. However, the credit risk formulation in the model is limited in a wide range of DSGE literature. A crucial challenge for future research will be to include features of Basel III, which will benefit the study of coordination between the monetary and the prudential policy. Finally, the attempt to set up a model under the ZLB interest rate is worthwhile to capture the effect of an unconventional monetary policy, which represents the situation that many countries are experiencing.

CHAPTER 5
CONCLUSION

In this dissertation, we aim to study monetary policy transmission regarding the role of housing and banking credit under the NK-DSGE model. We develop a two-sector NK-DSGE model with housing and credit constraints, described in chapter 3, and extend the model by incorporating the banking sector and embedding the endogenous LTV ratio presented in chapter 4. In detail, we focus on the following six issues.

The first issue is the role of housing in monetary policy transmission. We find that housing plays a crucial role through three main effects: (i) the wealth effect, (ii) the collateral effect, and (iii) the amplification effect (under credit relaxation). The amplification effect is our new contribution, which emphasizes the importance of the LTV ratio in monetary policy transmission. Given the result from the amplification effect, we give the policy recommendation that it is possible to stimulate an economy by increasing the LTV ratio (credit relaxation). However, readers should be aware that a high LTV ratio amplifies the impacts of a contractionary monetary policy.

Second is the relationship between housing and household consumption. The result shows that housing determines consumption. An increase in the house price induces household consumption to increase, particularly for households that rely on housing collateral to access credit to finance their consumption.

The third issue is the effect of a financial shock originating in the banking sector, that is, a credit supply shock (LTV shock) and a credit risk shock. The results indicate that (i) a reduction in the LTV ratio decreases bank profit and capital, which leads to an increase in the lending rate, and (ii) a higher credit risk causes banks to reduce the loan supply and increase the loan–deposit spread to compensate for the loss in profit and capital. We summarize that both financial shocks in banking activities cause a change in household consumption.

Fourth is the role of macroprudential policy (capital against risk-weighted assets). We find that monetary policy shocks and financial shocks cause banks to adjust their capital, credit supply, and loan–deposit spread.

The fifth issue is the implication of the endogenous LTV ratio. We observe that the endogenous LTV ratio amplifies the effect of a monetary policy shock but mutes the effect of a credit risk shock.

Sixth is the existence of banks in the NK-DSGE model. The presence of banks attenuates the impact of a contractionary monetary policy since a reduction in banks' leverage lowers the risk perception of housing credit. Thus, the effect of an interest rate shock is moderate.

In summary, the dissertation emphasizes the importance of banking activities. Banking credit tied to the value of housing collateral establishes a link between the financial and the real sector in the manner of the propagation of economic impacts.

As mentioned in previous chapters, the study succeeds in resolving the comovement problem in a two-sector DSGE model; however, unfortunately, three challenges remain. First, the relationship between the house price and the interest rate is problematic when the model incorporates the banking sector. Second, the small size of samples is not compatible with a large number of parameters. This limits the availability of Bayesian inference and may cause an identification problem in the estimated DSGE model. We instead employ calibration and believe that there is potential to develop it in future research. Third, we do not have much of an empirical foundation from the DSGE literature employing Thailand's data. Instead, we choose the value of parameters based on the existing literature, though we are concerned that some parameters may not fully reflect the behavior of the Thai economy.

So far, this dissertation is an exploratory work using a two-sector NK-DSGE model, which includes housing and credit constraints, using Thailand's data. This study paves the way for future research. We briefly outline some of the possible areas of research. First, the extension of the standard DSGE model to an open-economy DSGE model allows us to explore the role of the exchange rate in response to structural shocks. In addition, we can explain better the behavior of Thailand's economy concerning the housing market, which is strongly related to foreign investors. Second, the feature of the financial regulatory framework, that is, Basel III, is crucially beneficial for the study of coordination between monetary and prudential policy. Finally, the attempt to set up a model under the ZLB interest rate is worthwhile to capture the effect of an unconventional monetary policy, which represents the situation that many countries are experiencing.

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