MASTER THESIS

Should monetary policy pay attention to financial stability? A DSGE approach

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Declaration of authorship

I hereby proclaim that I wrote my master thesis on my own under the leadership of my supervisor and that the references include all resources and literature I have used.

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Prague, May 9, 2016

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Signature
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Extent of the thesis

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Abstract

After the recent financial crisis of 2007, a connection between monetary policy and financial stability has started to be thoroughly investigated. One of the particular areas of this research field deals with the role of various financial variables in the monetary policy rules. The main purpose of this research is to find whether direct incorporation of the financial variables in the monetary policy rule can bring macroeconomic benefits in terms of lower volatility of inflation and output. So far, the main emphasis of the research has been placed on the investigation of the augmented Taylor rules in the context of a closed economy. This thesis sheds light on the performance of the augmented Taylor rules in a small open economy. For this purpose, a New Keynesian DSGE model with two types of financial frictions is constructed. The model is calibrated for the Czech Republic. The thesis provides four conclusions. First, incorporation of the financial variables (asset prices and the volume of credit) in the monetary policy rule is beneficial for macroeconomic stabilization in terms of lower implied volatilities of inflation and output. Second, the usefulness of the augmented monetary policy rule is the most apparent in case of the shock originating abroad. Third, there is a strong link between the financial and the real side of an economy. Fourth, if the banking sector experiences a sharp drop in bank capital that brings this sector into decline that further translates into the whole economy, monetary policy is not able to achieve macroeconomic stability using its conventional tools.

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Abstrakt


JEL klasifikace
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Klíčová slova
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Topic characteristics

Standard monetary policy arrangements usually assume only one or at most two goals of central banks’ monetary policy – these are inflation and output. The other aspects of an economy, such as financial sector developments, are not directly incorporated into monetary policy rules. In this view, they are suppressed and no attention is paid to the evolution of the financial sector and its implications for monetary policy decisions.

However, the recent financial crisis starting in 2007 has brought new insights into the financial stability and its role in monetary policy. The roots of the crisis can be found in the U.S. financial sector. Even though that financial sector gave obvious signals about potential harmful development, the Fed did not pay attention to them and did not alter its policy rate accordingly. Therefore, the recent literature has started the discussion about the financial stability as an important, inseparable and direct part of the central banks’ decision making rule.

Two strands of opinions have emerged. The first strand defends the new approach stating that some kind of a financial stability indicator should be directly incorporated into the monetary policy rule. Such augmented rule takes into account the financial sector and its role in inflation development, and the rule then leads to more favourable long-term results. The future path of inflation is adjusted accordingly and makes economies more stable. On the other hand, the opposing strand argues that direct incorporation of the financial stability indicator into the rule is not optimal because the central bank’s role based on a stable inflation level is harmed. It is because a certain weight is put on financial stability and it is not possible to pursue two completely different goals of monetary policy.
(i.e. inflation and financial stability) by using only one monetary policy tool. Therefore, the proponents of this view say that it would be optimal to propose a new additional tool and separate these two goals into two different parts. Since this discussion is not clear cut, a lot of space is left for further investigation.

Hypotheses

1. A central bank pursuing inflation targeting regime achieves better performance under a policy rule which takes into account not only developments in inflation, but also a financial stability indicator compared to the pure inflation targeting rule.

2. A pre-emptive reaction of monetary policy taking into account a financial stability indicator reduces creation of possible future financial imbalances.

Methodology

In my thesis, I will compare and investigate the effectiveness and the implications of monetary policy rules considering financial stability indicator in the inflation targeting regime. The thesis will consist of three main sections. In the first section, the recent literature regarding financial stability and its connection to monetary policy will be discussed and approaches to modelling of various financial stability indicators within a DSGE framework will be introduced.

The second section will be devoted mainly to the construction of a small open economy DSGE model with financial frictions. I am planning to construct a benchmark small open economy DSGE model capturing a central bank pursuing inflation targeting regime. In such situation, the role of a central bank is to keep inflation on the pre-defined inflation target level within a certain band. Therefore, a major weight is put on inflation and other aspects, such as financial stability, are suppressed. Since my aim is to broaden the discussion in the Czech Republic, I will use a simplified version of the reaction function used by the Czech National Bank. Lastly, a financial stability condition will be implemented into the model. Thus, the role of the central bank is slightly altered and a certain weight is put on the financial stability as well.

The results of such altered model will be then compared to the baseline version which does not consider the financial stability as a secondary goal of monetary policy. The comparison, the effectiveness and the implications of these different
arrangements will be described by using impulse response functions depicting reactions of an economy to various shocks. The model will be calibrated for the Czech Republic. In the last section, a thorough discussion of the results and policy implications will be provided.

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2. Financial stability and financial stability indicators
3. Modelling financial aspects of monetary policy
   (a) Approaches to modelling financial frictions within DSGE framework
   (b) Incorporating financial stability indicator into monetary policy reaction function
4. A small open economy New Keynesian DSGE model with financial frictions
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Acronyms

AR       autoregression
AMPR     augmented monetary policy rule
CES      constant elasticity of substitution
CNB      Czech National Bank
CPI      consumer price index
DSGE     dynamic stochastic general equilibrium
ECB      European Central Bank
Fed      Federal Reserve system
GDP      gross domestic product
iid      independent and identically distributed
IRF      impulse response function
NK       New Keynesian
SD       standard deviation
U.S.     United States
UIP      uncovered interest parity
VAR      vector autoregression
1 Introduction

Monetary policy has come through significant developments during the past century. The central banks all over the world tried to find the optimal choice of monetary policy arrangement perfectly suitable for their economy. The alternatives that are at hand are, among others, inflation targeting, monetary targeting, or exchange rate targeting. Among these, inflation targeting has become one of the most reliable regimes and it has been implemented in many central banks in industrialised countries. Beside the prominent goal of price stability, most central banks have implemented output stability as a secondary objective of their monetary policy. This can be illustrated by so called dual mandate of the Federal Reserve System, where the Federal reserve system is responsible for price stability and economic well-being at the same time. Therefore, the traditional view on monetary policy has narrowed to consideration of the two mentioned variables – inflation and output. In accordance with this, the mainstream literature focusing on monetary policy operates with monetary policy rules that include deviations of inflation and output from their target values.

However, the recent financial crisis has shown that the variables pronounced by the traditional view on monetary policy may not convey sufficient amount of information. Since the financial sector plays an important role in each economy, any turmoil in this sector causes significant problems in the real side of the economy. Therefore, various financial variables have become the natural candidates for monitoring. Additionally, the interconnection between monetary policy and financial stability has began to be investigated. This stems from the fact that the roots of the financial crisis starting in 2007 can be found in the U.S. financial sector. Before the crisis, the prevailing view of the direct role of financial stability in monetary policy was that financial stability should not be considered at all. However, this attitude has changed and several new views have emerged – from the most radical ones stating that the inflation targeting regime has failed, to the opposing strand arguing that the monetary policy regimes having price stability as their main goal should be enhanced by financial stability objective.

The current research (both empirical and theoretical) regarding this topic is growing extensively. Nevertheless, there is still a lot to be explored and examined. The theoretical research is grounded on the DSGE modelling framework with the pronounced focus on the banking sector incorporation, because this sector was not a part of the models constructed before the crisis. Since this modelling framework
offers somewhat flexible modelling techniques, there can be found several different models characterized by the specific features of the banking sector. The majority of these theoretical papers employ closed economies models with a limited number of shocks.

The purpose of this research is to clarify whether the financial variables convey some additional information that can be identified as useful and beneficial for monetary policy decision making. In particular, the thesis focuses on the macroeconomic implications of the incorporation of the financial variables in a monetary policy rule. This problem is investigated using a New Keynesian DSGE model for a small open economy. The model is characterized by the banking sector modelling approach introduced by Gambacorta and Signoretti (2014) and it includes two types of financial frictions. Four main findings stand out from this thesis. First, the financial variables convey useful information that helps to stabilize macroeconomic developments in terms of lower implied volatilities. Second, the shocks originating in the foreign economy have a large impact on the domestic economy and the usefulness of the augmented rules is the most apparent in these events. Third, the developments in the financial side of the economy have significant effects on the real side. Fourth, in case of a significant turmoil in the financial sector represented by a sharp contraction in bank capital, monetary policy is not able to achieve macroeconomic stability using its conventional tools.

The thesis is structured as follows. Chapter 2 is devoted to the discussion about financial stability and its connection to monetary policy. This chapter also offers an overview of different views on the role of the central bank in the financial stability agenda. Chapter 3 summarizes the recent techniques of the financial frictions modelling. Each type of the given friction is described and it is complemented by the relevant theoretical as well as empirical research. Additionally, the financial stability indicators are discussed and their possible implementation in the Taylor rule is outlined. The two introductory chapters are followed by chapter 4 that focuses on the construction of a DSGE model, and chapter 5 deals with calibration. In chapter 6, the properties of the model are presented. First, the implied volatilities under different monetary policy rules are discussed. Based on this analysis, the most appropriate augmented monetary policy rule is selected to represent an alternative scenario. Second, the model is qualitatively assessed using impulse response functions under the baseline and alternative scenario. Chapter 6 also offers a comparison with the results of the recent research. The assessment of the model is complemented by the sensitivity and robustness
analyses that are provided in chapter 7. These exercises help to verify whether the model is robust to the changes in some key parameters and whether the results hold for different weights ascribed to the financial variables in the augmented monetary policy rule. Lastly, general conclusions are made in chapter 8.
2 Financial stability and financial stability indicators

Even though the concept of financial stability is known for several decades, there are still some discrepancies about its meaning. Therefore, this section introduces financial stability in general and specifies some of its basic definitions. Since the discussion of financial stability and its connection to monetary policy is not unambiguous, several views on financial stability and its role in monetary policy are offered. This section also outlines four possible financial stability indicators discussed in the literature. Moreover, each indicator description is complemented by a brief literature review.

2.1 Financial stability in general

In the last two decades, the functions of the central banks have changed considerably. Their primary function – maintenance of monetary stability – represented by one of the possible monetary policy regimes was complemented by another core function – financial stability.

As Schinasi (2003) explains, the incorporation of the financial stability function under the central banks’ roof is natural because of the following reasons. First, central banks are the only institutions which can provide the means of payments, and if needed, also immediate and unlimited amount of liquidity. Second, central banks safeguard national payment systems and maintain their perfect functioning. Third, naturally, central banks are keen on the smooth functioning of the banking system since it plays a crucial role in the monetary policy transmission mechanism. In the case of financial distress in the banking sector, the transmission mechanism is disrupted and the actions of central banks do not have desired impact. Lastly, one can find a clear connection between monetary stability and financial stability. This stems from the fact that when there is a period of financial instability, market sentiment is low as well as confidence and market players demand immediate liquidity represented by fiat money. This in turn means that the money supply and bank credit shrinks dramatically. If this process is not stopped and it is allowed to evolve into the spiral, the volume of monetary aggregates in the economy declines. This could cause the economy to divert from its potential output trajectory.
Although the term financial stability is used frequently, its definition is not uniform and no agreement was reached. Allen and Wood (2006) discuss this issue and they come to the conclusion that it is necessary to describe the characteristics of financial instability and then to define financial stability as a situation in which financial instability is unlikely to occur. Oosterloo and de Haan (2004) investigate this issue in a broader context of a central bank functioning and they give few examples of possible financial stability definitions used in practice. For example, one central bank defines financial stability as a smooth functioning of the financial system in ordinary times as well as in times of distress. “Financial stability in ordinary times” is understood as a situation in which the financial system does not contain any type of imbalances. Moreover, financial stability of the financial system is dependent not only on the ability of the system to absorb unexpected shocks, but also on the ability to work properly in case of financial distress.

Additionally, there exist two competing theories – the competition-fragility hypothesis and the competition-stability hypothesis. The competition-fragility hypothesis (e.g. Boot and Thakor 1993) states that higher competition in banking sector leads to instability of the financial system, while the competition-stability hypothesis (e.g. Boyd and De Nicoló 2005) asserts that competition promotes lower fragility of financial stability.

Since this thesis focuses on monetary policy conducted in a small open economy represented by the Czech Republic, it is convenient to state a financial stability definition used by the Czech National Bank (CNB) which can be found, for example, in CNB (2015):

“The CNB defines financial stability as a situation where the financial system operates with no serious failures or undesirable impacts on the present and future development of the economy as a whole, while showing a high degree of resilience to shock.”

2.2 Financial stability and monetary policy intertwined

Financial stability and monetary policy are not completely separated concepts. On the contrary, they are interlinked. Adrian and Liang (2014) argue that monetary policy may contribute to the creation of financial vulnerabilities, and therefore undermine financial stability.

Regarding asset markets, changes in monetary policy affect the pricing of
risky assets, such as in credit or housing markets. Bernanke and Kuttner (2005) conclude that monetary policy also affects expected cash flows. Moreover, Gertler and Karadi (2013), Gilchrist et al. (2014) and others have documented that easier monetary policy conditions can lead to lower credit risk premiums on corporate bonds. Monetary policy may also contribute to higher risk taking at financial institutions as it is shown by Allen and Gale (2000).

The banking sector is one of the key areas in monetary policy transmission. Lower policy rates imply a higher volume of banks’ lending leading to a shift in credit supply. In addition, under these conditions banks may take on more risk. Rajan (2005) shows that banks can reach for yield which leads in a higher amount of risky assets in their portfolios. Jiménez et al. (2012) investigate the same effect of loose monetary policy in Spain and they reach the same conclusion. Maddaloni and Peydró (2011) investigate the impact of lower policy rates on lending standards in the USA and the euro area. They find that there are less cautious lending standards in case of low policy rates.

The last sector mentioned by Adrian and Liang (2014) is non-financial sector. They specify the balance sheet channel of monetary policy and its impact on the net worth of borrowers. Literature regarding this transmission of monetary policy is extensive. The seminal paper by Bernanke et al. (1999) and their “financial accelerator” mechanism or the work of Kiyotaki and Moore (1997) are just few examples. Increase in the borrowers’ net worth leads to easier access to credit but financial frictions may cause an excessive increase in debt leading to a higher likelihood of default. Borio and White (2004) and Borio et al. (2011) have documented that the excess of credit in the non-financial sector can serve as a crucial indicator of increasing systemic risk.

Smets (2014) discusses the interconnections between macroprudential policy, financing conditions, price stability and real economy activity. The author concludes that monetary and macroprudential policy should be coordinated and possible side effects should be taken into account when making policy changes.

2.3 The recent financial crisis and clash of different approaches

Before the recent financial crisis of 2007-2008, the prevailing view of the direct role of financial stability in monetary policy was that financial stability should not
be considered at all. Woodford (2012) discusses arguments behind such opinion. A first argument relies on the fact that financial crises are not predictable enough. Therefore, it is not possible to “lean against” eventual risks in the financial sector. Second, there were doubts about how monetary policy can effectively suppress the build-up of risks regarding financial stability. A common view was that changes in the central banks’ short term interest rates are not enough to substantially influence the emergence of stock-market or real estate bubbles. Last argument is based on the well-known Tinbergen rule. This principle stipulates that each policy instrument should be assigned only one goal. Therefore, monetary policy is not the right candidate and a better tool should be developed.

However, the recent financial crisis has changed the attitude to the monetary policy framework considerably and several new views have emerged. The most radical ones are represented by DeGrauwe (2007) and Leijonhufvud (2008) who claim that the inflation targeting regime has failed and that the unfavourable consequences of the crisis are the products of this policy regime. Giavazzi and Giovannini (2010) contribute to this view by stating that inflation targeting can even increase the likelihood of a financial crisis emergence. On the other hand, Woodford (2012) argues that the inflation targeting regime as such is not to blame for the problems the whole world faced. He states that inflation targeting was designed and implemented with the aim to stabilize inflation expectations and to avoid a deflationary trap. Based on this, inflation targeting served us well.

In order to incorporate the financial stability objective, central bankers have introduced macroprudential policy amended by several new features. Despite the fact that most central banks did that, a debate still resonates about whether monetary policy regimes having price stability as their main goal should be enhanced by financial stability objective. As discussed by Smets (2014), there are three basic views.

The first view is called a modified “Jackson Hole consensus” which says that the monetary authority takes into account financial stability concerns only as long as they influence the price stability and economic activity developments. The modification resides in the introduction of macroprudential authority pursuing financial stability objective. In this setting, monetary and macroprudential authorities are separated and each has its own instruments.

The second view “leaning against the wind vindicated” argues that central banks focusing on the inflation outlook over the horizon of two to three years
suppress own ability to lean against potential build-ups of financial imbalances. This view is the reflection of the opinions of Borio and Lowe (2002), White (2006) and many others. These authors argue that macroprudential policy is not able to fully address a financial cycle because the financial cycle interacts non-linearly with the business cycle. Moreover, monetary policy is seen as a potential tool to affect risk taking. Therefore, monetary policy should consider financial stability as a secondary objective. This approach also brings new trade-off, because credibility of a central bank may be undermined since one tool pursues two goals. Thus, the central bank should stress that the price stability remains the primary goal. Monetary policy may become less straightforward, but set-up remains the same. Woodford (2012) comments this potential issue and argues that there will be no significant conflict between monetary policy and financial stability objectives. He states that there will be a tension, but this tension is similar to the conflict between price stability and output gap stabilization. Another potential trade-off is that a substantial reaction on the policy rates could be required to the extent that developments on financial markets are significantly affected. This may in turn cause fluctuations in inflation and output. The counter-argument is that not every interest rate hike is followed by recession and not to react at all may lead to even worse outcome. Assenmache-Wesche and Gerlach (2010) show that the policy rate should not be used to fight financial imbalances, while Fahr et al. (2013) investigate the performance of the inflation targeting regime altered by financial stability objective and they conclude that it leads to an improvement in macroeconomic performance.

The third (and the last) view is more extreme and places equality between financial and price stability. Proponents of this view (e.g. Brunnermeier and Sannikov 2014) argue that financial and price stability are so closely interconnected that it is not possible to separate them and even not to make a distinction between them. In this case, monetary policy decisions are aimed first to tackle potential problems in financial system in order to achieve its stability so that a smooth functioning of monetary policy transmission is ensured. Smets (2014) comments that a threat of financial dominance emerges, and therefore he suggests a strong coordination between both policies.

To summarize, each of the three mentioned views (not taking into account the first extreme one) stresses the importance of the interaction between financial stability and monetary policy. In spite of this, each of these approaches places a different emphasis on this interaction and understands the effectiveness of in-
dependent macroprudential policy distinctly. Moreover, each view sees monetary policy as a potential source of financial instability in a different light. Smets (2014) explains that if there is a large interaction between financial stability and monetary policy, cooperation would be needed, and therefore it is natural to have both policies under one roof. This author adds that if tools of macroprudential policy are not sufficiently effective and if they are not able to manage the financial cycle entirely, monetary policy instruments should focus on financial stability objective as well. On top of this, if monetary policy based on a price stability regime is a source of imbalances, then the financial stability consequences implied by monetary policy should be taken into account.

2.4 Financial stability indicators

The importance of financial stability seems to be increasing in the recent years. Based on the arguments mentioned above, the central banks which place more emphasis on financial stability than they did before may enhance their policy functions by additional term representing financial stability because the information conveyed by output gap and inflation may not reflect the situation sufficiently. There has been a substantial research devoted to exploration of financial stability indicators so far. Käfer (2014) offers an overview of financial stability indicators and their reflection in economic literature. There are four main streams: (1) exchange rates, (2) asset prices, (3) credit/leverage and (4) credit spreads. The last two types of indicators are of particular interest due to the recent U.S. subprime crisis and the European sovereign debt crisis.

2.4.1 Exchange rates

Connection between monetary policy and the exchange rate can be summarized as follows. First, the value of exchange rates affects prices of imported goods and inflation expectations. Second, movements in the exchange rate have an impact on the competitiveness of firms since appreciation in the domestic currency decreases the price of foreign goods in eyes of domestic consumers, while domestic goods are more expensive for foreign consumers. Third, capital flows are significantly dependent on the value of exchange rate. Subsequently, they affect credit and asset prices which may result in the build-up of financial imbalances. Additionally, if domestic firms or banks have a substantial portion of liabilities denominated in foreign currencies and these are not matched with the
same amount of dollarized assets, a debt value can indefensibly increase with exchange rate depreciation leading to threat of bankruptcy.

Ho and McCauley (2003), Mohanty and Klau (2004) and others conclude that exchange rates are of particular concern for emerging markets because economic conditions depend significantly on the value of the exchange rate in these countries. Svensson (2000) and Batini et al. (2003) find that the central bank’s reaction function augmented by the exchange rate could deliver more favourable results. Nevertheless, Batini et al. (2003) stress that the weight assigned to the exchange rate should be substantially smaller than the weights placed on inflation and output.

A general view of the incorporation of the exchange rate in the reaction function is cautious. A potential impact is rather modest and the performance of a central bank is not improved significantly. Therefore, policy rates should not react to the exchange rate movements considerably.

2.4.2 Asset prices

The discussion about asset prices and their role in monetary policy and financial stability is primarily concentrated on stock and house indices. Gilchrist and Leahy (2002) explain how changes in asset prices affect inflation and output. An increase in asset prices results in higher welfare of households which in turn implies increase in their consumption. Higher stock prices also represent better investment opportunities. Moreover, since the value of assets increases, the value of collateral increases as well. This means that the access to further financing is available and it leads to higher spending and investment. Therefore, increasing asset prices can indicate future inflationary pressures.

Caruana (2005) investigates the connection between asset prices and financial stability and concludes that significant increases in asset prices may lead to vulnerability of the financial sector, thus undermining financial stability. Bernanke et al. (1999) and Bernanke and Gertler (2001) examine the performance of variety of policy rules. The first paper concludes that a pure inflation targeting performs better than a strategy which includes reaction to stock prices, while the second identifies a little improvement in the performance of a rule augmented by asset prices. Cecchetti et al. (2000) and Cecchetti et al. (2002) oppose these papers. Their finding is that central banks should react to asset prices; however, they should not target them. It is important to stress that the authors use only
one specific shock with a specific duration of an asset bubble. To conclude, they claim that asset prices might be of use, but the reaction to the changes in asset prices should be considered on case-by-case basis. A rule-like behaviour does not seem to be appropriate.

Empirical evidence regarding this topic is broad. For example, Botzen and Marey (2010) focus on the euro area and they show that the European Central Bank (ECB) considered asset prices as a potential financial stability indicator (and reacted to it with some weight) even before the recent financial crisis. Lee and Son (2013) investigate reactions of the Federal Reserve System (Fed) and they find that the Fed reacted to the stock market developments in recessions while there has been no reaction in times of booms.

2.4.3 Credit/leverage

Another potential financial stability indicator is credit and leverage. There are papers (e.g. Borio and Lowe 2002, Detken and Smets 2004) which ascribe more prominent role to credit in asset price bubbles than the assets have themselves. Credit growth may cause increase in asset prices but higher asset prices consequently result in higher value of collateral required which in turn leads to a credit growth. Therefore, credit growth is seen as a potential threat to financial stability. Moreover, Adrian and Shin (2008) point out that stocks are held in portfolios of unleveraged investors. Thus, credit may play more important role in financial stability than asset prices do.

The recent literature focusing on the role of credit in monetary policy is broad. Theoretical papers exploring this connection have the following features: (1) they are based on DSGE modelling and a prominent role is ascribed to financial frictions, (2) regulatory instruments are often implemented, (3) credit growth and its relation to asset prices is emphasized.

Agénor et al. (2013) investigate a credit expansion caused by a shock in house market. They alter a basic Taylor rule with credit and also add a capital regulation mechanism. They find that monetary policy (i.e. without capital regulation intervention) is able to stabilize the economy in most cases. However, if the monetary authority is reluctant to change the main policy rate considerably in order to stabilize the economy sufficiently, then the capital regulation mechanism should be employed to complement monetary policy. Christiano et al. (2010) find that inflation and credit growth react asymmetrically in times of stock market
booms – inflation tends to be low while credit growth high. Therefore, simple reaction function would suggest no change in policy rate. They show that reacting to credit growth is beneficial and a central bank should be able to stabilize economy. Aydin and Volkan (2011) focus on the Korean economy. They conclude that reaction to financial stability indicator might be useful, but they find a difference in case of supply and demand shocks. In the first case, a significant improvement is found whereas in the latter there is none. Gelain et al. (2013) come to conclusion that central bank’s reaction to credit improves performance of some variables, while the variances of inflation and output are higher.

Regarding the empirical evidence, Borio and Lowe (2002) show that credit conveys important information about financial stability and they state that the Fed considered this indicator for financial stability purposes in its monetary policy at the beginning of the 21st century. Additionally, as Lee and Son (2013) in case of asset prices, Borio and Lowe (2002) find that the reaction to credit is also asymmetric (periods of expansions vs. periods of recessions).

To conclude, there is no common view on credit and its role in monetary policy. However, literature stresses the importance of credit as a conveyor of useful information. Additionally, there exists a strong connection between assets prices and credit. Therefore, both should be considered simultaneously.

2.4.4 Spreads

The last indicator suggested by the literature is spreads. This variable takes different forms – the most frequently discussed are lending/deposits, corporate, or sovereign spreads. The last mentioned form is of particular interest due to the recent European sovereign debt crisis which has been taking place since late 2009.

Since spreads have been discussed for relatively short time period, there is a limited amount of literature regarding this topic. Cúrdia and Woodford (2010) investigate the role of spreads in monetary policy. They build a New Keynesian DSGE model that has features allowing for differences between lending and deposit rates. Monetary authority reflects the size of spreads in its reaction function. This means, for example, that if there is an increase in the spread, the main policy rate is cut. They come to the conclusion that augmenting the rule by credit spreads improves the outcome with respect to baseline scenario without spreads. The optimal response on spreads to shocks is not uniform and it is differ-
ent for each case. Teranishi (2012) elaborates on the policy function with spreads which are the results of two different loan contracts. The model suggests that the optimal policy reaction is achieved under the augmented version of reaction function; however, the response to spreads is dependent on the characteristics of both types of loans.

Empirical evidence regarding this indicator is scarce and its findings are not clear since most of available papers focus on the mix of indicators rather than on spreads solely. Belke and Klose (2010) investigate the interest rate response of the Fed and the ECB before and during the recent financial crisis. The authors find that both central banks responded to rising spreads by lowering the main policy rates. Another example can be Bouvet and King (2011). These authors focus on the ECB and its reaction to rising sovereign spreads of Greece and Ireland. They claim that adding spreads to reaction function improves regression, but signs at each spread coefficient are different. Bouvet and King (2011) explain this interesting result by stating that both countries were fighting different debt problems.

Since spreads are the newest type of financial stability indicator and not much research has been done yet, some uncertainty about the results is in place. Nevertheless, there is a question how far central banks can go with interest rates cuts in order to decrease the size of the spread desirably. Since central banks are limited by zero lower bound, this could result in usage of unconventional monetary policy tools even in ordinary times.
3 Modelling financial aspects of monetary policy

3.1 Approaches to modelling financial frictions within DSGE framework

The standard approach to DSGE modelling is criticised for its inability to capture the characteristics of business and financial cycles (and the interaction between these two, the so-called feedback loop). In order to achieve harmonization with the observed economic fluctuations, the standard way of modelling relies on the use of shocks that are calibrated such that their effects are extensive and also persistent, which ensure that reactions to shocks are spread in time. Additionally, the standard approach assumes perfect financial markets. This means that economic agents have immediate access to unlimited amount of credit. The criticism of this approach is a motivation for the introduction of financial frictions into the DSGE structure. Financial frictions place constraints that make the access to funding limited. Financial accelerator is the mechanism through which financial frictions work. This mechanism amplifies small shocks in financial markets and transforms them into substantial shocks driving the real economy away from its natural state, and therefore causing fluctuations. As Brázdik et al. (2012) describes, there are generally three methods of modelling financial frictions in DSGE models. These are: (1) external finance premium, (2) collateral constraints and (3) banking sector.

3.1.1 External finance premium

In the world with perfect financial markets, a firm has always the opportunity to raise capital using external sources at the prevailing market interest rate. A share of future profit is then the cost of this financing. However, in the real world, such exchange is not always possible since certain restrictions on financing are in place as a result of information asymmetry. Therefore, the cost of external financing includes a premium a debtor is asked to pay to a creditor. The value of premium is dependent on many features, such as company’s financial position, and thus it is set individually.

From the perspective of the borrower, the external finance premium can be
defined as the difference between the cost of external funding and the opportunity cost of using own internal funding. Because of the extra costs related to external funding, the external finance premium has a positive sign. Debtor’s higher net worth, liquidity, or history full of successful projects reduces the cost of external financing, and therefore the premium decreases. Besley et al. (2008) has documented that the premium evolves counter-cyclically. In case that the economy is in expansion, the firms’ financial position improves, and therefore the value of premium decreases. Conversely, if the economy is hit by a negative shock, the premium’s value increases, which makes external funding more expensive. This, in turn, makes the financial position of a debtor even worse. The process then works as a spiral. The premium further increases, external funding for the debtor becomes more expensive, which causes the output of the firm to be negatively affected. Debtor’s net worth is negatively affected as well, causing the external finance premium to grow further. Thus, even a small adverse shock can have a substantial impact on the whole economy.

Lender, on the other hand, faces information asymmetry in that all information about the investment project is not known. Because of this fact, lenders have possibility to supervise the status of the investment project. However, monitoring of the investment project is associated with higher costs. Despite the additional costs, lenders incline to use monitoring because moral hazard occurs – borrowers would intend to report lower return than actual, and thus lenders would be worse off.

The pioneering work belonging to this category is Bernanke and Gertler (1989). The authors introduce entrepreneurs and lenders into their model. The role of entrepreneurs is to manufacture capital goods through investment projects using their own funding and external funding (borrowed from lenders). Capital goods are used by firms as inputs for goods production. In this model, only entrepreneurs posses all information about the investment project. Therefore, lenders pay extra monitoring costs to see the results of the project as well. Since uncertainty about the results of project and monitoring costs exist, a positive external finance premium emerges. Bernanke and Gertler (1989) show in their model, that a positive productivity shock has a favourable impact on the firm’s financial position leading to an increase in investment and capital production, which causes the economy to grow.

Bernanke et al. (1999) presented the most influential work regarding the financial accelerator mechanism. Their NK DSGE model captures (beside others)
producers of capital who disappear and arise randomly. This mechanism prevents producers of capital to be independent of external financing, since they do not have enough time to accumulate corresponding amount of resources in order to become self-sufficient. Capital goods are then used for the production of consumption goods. Because of the pro-cyclical nature of producers’ net worth, a counter-cyclical external finance premium appears. The authors claim that a financial accelerator mechanism may be an explanation of the extensive and persistent fluctuations of demand- and supply-side shocks.

There are several extensions of the model published by Bernanke et al. (1999). For example, Aoki et al. (2004) extend the model by introduction of investment in housing. In this case, instead of producers of capital, home-owners are modelled. The model delivers results which are in line with the features of the real data (such as housing investment).

General conclusion regarding the introduction of the external finance premium into the DSGE structure is that it improves the model results which are more in line with the real data characteristics. However, as Brázdik et al. (2012) point out, the ability of models to mimic asymmetries in the fluctuations is limited, because the current premium value is dependent only on the current state of capital producers and no attention is paid to expectations.

### 3.1.2 Collateral constraints

Another approach to financial frictions modelling is via collateral constraint. This technique places a restriction on available funds for financing. This limitation is a result of borrower’s balance sheet composition since the possibility of borrowing is limited by amount of the borrower’s assets that are used to secure loans. For this purpose, durable assets (such as property or long-term capital) are used. In case of the debtor’s investment project failure, the collateral is transferred to the lender. Therefore, the value of the collateral is a determinant of the possible loan value.

In case of a mild negative shock, the firm is able to control distortion by reduction of financial capital or by decrease in the consumption of resources. On the other hand, if a substantial negative shock emerges, the ability of the firm to absorb the shock may be paralysed because of the insufficient amount of the financial capital. As a consequence, the firm will tend to find external resources instead of selling own production facilities. However, the firm may not even
find external resources because of the existence of the collateral constraint. Such situation has a significant impact on the firm’s production. Therefore, collateral constraint serves as a shock propagator.

Kiyotaki and Moore (1997) investigate the implications of collateral constraint in case of fully secured loans. Their finding is that even a small productivity or income shock can cause significant fluctuations in the whole economy. In their model, there are two types of firms – constrained and unconstrained. The constrained firms use capital for production and also for borrowing. The propagation mechanism works as follows. A negative productivity leads to lower net worth of firms. Ability of constrained firms to borrow deteriorates, and therefore demand for investment and also for land decreases. This is followed by reduction in future output and potential income as well as investment in the subsequent periods. Because the markets must be in equilibrium, the unconstrained firms are forced to increase their demand for land, which requires the reduction of opportunity costs of holding land. The anticipated fall in opportunity costs is reflected by the decrease in the land price in the current period. This has a substantial impact on the constrained firms causing their situation even worse.

Kocherlakota (2000) presents an asymmetric financial accelerator. In his model it is assumed that land is a substitute for other durable assets used in production, such as machinery. As in the previous case, land serves as collateral as well. If the economy is hit by a significant negative demand shock, firms cannot withstand the situation and have to sell machinery. Since machinery and land are substitutes, price of land decreases. Because land is used as collateral, firm’s ability to borrow external resources decreases. Another example of collateral constraint modelling is provided by Iacoviello and Neri (2010). The authors focus on the housing market and they find that introduction of a collateral constraint amplifies a shock originating in the housing market, and that there are significant implications for the whole economy in this case.

In general, the literature finds that the amplification and the propagation of the shocks through the economy are dependent on assumptions of chosen model. Additionally, strong financial accelerator effect can be found in case of financial shocks since these directly affect the prices of assets used as collateral. On the contrary, the response of the accelerator mechanism is low in case of non-financial shocks.
3.1.3 Banking sector

Models that are characterised by one of the two discussed modelling approaches implicitly assume existence of banks. In this regard, the banking sector is suppressed and the emphasis is placed on the demand side of credit. Therefore, literature dealing with modelling of the banking sector tries to explain the role of banks in the financial system. There are several incentives to introduce banks into the DSGE structure. Very first papers point out the importance of various interest rates and their role in monetary policy decision making. The recent financial crisis has been another influential source since systemic risk in financial sector and risky portfolios played a key role in the build-up phase of the crisis.

Goodfriend and McCallum (2007) introduce the first model dealing with a banking sector in DSGE framework. Using their model, the authors explain the role of various interest rates in the economy. Moreover, they emphasize the importance of the model enhanced by a banking sector for the central bank. Their approach is based on the paper of Bernanke et al. (1999). The banking sector embodies both the credit and balance sheet channels. Loans are generated by the banking sector which is constructed similarly as a standard competitive firms’ sector. Goodfriend and McCallum (2007) use collateral and monitoring costs to serve as constraints. Capital and government bonds are used to back the loans. The authors also introduce cash-in-advance assumption. This assumption is a key factor which forms demand for deposits since households are required to hold respective amount of deposits before they start to consume.

Interestingly, this model encompasses two external finance premium effects which work in the opposite direction. The “banking attenuator” effect reduces the strength and persistence of a monetary policy shock. This is caused by the cash-in-advance assumption and by the construction of the production function of the competitive banking sector. Conversely, the “banking accelerator” effect works the other way around. The authors explain that the first effect outweighs the latter and the overall external finance premium effect is procyclical.

Completely different approach to the banking sector modelling is offered by Cúrdia and Woodford (2009). They introduce heterogeneous households of which half is lenders and the other half is borrowers. Since each household type has different attitude to the current and future consumption, two discount factors are present. As a consequence, two different interest rates emerge and thus the spread exists. Because of the heterogeneous composition of households, the cash-
in-advance assumption is not needed. The main conclusion of this paper is that the implementation of the credit channel in the DSGE model has very modest consequences for optimal monetary policy design.

Gerali et al. (2010) focus on the role of endogenous banking capital and its implications for banking intermediation. Unlike the previous research, imperfectly competitive banks are introduced in the deposit and the loan market. This method has significant implications for a central bank to the extent that the transmission of the main policy rate is not full.

3.1.4 Selected approach to financial frictions modelling

As the previous paragraphs suggest, the incorporation of financial frictions in DSGE models has favourable consequences. These extended models help to understand the historical episodes and the development of various economic variables in that time. Moreover, predictions based on such augmented models are more accurate, and therefore the monetary policy decisions are more appropriate. Despite these improvements, there is no common approach to the financial frictions modelling as opposed to almost unified stance in case of ordinary DSGE models. An explanation of this difference might entail the following generally known arguments:

- As the previous sections suggest, different alternatives of financial frictions have different consequences for the real economy, and therefore distinct results arise in each case.

- Only a limited amount of financial frictions can be modelled, otherwise the model becomes too complicated and its functioning may be harmed.

- Incorporation of more financial frictions into one model could make the results of the model inexplicable because of the interaction between the frictions.

- Modelling of financial frictions is a relatively young discipline. There are just few historical episodes which could help in the identification of the “correct” approach. Therefore, it is impossible to state which attitude is the most appropriate.

Based on these arguments, one needs to select only one or at most two of the alternative financial frictions modelling approaches. Since the aim of this thesis is
to investigate the implications of the credit volume and asset prices for monetary policy design and their suitability for monetary policy, banking sector approach combined with the collateral constraint mechanism is selected.

### 3.2 Incorporating financial stability indicator into monetary policy reaction function

#### 3.2.1 “Targeting financial stability”

A starting point of this discussion is the seminal work by Taylor (1993). In this paper, the author proposes the rule according to which a central bank sets its main policy rate \( i_t \) with respect to the developments in the equilibrium real interest rate \( \bar{r} \) and the current inflation rate \( \pi_t \). Moreover, the central bank takes into account the deviation of the current inflation rate from its target value \( \pi^* \) and the deviation of actual output \( y_t \) from its desired level \( y^* \). This relationship is described by the following equation:

\[
i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) \tag{1}
\]

where \( \alpha \) and \( \beta \) are the weights. As many authors have shown, in the presence of nominal wage and price rigidities the real interest rate plays a crucial role. Therefore, (1) can be rewritten as:

\[
r_t = i_t - \pi_t = \bar{r} + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) \tag{2}
\]

The implications of the Taylor rule are clear. If the actual level of inflation is above its target value \( (\pi_t > \pi^*) \) and/or output is above its desired level \( (y_t > y^*) \), then \( r_t > \bar{r} \). This means that the central bank should hike the real interest rate in order to slow the economy down. If the inequalities are in the opposite direction, then the real interest rate should be decreased. A key feature that the literature identifies about the Taylor rule is so called Taylor principle. The principle stipulates that the nominal interest rate must be increased more than the inflation rate in order to achieve stability. This implies that \( \alpha > 0 \).

Since central banks are more concerned about financial stability nowadays and since it seems that inflation and output does not convey sufficient amount of information, such simple rule as proposed by Taylor is no longer sufficient.
Therefore, the rule could be explicitly augmented by a term referring to some financial stability measure $f$. Equation (1) is then extended by term including the actual value of financial stability measure $f_t$, its target value $f^*$ and some weight $\gamma$:

$$i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) + \gamma(f_t - f^*)$$ (3)

As it was discussed in the previous section, several possibilities of the measure $f$ are at hand – exchange rates, asset prices, credit/leverage, or spreads. However, it is not obvious what should be respective target values of the financial stability measure $f^*$. In case of exchange rates, decision about the potential target value seems to be straightforward. On the other hand, regarding the rest of the measures discussed above, the situation is not so clear. For example, one cannot simply state what the tolerable level of spread is. In case this problem is overcome, another issue arises – weight $\gamma$. Central banks may set this value to some fixed level. Central banks may conversely allow this parameter to be time-varying so that different emphasis is placed on financial stability in different stages of the business or financial cycle.

### 3.2.2 Reacting to financial developments

An alternative to the “financial stability targeting” is a mere reaction to financial stability indicator. For example, Cúrdia and Woodford (2010) use such approach. In this case, a central bank reacts to developments in financial stability indicator with certain weight; however, it does not target some specific value. Then, equation (1) takes the following form:

$$i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) + \gamma f_t$$ (4)

where $f_t$ is the actual value of financial stability measure and $\gamma$ is a certain weight. The discussion about the target value is suppressed in this approach.

Nevertheless, the discussion about the appropriate weight $\gamma$ still remains. Regarding the USA and spreads, Taylor (2008) proposes 100% reaction, whereas Cúrdia and Woodford argue for response of less than 100%. More specifically, they find the optimal value of $\gamma$ to be 0.66 (i.e. monetary authority takes into account 66% of financial developments). The optimal value of $\gamma$ might be found using welfare analysis of monetary policy rule. It is important to mention that
this value will differ for each model because it will strongly depend on the model setting.

3.2.3 Reacting to future financial developments – forward-looking rule

It has long been understood that a forward-looking dimension in policy decision making (and in monetary policy especially) is needed. Alan Greenspan stressed this idea in 1994: “The challenge of monetary policy is to interpret current data on the economy and financial markets with an eye to anticipating future inflationary forces and to countering them by taking action in advance.” Batini and Haldane (1998) elaborate on the original idea of the Taylor rule. The authors construct and evaluate simple forward-looking policy rules which include expected inflation – so called inflation-forecast-based rules. By adopting their approach and disregarding the output targeting part\(^1\), the basic specification of the Taylor rule (1) can be generally modified as follows:

\[
i_t = \bar{r} + \pi_t + \alpha (E_t \pi_{t+j} - \pi^*)
\] (5)

where \(E_t \pi_{t+j}\) represents the expected inflation rate in time \(t+j\) and \(j\) takes value from the set \(\{0,1,2,\ldots\}\). Setting \(j = 0\) yields current-looking rule, while letting \(j\) being equal to the value from the set \(\{1,2,3,\ldots\}\) yields a forward-looking version of the policy rule reacting to the deviation of the forecast-based value of the inflation rate from its target value. Similarly, the policy rule can be augmented by the expected future value of financial stability measure \(f\):

\[
i_t = \bar{r} + \pi_t + \alpha (E_t \pi_{t+j} - \pi^*) + \gamma (E_t f_{t+k})
\] (6)

where \(k \in \{0,1,2,\ldots\}\). In this case monetary authority also focuses on future financial developments and adjusts its short-term policy rate with respect to the future financial imbalances. Values \(j\) and \(k\) may be different in that monetary authority can perceive a different horizon of both policies (inflation stability and financial stability).

\(^1\)For more details see Batini and Haldane (1998).
The model outlined in this section is built on several models. The fundamental features are adopted from the models derived by Brzoza-Brzezina and Makarski (2011) and Gambacorta and Signoretti (2014). The banking sector is modelled according to Gambacorta and Signoretti (2014), who simplify the seminal banking sector modelling approach introduced by Gerali et al. (2010). In this setting, banks collect deposits from households and issue loans to entrepreneurs. As a result, interest rate spread emerges. Banks also face a regulatory measure – optimal level of capital-to-asset ratio. The elements of the model related to the retail level are modelled as in Brzoza-Brzezina and Makarski (2011). Model of Brzoza-Brzezina and Makarski (2011) is updated based on few remarks made by Svačina (2015).

The model utilises two types of financial frictions: (i) entrepreneurs are constrained in borrowing from banks by the value of assets they possess; (ii) the central bank (in the role of regulatory authority) prescribes the optimal level of leverage to commercial banks – whenever the actual level of leverage deviates from the optimal level, commercial banks pay a cost. These frictions significantly affect the propagation mechanisms of shocks. More specifically, they connect the financial side of the economy with the real side in such a way that changes, for example, in entrepreneur’s net wealth or policy rate are relevant determinants of conditions in the credit market. Conversely, movements in supply of loans are influential factors in the activity in the real side of the economy. The first type of friction propagates through a collateral channel, while the second type of friction propagates through a credit supply channel.

The model described in this section diverges from some specific characteristics of the models mentioned above. Since the model combines features of several models, it allows for a richer structure, and therefore for additional analysis. Overall, this thesis introduces a small open economy DSGE model – a stochastic growth model with monopolistic competition at the retail level and at the banking sector, capital adjustment costs, capital utilization, nominal price rigidity and financial frictions.
4.1 Households

The economy is populated by rational households of measure $\gamma^H$. Each household consumes, works, saves money in a bank that pays the deposit rate, and purchases a non-contingent foreign bond which yields a risk-adjusted return. Households receive positive utility from consuming, while receive disutility from working. Preferences of a representative household are given by the following utility function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t_H A^C_t \log(C^H_t(j) - \nu C^H_{t-1}(j)) - \frac{(H_t(j))^{1+\phi}}{1+\phi},$$

(7)

where $C^H_t$ is consumption, $\nu C^H_{t-1}$ is the external habit stock with $\nu \in [0, 1]$ being a parameter characterizing the degree of habit persistence, $H_t$ is labour supply, $\phi$ is the inverse of the Frisch wage elasticity of labour supply, $\beta^H \in [0, 1]$ is the exogenous discount parameter, and $A^C_t$ is a consumption preference shock. Its deviation from the steady state is assumed to follow an AR(1) process with $\epsilon^C_t$ being normally distributed with zero mean and variance $\sigma^2_C$:

$$\hat{a}^C_t = \rho C \hat{a}^C_{t-1} + \epsilon^C_t,$$

(8)

The household’s budget constraint is specified as (in real terms):

$$C^H_t(j) + D_t(j) + \mathcal{E}_t B_t(j) \leq W_t H_t(j) + \frac{R_{t-1} D_{t-1}(j)}{\Pi_t} + \frac{R_{t-1}^* F_{t-1} \mathcal{E}_t B_t(j)}{\Pi_t} + T_t(j),$$

(9)

where $\Pi_t = P_t/P_{t-1}$ is the gross inflation rate with $P_t$ being the price level, $\mathcal{E}_t$ is the nominal exchange rate, $W_t$ is the real wage earned by household, $R_t$ is the gross nominal interest rate on saving deposits $D_t$, $R_t^* F_t$ is a risk adjusted nominal return paid on foreign bonds $B_t$ (denominated in foreign currency), $T_t$ represents a lump-sum transfer that includes the banking sector dividends and profits from the ownership of domestic retailers, importing retailers and capital goods producers. According to Adolfson et al. (2008), the debt-elastic risk premium is defined as:

$$F_t = \exp \left\{ \psi^* \left( \frac{\mathcal{E}_t B_t}{P_t Y_{G,t}} \right) \right\} A^U_{t}^{UIP} = \exp \left\{ \psi^* \left( \frac{L^*_t}{Y_{G,t}} \right) \right\} A^U_{t}^{UIP},$$

(10)

with $\mathcal{E}_t B_t/Y_{G,t} P_t$ being the real outstanding net foreign assets position of the
domestic economy with $Y_{G,t}$ referring to GDP and $\phi^* > 0$ being the parameter characterizing elasticity of the risk premium. $A_t^{UIP}$ is the debt-elastic risk premium shock. Its deviation from the steady state is assumed to follow an AR(1) process:

$$\hat{a}_t^{UIP} = \rho_{UIP} \hat{a}_{t-1}^{UIP} + \varepsilon_t^{UIP}$$

(11)

where $\varepsilon_t^{UIP}$ is normally distributed with zero mean and variance $\sigma_{UIP}^2$.

Each household chooses consumption $C_t^H$, labour supply $H_t$, bank deposits $D_t$, and foreign bonds $B_t$ in order to maximize its lifetime discounted utility (7) with respect to the budget constraint (9). Combining first-order conditions of the maximization problem yields (after imposing symmetry):

$$\left(H_t\right)^{\phi} = \left(C_t^H - \iota C_{t-1}^H\right)^{-1} W_t A_t^C$$

(12)

$$R_t = \frac{1}{\beta_H} \mathbb{E}_t \left\{ \frac{C_{t+1}^H - \iota C_t^H}{C_t^H - \iota C_{t-1}^H} A_t^C \Pi_{t+1} \right\}$$

(13)

$$\frac{R_t}{R_t^*} = \mathbb{E}_t \left\{ \frac{Q_{t+1} \Pi_{t+1}}{Q_t \Pi_{t+1}} \right\} F_t$$

(14)

Equation (12) is the intra-temporal condition defining the trade-off between consumption and leisure, equation (13) is the Euler equation describing the optimal path of consumption, and (14) refers to the standard UIP condition.

### 4.2 Entrepreneurs

Entrepreneurs are modelled as in Gerali et al. (2010). The economy is populated by entrepreneurs of measure $\gamma^E$ who consume, buy capital, hire labour from households and borrow from banks. They combine production resources and external financing in order to produce wholesale output. They are risk-neutral. In the production of wholesale goods, entrepreneurs face a financing constraint which is the source of financial accelerator.

Each entrepreneur only cares about his/her consumption. By choosing optimal levels of consumption $C_t^E$, capital $K_t^K$, the degree of capital utilization $U_t$, labour $H_t$ and loans from banks $L_t$, the entrepreneur maximizes the utility
function:

$$E_0 \sum_{t=0}^{\infty} \beta_t E^0 \log(C_t^E(j) - \iota C_{t-1}^E(j))$$

subject to the budget constraint:

$$C_t^E(j) + W_t H_t(j) + \frac{R_t L_{t-1}(j)}{\Pi_t} + Q^K_t K^K_{t-1}(j) + \psi(U_t(j)) K^K_{t-1}(j)$$

$$\leq \frac{Y_t^W(j) P^W_t}{P_t} + L_t(j) + Q^K_t (1 - \delta_K) K^K_{t-1}(j)$$

where $\iota \in [0, 1]$ is a parameter characterizing the degree of habit persistence, $\delta_K$ represents the depreciation of capital, $Q^K_t$ is the real price of capital, $\psi(U_t) K^K_{t-1}$ represents a real cost of setting a level $U_t$ of capital utilization, and $P^W_t$ is the price of wholesale good. The production function is defined as:

$$Y_t^W(j) = A_t Y_t^Y [K^K_{t-1}(j) U_t(j)]^\alpha (H_t(j))^{1-\alpha}$$

where $K^K_{t-1}$ is capital purchased at time $t$, $H_t$ is labour supplied by households and $A_t^Y$ is a productivity shock. Its deviation from the steady state is assumed to follow an AR(1) process with $\varepsilon_t^Y$ being normally distributed with zero mean and variance $\sigma^2_Y$:

$$\delta_t^Y = \rho_Y \delta_{t-1}^Y + \varepsilon_t^Y$$

As in Iacoviello (2005), entrepreneurs are limited in the amount of borrowing, because banks insist on entrepreneurs to possess sufficient amount of collateral. The original approach by Iacoviello (2005) is modified according to Gerali et al. (2010), who propose that entrepreneurs are constrained by holdings of capital. This innovation is likely to be more realistic, since entrepreneurs use houses (i.e., real estate) as collateral in Iacoviello (2005). Capital seems to better represent overall balance-sheet condition, and therefore the creditworthiness of a firm. The borrowing constraint is defined as:

$$R^L_t L_t(j) \leq m \mathbb{E}_t \{Q^K_t \Pi_{t+1} (1 - \delta_K) K^K_{t-1}(j)\}$$

where $m$ is the LTV ratio chosen by the commercial banks.

First-order conditions of above specified optimization problem are (after im-
posing symmetry):
\[
\lambda_{E, t}^E = \frac{1}{C_t^E - tC_{t-1}^E} \tag{20}
\]
\[
\lambda_{E, t}^E Q_t^K = \beta E \lambda_{E, t+1}^Y [\alpha A_t^Y U_{t+1}^\alpha (K_{t-1}^K)^{\alpha-1} H_{t+1}^{1-\alpha} p_{t+1}^W + Q_{t+1}^K (1 - \delta_K) - \psi(U_{t+1})] + \lambda_{E, t}^E m Q_{t+1}^K \Pi_{t+1} (1 - \delta_K) \tag{21}
\]
\[
\psi'(U_t) = \alpha A_t^Y [U_t (I_{t-1})]^{\alpha-1} H_{t-1}^\alpha p_t^W \tag{22}
\]
\[
W_t = (1 - \alpha) A_t^Y [U_t (j_{t-1})]^{\alpha} H_{t-1} - \alpha A_t^Y [U_t (j_{t-1})]^{\alpha-1} H_{t-1}^\alpha p_t^W \tag{23}
\]
\[
\lambda_{E, t}^E = \lambda_{E, t}^L R_t^L + \beta E \lambda_{E, t+1}^Y \frac{R_t^L}{\Pi_{t+1}} \tag{24}
\]

where \( P_t^W = P_t^W / P_t \) is the real wholesale price.

4.3 Capital producers

Following Gerali et al. (2010), capital producers combine existing undepreciated capital stock purchased from entrepreneurs (at nominal price \( P_t \)) with unsold final goods purchased from retailers as investment goods, \( I_t \), in order to produce new capital \( K_{t+1}^K \). Capital is subject to depreciation represented by the depreciation rate \( \delta_K \). Therefore, depreciated capital is replaced with the new capital. The aggregate capital stock evolves according to:
\[
K_t^K = \Phi \left( \frac{I_t}{I_{t-1}} \right) + (1 - \delta_K) K_{t-1}^K \tag{25}
\]

where \( \Phi(\cdot) \) is concave and increasing production function. Production of capital is subject to quadratic adjustment costs. Therefore, production function of capital is defined as:
\[
\Phi \left( \frac{I_t}{I_{t-1}} \right) = I_t - \frac{\kappa_K}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 I_t \tag{26}
\]

where \( \kappa_K > 0 \) is an adjustment cost parameter.

Capital producers choose the optimal level of investment in order to maximize profits (in real terms):
\[
E_0 \sum_{t=0}^{\infty} \Lambda_{0, t} \left\{ Q_t^K (K_t^K - (1 - \delta_K) K_{t-1}^K) - I_t \right\} \tag{27}
\]

where \( \Lambda_{0, t} \) is a stochastic discount factor. Using law of motion of capital, opti-
mization collapses to:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left\{ Q^K_t \left[ 1 - \frac{\kappa_K}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t - I_t \right\}$$ (28)

Optimization yields a first order condition:

$$Q^K_t \left[ 1 - \kappa_K \left( \frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} - \frac{\kappa_K}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right] - 1 + \beta_H \frac{U''(C_{t+1})}{U''(C_t)} \left[ Q^K_{t+1} \kappa_K \left( \frac{I_{t+1}}{I_t} - 1 \right) \frac{I_{t+1}^2}{I_t^2} \right] = 0$$ (29)

which determines the supply of capital. Moreover, it is the Tobin’s Q equation describing the relationship between the price of capital and the marginal adjustment costs. Capital adjustment costs serve as a decelerator of the response of investment to shocks, which enables the price of capital to vary.

### 4.4 Final goods producers

Final goods producers aggregate differentiated products purchased from domestic retailers $Y_{H,t}(j_H)$ and importing retailers $Y_{F,t}(j_F)$ into a composite good, which is then sold in a market. Producers utilise technology of the form:\footnote{Both components of the technology are defined by the standard constant elasticity of substitution (CES) functions as $Y_{H,t} = \left( \int_{0}^{1} Y_{H,t}(j_H)^{\frac{1+\mu_H}{\nu_H}} dj_H \right)^{1+\mu_H}$ and $Y_{F,t} = \left( \int_{0}^{1} Y_{F,t}(j_F)^{\frac{1+\mu_F}{\nu_F}} dj_F \right)^{1+\mu_F}$.}

$$Y_t = \left[ \frac{\mu}{1+\mu} Y_{H,t}^{\frac{1+\mu}{1+\mu}} + (1 - \mu) \frac{\mu}{1+\mu} Y_{F,t}^{\frac{1+\mu}{1+\mu}} \right]^{1+\mu}$$ (30)

where $\mu$ is the elasticity of substitution between domestic goods and imported goods, and $\eta \in [0; 1]$ measures the degree of openness. The optimization yields the following demand functions for differentiated goods:

$$Y_{H,t}(j_H) = \left( \frac{P_{H,t}(j_H)}{P_{H,t}} \right)^{-\frac{1+\mu_H}{\nu_H}} Y_{H,t}$$ (31)

$$Y_{F,t}(j_F) = \left( \frac{P_{F,t}(j_F)}{P_{F,t}} \right)^{-\frac{1+\mu_F}{\nu_F}} Y_{F,t}$$ (32)
where $\mu_H$ and $\mu_F$ measure the substitutability of goods, and demands for aggregate goods are:

\[
Y_{H,t} = \eta \left( \frac{P_{H,t}}{P_t} \right)^{-\frac{1+\mu}{\mu}} Y_t \tag{33}
\]

\[
Y_{F,t} = (1 - \eta) \left( \frac{P_{F,t}}{P_t} \right)^{-\frac{1+\mu}{\mu}} Y_t \tag{34}
\]

The aggregate price indices are given by:

\[
P_{H,t} = \left( \int_0^1 P_{H,jH}(jH)^{-\frac{1}{\mu_H}} djH \right)^{-\mu_H} \tag{35}
\]

\[
P_{F,t} = \left( \int_0^1 P_{F,jF}(jF)^{-\frac{1}{\mu_F}} djF \right)^{-\mu_F} \tag{36}
\]

and the aggregate consumer price index (CPI) is given by the Dixit-Stiglitz function:

\[
P_t = \left[ \eta P_{H,t}^{-\frac{1}{\mu_H}} + (1 - \eta) P_{F,t}^{-\frac{1}{\mu_F}} \right]^{-\mu} \tag{37}
\]

For simplicity it is assumed that aggregate demand for exports takes the same form as (34), only with different parameters:

\[
Y_{H,t}^* = (1 - \eta^*) \left( \frac{P_{H,t}^*}{P_t^*} \right)^{-\frac{1+\mu^*}{\mu}} Y_t^* \tag{38}
\]

### 4.5 Retailers

In the economy, there exists three types of monopolistically competitive retailers: home goods retailers, importing retailers and exporting retailers. The aim of retailers is to differentiate respective goods and earn profits. There are no costs related to differentiation of the products. All three types of retailers face a variant of Calvo-pricing scheme proposed by Calvo (1983) in order to introduce nominal rigidities into the model.

#### 4.5.1 Home goods retailers

Home goods retailers redistribute goods produced by entrepreneurs to final goods producers. They purchase wholesale goods from entrepreneurs at the wholesale
price $P^W_t$ and resell them at their retail price.

Home goods retailers face each period an exogenous probability $(1 - \theta_H)$ of re-optimizing their prices. Let $P_{H,t}(j_H)$ denotes the price set by the home goods retailer $j_H$ in time $t$ and $\tilde{P}_{H,t}(j_H)$ denotes the retailer’s re-optimized price. In each time period $t + \tau$, a portion of home goods retailers $(1 - \theta_H)$ re-optimize their price from period $t$ such that:

$$P_{H,t+\tau}(j_H) = \left(\prod_{s=1}^{\tau}(1 - \varsigma_H)\Pi + \varsigma_H\Pi_{t+s-1}\right)\tilde{P}_{H,t}(j_H) = X_{H,t,\tau}\tilde{P}_{H,t}(j_H) \quad (39)$$

where $X_{H,t,\tau}$ is the nominal indexation factor in time $\tau$ of price reset in period $t$, and $\varsigma_H \in [0, 1]$ measures the degree of inflation indexation. The rest of the retailers of measure $\theta_H$ who do not re-optimize their price, update price according to steady-state inflation and previous period CPI inflation:

$$P_{H,t+1}(j_H) = [(1 - \varsigma_H)\Pi + \varsigma_H\Pi_t]P_{H,t}(j_H) \quad (40)$$

Each retailer faces a demand schedule of the form:

$$Y_{H,t+\tau}(j_H) = \left(\frac{X_{H,t,\tau}\tilde{P}_{H,t}(j_H)}{P_{H,t+\tau}}\right)^{-\frac{1+\mu_H}{\tau_H}}Y_{H,t+\tau} \quad (41)$$

where $\mu_H$ measures substitutability of goods.

Retailers maximize the expected discounted profit given by (42) subject to the demand schedule (41):

$$\mathbb{E}_0\sum_{\tau=0}^{\infty}\theta_H^\tau\Lambda_{t,\tau+\tau}\left\{\frac{Y_{H,t+\tau}(j_H)}{P_{t+\tau}}\left[X_{H,t,\tau}\tilde{P}_{H,t}(j_H) - P^W_{t+\tau}\right]\right\} \quad (42)$$

where $\Lambda_{t,\tau+\tau} = \beta_H^\tau U'(C_{t+\tau})/U'(C_t)$ is a stochastic discount factor.\(^3\) The maximization problem yields a first order condition:

$$\mathbb{E}_0\sum_{\tau=0}^{\infty}\theta_H^\tau\Lambda_{t,\tau+\tau}\left\{-\frac{1}{\mu_H}\left\{[x_{H,t,\tau}\tilde{p}_{H,t}(j_H) - (1 + \mu_H)p^W_{t+\tau}^W]Y_{H,t+\tau}(j_H)\right\}\right\} \quad (43)$$

where $x_{H,t,\tau} = X_{H,t,\tau}/\prod_{s=1}^{\tau}\Pi_{t+s}$ is the real indexation factor, $p^W_{t+\tau}^W = P^W_{t+\tau}/P_{t+\tau}$

\(^3\)Since it is assumed that households are owners of the retailers, all profits belong to households. Therefore, in discounting retailer’s future profit, the stochastic discount factor takes into account constant discount factor $\beta_H$ and perception of different marginal utilities in each time period.
is the real price of wholesale goods, and \( \tilde{p}_{H,t}(j_H) = \tilde{P}_{H,t}(j_H)/P_t \) is the real price set by optimizing retailers.

### 4.5.2 Exporting retailers

Exporting retailers redistribute goods produced by entrepreneurs to foreign households. They purchase wholesale goods from entrepreneurs at the wholesale price \( P_t^W \) and resell them at their retail price.

Let \( P^*_t(j_H^*) \) denotes the price set by the exporting retailer \( j_H^* \) in time \( t \) and \( \tilde{P}^*_t(j_H^*) \) denotes the retailer’s re-optimized price. In each time period \( t + \tau \), a portion of importing retailers \( (1 - \theta_H^*) \) re-optimize their price from period \( t \) such that:

\[
P^*_t(j_H^*) = \left( \prod_{s=1}^{\tau} (1 - \zeta_H^s) \Pi^* + \zeta_H^s \Pi^t_{s+1} \right) \tilde{P}^*_t(j_H^*) = X^*_{t,\tau} \tilde{P}^*_t(j_H^*)
\]  

(44)

where \( X^*_{t,\tau} \) is the nominal indexation factor in time \( \tau \) of price reset in period \( t \), and \( \zeta_H^s \in [0,1] \) measures the degree of inflation indexation. The rest of the retailers of measure \( \theta_H^* \) who do not re-optimize their price, update price according to steady-state inflation and previous period CPI inflation:

\[
P^*_{t+1}(j_H^*) = [(1 - \zeta_H^*) \Pi^* + \zeta_H^* \Pi^t_{s+1}] P^*_t(j_H^*)
\]  

(45)

Each retailer faces a demand schedule of the form:

\[
Y^*_{t,\tau}(j_H^*) = \left( \frac{X^*_{t,\tau} \tilde{P}^*_t(j_H^*)}{P^*_{t,\tau}} \right)^{1+\mu_H^*} Y^*_{t,\tau}
\]  

(46)

where \( \mu_H^* \) measures substitutability of goods.

Retailers maximize the expected discounted profit given by (47) subject to the demand schedule (46):

\[
\mathbb{E}_0 \sum_{\tau=0}^{\infty} (\theta_H^*)^\tau \Lambda_{t,\tau} \mathbb{E}_{t+\tau} \left\{ \frac{Y^*_{t,\tau}(j_H^*)}{P^*_{t,\tau}} \left[ X^*_{t,\tau} \tilde{P}^*_t(j_H^*) - \frac{P^W_{t,\tau}}{\mathbb{E}_{t+k}} \right] \right\}
\]  

(47)

where \( \Lambda_{t,\tau} = \beta_H U''(C_{t+\tau})/U'(C_t) \) is a stochastic discount factor.\(^4\) The maxi-

\(^4\)It is assumed that domestic households are owners of exporting retailers. Therefore, discount factor of domestic households is used.

31
mization problem yields a first order condition:

$$
E_0 \sum_{\tau=0}^{\infty} (\theta_H^*)^\tau \Lambda_{t,t+\tau} \left( -\frac{1}{\mu_H^*} \right) \left\{ x_{t,\tau}^* \tilde{p}_{H,t}^*(j_H^*) - (1 + \mu_H^*) \left( \frac{p_{t+\tau}^W}{Q_{t+\tau}} \right) Y_{H,t,t+\tau}^*(j_H^*) \right\} \quad (48)
$$

where $x_{t,\tau}^* = X_{t,\tau}^* / \Pi_{s=1}^\tau \Pi_t^* s$ is the real indexation factor and $\tilde{p}_{H,t}^*(j_H^*) = \tilde{P}_{H,t}^*(j_H^*) / P_t$ is the real price set by optimizing retailers.

### 4.5.3 Importing retailers

Importing retailers are modelled in the same manner as home goods retailers. It is assumed that the law of one price holds at the wholesale level. Therefore, these retailers purchase the products from foreign entrepreneurs at price $E_t P_t^*$ (which can be rewritten as $Q_t P_t^*$) expressed in domestic currency and they redistribute imported products at the retail price $P_{F,t}^*$. Since retailers have some degree of power in setting their prices, law of one price does not hold necessarily (i.e. $P_{F,t}^* \neq E_t P_t^*$). Hence, this feature introduces the incomplete exchange rate pass-through into the model.

Similarly, let $P_{F,t}^*(j_F)$ denotes the price set by the importing retailer $j_F$ in time $t$ and $\tilde{P}_{F,t}^*(j_F)$ denotes the retailer’s re-optimized price. In each time period $t + \tau$, a portion of importing retailers $(1 - \theta_F^*)$ re-optimize their price from period $t$ such that:

$$
P_{F,t,t+\tau}^*(j_F) = \left( \prod_{s=1}^\tau [(1 - \varsigma_F) \Pi + \varsigma_F \Pi_{t+s-1}] \right) \tilde{P}_{F,t}^*(j_F) = X_{F,t,\tau} \tilde{P}_{F,t}^*(j_F) \quad (49)
$$

where $X_{F,t,\tau}$ is the nominal indexation factor in time $\tau$ of price reset in period $t$, and $\varsigma_F \in [0,1]$ measures the degree of inflation indexation. The rest of the retailers of measure $\theta_F$ who do not re-optimize their price, update price according to steady-state inflation and previous period CPI inflation:

$$
P_{F,t+1}^*(j_F) = [(1 - \varsigma_F) \Pi + \varsigma_F \Pi_t] P_{F,t}^*(j_F) \quad (50)
$$

As a modelling simplification, it is assumed that retailers in foreign economy coincide with foreign entrepreneurs, and therefore there is no distinction between foreign wholesale price and foreign retail price.
Each retailer faces a demand schedule of the form:

$$Y_{F,t,t+\tau}(j_F) = \left( \frac{X_{F,t,\tau} \tilde{P}_{F,t}(j_F)}{P_{F,t+\tau}} \right)^{\frac{1+\mu_F}{\mu_F}} Y_{F,t+\tau}$$  \hspace{1cm} (51)

where $\mu_F$ measures substitutability of goods.

Retailers maximize the expected discounted profit given by (52) subject to the demand schedule (51):

$$\mathbb{E}_0 \sum_{\tau=0}^{\infty} \theta_{F,\tau} \Lambda_{t+\tau}^* \left\{ \frac{Y_{F,t,t+\tau}(j_F)}{P_{t+\tau}} \left[ X_{F,t,\tau} \tilde{P}_{F,t}(j_F) - P_{t+\tau} Q_{t+k} \right] \right\}$$  \hspace{1cm} (52)

where $\Lambda_{t+\tau}^* = (\beta_H^*)^U'(C_{t+\tau})/U'(C_t)$ is a stochastic discount factor of foreign households.\footnote{The stochastic discount factor takes the similar form as the stochastic discount factor of domestic households. It is assumed that importing retailers are owned by foreign households. Therefore, the specifics of foreign economy are taken into account.} The maximization problem yields a first order condition:

$$\mathbb{E}_0 \sum_{\tau=0}^{\infty} \theta_{F,\tau} \Lambda_{t+\tau}^* \left\{ \frac{x_{F,t,\tau} \tilde{p}_{F,t}(j_F) - (1 + \mu_F) Q_{t+\tau}}{\tilde{p}_{F,t}(j_F)} \right\}$$  \hspace{1cm} (53)

where $x_{F,t,\tau} = X_{F,t,\tau} / \prod_{s=1}^{\tau} \Pi_{t+s}$ is the real indexation factor and $\tilde{p}_{F,t}(j_F) = \tilde{P}_{F,t}(j_F)/P_t$ is the real price set by optimizing retailers.

### 4.6 Commercial banking sector

The banking sector is modelled according to Gambacorta and Signoretti (2014).

Commercial banks (henceforth banks) possess certain market power in intermediation, which enables them to change rates on deposits and loans in response to various shocks. Banks have to obey a balance-sheet condition stating that $\text{loans} = \text{deposits} + \text{capital}$. Banks also face an “optimal” exogenous target for capital-to-asset ratio (i.e., the inverse of leverage), which can be seen as a simplified tool to study implications of capital requirements set by regulatory authorities. Additionally, the model allows for a feedback loop between financial sector and the real side of the economy. In case of subdued macroeconomic conditions, banks might respond to the situation by cutting the volume of issued loans, and therefore aggravating the original conditions.

The banking sector is composed of a continuum of banks indexed by $j \in (0, 1)$.\footnote{The stochastic discount factor takes the similar form as the stochastic discount factor of domestic households. It is assumed that importing retailers are owned by foreign households. Therefore, the specifics of foreign economy are taken into account.}
Individual bank consists of two units - wholesale and retail. The role of the wholesale unit is to collect deposits from households and to issue wholesale loans. The retail unit purchases wholesale loans, differentiates them and resells them to entrepreneurs.

### 4.6.1 Wholesale branch

The wholesale unit of each bank operates under perfect competition. The wholesale unit collects deposits \( D_t \) from households at the rate set by the central bank \( R_t \) and issues wholesale loans \( L_t \) at the wholesale rate \( R_t^{WL} \). The balance sheet of the wholesale branch consists of bank capital \( K_t^B \) and deposits \( D_t \) on the liability side, while on the asset side can be found wholesale loans \( L_t \) (all in real terms). Bank faces an optimal value of capital-to-asset ratio \( \nu_B \). Whenever the actual capital-to-asset ratio \( K_t^B/L_t \) diverts from the target value \( \nu_B \), the bank pays a quadratic adjustment cost parametrized by \( \kappa_B \). This feature implies that bank leverage ratio determines loans interest rates, which generates feedback loop between the real side of the economy and financial sector. Bank capital evolves according to:

\[
K_t^B = (1 - \delta_B) \frac{K_{t-1}^B}{A_t^B} + \Xi_t^B - \frac{1}{\nu_B} (54)
\]

where \( \delta_B \) represents the cost for managing the bank’s capital position, and \( \Xi_t^B \) are overall profits of the bank as outlined by equation (59). For simplicity it is assumed that the commercial banks have no dividend policy. \( A_t^B \) is a bank capital shock. Its deviation from the steady state is assumed to follow an AR(1) process with \( \varepsilon_t^B \) being normally distributed with zero mean and variance \( \sigma_B^2 \):

\[
\hat{a}_t^B = \rho_B \hat{a}_{t-1}^B + \varepsilon_t^B (55)
\]

The wholesale unit of the bank chooses the optimal level of deposits and loans in order to maximize profit:

\[
R_t^{WL} L_t(j) - R_t D_t(j) - \frac{\kappa_B}{2} \left( \frac{K_t^B(j)}{L_t(j)} - \nu_B \right)^2 K_t^B(j) (56)
\]

subject to the balance constraint \( L_t = D_t + K_t^B \), while taking the gross interest rate \( R_t \) and the gross wholesale rate on loans \( R_t^{WL} \) as given. Combining the first-
order conditions yields the relationship between the capital-to-asset ratio \( K_t^B / L_t \) and the spread between wholesale rates on deposits and loans:

\[
R_t^{WL} - R_t = -\kappa_B \left( \frac{K_t^B(j)}{L_t(j)} - \nu_B \right) \left( \frac{K_t^B(j)}{L_t(j)} \right)^2
\]  \( (57) \)

The left-hand side of the above equation represents the marginal benefit from lending (i.e., an increase in profits from one loan issued), while the right-hand side represents the marginal cost from lending. Banks choose the optimal level of loans such that costs and benefits stemming from changing the leverage ratio are equalized at the margin.

### 4.6.2 Retail branch

Retail branches of banks operate in a monopolistically competitive market. The retail branch purchases wholesale loans from the wholesale branch, differentiates them at no cost and resells them to entrepreneurs. It is assumed, that retail branch applies constant mark-up \( \mu_B \) on the wholesale loan rate \( R_t^{WL} \). Therefore, the retail loan rate is defined as:

\[
R_t^L = R_t^L - \kappa_B \left( \frac{K_t^B(j)}{L_t(j)} - \nu_B \right) \left( \frac{K_t^B(j)}{L_t(j)} \right)^2 + \mu_B
\]  \( (58) \)

Bank profits combine all the partial net earnings. Aggregate bank profits (in real terms) are given by:

\[
\Xi_t^B = R_t^L L_t - R_tD_t - \frac{\kappa_B}{2} \left( \frac{K_t^B}{L_t} - \nu_B \right)^2 K_t^B
\]  \( (59) \)

### 4.7 Central bank

Policy of the central bank is described by a few different monetary policy rules. First, since this thesis focuses on the Czech Republic, a simplified version of the monetary policy rule of the Czech National Bank is outlined. Second, because financial sector significantly affects the real side of the economy, reaction functions augmented by several financial variables are introduced.
4.7.1 Conventional monetary policy rule

In the baseline model, the central bank adjusts the policy rate, \( R_t \), in response to deviations of inflation, \( \Pi_t \), from its steady-state value. This representation of policy resembles state in which the central bank does not explicitly adjust its policy rate with respect to financial disturbances. Following Andrle et al. (2009), the Czech National Bank implements a regime of inflation targeting with interest rate smoothing. This specific rule takes form:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\varrho_{\Pi}} \left( \frac{\Psi_t}{\Psi} \right)^{\varrho_{\Psi}} \right)^{1-\rho_R}
\]  

(60)

where \( R \) and \( \Pi \) are the steady-state values of \( R_t \) and \( \Pi_t \) respectively, \( \rho_R \) depicts inflation persistence, \( \varrho_{\Pi} \) is a weight characterizing the importance of inflation deviation.

4.7.2 Augmented monetary policy rules (AMPRs)

Compared to the baseline scenario, the central bank reflects developments in financial sector in its policy rule. Generally, AMPR takes the form:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\varrho_{\Pi}} \left( \frac{\Psi_t}{\Psi} \right)^{\varrho_{\Psi}} \right)^{1-\rho_R}
\]  

(61)

where \( \Psi_t \) represents financial variable with \( \Psi \) being its steady state value and \( \varrho_{\Psi} \) being respective assigned weight.

Credit (AMPR I)

The developments in credit market have a significant impact on the real side of the economy, because increase in credit supply encourages economic players to be more active. This augmented rule accounts for credit volume under two considerations. Since there has been reached no agreement about the role of credit in financial stability yet, the central banks reacts: (i) by encouraging credit to firms (i.e., non-financial sector), or (ii) by discouraging credit. The AMPR I is given by:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\varrho_{\Pi}} \left( \frac{L_t}{L} \right)^{\varrho_{L}} \right)^{1-\rho_R}
\]  

(62)
where \( L_t \) refers to loans granted to entrepreneurs, \( L \) is its steady state value and \( \varrho_L \leq 0 \) is assigned weight. Following Aydin and Volkan (2011), \( \varrho_L \) is set to \( \pm 0.3 \).

**Asset prices (AMPR II)**

Following Gambacorta and Signoretti (2014), the central bank accounts for asset prices (which are represented by \( Q^K_t \)) in its monetary policy rule. To motivate this rule, assume increase in asset prices. Such movement implies a higher value of collateral that can be pledged against loan. This in turn enhances investment and spending. Therefore, rising asset prices could indicate a future inflationary pressures. The AMPR II is described by:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\varrho_{\Pi}} \left( \frac{Q^K_t}{Q^K} \right)^{\varrho_{Q^K}} \right)^{1-\rho_R}
\]

where \( Q^K \) is its steady state value of \( Q^K_t \) and \( \varrho_Q > 0 \) is assigned weight.

**Credit and asset prices combined (AMPR III)**

The last augmented monetary policy rule combines both mentioned financial variables – credit and asset prices. The AMPR III is defined as:

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\varrho_{\Pi}} \left( \frac{L_t}{L} \right)^{\varrho_L} \left( \frac{Q^K_t}{Q^K} \right)^{\varrho_{Q^K}} \right)^{1-\rho_R}
\]

where the weights are the same as in the previous augmented rules.

**4.8 Foreign sector**

The foreign sector is represented by simple AR(1) processes. Even though that the recent literature employs VAR models as a representation of the foreign sector (such as Christiano et al. 2011), this thesis does not follow this approach for the following reason. The VAR model is complicated and the coefficients are estimated so as to maximize the criterion function and to fit the data. The results of the VAR estimation are not straightforward and there is no economic intuition behind the estimated values of respective coefficients. Moreover, the VAR model entails additional dynamics that cannot be described easily and it introduces unclear oscillations in the responses to the foreign shocks. Therefore,
the foreign sector is represented by the following system of equations:

\[
\begin{pmatrix}
\hat{y}_t
\
\hat{\pi}_t
\
\hat{r}_t
\end{pmatrix} = \begin{pmatrix}
\rho_{y^*} & 0 & 0 \\
0 & \rho_{\pi^*} & 0 \\
0 & 0 & \rho_{r^*}
\end{pmatrix}
\begin{pmatrix}
\hat{y}_{t-1}
\
\hat{\pi}_{t-1}
\
\hat{r}_{t-1}
\end{pmatrix} + \begin{pmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\varepsilon_{y_t}^y \\
\varepsilon_{\pi_t}^\pi \\
\varepsilon_{r_t}^r
\end{pmatrix}
\]  

(65)

where \(\varepsilon_{y_t}^y \sim iid(0, \sigma_{y^*}^2)\), \(\varepsilon_{\pi_t}^\pi \sim iid(0, \sigma_{\pi^*}^2)\), \(\varepsilon_{r_t}^r \sim iid(0, \sigma_{r^*}^2)\), and the autocorrelation coefficients \(\rho_{y^*}, \rho_{\pi^*}, \rho_{r^*} \in [0, 1]\).

4.9 Market clearing conditions and GDP

It is assumed, that banks use all deposits and bank capital to originate loans. Therefore, the following condition has to be met in equilibrium:

\[
L_t = D_t + K_t^B
\]  

(66)

In market for final goods has to hold that:

\[
C_t + I_t + \psi(U_t)K_{t-1}^K + \delta_B \frac{K_B^{t-1}}{\Pi_t} = Y_t
\]  

(67)

where aggregate consumption \(C_t\) is composed of two ingredients – consumption of households and consumption of entrepreneurs:

\[
C_t = \gamma^HC_t^H + \gamma^EC_t^E
\]  

(68)

where \(\gamma^H + \gamma^E = 1\).

Aggregate production of wholesale goods has to satisfy demand from home economy as well as demand from foreign economy:

\[
Y_t^W = \int_0^1 Y_{H,t}(j) dj + \int_0^1 Y_{H,t}^*(j) dj
\]  

(69)

Balance of payments ensures that supply of new loans to foreign economy
equals interest rate payments on previous debt plus nominal net exports:

\[
\int_0^1 \mathcal{E}_t P_{H,t}^*(j_H^*) Y_{H,t}^*(j_H^*) dj_H^* + \mathcal{E}_t L_t^* \\
= \int_0^1 P_{F,t}(j_F^*) Y_{F,t}(j_F^*) dj_F + R_{t-1}^* F_{t-1} \mathcal{E}_t L_{t-1}^* \tag{70}
\]

Lastly, gross domestic product \(Y_{G,t}\) is defined as a sum of final goods exploited in domestic economy and net exports:

\[
P_t Y_{G,t} = P_t Y_t + \int_0^1 \mathcal{E}_t P_{H,t}^*(j_H^*) Y_{H,t}^*(j_H^*) dj_H^* - \int_0^1 P_{F,t}(j_F^*) Y_{F,t}(j_F^*) dj_F \tag{71}
\]
5 Calibration for the Czech Republic

The whole model is calibrated. The parameters are calibrated based on studies focusing on the Czech Republic or studies employing similar model mechanisms (when Czech studies not available), and own computations using data from ARAD database. The sample period used for the computations ranges from 2000Q1 to 2014Q4. Tables 4 and 5 summarize calibration. There is a block of parameters that is calibrated directly, while the rest of the parameters are computed based on the steady-states relationships.

Based on own computations, the following steady-states ratios are calibrated such that \( \frac{C}{Y_G} = 0.5177 \), \( \frac{L}{Y_G} = 0.1538 \), \( \frac{P_L}{Y_G} = 0.6139 \), \( \frac{P^*_H}{Y_G} = 0.2107 \), and \( \frac{P^*_H}{Y_G} = 0.243 \).\(^8\) Steady state ratio of derivatives of capital utilization is set arbitrarily (in line with other studies) to 0.2, while the rate of capital adjustment costs \( \kappa_K \) is calibrated to 3. Capital share in production (\( \alpha \)) and the depreciation rate of capital (\( \delta_K \)) are set standardly to 0.3 and 0.035 respectively. Exogenous discount factors of households and entrepreneurs are calibrated such that entrepreneurs and foreign households are more impatient than domestic households – \( \beta_H = 0.9900 \), \( \beta_E = 0.9800 \) and \( \beta^*_H = 0.9850 \). These values are in line with DSGE literature and also with the studies related to the Czech Republic (e.g. Malovaná 2014). It is assumed that the economy is covered by 75% of households, which makes the coverage of entrepreneurs to be 25%. The steady state of inflation is expected to be 2% (which corresponds to the average of the Czech inflation level across the investigated time period and it also corresponds to the inflation target of the Czech National Bank) which leads to the steady state value of home policy interest rate 2.0202. The foreign counterparts to these two variables are calibrated to slightly lower values. The steady state ratio of foreign debt to GDP is assumed to be 1.\(^9\)

External habit persistence parameter \( \iota \) equals 0.7, which is in line with the recent study of Havránek et al. (2015). Based on Babecký et al. (2012), wage elasticity \( \phi \) is calibrated to 1.88. Adopting estimations of Tvrz (2012) and Svačina (2015), Calvo parameters are calibrated as follows: home goods parameter \( (\theta_H = 0.4) \), imported goods parameter \( (\theta_F = 0.5) \), exported goods parameter \( (\theta^*_H = 0.5) \). Using estimations of Svačina (2015), inflation indexation parameters are \n
---

\(^8\)The last two values take into account only final consumption (the intermediate goods are not considered).

\(^9\)The ratio of foreign debt to GDP does not resemble the reality well. This particular value is selected due to the fast convergence.
calibrated such that $\varsigma_H = 0.3233$, $\varsigma_H^* = 0.4949$ and $\varsigma_F = 0.3428$. Elasticities of substitution for domestic and foreign goods are set at $\mu = 1.87$ and $\mu^* = 1.923$ based on Ryšánek et al. (2011).

Regarding the commercial banking sector, the optimal level of capital-to-asset ratio ($\nu_B$) is set at 9% according to Basel II Accord.\textsuperscript{10} Following Gambacorta and Signoretti (2014), the rate of bank capital adjustment costs, share of bank capital used in capital maintenance and mark-up on loans are set at 11.49, 0.059 and 0.1 respectively. Based on Ryšánek et al. (2011), interest rate persistence $\rho_M = 0.83$ and weight put on inflation $\varrho_\Pi = 1.7$. Lastly, the autocorrelations coefficients of the exogenous processes are calibrated based on Svačina (2015) and Brzoza-Brzezina and Makarski (2009): $\rho_{y^*} = 0.8024$, $\rho_{r^*} = 0.6256$, $\rho_r = 0.7570$, $\rho_{UIP} = 0.4798$, $\rho_M = 0.1040$, $\rho_Y = 0.3642$, $\rho_B = 0.4138$, and $\rho_C = 0.6980$.

\textsuperscript{10}In particular, Basel II Accord refers to risk-weighted assets. Thus, the overall ratio of capital and assets is lower in reality. Nevertheless, as chapter 7 shows, the results are robust to changes in this particular parameter.
6 Properties of the model

The performance of the baseline monetary policy rule and its augmented versions is investigated using two approaches. First, the properties of the model under different monetary policy rules are assessed based on implied volatilities. Second, the qualitative assessment is done via the impulse response functions.

6.1 Variability

As it was mentioned earlier, the ultimate goal of the CNB is to maintain the price stability. Beside this prominent goal, the CNB also maintains stable economic growth unless the primary goal of price stability is not harmed. Therefore, the following analysis also focuses on GDP in addition to inflation as the most prominent indicator. Moreover, the traditional approach is to investigate implications of different monetary policy rules for both variables.

Volatility of two selected variables is measured by implied standard deviations which is the common approach to the measurement of variability. This approach is chosen because the standard errors of the shocks are small in their magnitude which implies that the second central moments of simulated series are negligible. Each monetary policy rule is characterised by different variables, and therefore each variable is represented by a different weight. The values of the respective weights on the financial variables are chosen based on Gambacorta and Signoretti (2014), and Aydin and Volkan (2011). Table 1 recapitulates calibration of the monetary policy rules.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>$\varrho_{P} = 1.7$</td>
</tr>
<tr>
<td>AMPR I +</td>
<td>$\varrho_{P} = 1.7$, $\varrho_{L} = 0.3$</td>
</tr>
<tr>
<td>AMPR I −</td>
<td>$\varrho_{P} = 1.7$, $\varrho_{L} = -0.3$</td>
</tr>
<tr>
<td>AMPR II</td>
<td>$\varrho_{P} = 1.7$, $\varrho_{Q} = 0.5$</td>
</tr>
<tr>
<td>AMPR III</td>
<td>$\varrho_{P} = 1.7$, $\varrho_{L} = -0.3$, $\varrho_{Q} = 0.5$</td>
</tr>
</tbody>
</table>

The results of the analysis are summarized in table 2. The table includes the results for inflation and GDP and it also provides an overall effect represented by
the weighted sum. The weighted sum is defined as:

\[ SD(\pi) + \omega \cdot SD(GDP) \]  

(72)

where the value of the weight \( \omega \) is set at 0.09, since Ryšánek et al. (2011) estimate this value to represent the weight ascribed to output in their Taylor rule.\(^{11}\) The table contains implied volatilities caused by all the shocks that were discussed in the section devoted to the model construction.

The simulations lead to the following conclusions. First, the most obvious is that reacting to any kind of shock by discouraging credit (AMPR I +) does not seem to be beneficial for inflation stability. The results regarding the stability of GDP are mixed in this case and they are shock-dependent. On the other hand, monetary policy under the AMPR I with a negative coefficient delivers significantly favourable results in inflation stabilization than the baseline rule and such augmented rule proves to be a good stabilizer. The only exception is the shock that originates in the financial sector (shock into bank capital). These results are in line with the finding of Aydin and Volkan (2011) who implement the similar policy rule, however, in the different model setting with a significantly lower amount of shocks. This suggests that credit could be a useful source of information for monetary authorities. Moreover, the results show that reacting negatively on policy rate to the developments of the credit volume in the economy outperforms significantly the latter possibility with the positive coefficient.

Second, using asset prices as the only financial variable in the policy rule does not seem to be optimal. On the other hand, combining asset prices with the credit volume delivers the best results under investigated options. This suggests that asset prices and credit volume are interconnected and if they are considered to be implemented, than only jointly. This finding is consistent with the result of Gambacorta and Signoretti (2014) who report the combined rule to be the most appropriate. Considering weighted volatility, table 2 shows that reacting to the financial developments by adjusting policy rate based on movements in asset prices and the credit volume delivers significant improvements in all the cases except for the bank capital shock. The results are plausible in case of inflation stabilization, while the simulations does not give a clear message in case of stability of GDP.

\(^{11}\)The robustness of the results to different values of \( \omega \) is verified in chapter 7.
Table 2: Variability under different monetary policy rules

<table>
<thead>
<tr>
<th>Shock to</th>
<th>Rule</th>
<th>Volatility</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inflation</td>
<td>GDP</td>
<td>Weighted sum</td>
<td></td>
</tr>
<tr>
<td>Productivity</td>
<td>Baseline</td>
<td>0.0106</td>
<td>0.0080</td>
<td>0.0113</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I +</td>
<td>0.0124</td>
<td>0.0070</td>
<td>0.0130</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I −</td>
<td>0.0086</td>
<td>0.0095</td>
<td>0.0095</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR II</td>
<td>0.0107</td>
<td>0.0079</td>
<td>0.0114</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR III</td>
<td>0.0088</td>
<td>0.0093</td>
<td>0.0096</td>
<td></td>
</tr>
<tr>
<td>UIP</td>
<td>Baseline</td>
<td>0.0039</td>
<td>0.0054</td>
<td>0.0044</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I +</td>
<td>0.0048</td>
<td>0.0058</td>
<td>0.0053</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I −</td>
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<td>0.0048</td>
<td>0.0033</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR II</td>
<td>0.0042</td>
<td>0.0055</td>
<td>0.0047</td>
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<tr>
<td></td>
<td>AMPR III</td>
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<td>0.0047</td>
<td>0.0032</td>
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</tr>
<tr>
<td>Bank capital</td>
<td>Baseline</td>
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<td>0.0025</td>
<td>0.0012</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I +</td>
<td>0.0016</td>
<td>0.0026</td>
<td>0.0018</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I −</td>
<td>0.0013</td>
<td>0.0024</td>
<td>0.0015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR II</td>
<td>0.0011</td>
<td>0.0025</td>
<td>0.0013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR III</td>
<td>0.0012</td>
<td>0.0024</td>
<td>0.0014</td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>Baseline</td>
<td>0.0042</td>
<td>0.0096</td>
<td>0.0051</td>
<td></td>
</tr>
<tr>
<td>preference</td>
<td>AMPR I +</td>
<td>0.0040</td>
<td>0.0096</td>
<td>0.0049</td>
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<tr>
<td></td>
<td>AMPR I −</td>
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<td>0.0098</td>
<td>0.0055</td>
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<tr>
<td>Foreign inflation</td>
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<td>0.0017</td>
<td>0.0012</td>
<td></td>
</tr>
<tr>
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<td>AMPR I +</td>
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<td>0.0019</td>
<td>0.0015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I −</td>
<td>0.0007</td>
<td>0.0016</td>
<td>0.0008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR II</td>
<td>0.0011</td>
<td>0.0018</td>
<td>0.0013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR III</td>
<td>0.0007</td>
<td>0.0015</td>
<td>0.0008</td>
<td></td>
</tr>
<tr>
<td>Foreign interest rate</td>
<td>Baseline</td>
<td>0.0021</td>
<td>0.0026</td>
<td>0.0023</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I +</td>
<td>0.0026</td>
<td>0.0028</td>
<td>0.0029</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I −</td>
<td>0.0014</td>
<td>0.0022</td>
<td>0.0016</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR II</td>
<td>0.0022</td>
<td>0.0027</td>
<td>0.0024</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR III</td>
<td>0.0013</td>
<td>0.0021</td>
<td>0.0015</td>
<td></td>
</tr>
<tr>
<td>Foreign output</td>
<td>Baseline</td>
<td>0.0007</td>
<td>0.0010</td>
<td>0.0008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR I +</td>
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<td>0.0011</td>
<td>0.0008</td>
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</tr>
<tr>
<td></td>
<td>AMPR I −</td>
<td>0.0006</td>
<td>0.0010</td>
<td>0.0007</td>
<td></td>
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<tr>
<td></td>
<td>AMPR II</td>
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<td>0.0011</td>
<td>0.0008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMPR III</td>
<td>0.0005</td>
<td>0.0009</td>
<td>0.0006</td>
<td></td>
</tr>
</tbody>
</table>

Source: Dynare output, own computations.
6.2 Impulse response functions

This subsection includes description of the reactions of the model to various shocks using the impulse response functions. Each figure depicts responses under two monetary policy rules out of five alternatives discussed in the previous paragraphs. These are the baseline rule and the AMPR III. The AMPR III was chosen in that it is identified to be the most beneficial for monetary policy based on the volatility analysis. All figures presented in this section depict percentage deviations from the steady state values of the respective variables. The IRFs of the baseline scenario are discussed at first and dynamics under the AMPR III is summarized at the end of each section.

6.2.1 Domestic shocks

The response of the model to a positive technology shock is depicted in figure 1. The positive technology shock causes an improvement in the production process which makes production more efficient. This innovation is accompanied by higher output and lower prices of the products. As a result, inflation decreases. The real exchange rate depreciates which causes imports to be more expensive while exports become more attractive for foreign consumers due to lower domestic prices and the real exchange rate depreciation. Therefore, imports fall and exports rise which results in an increase in the net exports. Given this dynamic, the central bank responds by decrease in policy rate so that inflation is brought back to the target. Regarding the financial side of the economy, the loan rate falls on impact because of the relaxed conditions in the economy. The lending is cheaper and demand for credit increases which in turn forces the commercial banks to expand their balance sheets and leverage. Since entrepreneurs possess more credit, the investment spending rises with a delay.\footnote{The initial negligible drop in investment is caused by adjustment cost imposed on capital and by the collateral constraint.}

Figure 2 illustrates an unexpected contraction in bank capital. The shock is calibrated such that the impact of loss in bank capital is persistent and it has a significant effect on the real side of the economy. This exercise serves to illustrate the transmission mechanisms and the importance of the financial sector in the economy. An unexpected negative shock causes bank capital to deteriorate. Since a sufficient amount of bank capital is needed in order to produce loans, the loan supply decreases dramatically which results in highly leveraged banking sector.
Given that the loan supply is low, entrepreneurs do not possess enough resources for investment activities and investment falls. At the same time, firms want to hire more workers, they push up wages which results in higher consumption. However, the persistence of the shock causes the real activity to further decline and GDP reaches its trough in the fourth quarter. The central bank reacts to increased inflation (caused by higher wages and financing cost) by a moderate hike of the policy rate. Since the real exchange rate depreciates, entrepreneurs want to make the most profitable deals and exports grow. However, growth of export is negligible (values of order $10^{-4}$). On the other hand, there are not enough resources and imports fall dramatically. Overall, contraction in bank capital has significant implications for economic activity and it pushes the economy into deep and prolonged recession.

Impulse responses to a positive UIP shock are depicted in figure 3. Higher risk premium translates into severe depreciation of the real exchange rate. This depreciation is reflected in significant growth of exports and fall in imports. Both movements are recorded in higher GDP. Increase in inflation is accommodated by a strong response on the policy rate. Since the loan rate increases as well, borrowing becomes too expensive, demand for credit decreases, and therefore bank leverage decreases.

A domestic supply side shock is represented by a positive consumption preference shock (illustrated by figure 4). The positive shock in consumption prefer-
Figure 2: IRF – bank capital loss

- GDP
- Investment
- Inflation
- Real exchange rate
- Policy rate
- Loan rate
- Export
- Import
- Leverage

Baseline - AMPR III

Figure 3: IRF – UIP shock

- GDP
- Investment
- Inflation
- Real exchange rate
- Policy rate
- Loan rate
- Export
- Import
- Leverage

Baseline - AMPR III

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ences causes households to consume more because they value present consumption more than future one. Therefore, their willingness to spend more hours by working increases because higher disposable income represents higher consumption. Labour supply increases, marginal product of physical capital also increases, which stimulates higher investment. Because of higher economic activity, both GDP and inflation increase. The central bank reacts by increasing policy rate in order to decrease inflation. The real exchange rate appreciates on impact causing exports to fall and imports to increase.

Figure 4: IRF – consumption preference shock

Under the AMPR III, the central bank reacts almost in the same manner as in the baseline scenario in case of the shocks to technology and UIP. It is because of the construction of the AMPR III where the weights on financial variables have opposite signs and the respective variables move in inverse directions. Therefore, the responses are almost identical. On the other hand, financial shock – bank capital loss, forces the central bank to react differently. In this particular case, the monetary authority wants to counter attack the adverse implications of the contraction by cutting policy rate even more. However, the shock is excessively persistent and reacting to contemporaneous financial developments causes the situation in the banking sector to deteriorate. Lowering policy rate does not bring any improvement in the overall economic activity. Since low rates do not attract deposits, the commercial banks cannot issue loans (because of the balance
sheet identity) which dampens investment activity and brings inflation down. A similar explanation can provided in case of the consumption preference shock. Even though the response of the central bank is almost identical as in the baseline scenario, households give preference to consumption rather than deposits. Since deposits are lower, the commercial banks cannot issue so many loans which dampens investment activity that is responsible for lower GDP and inflation. This transmission suggests that the model works according to “loanable funds theory”. However, this exact responses may not be expected in reality. Since this feature of the model is questionable, it is regarded as a challenge for further research.

6.2.2 Foreign shocks

Lastly, figures 5, 6 and 7 depict the responses of the domestic variables to the shocks originating in the foreign economy. Because the small open economy is significantly dependent on the conditions of economy that represents its trading partner, various foreign disturbances have a considerable impact on the home economy. Therefore these shocks are of a particular interest.

Figure 5 demonstrates the responses to a positive innovation in the foreign output. Excess foreign demand stimulates exports of the domestic economy substantially. As a result, production and investment increase on impact in order to satisfy higher foreign demand. Because marginal costs of production are growing, inflation rises. The central bank accommodates this movement in inflation by hiking policy rate. Due to the intervention of the central bank, the real exchange rate appreciates which causes imports to increase. Given the response of the central bank, the loan rate increases as well, which leads to a slump in demand for loans. Therefore, bank leverage decreases.

Figure 6 shows the reactions of the variables to a positive foreign interest rate shock. Higher foreign interest rate causes the real exchange rate to depreciate on impact, which stimulates the demand for domestic exports. Since the price of imports is disadvantaged by the movement of the real exchange rate, imports fall. A higher domestic production and depreciated exchange rate generate inflationary pressures that are countered by the response of central bank to increase policy rate.

A positive shock to foreign inflation is depicted by figure 7. The shock is followed by the appreciation of the real exchange rate which is mirrored in higher
Figure 5: IRF – foreign output shock

Figure 6: IRF – foreign interest rate shock
imports and drop in exports. These two effects are severe and the economy experiences recession. This creates the downward pressure on inflation. The central bank is forced to decrease policy rate in order to support production and to increase inflation. The loan rate follows the dynamics of policy rate. In response to this, the commercial banks expand their balance sheets in the following periods in order to satisfy a higher demand for credit. This is followed by heightened investment in the subsequent quarters.

Figure 7: IRF – foreign inflation shock

The same reasoning for dynamics of responses under the alternative scenario holds in this case. The dynamics of the model is considerably affected by the amount of deposits and loans issued. Based on the discussion in the previous subsection, when using the augmented rule, the macroeconomic benefits in terms of lower volatilities seems to be significant in case of the disturbances stemming from abroad. The most pronounced effects can be observed in the event of the shocks in inflation and interest rate, where the financial variables brings useful additional information about future inflationary developments and the monetary authority adjusts its policy rate in accordance with this.
6.3 Comparison with similar studies

Compared to the findings of Gambacorta and Signoretti (2014), change of the dynamics under the alternative rule compared to the baseline scenario is not so pronounced. It might be caused by the different construction of the whole model. The model presented in this thesis is more complicated and it also encompasses additional features that are responsible for different responses. Moreover, the model represents an open economy, while Gambacorta and Signoretti (2014) construct a closed economy model. Moreover, their model seems to be highly stylized. Their model shows that most beneficial for macroeconomic stability is to implement the augmented monetary policy rule; however, the coefficient on loans is positive.

On the other hand, results of a closed economy model constructed by Aydin and Volkan (2011) suggest that the responses of variables to various shocks are qualitatively and quantitatively almost identical under different monetary policy rules. Their research suggests that almost any kind of financial variable possess useful information; however, their results regarding implied volatilities vary considerably across different shocks and different monetary policy rules. This shows that reacting to financial variables is likely to bring some benefits for macroeconomic stability. Nevertheless, the gains are shock- and model-dependent.
7 Sensitivity analysis and robustness check

First, this chapter offers comparison of implied volatilities under the AMPR III with different weights assigned to the financial variables. Second, the robustness of the results to changes of a selected number of parameters is verified.

7.1 Volatility under the AMPR III with different weights

The following exercise helps to find out to what extent the weights ascribed to the financial variables modify volatility of inflation and output as opposed to baseline calibration of the AMPR III. The weight put on inflation in the policy rule is kept to be fixed at its baseline value 1.7, and therefore, it is not further reported. Table 3 summarizes the results of the repeated simulations for the different combinations of weights put on the financial variables under the all shocks considered (domestic as well as foreign).

Focusing on the cases when more pronounced weight is given to developments in the financial variables, all the shocks, except for the bank capital shock, imply less weighted volatility than the shocks under the baseline calibration do. Deterioration of the performance of the AMPR III in case of the bank capital shock (when there is higher weight ascribed to the credit volume and asset prices) resides in the fact that the most beneficial rule is identified to be the baseline (conventional) rule in this case, as it was shown in the previous chapter. From this implies that reacting with even higher weights causes stronger distortions.

Conclusions made in the previous paragraph are supported by the upper rows in each “shock category”. In comparison to baseline calibration of the AMPR III with weights \( g_L = -0.3 \) and \( g_Q = 0.5 \), more modest reactions to financial developments bring less macroeconomic stability than more aggressive reactions and they are more distorting in this sense. On the other, in some particular cases, too aggressive reaction on the financial variables brings less stabilization than more moderate reactions (this can be seen in case of the technology shock and the UIP shock). Overall, this investigation shows that the initial weights considered in the AMPR III are not optimal (as regards macroeconomic stabilization) and a more suitable combination could be found. Nevertheless, even the augmented rule with weights that are less emphasized delivers improvements that are significant. Therefore, conclusions reached in this thesis should be considered from the
qualitative perspective rather than quantitative.

Table 3: Sensitivity analysis

<table>
<thead>
<tr>
<th>Shock to</th>
<th>Weights</th>
<th>Volatility</th>
<th>Inflation</th>
<th>GDP</th>
<th>Weighted sum</th>
<th>Gain&lt;sup&gt;(a)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>-0.1</td>
<td>0.1</td>
<td>0.0099</td>
<td>0.0085</td>
<td>0.0107</td>
<td>-11%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0.5</td>
<td>0.0081</td>
<td>0.0102</td>
<td>0.0090</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>1.0</td>
<td>0.0084</td>
<td>0.0098</td>
<td>0.0093</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>1.5</td>
<td>0.0086</td>
<td>0.0096</td>
<td>0.0095</td>
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</tr>
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<td>0.0035</td>
<td>0.0052</td>
<td>0.0040</td>
<td>-23%</td>
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<td>-0.5</td>
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<td>0.0023</td>
<td>0.0043</td>
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<td>1.5</td>
<td>0.0025</td>
<td>0.0044</td>
<td>0.0029</td>
<td>10%</td>
</tr>
<tr>
<td>Bank capital</td>
<td>-0.1</td>
<td>0.1</td>
<td>0.0009</td>
<td>0.0024</td>
<td>0.0011</td>
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<tr>
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<td>-0.5</td>
<td>0.5</td>
<td>0.0020</td>
<td>0.0024</td>
<td>0.0022</td>
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</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>1.0</td>
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<td>0.0023</td>
<td>0.0019</td>
<td>-35%</td>
</tr>
<tr>
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<td>1.5</td>
<td>0.0016</td>
<td>0.0023</td>
<td>0.0018</td>
<td>-28%</td>
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<td>Consumption</td>
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<td>0.1</td>
<td>0.0039</td>
<td>0.0095</td>
<td>0.0048</td>
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<td>0.0092</td>
<td>0.0035</td>
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<td>-0.5</td>
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<td>0.0090</td>
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<td>0.0089</td>
<td>0.0026</td>
<td>30%</td>
</tr>
<tr>
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<td>0.1</td>
<td>0.0006</td>
<td>0.0010</td>
<td>0.0007</td>
<td>-19%</td>
</tr>
<tr>
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<td>-0.5</td>
<td>0.5</td>
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<td>0.0009</td>
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<td>1.5</td>
<td>0.0003</td>
<td>0.0008</td>
<td>0.0004</td>
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<tr>
<td>Foreign inflation</td>
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<td>0.1</td>
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<td>0.0017</td>
<td>0.0011</td>
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<tr>
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<td>-0.5</td>
<td>0.5</td>
<td>0.0006</td>
<td>0.0014</td>
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<tr>
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<td>-0.5</td>
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<td>0.0006</td>
<td>0.0014</td>
<td>0.0007</td>
<td>13%</td>
</tr>
<tr>
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<td>1.5</td>
<td>0.0006</td>
<td>0.0015</td>
<td>0.0007</td>
<td>12%</td>
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<td>Foreign interest rate</td>
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<td>0.1</td>
<td>0.0018</td>
<td>0.0024</td>
<td>0.0020</td>
<td>-35%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>0.5</td>
<td>0.0010</td>
<td>0.0019</td>
<td>0.0012</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>1.0</td>
<td>0.0010</td>
<td>0.0019</td>
<td>0.0012</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>1.5</td>
<td>0.0010</td>
<td>0.0019</td>
<td>0.0012</td>
<td>21%</td>
</tr>
</tbody>
</table>

Source: Dynare output, own computations.
Note: (a) percentage deviation of volatility from baseline calibration of the AMPR III ($\varrho_L = -0.3$, $\varrho_Q = 0.5$); a positive value represents gain, a negative value represents loss.
7.2 Robustness verification

The following analysis shows to what extent is the model sensitive to the changes in calibration of several variables. In particular, calibration of the several key parameters is changed, simulations with the baseline (conventional) rule and the AMPR III are repeated for all the shocks and the difference in implied volatilities between these two rules is recorded and compared. The parameters that are analysed can be categorized in three groups:

(i) the banking sector parameters: the target value of capital-to-asset ratio $\nu_B$ and the rate of capital adjustment costs $\kappa_B$;

(ii) the parameters reflecting the stickiness: the rate of investment adjustment cost $\kappa_K$ and the inverse of the Frisch elasticity of labour supply $\phi$;

(iii) the interest rate smoothing parameter $\rho_R$.

The results of the robustness analysis are summarized in figures 8 and 9.

Regarding the banking sector parameters (first rows in both figures), the results are almost the same when changing the values of $\kappa_B$ and $\nu_B$. These two parameters (in a multiplicative form) are responsible for the loan supply (in particular, they affect its slope). However, based on the values considered, the multiplication of these parameters is small in its magnitude such that the dynamics of the model is not affected considerably. As regards the second group of parameters, the augmented rule seems to be even more beneficial in case of a higher stickiness. Justification for the result regarding the adjustment cost parameter $\kappa_K$ is as follows: when $\kappa_K$ is close to zero, price of assets is very sticky and it almost does not move. From this implies that the augmented rule brings less macroeconomic benefits.

Lastly, the results of the model are not subject to the changes in the smoothing of the policy rate. The only exception is the case of the bank capital shock. When the persistence parameter is lower than 0.75, reacting to the financial variables seems not to be distorting and there is neither loss nor gain with respect to the baseline rule. The opposite holds for the foreign shocks – for high values of $\rho_R$, the AMPR III delivers more favourable results than the baseline rule. To summarize, despite slight quantitative differences in several cases, the AMPR III brings benefits over the baseline rule for different values of the key parameters.
ters. Therefore, conclusions drawn from the initial simulations seem to be robust.

Figure 8: Robustness check – domestic shocks

Source: Dynare output, own computations.
Note: a vertical axis depicts the difference between implied volatilities of the baseline (conventional) rule and the AMPR III.

The last exercise shows gains of the AMPR III with respect to the baseline rule with changing weight ascribed to GDP, \( \omega \), in the weighted sum described by equation (72). As figure 10 shows, for different weights \( \omega \), the AMPR III achieves higher macroeconomic stability in terms of implied volatility in comparison to the baseline rule. However, gain is decreasing with increasing value of \( \omega \). The only exception is the bank capital shock, when implementation of the AMPR III seems to have plausible implications for stabilization of GDP (decreasing loss with increasing \( \omega \)). The analysis suggests that the AMPR III brings significantly lower volatilities in case of inflation, while volatility stabilization regarding GDP is questionable and the rule does not perform so well in this regard (volatility in GDP rather increases with implementation of the AMPR III). Nevertheless, when considering stable inflation to be the ultimate goal of monetary policy, gains in terms of lower volatility in GDP are secondary.
Figure 9: Robustness check – foreign shocks

Bank capital adjustment cost ($\kappa_B$)

Capital-to-asset ratio ($\nu_B$)

Interest rate persistence ($\rho_R$)

Inverse Frisch elasticity ($\phi$)

Physical capital adjustment cost ($\kappa_K$)

Source: Dynare output, own computations.
Note: A vertical axis depicts the difference between implied volatilities of the baseline (conventional) rule and the AMPR III.

Figure 10: Robustness check – weight on GDP $\omega$

Domestic shocks

Foreign shocks

Source: Dynare output, own computations.
Note: A vertical axis depicts percentage difference with respect to the baseline rule; a positive value represents gain, a negative value represents loss.
8 Conclusion

Financial stability and its connection to monetary policy has become one of the most prominent topics discussed in the field of macroeconomics and monetary economics. In the light of the recent financial crisis, the natural question that has arisen is whether two conventional macroeconomic indicators – inflation and output – are sufficient ingredients of the monetary policy rules. Because of the strong relationship between the financial sector and the real side of the economy, the role of the financial variables within the monetary policy rules started to be investigated. Despite the research is growing extensively in this field, the topic is rather new and there is a lot to be examined. Moreover, most studies focus on the closed economies. The purpose of this thesis is to test the augmented monetary policy rules in the DSGE model for the small open economy that is represented by the Czech Republic.

This thesis contributes to the existing theoretical evidence by the analysis of the augmented monetary policy rules in the small open economy context. The results show that reacting to the financial variables might be beneficial for the inflation and output stabilization, and therefore for the monetary authority. The analyses show that reacting by the augmented rule (where a positive weight is ascribed to asset prices and a negative weight to credit volume) might bring decrease in inflation and output variability of up to 30%, depending on the shock. The gains are obvious in case of foreign shocks that affect the developments in the small open economy considerably. On the other hand, reacting to the financial variables is counterproductive in case of the severe shock to bank capital. Additionally, the model depicts the importance of the financial sector for the real side of the economy. This connection is most evident in case of bank capital loss, when under-capitalised commercial banks are not able to produce loans and the economy experiences deep recession.

Even though the results seem to be promising, they should be interpreted with certain caution. First, the model does not include any features related to the financial stress (such as an endogenous exit of non-financial firms or the crashes of the commercial banks) that are typical for a financial crisis. Therefore, the augmented rules are tested in normal times and the importance of the augmented rules might be even higher in case of non-ordinary times. Second, the model is linearised. This technique removes any non-linearity which might be characteristic for the crisis periods. Third, the results should be taken as qualitative rather than
quantitative. The model is highly stylized, the coefficients are computed based on simplified routines and optimization methods. Therefore, they are likely not to resemble the reality precisely. Fourth, the model demonstrates that it could work according to “loanable funds theory”.

To summarize, the model indicates that the financial variables can be useful in monetary policy decision making since the connection between the financial side and the real side of the economy is significant. Therefore, the financial variables are likely to indicate future inflationary developments and the policy rate should be adjusted accordingly. On the other hand, the model shows that monetary policy itself is not able to respond optimally when an abrupt shock hits the financial sector. This might suggest that rather unconventional monetary policy tool should be implemented. The results of the model are subject to the robustness check that indicates that the results are robust to the changes in the key parameters.

This thesis could serve as a building block for further research. As it is mentioned above, the model could be extended by modelling some specific features related to the financial stress. It would be interesting to test the augmented rules in richer environment where the motivation for the use of the augmented rule is even higher. Second, the theoretical results should be verified by empirical methods in order to test the policy rules in the context of real developments. Third, since the model presented in this thesis seems to work according to “loanable funds theory” and there are several approaches to the banking sector modelling, the augmented rule could be tested using another modelling alternative.
References


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Appendix A: the full model equation block

The log-linearised system

The following equations characterize the model.

Households

Debt-elastic risk premium (10):

\[ \hat{f}_t = \psi^* \frac{L^*}{Y_G} \hat{l}_t - \psi^* \frac{L^*}{Y_G} \hat{y}_{G,t} + \hat{a}_t^{UIP} \]

Intra-temporal optimality condition between consumption and leisure (12):

\[ \hat{h}_t = \frac{\hat{w}_t}{\phi} - \frac{\hat{c}_H}{(1-t)\phi} + \hat{a}_t^C \]

Inter-temporal optimality condition (13):

\[ \hat{r}_t = \frac{\hat{z}_t^{H+1} - \hat{z}_t^H}{1-t} - \frac{\hat{z}_t^{H+1} - \hat{z}_t^H}{1-t} + \mathbb{E}_t \{ \hat{\pi}_{t+1} \} + \hat{\alpha}_t^C - \hat{\alpha}_{t+1}^C \]

UIP condition (14):

\[ \hat{r}_t - \hat{r}_t^* = \mathbb{E}_t \{ \hat{q}_{t+1} \} - \hat{q}_t + \mathbb{E}_t \{ \hat{\pi}_{t+1} \} - \mathbb{E}_t \{ \hat{\pi}_{t+1}^* \} + \hat{f}_t \]

Entrepreneurs

Flow of funds (16):

\[ \frac{\gamma^E}{C} - \frac{C}{Y_G} \hat{c}_t^E = \frac{p_W^W}{Y_G} (\hat{p}_t^W + \hat{y}_t^W) + \frac{1 - \delta_K}{\delta_K} \frac{I}{Y_G} (\hat{q}_t^K + \hat{k}_{t-1}^K) + \frac{L}{Y_G} \hat{l}_t - \frac{W H}{Y_G} (\hat{w}_t + \hat{h}_t) - \frac{I}{\delta_K Y_G} (\hat{q}_t^K + \hat{k}_{t}^K) - \frac{\psi'(1)}{\delta_K Y_G} \hat{u}_t - \frac{R^L}{\Pi Y_G} (\hat{r}_{t-1}^L + \hat{l}_{t-1} - \hat{\pi}_t) \]

Production function (17):

\[ \hat{y}_t^W = \alpha \hat{k}_{t-1}^K + \alpha \hat{u}_t + (1 - \alpha) \hat{h}_t + \hat{a}_t^Y \]
Collateral constraint (19):

\[ \hat{r}_t^L + \hat{I}_t = \mathbb{E}_t\{\hat{q}_{t+1}^K\} + \mathbb{E}_t\{\hat{\pi}_{t+1}\} + \hat{k}_t^K \]

Marginal utility of entrepreneurial consumption (20):

\[ \hat{\lambda}_{1,t}^E = \frac{\hat{c}_{t-1}^E - \hat{c}_t^E}{1 - \tau} \]

Optimal level of capital (21):

\[ \hat{q}_{t}^K = (1 - \delta_K)\beta_E\mathbb{E}_t\{\hat{q}_{t+1}^K + \hat{\lambda}_{1,t+1}^E - \hat{\lambda}_{1,t}^E\} + \beta_E\psi'(1)\mathbb{E}_t\left\{\hat{\lambda}_{1,t+1}^E - \hat{\lambda}_{1,t}^E + \frac{\psi''(1)}{\psi'(1)}\hat{u}_{t+1}\right\} \]

\[ +m(1 - \delta_K)\Pi \left[ \left(1 - \beta_E\right) - \beta_E \frac{1}{R_L} \right] \mathbb{E}_t\{\hat{q}_{t+1}^K\} - \frac{1}{R_L} \mathbb{E}_t\{\hat{r}_t^L - \hat{\pi}_{t+1}\} \]

\[ -\beta_E \frac{1}{\Pi} \mathbb{E}_t\{\hat{\lambda}_{1,t+1}^E - \hat{\lambda}_{1,t}^E\} \]

Capital utilization (22):

\[ \hat{u}_t = \frac{\psi'(1)}{\psi''(1)}[\hat{p}_t^W + (1 - \alpha)(\hat{h}_t - \hat{u}_t - \hat{k}_{t-1}^K) + \hat{a}_t] \]

Labour demand (23):

\[ \hat{w}_t = \hat{p}_t^W + \alpha \hat{k}_{t-1}^K + \alpha \hat{u}_t - \alpha \hat{h}_t + \hat{a}_t \]

**Capital producers**

Law of motion of capital (25):

\[ \hat{k}_t^K = \delta_K \hat{i}_t + (1 - \delta_K)\hat{k}_{t-1}^K \]

Price of capital (29):

\[ \hat{q}_t^K = \frac{1 + \beta_H}{\kappa_K} \hat{i}_t - \frac{1}{\kappa_K} \hat{i}_{t-1} - \frac{\beta_H}{\kappa_K} \mathbb{E}_t\{\hat{i}_{t+1}\} \]
Final goods producers

Technology (30):

\[
\hat{y}_t = \eta \frac{Y_H}{Y} \hat{y}_{H,t} + (1 - \eta) \frac{Y_F}{Y} \hat{y}_{F,t}
\]

Demand for home goods (33):

\[
\hat{y}_{H,t} = -\frac{1 + \mu}{\mu} \hat{p}_{H,t} + \hat{y}_t
\]

Demand for imports (34):

\[
\hat{y}_{F,t} = -\frac{1 + \mu}{\mu} \hat{p}_{F,t} + \hat{y}_t
\]

Demand for exports (38):

\[
\hat{y}_{H,t}^* = -\frac{1 + \mu^*}{\mu^*} \hat{p}_{H,t}^* + \hat{y}_t^*
\]

Retailers

Domestic goods price (43):

\[
\frac{\theta_H}{1 - \theta_H}(\hat{p}_{H,t} - \hat{p}_{H,t-1} + \hat{\pi}_t - \varsigma_H \hat{\pi}_{t-1}) = (1 - \beta_H \theta_H)(\hat{p}_t^W - \hat{p}_{H,t}) + \frac{\beta_H \theta_H}{1 - \theta_H}(E_t\{\hat{p}_{H,t+1}\} - \hat{p}_{H,t} + E_t\{\hat{\pi}_{t+1}\} - \varsigma_H \hat{\pi}_t)
\]

Exported goods price (48):

\[
\frac{\theta_H^*}{1 - \theta_H^*}(\hat{p}_{H,t}^* - \hat{p}_{H,t-1}^* + \hat{\pi}_t^* - \varsigma_H^* \hat{\pi}_{t-1}^*) = (1 - \beta_H \theta_H^*)(\hat{p}_t^W - \hat{q}_t - \hat{p}_{H,t}) + \frac{\beta_H \theta_H^*}{1 - \theta_H^*}(E_t\{\hat{p}_{H,t+1}^*\} - \hat{p}_{H,t}^* + E_t\{\hat{\pi}_{t+1}^*\} - \varsigma_H \hat{\pi}_t^*)
\]

Imported goods price (53):

\[
\frac{\theta_F}{1 - \theta_F}(\hat{p}_{F,t} - \hat{p}_{F,t-1} + \hat{\pi}_t - \varsigma_F \hat{\pi}_{t-1}) = (1 - \beta_H \theta_F)(\hat{q}_t - \hat{p}_{F,t}) + \frac{\beta_H \theta_F}{1 - \theta_F}(E_t\{\hat{p}_{F,t+1}\} - \hat{p}_{F,t} + E_t\{\hat{\pi}_{t+1}\} - \varsigma_F \hat{\pi}_t)
\]
Commercial banking sector

Bank capital (54):
\[ \hat{k}_t^B = \delta_B \hat{\xi}_t^B + (1 - \delta_B)(\hat{k}_{t-1}^B - \hat{a}_t^B) \]

Spread (58):
\[ \hat{r}_t^L R^L - \hat{r}_t R = -\kappa_B \nu_B (\hat{k}_t^B - \hat{l}_t) \]

Bank profits (59):
\[ \hat{\xi}_t^B = \frac{(R + \mu_B) \left( \frac{R \hat{r}_t - \kappa_B \nu_B (\hat{k}_t^B - \hat{l}_t)}{R^L} + \hat{l}_t \right) - R(1 - \nu_B)(\hat{r}_t + \hat{d}_t)}{R \nu_B + \mu_B} \]

Central bank

Conventional monetary policy rule (60):
\[ \hat{r}_t = \rho_R \hat{r}_{t-1} + (1 - \rho_R)(\varrho_B \hat{\pi}_t) \]

AMPR I (62):
\[ \hat{r}_t = \rho_R \hat{r}_{t-1} + (1 - \rho_R)(\varrho_B \hat{\pi}_t + \varrho_L \hat{\ell}_t) \]

AMPR II (63):
\[ \hat{r}_t = \rho_R \hat{r}_{t-1} + (1 - \rho_R)(\varrho_B \hat{\pi}_t + \varrho_Q \hat{q}_K^t) \]

AMPR III (64):
\[ \hat{r}_t = \rho_R \hat{r}_{t-1} + (1 - \rho_R)(\varrho_B \hat{\pi}_t + \varrho_L \hat{\ell}_t + \varrho_Q \hat{q}_K^t) \]
Foreign sector

The system of AR(1) equations (65):
\[
\begin{pmatrix}
\hat{y}_t^* \\
\hat{\pi}_t^* \\
\hat{r}_t^*
\end{pmatrix} =
\begin{pmatrix}
\rho y_t^* & 0 & 0 \\
0 & \rho \pi_t^* & 0 \\
0 & 0 & \rho r_t^*
\end{pmatrix}
\begin{pmatrix}
\hat{y}_{t-1}^* \\
\hat{\pi}_{t-1}^* \\
\hat{r}_{t-1}^*
\end{pmatrix} +
\begin{pmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\varepsilon_t^y \\
\varepsilon_t^\pi \\
\varepsilon_t^r
\end{pmatrix}
\]

Market clearing conditions and GDP

Commercial bank constraint (66):
\[
\hat{l}_t = (1 - \nu_B)\hat{d}_t + \nu_B \hat{k}_t^B
\]

Final goods (67):
\[
\frac{C}{Y_G} \hat{c}_t + \frac{I}{Y_G} \hat{i}_t + \frac{\psi'(1)}{\delta K Y_G} \hat{u}_t + \frac{\Xi_B}{Y_G} (\hat{k}_{t-1}^B - \hat{\pi}_t) = \frac{Y}{Y_G} \hat{y}_t
\]

Aggregate consumption (68):
\[
\hat{c}_t = \gamma^H \frac{C}{C} \hat{c}_t^H + \gamma^E \frac{C}{C} \hat{c}_t^E
\]

Wholesale goods (69):
\[
\hat{y}_t^W = \frac{Y_H}{Y_H + Y_H^*} \hat{y}_{H,t} + \frac{Y_H^*}{Y_H + Y_H^*} \hat{y}_{H,t}
\]

Balance of payments (70):
\[
\frac{p_F Y_F}{Y_G} (\hat{p}_{F,t} + \hat{y}_{F,t}) + \frac{L^* R}{Y_G} (\hat{q}_t - \hat{q}_{t-1} + \hat{f}_{t-1} + \hat{r}_{t-1}^* - \hat{\pi}_{t-1}^* + \hat{\pi}_{t-1}^*) = 
\]
\[
\frac{p_H Y_H^* Q}{Y_G} (\hat{q}_t + \hat{p}_{H,t} + \hat{y}_{H,t}) + \frac{L^*}{Y_G} \hat{l}_t
\]

Gross domestic product (71):
\[
\hat{y}_{G,t} = \frac{Y}{Y_G} \hat{y}_t + \frac{p_H^* Y_H^* Q}{Y_G} (\hat{p}_{H,t} + \hat{y}_{H,t} + \hat{q}_t) - \frac{p_F Y_F}{Y_G} (\hat{p}_{F,t} + \hat{y}_{F,t})
\]
**Remaining exogenous processes**

Consumption preference shock (8):

\[ \hat{a}^C_t = \rho C \hat{a}^C_{t-1} + \varepsilon^C_t \]

Debt-elastic risk premium shock (11):

\[ \hat{a}^{UIP}_t = \rho_{UIP} \hat{a}^{UIP}_{t-1} + \varepsilon^{UIP}_t \]

Productivity shock (18):

\[ \hat{a}^Y_t = \rho Y \hat{a}^Y_{t-1} + \varepsilon^Y_t \]

Bank capital shock (55):

\[ \hat{a}^B_t = \rho_B \hat{a}^B_{t-1} + \varepsilon^B_t \]
### Appendix B: calibration

Table 4: Values of parameters (1/2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital producers</strong></td>
<td></td>
</tr>
<tr>
<td>$\psi'(1)$</td>
<td>capital utilization parameter</td>
</tr>
<tr>
<td>$\psi'(1)/\psi''(1)$</td>
<td>capital utilization parameter</td>
</tr>
<tr>
<td>$\kappa_K$</td>
<td>rate of capital adjustment costs</td>
</tr>
<tr>
<td>$\delta_K$</td>
<td>rate of capital depreciation</td>
</tr>
<tr>
<td><strong>Central bank</strong></td>
<td></td>
</tr>
<tr>
<td>$\varrho_Q$</td>
<td>financial side weight – asset prices</td>
</tr>
<tr>
<td>$\varrho_L$</td>
<td>financial side weight – credit</td>
</tr>
<tr>
<td>$\varrho_{\Pi}$</td>
<td>inflation weight</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td>interest rate smoothing</td>
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<tr>
<td><strong>Commercial banking sector</strong></td>
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<tr>
<td>$\nu_B$</td>
<td>capital-to-asset ratio target value</td>
</tr>
<tr>
<td>$\mu_B$</td>
<td>mark-up on loan rate</td>
</tr>
<tr>
<td>$\kappa_B$</td>
<td>rate of capital adjustment costs</td>
</tr>
<tr>
<td>$\delta_B$</td>
<td>share of bank capital used in capital maintenance</td>
</tr>
<tr>
<td><strong>Entrepreneurs</strong></td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>capital share in production</td>
</tr>
<tr>
<td>$\beta_E$</td>
<td>exogenous discount factor</td>
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<td>$m$</td>
<td>LTV ratio</td>
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<tr>
<td>$\gamma_E$</td>
<td>share of entrepreneurs in the economy</td>
</tr>
<tr>
<td><strong>Exogenous processes</strong></td>
<td></td>
</tr>
<tr>
<td>$\rho_B$</td>
<td>AR(1) parameter of bank capital shock</td>
</tr>
<tr>
<td>$\rho_C$</td>
<td>AR coefficient of consumption preference shock</td>
</tr>
<tr>
<td>$\rho_Y$</td>
<td>AR(1) parameter of domestic productivity shock</td>
</tr>
<tr>
<td>$\rho_{UIP}$</td>
<td>AR(1) parameter of risk premium shock</td>
</tr>
<tr>
<td><strong>Final goods producers</strong></td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td>elasticity of substitution of domestic goods</td>
</tr>
<tr>
<td>$\mu^*$</td>
<td>elasticity of substitution of foreign goods</td>
</tr>
<tr>
<td>$\eta$</td>
<td>degree of openness</td>
</tr>
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</table>
Table 5: Values of parameters (2/2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td><strong>Foreign sector</strong></td>
<td></td>
</tr>
<tr>
<td>$\rho_{\pi^*}$</td>
<td>0.6256</td>
</tr>
<tr>
<td>$\rho_{r^*}$</td>
<td>0.7570</td>
</tr>
<tr>
<td>$\rho_{y^*}$</td>
<td>0.8024</td>
</tr>
<tr>
<td>$\psi^*$</td>
<td>0.0005</td>
</tr>
<tr>
<td>$\beta_H^*$</td>
<td>0.9850</td>
</tr>
<tr>
<td><strong>Households</strong></td>
<td></td>
</tr>
<tr>
<td>$\beta_H$</td>
<td>0.9900</td>
</tr>
<tr>
<td>$\iota$</td>
<td>0.7000</td>
</tr>
<tr>
<td>$\phi$</td>
<td>1.8800</td>
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<tr>
<td>$\gamma_H$</td>
<td>0.7500</td>
</tr>
<tr>
<td><strong>Retailers</strong></td>
<td></td>
</tr>
<tr>
<td>$\theta_H^*$</td>
<td>0.5000</td>
</tr>
<tr>
<td>$\theta_H$</td>
<td>0.4000</td>
</tr>
<tr>
<td>$\theta_F$</td>
<td>0.5000</td>
</tr>
<tr>
<td>$\varsigma_H$</td>
<td>0.4949</td>
</tr>
<tr>
<td>$\varsigma_H$</td>
<td>0.3233</td>
</tr>
<tr>
<td>$\varsigma_F$</td>
<td>0.3428</td>
</tr>
<tr>
<td><strong>Steady states</strong></td>
<td></td>
</tr>
<tr>
<td>$\Xi^B/Y_G$</td>
<td>0.5924</td>
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<tr>
<td>$C/Y_G$</td>
<td>0.5177</td>
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<tr>
<td>$\Pi$</td>
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<tr>
<td>$C^E/C$</td>
<td>0.4582</td>
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<tr>
<td>$p_H^W Y^Q_H/Y_G$</td>
<td>0.2430</td>
</tr>
<tr>
<td>$Y^H_H/(Y^H_H+Y^*_H)$</td>
<td>0.2430</td>
</tr>
<tr>
<td>$L^*/Y_G$</td>
<td>1.0000</td>
</tr>
<tr>
<td>$R$</td>
<td>2.0202</td>
</tr>
<tr>
<td>$Y_H/(Y^H_H+Y^*_H)$</td>
<td>0.7570</td>
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<tr>
<td>$C^H/C$</td>
<td>1.1806</td>
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<tr>
<td>$p_F Y^F/Y_G$</td>
<td>0.2107</td>
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<tr>
<td>$I/Y_G$</td>
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<td>$R^L$</td>
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<tr>
<td>$L/Y_G$</td>
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<tr>
<td>$Y/Y_G$</td>
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<tr>
<td>$p^W Y^W/Y_G$</td>
<td>0.8333</td>
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