# Measuring the Driving Forces of the Owner-Occupied and Rental Housing Markets - A DSGE Analysis

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### Abstract

This thesis analyses the developments of the U.S. owner-occupied and rental housing markets. Furthermore, it evaluates whether loose monetary policy fuelled the housing boom and therefore contributed heavily to the latest financial crisis. The dissertation findings originate from two estimated DSGE models which accommodate a combination of various, distinct features. In contrast to the literature, I introduce a banking sector into the model economy and allow for a choice between either renting or owning a home. Accounting for these characteristics enables us to capture frictions arising from the banking sector on the one hand and to properly model the change in the homeownership structure on the other. Based on this framework, the second DSGE model relaxes the assumption of a fixed housing supply and introduces sticky prices into the consumption sector. The contributions of this dissertation are twofold. First, it determines the driving forces behind the pre and post-crisis movements of the rental and owner-occupied housing sectors. The results suggest that the latest rise in rental housing is driven by a combination of various factors, such as default, bank lending, change in preferences and news about the economic outlook. Furthermore, news about future productivity increases had a significant effect on house prices before and after the financial crisis. A robustness check confirms these findings. The second contribution is to show that accommodative pre-crisis monetary policy was not the main cause of the latest housing boom, as argued in one branch of the literature. Instead, bank lending behaviour and fundamentals played a key role in the expansion of the owner-occupied housing market. The dissertation finishes with a macroprudential policy evaluation.

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### Introduction

Housing has made it into mainstream economics and is an essential component in modern financial friction models. Recent events have shown that housing market developments are not just the result of various macroeconomic changes, but can also trigger substantial business cycle fluctuations. U.S. housing wealth (i.e. the residential capital stock at market price), is considerably larger than GDP and fluctuates substantially over time. Between 1952 and 2008, the average housing wealth to GDP ratio was 1.5. However, in 2005 this ratio reached a value of 2.26. This year also marks the start of the housing market correction, where growth in housing wealth and the ratio of housing investment to GDP fell dramatically (Iacoviello 2010).

Today we know that housing was at the roots of the latest financial crisis, which has caused severe devastation to the U.S. economy. Pre-crisis developments showed alarming trends for many housing variables that were either misjudged or remained unnoticed by governments and authorities. What followed was a sharp contraction of housing markets accompanied by falling asset prices and a collapse of residential investment. In addition to this, owner-occupied housing experienced a rapid increase in the years leading up to the crisis, whereas rental housing showed a decline. However, this comes to a halt right before the outbreak of the Great Recession. Owner-occupied housing declined from 2009 onwards and rental housing instead increased steeply. Figure 1 illustrates these developments of both housing sectors.



Figure 1: Rental Housing vs. Owner-occupied Housing; Source: U.S. Census Bureau

The crisis not only effected the credit supply and various other channels of the economy, but also triggered a change in the homeowner status of many households. Based on these facts the objectives of this dissertation are twofold: First, it investigates the driving forces behind both housing markets. Second, the thesis measures to what extent monetary policy has influenced the pre-crisis expansion of household debt and house prices. The underlying methodology is an estimated DSGE model, which accommodates a banking sector and explicitly features a choice between rental and owner-occupied housing. The framework is also equipped with collateral constraints that allow households to borrow against their homes values. As an asset price drop can have severe consequences to the borrowing ability of agents, this mechanism is better known as a financial accelerator. Through the additional constraint, shocks get amplified and intensify the responses of economic agents. It was first developed by Kiyotaki and Moore (1997) and later updated by Iacoviello (2005), who replaced land by housing. There is a second, very popular financial accelerator approach, which is widely used in the literature. Again, this mechanism was introduced long before the financial crisis by Bernanke and Gertler (1989). The origins of this type of financial accelerator framework go back to the costly state verification methodology proposed by Townsend (1979). The state of the borrowers' balance sheet takes up a crucial role under this mechanism. It shows that the net worth of a borrower/entrepreneur is inversely correlated with the agency costs (e.g. monitoring of a loan) of undertaking physical investments. This triggers an accelerating effect on investments. The net worth of borrowers is likely to be high during good times of the economy and low during bad times. More solvent consumers will cause a rise in demand for investments and amplify the economic boom phase. The opposite will occur during bad times (Bernanke and Gertler 1989). The two concepts discussed above are two common ways to introduce financial frictions into our models and the paper by Forlati and Lambertini (2011) has even combined both mechanisms.

Since this dissertation focusses specifically on the developments of the U.S. housing market, the collateral constraint framework has been chosen for the models presented in chapter 1 and 2. As it is standard in the literature, housing consumption in the form of housing services enters the utility function of households.<sup>1</sup> Houses are a durable good and can be used for two purposes. First, it serves as collateral for borrowers and second, it delivers utility services. In other words, the households' accumulated housing stock provides them with a flow of housing services. This collateralizable stock of housing can then be used for their borrowing activities. The flow of residential investment shows up in the borrower's budget constraint in the form of  $H_t - (1 - \delta)H_{t-1}$ , where  $H_t$  represents housing services (i.e. the end-of-period housing stock) and  $\delta$  the depreciation of the durable good (Monacelli 2009). Furthermore, I assume proportionality between the stream of housing services and the stock of housing.

As we are going to see later, the demand for housing is subject to an exogenous shock. The disturbance enters the utility function of agents and depending on the sign it either triggers a reduction or increase in the demand for homes. This exogenous process is better known as a housing demand shock. Figure 2 delivers evidence why previous studies have implemented this type of shock. Even though it was more expensive to buy a house during the pre-crisis years, home sales increased sharply until the end of 2005. The collapse of the housing market caused a severe contraction of home sales between 2006 and 2008. As affordability<sup>2</sup> of homes increased in the years after the crisis home sales did not follow the same trend. Hence, these developments reflect the rise and decline in the demand for homes before and after the housing boom. The preference shock therefore captures shifts in the demand towards housing which can be caused by changing age shares of a country's total population (Sun and Tsang 2017). Modelling these socio-economic factors in a DSGE setup can be difficult and hence we assume that they are represented by an exogenous process.

This dissertation contributes to the literature in two directions. First, it finds that the latest changes in the U.S. home ownership structure were caused by a combination of four factors. These are default, household preferences, bank lending and news about the economic outlook. The results confirm and extend the findings outlined in the report of the Joint Center for Housing Studies (2013). News about the economic outlook

<sup>&</sup>lt;sup>1</sup>See for example the papers by Davis and Heathcote (2005), Chang (2000), Baxter (1996), Greenwood and Hercowitz (1991) or Matsuyama (1990).

<sup>&</sup>lt;sup>2</sup>The affordability index comes from the National Association of Realtors (NAR). The index shows whether or not a typical household is able to qualify for a mortgage in order to buy a typical home. The typical household corresponds to the median income family as defined by the U.S. Bureau of the Census. A typical home is described as the national median-priced, existing single-family home as computed by NAR. The current interest on mortgages is defined as the effective rate on loans coming from the Housing Finance Board. These parameters are used to illustrate if the median income household is able to obtain a mortgage for a median-priced house. For example, if the index takes the value 100 then this means that a household with a median income has exactly enough financial resources available to qualify for a mortgage on a typical home.

are also an important driving force behind rental and house price fluctuations. This is in line with the study conducted by Lambertini, Mendicino, and Punzi (2017), which confirms that TFP news are able to trigger a boom and bust of the housing market. Second, the results of this dissertation show that monetary policy only played a minor role in the dangerous pre-crisis growth of household debt and house prices. The literature on this topic has produced ambiguous outcomes. For example papers by Eickmeier and Hofmann (2013) and Bordo, Landon-Lane, et al. (2014) conclude that accommodative monetary policy played a key role during the time prior to the crisis. In contrast, studies by Dokko et al. (2011) and Nelson, Pinter, and Theodoridis (2018) illustrate that monetary policy was not the main cause behind pre-crisis developments. The model in this dissertation identifies fundamentals and bank lending as the main contributors behind the swift increase in home prices and household loans in the years leading up to the financial crisis. Regarding the latter, Demyanyk and Van Hemert (2009) and Dell'Ariccia, Igan, and Laeven (2008) show that excessive risk taking by banks rose and lending standards deteriorated sharply.



Figure 2: Home Sales and Housing Affordability; Source: Taken from the presentation by Bullard (2012)

The question remains in what way this dissertation differs from the studies mentioned above. First of all both chapters, 1 and 2, include a rental market and feature a banking sector. In most of the literature the latter is

usually assumed away and financial frictions can only arise from the household's side. However, the banking sector played an important role before and after the financial crisis. Therefore, I relax this assumption and allow for banks, which themselves are credit constrained. Furthermore, the dissertation models endogenously the construction of new homes. A construction sector is often non-existent in many DSGE studies due to the assumption of a constant housing supply. However, figure 3 illustrates that construction activity of new homes<sup>3</sup> increased constantly between the early 1990s and 2006. With the contraction of the housing market construction activity drops dramatically and reaches a low in 2009.



Figure 3: Housing Starts: New Privately Owned Housing; Source: U.S. Census Bureau

The outline of this dissertation is as follows. Chapter 1 develops a DSGE model, which allows for a rental and owner-occupied housing market. Furthermore, it combines traditional financial frictions with disruptions arising from a banking sector. Additionally, news shocks are introduced into the TFP shock structure, following the work of Schmitt-Grohé and Uribe (2012). In chapter 2, I relax the assumption of a constant housing supply and account for price rigidities in the consumption sector. Chapter 3 presents a discussion about policy implications based on the results in chapter 2. Furthermore, it evaluates the welfare implications of such prudential measures. The relevant literature is discussed separately in each of the chapters. Finally, the dissertation finishes with concluding remarks. However, before we arrive at the main body of the thesis, the next section discusses briefly the estimation strategy used in this dissertation.

<sup>&</sup>lt;sup>3</sup>The U.S. Census Bureau refers to housing starts as the construction of new housing, where the "start of construction occurs when excavation begins for the footings or foundation of a building".

### **Bayesian Estimation**

A popular approach in applied work is the use of Bayesian techniques to determine the underlying model coefficients. One advantage of this estimation procedure is the incorporation of prior information about the parameters in question. Therefore, this section briefly outlines the estimation procedure applied to the models presented in this thesis. The heart of Bayesian econometrics is Bayes' theorem. Consider two random variables denoted by C and D. The joint probability of C and D occurring at the same time can be defined as:

$$p(C, D) = p(C | D) p(D),$$
 (1)

where p(C, D) stands for the probability of C and D occurring, p(C | D) is the conditional probability of C occurring depending on D having occurred and p(D) is the marginal probability of D. Alternatively, the joint probability of C and D could have been defined as:

$$p(C, D) = p(D | C) p(C).$$
 (2)

This allows us to solve for p(D | C) by equating both expressions, which yields the following key result:

$$p(D | C) = \frac{p(C | D)p(D)}{p(C)}.$$
(3)

We have derived Bayes' rule. However, in practice things are slightly more complicated. The majority of economic models consists of many different coefficients and when taken to the data, various observables have been chosen for the estimation. Let now y be a matrix or vector of data and  $\mathcal{B}$  a matrix or vector of parameters which aims to explain y. Based on the data y, we are interested in finding out about the values in  $\mathcal{B}$ . Applying Bayes' rule and replacing D by  $\mathcal{B}$  and C by y we end up with:

$$p(\mathcal{B} | y) = \frac{p(y | \mathcal{B})p(\mathcal{B})}{p(y)}.$$
(4)

For us  $p(\mathcal{B} | y)$  is the expression of fundamental interest. It answers the question what our knowledge of  $\mathcal{B}$  is, given the underlying data. As we are only concerned about the parameters described by  $\mathcal{B}$ , we can ignore the denominator p(y) since it does not involve  $\mathcal{B}$ . This leaves us with the result:

$$p(\mathcal{B} \mid y) \propto p(y \mid \mathcal{B})p(\mathcal{B}).$$
(5)

The left hand side  $p(\mathcal{B} | y)$  is better known as the posterior density. The first term on the right hand side  $p(y | \mathcal{B})$  is referred to as the likelihood function and  $p(\mathcal{B})$  stands for the prior density. The above relationship therefore states that the posterior density is proportional to the likelihood times the prior. It is also often called the posterior kernel. In other words, the posterior  $p(\mathcal{B} | y)$  combines the information contained in the data with our prior view. We can also treat equation 5 as an updating rule, where our prior beliefs are updated after having seen the data (Koop 2003).

The prior density  $p(\mathcal{B})$ , is not related to the data and therefore consists of any non-data information describing the parameter vector  $\mathcal{B}$ . Put differently, it summarises our knowledge about  $\mathcal{B}$  before seeing the data. For better illustration assume that  $\mathcal{B}$  is a parameter which represents returns to scale in the production of output. Usually it is a reasonable assumption that returns to scale are more or less constant. Thus, before we consult the data we have prior knowledge about  $\mathcal{B}$  and we would expect it to be roughly one. For this reason, the prior information is considered a controversial aspect of Bayesian techniques, as it is subjective. The likelihood function,  $p(y | \mathcal{B})$ , describes the density of the data conditional on the model's parameters. It is also known as the data generating process. For example, in the linear regression model it is often assumed that the disturbances follow a Normal distribution. This in turn implies that  $p(y | \mathcal{B})$  is described by a Normal density. Furthermore, a central part of Bayesian thinking is to accept that unknown things such as parameters, models and future data are random variables. It allows us to apply simple probabilistic rules and to conduct statistical inference (Koop 2003).

Applying Bayesian techniques to macro models has three central advantages. First, as pointed out by Fernández-Villaverde and Rubio-Ramírez (2004), Bayesian methods exhibit strong small sample properties. This is particularly important for real life applications. The Bayesian approach yields a very strong performance when used to estimate dynamic general equilibrium frameworks. Second, pre-sample information is in most cases extremely rich and very useful. Thus, it would be wrong not to take into account such valuable information and omit it from the analysis. For example, microeconometric evidence can help us to construct our priors. If there is a large set of studies which have estimated the discount factor of individuals between 0.9 and 0.99 then any sensible prior should reflect this information (Fernández-Villaverde 2010). Third, Bayesian methods allow us to compare different models based on their log marginal data density. The model with the highest log marginal density (i.e. the most likely model) is preferred over the other models with a lower density. The marginal density summarises the likelihood of the data conditional on the model (Koop 2003, An and Schorfheide 2007).

Having reviewed the fundamental theorem of Bayesian econometrics, we can now move on to the estimation strategy, following An and Schorfheide (2007). The models in this thesis are solved with the help of a first order perturbation approximation. We then can apply the Kalman filter to the resulting linear state space system. This allows us to construct the likelihood function of the underlying model. The next step involves finding the mode(s) of the posterior distribution, which is obtained by maximising the posterior kernel with respect to each parameter. The posterior distribution is simulated around the computed mode using the Random Walk Metropolis-Hastings (RWMH) algorithm. The RWMH procedure is useful in cases where we cannot find a good approximation density for the posterior (Koop 2003).

More technically, the detailed steps are:

- 1. Maximise the log posterior kernel log  $p(y | B) + \log p(B)$ , with respect to every parameter in B, in order to find the posterior mode  $B^*$ . This is done by using a numerical optimisation algorithm.
- 2. Obtain  $\widetilde{\Pi}$ , which is the inverse of the Hessian at the posterior mode  $\mathcal{B}^*$ .
- 3. Define a starting value by taking a draw  $\mathcal{B}^{(0)}$  from the proposal distribution  $N(\mathcal{B}^*, c_0^2 \widetilde{\Pi})$  or directly set a specific starting value.
- 4. For  $s = 1, ..., n_{sim}$ , draw  $\Delta$  from the proposal distribution  $N(\mathcal{B}^{(s-1)}, c^2 \widetilde{\Pi})$ . The total number of iterations is given by  $n_{sim}$ . A jump from  $\mathcal{B}^{(s-1)}$  is accepted ( $\mathcal{B}^{(s)} = \Delta$ ) with probability  $min\{1, r(\mathcal{B}^{(s-1)}, \Delta|y)\}$ and rejected ( $\mathcal{B}^{(s)} = \mathcal{B}^{(s-1)}$ ) otherwise. Let the acceptance probability be

$$r(\mathcal{B}^{(s-1)}, \Delta|y) = \frac{p(y|\Delta)p(\Delta)}{p(y|\mathcal{B}^{(s-1)})p(\mathcal{B}^{(s-1)})} = \frac{Posterior(\Delta)}{Posterior(\mathcal{B}^{(s-1)})}.$$
(6)

Note that the scale factor  $c^2$  effects the acceptance rate and should be adjusted in such a way that the Markov chain explores the entire domain of the posterior distribution. This is crucial, as otherwise the chain gets stuck in tale or other regions of the posterior density. For example if the acceptance rate is too small, then the vast majority of candidate draws  $\Delta$  are always rejected.<sup>4</sup> This implies that the chain doest not move sufficiently and we need a huge number of  $n_{sim}$  for the chain to explore the entire posterior density. On

<sup>&</sup>lt;sup>4</sup>A high and low acceptance rate is also reflected by a large and small covariance matrix, respectively. Hence, adjusting the scale factor  $c^2$  allows us to alter the acceptance probability. See Koop (2003), pp. 97-99 for a detailed discussion.

the other hand, a high acceptance probability indicates that  $\Delta$  and  $\mathcal{B}^{(s-1)}$  will tend to be very close to each other. As before, in order for the chain to cover the entire posterior density, we require an extremely large value for  $n_{sim}$  (Koop 2003). Having successfully constructed the posterior distribution with the algorithm above, we then choose the posterior mean as the point estimate of the parameter.

It is important to highlight that the above algorithm relies on the inverse of the Hessian, which is often the most efficient way to estimate a model. However, Chib and Greenberg (1995) have shown that asymptotically the Monte Carlo Markov Chain explores the entire posterior parameter space from any point. In fact we only require a positive definite proposal density, which makes the use of the inverse Hessian redundant. However, as this is an asymptotic property, we would require a higher number of draws in order to construct the ergodic distribution. Therefore, working with the inverse Hessian is preferred to alternative procedures.

As we are going to see later, the chosen prior distributions of the parameters in question are in line with the existing literature. This avoids arbitrarily picking the parameter priors. Bayesian estimation allows for prior beliefs about the model coefficients, which is different to the maximum likelihood approach. The latter focusses just on maximising the likelihood (i.e.  $p(y|\mathcal{B})$ ) and therefore it is not necessary to introduce prior beliefs. As Koop (2003) describes it, Bayesian estimation can be treated as an updating process, where prior knowledge is injected and then updated by the data. Thus, the resulting posterior distribution contains data and non-data information. Given the prior distributions and the underlying data, the frameworks presented in this thesis can be considered as the most likely DSGE models.<sup>5</sup> Having reviewed the estimation approach used in this analysis, we can now progress to the first chapter of the dissertation.

<sup>&</sup>lt;sup>5</sup>Note, a comparison between both models, based on the log marginal densities, would be invalid due to different datasets and (implicitly) truncated prior distributions.

Chapter 1

What Explains the Latest Increase in the U.S. Rental Housing Sector? Evidence from an Estimated DSGE Model

### 1.1 Introduction

The 2007 financial crisis has not only left many banks and businesses struggling but also triggered a change in the U.S. homeowner structure. Looking at recent housing inventory data, it is evident that there has been a shift away from owner-occupied towards rental housing. Figure 1.1 depicts the rental housing stock relative to the owner-occupied housing stock. The series is log transformed and quadratically detrended. The ratio consistently increased between 1985 and the mid 1990s. Due to the efforts of the United States Department of Housing and Urban Development, owner-occupied housing rises and causes the ratio to fall. However, with the start of the financial crisis the ratio kept increasing and reached a new high in 2010. This development is due to a rise in the rental housing inventory and a decrease in owner-occupied housing.<sup>6</sup>



Figure 1.1: Ratio of rental to owner-occupied housing: 1985Q1 - 2010Q4, Source: U.S. Census Bureau

Recent research by the Joint Center for Housing Studies (2013) confirms that there has been an increase in the demand for rental property over owner-occupied housing. Not surprisingly the study identifies the Great Recession as one of the key driving forces behind the latest expansion of the rental market. Loan defaults and home foreclosures have changed the status of many households from homeowners to renters. This triggered an increase in the rental housing stock, as former owner-occupied properties became rental homes. Additionally to insolvency, households experienced further risks of home ownership during the crisis. One example is the inflicted wealth loss due to decreasing home values. Furthermore, news about the economic outlook before and after the crisis could have also influenced households' decisions to either buy a new home or stay in a rental property. The most important contribution of this chapter is the analysis of how banking

 $<sup>^{6}</sup>$ The ratio is the fraction of the two time series depicted in figure 1.

frictions, loan defaults and productivity news have affected the rental and owner-occupied housing markets. So far studies have ignored these crucial factors when it comes to studying the dynamics of both housing sectors. Therefore, this chapter develops a comprehensive DSGE framework to shed new light on this topic.

As I take the model to the data, I use a modified version of the extended Iacoviello (2015) framework which features loan defaults of households and a rich set of frictions. The environment is inhabited by three economic agents: a heterogeneous household, who is divided into a saver and a borrower, bankers and entrepreneurs. In this model banks take up an intermediary role and act as a valve for the flow of resources between lenders and borrowers. More specifically, banks provide household borrowers and entrepreneurs with loans and collect deposits from savers. In addition to this, banks are exposed to loan defaults which arise from the supply and demand side. Hence, allowing for banks to exist introduces a new channel into the model and combines financial and banking frictions. As Iacoviello (2015) shows,<sup>7</sup> the existence of a banking sector has an amplifying impact on house prices which is therefore of particular importance for this study. The second reason why banks are in the model, is based on the results of a Bayesian model comparison conducted by Iacoviello (2015). It shows that the model with a banking sector is preferred to the one without.<sup>8</sup> Finally, as the financial crisis showed, banks played an important role in the latest boom and bust of the U.S. economy.

I assume that only savers accumulate rental housing and earn income by letting it to borrowers.<sup>9</sup> This in turn means that borrowers have to choose between either owner-occupied or rental housing. Hence, it is assumed that these two housing types are substitutes in the borrower's utility function. In terms of modelling I follow the approach described in Mora-Sanguinetti and Rubio (2014). Entrepreneurs form the supply side of the model economy, as they hire labour and capital from household savers in order to produce the final good. Moreover, entrepreneurs also accumulate real estate which enters the production function as an additional input. As household borrowers, entrepreneurs face a collateral constraint which determines the amount of loans they can obtain from banks. News is implemented in the TFP shock process and captures how agents react to future changes in productivity. This builds on the fact that usually a rise in TFP materialises in a GDP increase. Similarly, the opposite happens for a drop in TFP. Hence, a positive news shock for example influences the agents' resource allocation today, as they have information that future productivity and output is about to increase.

<sup>&</sup>lt;sup>7</sup> Iacoviello (2015) compares the impulse responses of his banking sector model to a framework with traditional financial frictions. In the non-banking model frictions arise, because entrepreneurs and household borrowers directly obtain loans from household savers.

<sup>&</sup>lt;sup>8</sup>The model without banks relies on traditional financial frictions, where patient households act as lenders.

<sup>&</sup>lt;sup>9</sup>For simplicity I assume that savers do not demand rental services and hence preferences are not homogeneous across impatient and patient households. Ortega, Rubio, and Thomas (2011) show that their main findings are only marginally affected if they relax this assumption.

A key finding of this paper is that housing and rental markets are significantly driven by TFP news. The model results show that more than 60 percent of rental and house price fluctuations are determined by productivity news shocks. However, the latest changes in the U.S. home ownership structure are determined by a combination of different shocks. The key contributors are TFP news, default, preferences<sup>10</sup> and bank lending. Before the financial crisis, loan-to-value and investment innovations accounted for a substantial fraction of the decline in the rental to owner-occupied housing ratio. Interestingly, productivity news shocks are found to be a dominant driving force behind the recent contraction of house prices. Rental price movements are mainly determined by technology, preference and housing demand shocks. The magnitude of the shocks increases after the year 2000 and peaks during the financial crisis. I reach the same conclusion as Sun and Tsang (2017) that variations in house prices remain almost unaffected by the housing demand shock. The model results discussed in this paper are related to a part of the housing literature which identifies fundamentals as the main cause of the housing boom. However, the majority of research finds that the housing demand shock takes up a very central role in explaining the rapid growth and contraction of the housing market. The only problem of this disturbance is its source, as this shock typically absorbs socio-economic factors. Therefore it is difficult to identify what factors drive the housing demand shock. In fact, housing demand and preference shocks appear to be determined by the same variables (see Sun and Tsang (2017)).<sup>11</sup> The aim of this chapter is not to prove an entire literature and its empirical evidence on the housing boom wrong. But rather to offer additional evidence that fundamentals also played an important role in the latest upswing and contraction of the housing market.

Since the financial crisis, the housing literature has experienced rapid growth. However, estimated DSGE models which take into account the rental housing sector are scarce. The most closely related article to this study is the paper by Sun and Tsang (2017). The authors estimate a modified version of the Iacoviello and Neri (2010) framework, which is one of the workhorse models in the business cycle housing literature. Sun and Tsang (2017) introduce a rental market via the supply side of the economy. Entrepreneurs provide borrowers and savers with rental services by using retailers. This is different to the approach described in this paper. Additionally, even though Sun and Tsang (2017) estimate their model on a data set which contains information about the financial crisis, they do not allow for loan defaults and abstract from banking frictions. However, according to the Joint Center for Housing Studies (2013), loan defaults have played a crucial role in the latest developments of the housing sector. Lambertini, Mendicino, and Punzi (2017) use a calibrated

 $<sup>^{10}</sup>$ Note, I use the terms preference shock, aggregate spending shock and intertemporal preference shock interchangeably.

<sup>&</sup>lt;sup>11</sup>The authors find that the housing demand shock is determined by different population age shares, consumer sentiment and the employment-population ratio. In contrast, the preference shock is effected by population age, consumer sentiment and uncertainty. These factors are difficult to model in a DSGE context and get therefore absorbed by the shock processes. A misspecification is likely to cause a high correlation of the smoothed (estimated) shock series. This is necessary such that the model fits the data (Paccagnini 2017).

version of the Iacoviello and Neri (2010) model, in order to investigate the effects of news shocks on the housing economy. For this reason they introduce anticipated components into the shock processes of their model. A central finding of their paper is that housing booms are produced by positive TFP news in the consumption sector. Furthermore, house price increases are triggered by negative news on productivity in the construction sector and by news on a cut of the policy rate. This confirms the empirical results outlined in this chapter. However, the authors abstract from a rental and banking sector. In contrast to the previous two studies, Miao, Wang, and Zha (2014) do not only observe the smoothness of rental prices but also notice that variations in the price-rent ratio seem to move with output. In order to account for those features, their medium-scale DSGE model accommodates a rental market which has been introduced via the household's problem. A central feature of their model is the fact that firms face a liquidity constraint. The estimation output shows that the liquidity premium shock accounts for most of the price-rent fluctuations and explains 30 percent of the output variations over a forecast horizon of six years.

Research by Mora-Sanguinetti and Rubio (2014), Rubio (2014) or Ortega, Rubio, and Thomas (2011) analyse the impact of various policy and non-policy factors on the rental market. For example, Mora-Sanguinetti and Rubio (2014) evaluate the macroeconomic impact of two different housing market reforms in the case of Spain. Those measures include a rise in the VAT rate for new home buyers and the removal of the deduction for home purchases. The study finds that both reforms trigger an increase in the rental housing sector but lead to a drop in GDP and employment, which results from a contraction of the construction sector. Further, Rubio (2014) looks at the effect of monetary policy and subsidies on homeownership. The author's DSGE model shows that an increase in interest rates leads to contraction in economic activity and hurts at the same time home buyers. Higher interest rates on loans decrease owner-owner occupied housing and stimulate rental housing. Furthermore, the study shows that a subsidy on home purchases has two implications. First, it diminishes the share of rental housing. Second, the subsidy leads to rise in household debt. As in the previous paper, Ortega, Rubio, and Thomas (2011) consider the effects of subsidies towards home purchases. Despite this similarity the authors use a small open economy DSGE model for Spain. The results indicate that scrapping the home purchases subsidy results in a rise of rental housing. Furthermore, subsidies targeting rent payments and improvements in the production of rental services produce an identical outcome as the house purchases subsidy.

However, at the core of these studies lies a simulated DSGE model which has not been taken to the data. Therefore, there is no empirical evidence for some of the calibrated parameters, especially the ones effecting the rental market. This paper can be also related to a non DSGE-literature, which focuses on the pricerent ratio. The fact that rents appear to be smoother in the data than house prices has triggered various research projects, investigating the dynamics of the price-rent ratio. Studies by Favilukis, Ludvigson, and Van Nieuwerburgh (2017), Sun and Tsang (2018) or Fairchild, Ma, and Wu (2015) analyse the dynamics of the price-rent ratio from different angles.

The paper by Favilukis, Ludvigson, and Van Nieuwerburgh (2017) develops a general equilibrium model equipped with two new features which have not been considered by current macro housing studies. The authors introduce aggregate business cycle risk and a realistic distribution of wealth. The latter is captured by two different types households. A small minority of households are born "rich", as they are given a deliberate bequest. The majority of households are given either no or a very low amount of bequest. Hence, these type of households have to start working life with a small fraction of wealth. The study finds that a house price boom is driven by a loosening of financing constraints. Furthermore, the results show that a drop in the housing risk premium entirely determines the boom in house prices. The risk premium is what the authors define as the rise in the expected future return of housing in relation to the interest rate. Finally, based on their model findings, Favilukis, Ludvigson, and Van Nieuwerburgh (2017) also point out that low interest rates fail to explain high home values.

Sun and Tsang (2018) take a different approach with a VAR model estimated on data consisting of U.S. Metropolitan Statistical Areas (MSAs). The bias-corrected estimates show that higher regulated MSAs exhibit stronger variations in the rent-price ratio. The authors also find that a greater fraction of these variations is explained by real interest rates. Moreover, the response of house prices to an interest rate shock is stronger in more regulated MSAs. In contrast to the two papers above, Fairchild, Ma, and Wu (2015) construct a dynamic factor model in order to investigate the price-rent ratios of 23 major housing sectors. They decompose the price-rent ratio into independent local and national factors and relate them to housing market fundamentals. Their findings suggest that a large fraction of housing market fluctuations occur on a local level. However, since 1999 national factors have become more important than local ones in explaining housing market fluctuations. Overall, the study finds that changes in the housing market fluctuations.

The structure of the chapter is organised as follows. Section 1.2 outlines the model economy and illustrates how rental and owner-occupied housing is implemented into the framework. Section 1.3 and Section 1.4 describe the data used for the estimation process and discuss the prior and posterior distributions. The mean impulse responses, the shock and variance decompositions are presented in Section 1.5. Robustness tests are performed and illustrated in Section 1.6 and section 1.7 concludes.

### 1.2 The Model

The model economy is based on the extended setup of the Iacoviello (2015) paper, which features three different types of agents: households, banks and entrepreneurs. Following the approach of Mora-Sanguinetti and Rubio (2014), I implement a home ownership structure into the framework mentioned above. Savers are now able to convert a certain fraction of their owner-occupied housing stock into rental services, which they can let to borrowers. This setup enables me to study the behavior of the rental and mortgaged housing market over the business cycle and in the light of an upcoming financial crisis. Each economic agents is represented by a continuum of measure one.

#### 1.2.1 Patient Households

A continuum of measure one savers discount at rate  $\beta_H$  and maximise their lifetime utility by choosing consumption  $C_{H,t}$ , housing services  $H_{H,t}$  and hours worked  $N_{H,t}$ .

$$E_0 \sum_{t=0}^{\infty} \beta_H^t \Big[ A_{p,t} (1-\eta) \log(C_{H,t} - \eta C_{H,t-1}) + j A_{j,t} A_{p,t} \log(H_{H,t}) + \tau \log(1-N_{H,t}) \Big]$$
(1.1)

subject to the following budget constraint:

$$C_{H,t} + \frac{K_{H,t}}{A_{K,t}} + D_t + q_t \left[ (H_{H,t} - H_{H,t-1}) + (H_{r,t} - H_{r,t-1}) \right] + ac_{KH,t} + ac_{DH,t} = \left( R_{M,t} z_{KH,t} + \frac{1 - \delta_{KH,t}}{A_{K,t}} \right) K_{H,t-1} + R_{H,t-1} D_{t-1} + W_{H,t} N_{H,t} + q_{r,t} \Omega_r H_{r,t}$$

$$(1.2)$$

The parameter  $\eta$  in the patient household's utility function represents external habits in consumption. The preference shock  $A_{p,t}$  effects simultaneously the choices of consumption and housing, whereas  $A_{j,t}$  stands for the housing demand shock. The labour supply parameter is represented by  $\tau$  and the parameter j captures the utility weight of housing and the degree of proportionality between housing services and its stock.<sup>12</sup> The patient household's budget constraint shows that savers deposit  $D_t$  and receive a gross return of  $R_{H,t}$ . Furthermore they accumulate owner-occupied real estate  $H_{H,t}$  and rental housing  $H_{R,t}$ , where  $q_t$  is the price of housing. Savers provide capital  $K_{H,t}$  to entrepreneurs which are multiplied by the utilisation rate  $z_{KH,t}$ . The rental rate of capital is  $R_{M,t}$  and capital itself depreciates according to a depreciation function denoted

<sup>&</sup>lt;sup>12</sup>The stream of housing services is therefore equal to the product of the housing stock times the proportionality constant j. Hence, the flow of housing services is a fraction of the housing stock. Normalising j = 1 would imply a one-to-one relationship between the stock of housing and service.

by  $\delta_{KH,t}$ . Savers are able to convert their rental property into rental services  $Z_t$ , which they then let to borrowers. The transformation process is captured by the production function  $Z_t = \Omega_r H_{r,t}$ . The parameter  $\Omega_r$  measures the efficiency in converting rental property into rental services. Note that I interpret  $\Omega_r$  as a pure efficiency parameter, hence it is restricted to take values greater than unity. In other words, savers cannot use their entire rental housing stock to produce rental services.  $\Omega_r$  therefore acts as a friction between the supply and demand of rental housing services.<sup>13</sup> However, in Ortega, Rubio, and Thomas (2011) and Mora-Sanguinetti and Rubio (2014) the efficiency parameter  $\Omega_r$  is allowed to exceed 1. Sun and Tsang (2017) for example assume a one-to-one relationship between rental services and the rental housing stock. Patient households receive rent payments according to  $q_{r,t}\Omega_r H_{r,t}$  at a rental rate  $q_{r,t}$ . The terms  $a_{CKH,t}$  and  $a_{CDH,t}$  are the respective (quadratic and convex) external adjustment costs for capital and deposits. They are defined as:

$$ac_{KH,t} = \frac{\phi_{KH}}{2} \frac{(K_{H,t} - K_{H,t-1})^2}{K_H}$$
(1.3)

$$ac_{DH,t} = \frac{\phi_{DH}}{2} \frac{(D_t - D_{t-1})^2}{D}$$
(1.4)

 $K_H$  and  $D_H$  are the respective steady state expressions for capital and deposits. The depreciation function  $\delta_{KH,t}$  takes the following form:

$$\delta_{KH,t} = \delta_{KH} + b_{KH} \left[ 0.5 \,\zeta'_H z_{KH,t}^2 + (1 - \zeta'_H) z_{KH,t} + (0.5 \,\zeta'_H - 1) \right] \tag{1.5}$$

The functional form of the depreciation function is the same as the one described in Iacoviello (2015). It assumes that the depreciation of physical capital is convex in the utilisation rate  $z_{KH,t}$ . The curvature of the depreciation function is determined by  $\zeta'_H = \frac{\zeta_H}{1-\zeta_H}$ . A value of  $\zeta_H = 0$  leads to  $\zeta'_H = 0$ . Letting  $\zeta_H$  approach 1, results in  $\zeta'_H$  approaching infinity and implies that  $\delta_{KH,t}$  remains constant. Defining  $b_{KH} = \frac{1}{\beta_H} + 1 - \delta_{KH}$ ensures a steady state utilisation rate  $z_{KH}$  of one. As habits, adjustment costs are assumed to be external. Finally, let  $u_{HH,t} = \frac{jA_{j,t}A_{p,t}}{H_{H,t}}$ . The equilibrium conditions of the patient household are:

$$C_{H,t}: \qquad u_{CH,t} = \frac{A_{p,t}(1-\eta)}{C_{H,t} - \eta C_{H,t-1}}$$
(1.6)

$$D_t: \qquad u_{CH,t}\left(1 + \frac{\partial ac_{DH,t}}{\partial D_t}\right) = \beta_H E_t(u_{CH,t+1}R_{H,t}) \tag{1.7}$$

<sup>&</sup>lt;sup>13</sup>One interpretation of this would be if a households decides to move out of his rental home it will take some until it can be rented out again.

$$N_{H,t}: \qquad u_{CH,t}W_{H,t} = \frac{\tau}{1 - N_{H,t}}$$
 (1.8)

$$K_{H,t}: \qquad \beta_H E_t \Big[ u_{CH,t+1} \bigg( R_{M,t+1} z_{KH,t+1} + \frac{1 - \delta_{KH,t+1}}{A_{K,t+1}} \bigg) \Big] = u_{CH,t} \bigg( \frac{1}{A_{K,t}} + \frac{\partial a c_{KH,t}}{\partial K_t} \bigg)$$
(1.9)

$$H_{H,t}: \qquad q_t u_{CH,t} = u_{HH,t} + \beta_H E_t(q_{t+1} u_{CH,t+1}) \tag{1.10}$$

$$z_{KH,t}: \qquad R_{M,t} = \frac{\partial \delta_{KH,t}}{\partial z_{KH,t}} \tag{1.11}$$

$$H_{R,t}: \qquad \beta_H E_t(u_{CH,t+1}q_{t+1}) = u_{CH,t}(q_t - q_{r,t}\,\Omega_r) \tag{1.12}$$

#### 1.2.2 Impatient Households

There are two substantial differences between patient and impatient households. First of all, impatient households discount at a rate  $\beta_S < \beta_H$ . Second, borrowers have access to the loan market and are able use their current mortgaged housing stock  $H_{S,t}$  as collateral. Hence, those type of households face a collateral constraint. The borrower's utility function is given by:

$$E_0 \sum_{t=0}^{\infty} \beta_S^t \Big[ A_{p,t} (1-\eta) \log(C_{S,t} - \eta C_{S,t-1}) + j A_{j,t} A_{p,t} \log(\widetilde{H}_{S,t}) + \tau \log(1-N_{S,t}) \Big]$$
(1.13)

where

$$\widetilde{H}_{S,t} = \left[\theta_S^{1/\kappa_s}(H_{S,t})^{\frac{\kappa_s-1}{\kappa_s}} + (1-\theta_S)^{1/\kappa_s}(Z_t)^{\frac{\kappa_s-1}{\kappa_s}}\right]^{\frac{\kappa_s}{\kappa_s-1}}$$

subject to

$$C_{S,t} + q_{r,t}Z_t + q_t(H_{S,t} - H_{S,t-1}) + R_{S,t-1}L_{S,t-1} - \varepsilon_{H,t} + ac_{SS,t} = L_{S,t} + W_{S,t}N_{S,t}$$
(1.14)

where

$$ac_{SS,t} = \frac{\phi_{SS}}{2} \frac{(L_{S,t} - L_{S,t-1})^2}{L_S}$$
(1.15)

and

$$L_{S,t} \le \rho_S L_{S,t-1} + (1 - \rho_S) m_S A_{MH,t} E_t \left(\frac{q_{t+1}}{R_{S,t}} H_{S,t}\right)$$
(1.16)

Impatient households have to decide whether they want to take out a mortgage and buy a house, or live in a rental property provided by the patient households. For this reason borrowers derive utility from both, mortgaged housing and rental services, which is captured by the CES aggregator  $\tilde{H}_{S,t}$ .  $\theta_S$  is the preference share for mortgaged housing and  $\kappa_S$  stands for the elasticity of substitution between rental and owneroccupied housing. The expenditure side of the budget constraint contains rental services  $Z_t$ , the mortgaged housing stock  $H_{S,t}$  and loan payments  $L_{S,t}$  at a gross interest rate  $R_{S,t}$ . The term  $ac_{SS,t}$  reflects the loan adjustment costs of the impatient household. The budget constraint of impatient households contains a positive wealth redistribution shock  $\varepsilon_{H,t}$ , which occurs when borrowers default on their loans.<sup>14</sup> Those loan defaults hit the bank balance sheet in the form of losses but leave households better off, as they do not have to pay back their debt. The default shock  $\varepsilon_{H,t}$  therefore transfers wealth from banks to borrowers.

The borrowing constraint shows that the current value of loans depends on last period's stock of debt plus the collateral in the form of the expected future value of housing. The inertia  $\rho_S$  ensures a slow adjustment of the collateral constraint and  $A_{MH,t}$  represents a positive shock, which increases the quantity borrowed by the household. This shock can be interpreted as laxer credit-screening standards by banks, which increases the loan-to-value ratio (LTV)  $m_S$ . The latter can be adjusted in a countercyclical manner and is therefore often interpreted as a macroprudential parameter.

It is important to highlight that the above formulation does not imply that impatient households live simultaneously in a mortgaged and rented home. Here it is assumed that some fraction of the large borrower-type household chooses to live in a rental house and the rest in a owner-occupied home. Hence, aggregating over all borrower-type households leaves us with the above budget constraint. This is equivalent to the "within a family" approach of Gertler and Karadi (2011).

The first order conditions are:

$$C_{S,t}: \qquad u_{CS,t} = \frac{A_{p,t}(1-\eta)}{C_{S,t} - \eta C_{S,t-1}}$$
(1.17)

$$L_{S,t}: \qquad u_{CS,t}\left(1-\lambda_{S,t}-\frac{\partial ac_{SS,t}}{\partial L_{S,t}}\right) = \beta_S E_t[u_{CS,t+1}(R_{S,t}-\rho_S\lambda_{S,t+1})] \tag{1.18}$$

<sup>&</sup>lt;sup>14</sup>Default in this model is assumed to be an exogenous process. However, default can be endogenised by defining a threshold value which ultimately determines whether agents are unable to pay back their mortgages. See for example the work by Lambertini, Nuguer, and Uysal (2017).

$$N_{S,t}: \qquad u_{CS,t}W_{S,t} = \frac{\tau}{1 - N_{S,t}}$$
(1.19)

$$H_{S,t}: \qquad u_{HS,t} + \beta_S E_t(u_{CS,t+1}q_{t+1}) = u_{CS,t} \Big[ q_t - \lambda_{S,t}(1-\rho_S) m_S A_{MH,t} E_t \left(\frac{q_{t+1}}{R_{S,t}}\right) \Big]$$
(1.20)

$$Z_t: u_{ZS,t} = q_{r,t} u_{CS,t} (1.21)$$

where  $u_{ZS,t} = A_{j,t}A_{p,t}\frac{j}{\tilde{H}_{S,t}}\left[\frac{(1-\theta_S)\tilde{H}_{S,t}}{Z_t}\right]^{\frac{1}{\kappa_S}}$  and  $u_{HS,t} = A_{j,t}A_{p,t}\frac{j}{\tilde{H}_{S,t}}\left[\frac{\theta_S\tilde{H}_{S,t}}{H_{S,t}}\right]^{\frac{1}{\kappa_S}}$ . The entrepreneur's and banker's problem remain unchanged and are modelled as described in Iacoviello (2015).<sup>15</sup>

#### 1.2.3 Shock Processes

The model contains in total eight structural shocks, which follow the usual AR(1) structure. The respective mean zero shock processes are: the default shock of entrepreneurs  $\varepsilon_{E,t}$ , default shock of impatient households  $\varepsilon_{H,t}$ , housing preference shock  $A_{j,t}$ , capital shock  $A_{K,t}$ , LTV ratio shock of entrepreneurs  $A_{ME,t}$ , LTV ratio shock of impatient households  $A_{ME,t}$ , aggregate spending shock  $A_{p,t}$  and the technology shock  $A_{Z,t}$ .

$$\varepsilon_{E,t} = \rho_{be} \varepsilon_{E,t-1} + \upsilon_{E,t} \qquad \upsilon_E \sim N(0, \sigma_{be}) \tag{1.22}$$

$$\varepsilon_{H,t} = \rho_{bh} \varepsilon_{H,t-1} + \upsilon_{H,t} \qquad \upsilon_H \sim N(0, \sigma_{bh}) \tag{1.23}$$

$$\log A_{j,t} = \rho_j \log A_{j,t-1} + v_{j,t} \qquad v_{j,t} \sim N(0,\sigma_j)$$
(1.24)

$$\log A_{K,t} = \rho_j \log A_{K,t-1} + v_{K,t} \qquad v_{K,t} \sim N(0,\sigma_k)$$
(1.25)

$$\log A_{ME,t} = \rho_{me} \log A_{ME,t-1} + v_{ME,t} \qquad v_{ME,t} \sim N(0,\sigma_{ME})$$
(1.26)

$$\log A_{MH,t} = \rho_{mh} \log A_{MH,t-1} + v_{MH,t} \qquad v_{MH,t} \sim N(0,\sigma_{MH})$$
(1.27)

$$\log A_{p,t} = \rho_p \log A_{p,t-1} + v_{p,t} \qquad v_{p,t} \sim N(0,\sigma_p)$$
(1.28)

$$\log A_{Z,t} = \rho_z \log A_{Z,t-1} + v_{z,t}^0 + v_{z,t-4}^4 + v_{z,t-8}^8$$
(1.29)

where

<sup>&</sup>lt;sup>15</sup>The technical appendix provides a detailed description of the banker's and entrepreneur's problem.

$$v_{z,t}^0 \sim N(0,\sigma_z^0), \ v_{z,t}^4 \sim N(0,\sigma_z^4), \ v_{z,t}^8 \sim N(0,\sigma_z^8)$$

The technology shock features an anticipated and unanticipated component, denoted by  $v_{z,t-4}^4$  and  $v_{z,t}^0$  respectively. In terms of notation and structure, the shocks are modelled as described in Schmitt-Grohé and Uribe (2012) or Born, Peter, and Pfeifer (2013). The TFP element  $v_{z,t-4}^4$  represents a four-period-ahead announcement about the level of technology. Economic agents have already learned about this anticipated innovation in period t - 4 but it will only effect the level of  $A_{z,t}$  in period t. An alternative interpretation of this is that the today's news about the level of technology  $v_{z,t}^4$  only trigger a change in period t + 4 of future TFP, i.e.  $A_{z,t+4}$ . Similarly,  $v_{z,t}^8$  corresponds to a eight-period-ahead announcement about the level of technology. In contrast,  $v_{z,t}^0$  is the surprise component, which corresponds to the standard RBC type technology shock. A real life example to illustrate the mechanism of a news shock is the discovery of a giant, new oil field. It can take on average four to six years until the discovery materialises in an increase in GDP (Arezki, Ramey, and Sheng 2017).

### **1.3** Data and Calibration

I re-estimate the model using a slightly modified version of the Iacoviello (2015) dataset,<sup>16</sup> which consists in total of ten observables: loan losses of businesses, loan losses of households, loans to business, loans to households, real consumption, real nonresidential investment, real house prices, real housing rents and the ratio of rental to owner-occupied housing. The data source for housing rents is provided by the Bureau of Labor statistics and the rental to owner-occupied housing ratio has been obtained from the U.S. Census Bureau. In the model this ratio corresponds to  $\frac{H_{r,t}}{H_{H,t}+H_{S,t}}$ , where owner-occupied housing is defined as  $H_{H,t} + H_{S,t}$ . The model's parameters are estimated on U.S. quarterly data ranging from 1985Q1 to 2010Q4. Each time series has been log transformed and detrended by the same quadratic trend, except the data for loan losses which have been demeaned. Thus, all corresponding model observables have a mean of zero. Figure 1.2 presents the time series used for the estimation process in percentage deviation from their steady states.<sup>17</sup>

 $<sup>^{16}</sup>$ See the data appendix outlined in Iacoviello (2015).

<sup>&</sup>lt;sup>17</sup>Note, for the estimation procedure the observables are fed into model in absolute deviations and therefore are not multiplied by the factor 100.



Figure 1.2: Data used for estimation

*Notes:* The y-axis depicts percentage deviation from a quadratic trend. Loan losses (households/entrepreneurs) are shown as a percentage share of GDP and are demeaned.

Real Consumption starts to drop sharply in 1990 and falls slightly below -4 percent in the last quarter of 1991. The reason behind this development is the 1990-1991 recession. Walsh (1993) identifies contractionary monetary policy and the drop in business and consumer confidence, due to the Gulf crisis, as the main causes of the recession. The Federal Reserves' target at the time was to gradually lower inflation until it would be close to zero. However, these restrictive monetary policy actions had an additional weakening impact on the U.S. economy. The 1990-1991 recession could also explain the sudden decline of most the observables in the early 1990s. Further government actions such as the Housing and Community Development Act of 1987 and 1992 may have increased residential investment and therefore contributed the decline in business investment.

As in Iacoviello (2015), I calibrate the discount factors  $\beta_H$ ,  $\beta_S$ ,  $\beta_B$ ,  $\beta_E$ ; the total capital share in production  $\alpha$ ; the leverage parameters  $m_S$ ,  $m_H$ ,  $m_K$ ; the ratio of wages paid in advance  $m_N$ ; the liability to asset ratios  $\gamma_E$ ,  $\gamma_S$ ; the housing preference share j, the depreciation rates  $\delta_{KE}$ ,  $\delta_{KH}$ ; and the labour supply parameter  $\tau$ . Table 1.1 shows the calibrated parameters. Setting the discount factor  $\beta_H = 0.9925$  yields a 3 percent annual steady state return on deposits.<sup>18</sup> Calibrating  $\beta_B$  and  $\beta_S$  at 0.945 and 0.94 respectively, implies a 5 percent annual steady state return on loans. By choosing  $m_N = 1$  it is assumed that all labour has to be paid in advance. The assumption that the borrower's discount factor is smaller than a weighted average

<sup>&</sup>lt;sup>18</sup>This can be easily shown by using the following transformation:  $R_H^{annual} = 400 \cdot (R_H^{quarterly} - 1)$ .

of the banker's and saver's discount factors ensures that impatient households want to borrow and to be credit constrained in equilibrium (Iacoviello 2015). This also explains the difference between the saver's and banker's discount factor. Based on the underlying calibration, the model produces a steady state investmentto-output ratio of 0.25. Consistent with the data, the calibrated parameters show that the owner-occupied housing stock is substantially larger than the rental housing stock.

Parameter		Value
Discount factor Saver (S)	$\beta_H$	0.9925
Discount factor Borrower (HB)	$\beta_S$	0.94
Discount factor Banker	$\beta_B$	0.945
Discount factor Entrepreneur (E)	$\beta_E$	0.94
Total capital share in production	$\alpha$	0.35
Housing LTV ratio, HB	$m_S$	0.9
Housing LTV ratio, E	$m_H$	0.9
Capital LTV ratio, E	$m_K$	0.9
Wage bill paid in advance	$m_N$	1
Bankers' liabilities to assets ratios	$\gamma_E,\gamma_S$	0.9
Housing preference share	j	0.075
Capital depreciation rates	$\delta_{KE}, \delta_{KH}$	0.035
Labor supply parameter	au	2

Table 1.1: Calibrated Parameters

### **1.4** Prior and Posterior Distributions

Following An and Schorfheide (2007), I use Bayesian techniques to obtain estimates of the underlying structural parameters. The likelihood function is constructed with the help of the Kalman filter and the mode of the posterior distribution is found by applying a numerical optimisation algorithm. Finally the posterior distribution is simulated around the mode using the Random-Walk Metropolis (RWH) algorithm. To ensure full parameter convergence, 1,000,000 draws and two chains have been chosen for the RWH procedure, with a burn-in rate of 50 percent. Table 1.2 and 1.3 present the prior and simulated posterior distributions of the underlying structural parameters and shock processes.

Parameter		Prior Dis	tributior	1	Posterio	or Distrib	ution
		Density	Mean	Std	10%	Mean	90%
Habit in consumption	η	Beta	0.5	0.15	0.3184	0.4013	0.4801
Deposit adj. cost, Banks	$\phi_{DB}$	Gamma	0.25	0.125	0.0803	0.2749	0.4629
Deposit adj. cost, S	$\phi_{DH}$	Gamma	0.25	0.125	0.0289	0.1203	0.2054
Capital adj. cost, E	$\phi_{KE}$	Gamma	1	0.5	3.7735	4.8391	5.8334
Capital adj. cost, S	$\phi_{KH}$	Gamma	1	0.5	2.6856	3.5119	4.2824
Loans to E adj. cost, Banks	$\phi_{EB}$	Gamma	0.25	0.125	0.0386	0.1422	0.2408
Loans to E adj. cost, E	$\phi_{EE}$	Gamma	0.25	0.125	0.0458	0.1588	0.2711
Loans to B adj. cost, Banks	$\phi_{SB}$	Gamma	0.25	0.125	0.0906	0.3284	0.5540
Loans to B adj. cost, HB	$\phi_{SS}$	Gamma	0.25	0.125	0.3082	0.6048	0.8941
Elast. of substitution housing	$\kappa_S$	Normal	2	0.5	3.0045	3.6031	4.2130
Capital share of E	$\mu$	Beta	0.5	0.10	0.3019	0.3561	0.4092
Housing share of E	ν	Beta	0.04	0.01	0.0094	0.0140	0.0185
Efficiency rental housing services	$\Omega_r$	Beta	0.5	0.2	0.1451	0.3119	0.4771
Inertia in capital adequacy constraint	$\rho_D$	Beta	0.25	0.1	0.0760	0.2183	0.3592
Inertia in E borrowing constraint	$ ho_E$	Beta	0.25	0.1	0.6021	0.6738	0.7446
Inertia in HB borrowing constraint	$ ho_S$	Beta	0.25	0.1	0.7890	0.8289	0.8671
Wage share, HB	$\sigma$	Beta	0.3	0.05	0.5380	0.5703	0.6036
Weight owner-occup. housing	$\theta_S$	Beta	0.5	0.2	0.3637	0.6341	0.9194
Curvature for utilisation function, E	$\zeta_E$	Beta	0.2	0.1	0.1797	0.3665	0.5459
Curvature for utilisation function, HB	$\zeta_H$	Beta	0.2	0.1	0.7311	0.8097	0.8910

Table 1.2: Prior and Posterior Distributions, Structural Parameters

For the estimation procedure I adopt the same prior distributions for the structural parameters and shock processes as outlined in Iacoviello (2015). The newly introduced parameters  $\Omega_r$  and  $\theta_s$  have a very loose beta prior distribution with mean 0.5 and standard deviation 0.2. The standard deviation of the prior distribution for the elasticity of substitution between rental and mortgaged housing  $\kappa_s$  has been set to 0.5. The prior mean of 2 is based on the study by Mora-Sanguinetti and Rubio (2014).

Re-estimating the model on the extended dataset delivers very similar estimates for the inertias  $\rho_D$ ,  $\rho_E$  and  $\rho_S$ ; externals consumption habits  $\eta$ ; the deposit adjustment cost parameter  $\phi_{DH}$ ; the share of constrained entrepreneurs  $\mu$ ; and  $\zeta_E$ . Given the new dataset, the share of constrained households  $\sigma$  is found to be 0.57, which is consistent with the findings of Guerrieri and Iacoviello (2017) when TFP is used as an observable. The rental housing efficiency parameter  $\Omega_r$  is found to be slightly smaller than its prior mean of 0.5.  $\theta_S$  the weight of the impatient households towards owner-occupied housing is estimated at 0.63. This is in

line with the findings of Sun and Tsang (2017), who estimate the preference weight at 0.47. Interestingly, the elasticity of substitution between home ownership and rent  $\kappa_S$  is 3.6, which is considerably higher than the initial prior mean. This indicates that both housing types are more elastic than initially assumed by Mora-Sanguinetti and Rubio (2014). The housing share parameter  $\nu$  is found to be 0.014 and is slightly smaller than the estimate obtained by Iacoviello (2015). The above parameter estimates imply a steady state price-rent ratio of 37.66 and a rental/homeowner ratio of 37.91 percent, which are close to their respective data counterparts.

Turning to the shock processes, the estimation results show a high level of persistence for all AR(1) shocks ranging from 0.84 to 0.99. Based on the new dataset the estimation produces very similar estimates for the autoregressive parameters. The only exception is the persistence of the productivity shock, which is found to be higher than in the original study. Turning to the standard deviation of the shocks, the picture is slightly different. Compared to the original study, the findings indicate a much higher standard deviation for the household LTV and investment shock. In fact, the former is considerably larger and is estimated at 0.0737, whereas Iacoviello (2015) obtains a value of only 0.0081. The opposite is the case for the housing demand shock, which is found to be smaller and has declined by 0.025. The four and eight period ahead TFP news standard deviations are almost identical in their respective sizes. As these shock turn out to be crucial for the variance and historical shock decomposition, section 1.6 performs various robustness checks on the estimates.

Parameter		Prior Distribution			Posterior Distribution			
		Density	Mean	Std	10%	Mean	90%	
Autocor. E default shock	$ ho_{be}$	Beta	0.8	0.1	0.8901	0.9338	0.9811	
Autocor. B default shock	$ ho_{bh}$	Beta	0.8	0.1	0.9230	0.9514	0.9809	
Autocor. housing demand shock	$ ho_j$	Beta	0.8	0.1	0.8377	0.8967	0.9604	
Autocor. investment shock	$ ho_k$	Beta	0.8	0.1	0.9715	0.9790	0.9866	
Autocor. LTV shock, E	$\rho_{me}$	Beta	0.8	0.1	0.7717	0.8376	0.9044	
Autocor. LTV shock, B	$ ho_{mh}$	Beta	0.8	0.1	0.8876	0.9201	0.9527	
Autocor. preference shock	$ ho_p$	Beta	0.8	0.1	0.8372	0.8728	0.9090	
Autocor. technology shock	$\rho_z$	Beta	0.8	0.1	0.9899	0.9944	0.999(	
Std default shock, E	$\sigma_{be}$	Inv.gamma	0.0025	0.025	0.0009	0.0011	0.0012	
Std default shock, B	$\sigma_{bh}$	Inv.gamma	0.0025	0.025	0.0012	0.0014	0.0015	
Std housing demand shock	$\sigma_{j}$	Inv.gamma	0.05	0.05	0.0088	0.0103	0.0118	
Std investment shock	$\sigma_k$	Inv.gamma	0.005	0.025	0.0634	0.0737	0.0836	
Std LTV shock, E	$\sigma_{me}$	Inv.gamma	0.0025	0.025	0.0153	0.0203	0.0253	
Std LTV shock, B	$\sigma_{mh}$	Inv.gamma	0.0025	0.025	0.0228	0.0295	0.0358	
Std preference shock	$\sigma_p$	Inv.gamma	0.005	0.025	0.0136	0.0159	0.0182	
Std technology shock, unantic.	$\sigma_z^0$	Inv.gamma	0.005	0.025	0.0081	0.0095	0.0109	
Std technology shock, antic.	$\sigma_z^4$	Inv.gamma	0.005	0.025	0.0143	0.0171	0.0199	
Std technology shock, antic.	$\sigma_z^8$	Inv.gamma	0.005	0.025	0.0153	0.0183	0.0211	

 Table 1.3: Prior and Posterior Distributions, Shock Processes
### 1.5 Results

This section discusses the estimated mean impulse responses and the conditional and historical shock decomposition.

#### 1.5.1 Impulse Response Functions

All IRFs of the key variables described in this section are computed in percentage deviations from their respective steady states.



Figure 1.3: Impulse response to a one standard error household default shock

The impact of a household default shock is illustrated in figure 1.3 above. Similar to Iacoviello (2015), impatient household benefit from defaulting on their loans in this model because they are unable to pay their agreed loan instalments. Hence, this makes impatient households better off, which materialises in an increase in consumption and mortgaged housing. The opposite is the case for savers. Patient households not only reduce their supply of capital to the entrepreneur, due to fall in the rental rate, but also cut back on their accumulation of housing. Instead, they increase their rental housing stock and supply more rental housing services. However, as borrowers accumulate more mortgaged housing they demand less rental services. As a result rental prices decline. The default shock causes a reduction in the consumption of entrepreneurs and ultimately leads to a decline in real estate. As the shock triggers a negative response of the housings stocks accumulated by the saver and entrepreneur, house prices have to decrease in order to stimulate demand for these agents and offset the positive housing developments of the mortgaged and rental housing stock. The assumption of flexible house prices ensures that the housing supply remains fixed and markets clear. Allowing for a rental housing sector inflicts additional pressure on house prices, especially if there is a trade-off between mortgaged and rental housing. Overall, the household default shock causes a contraction of economic activity, which can be explained by the shortage of funds supplied to entrepreneurs by households. Finally, the total amount of loans in the economy decreases because of two reasons. First, borrowers experience a positive wealth transfer. Second, entrepreneurs face decreasing collateral values triggered by falling housing prices, which limits their borrowing.



Figure 1.4: Impulse response to a one standard error aggregate spending shock

The effect of an aggregate spending shock is depicted in figure 1.4. Overall, the resulting impulse responses of the preference shock look very similar to the dynamics of a positive housing demand shock. However, as we can see from figure 1.4, the aggregate spending shock raises both, consumption and the demand for housing. Therefore, it is important to stress that the preference shock triggers a direct increase in  $C_{H,t}$  and  $C_{S,t}$  as well as the demand for housing described by  $H_{H,t}$  and  $\tilde{H}_{S,t}$ . In contrast, a positive housing demand shock would only lead to increase in the demand for  $H_{H,t}$ ,  $\tilde{H}_{S,t}$ . Borrowers can only accumulate more mortgaged homes by supplying more labour to the entrepreneur and substituting them for rental services. This leads to a drop in the rental housing sector, as savers stop acquiring rental homes and start expanding their owner-occupied housing stock. Even though there is a decline in the supply of rental services, impatient households still demand them (i.e. reduction in  $Z_t > H_{r,t}$ ) which causes rental prices to go up. House prices in turn have to fall in order to boost the savers accumulation of  $H_{H,t}$ . This is necessary in order to offset the decline in the rental housing sector and ensure market clearing.



Figure 1.5: Impulse response to a one standard error housing demand shock

Figure 1.5 depicts the effect of a pure, positive housing demand shock  $A_{j,t}$  to the utility function of the borrower and saver. Therefore, it increases directly the demand for  $H_{H,t}$  and  $\tilde{H}_{S,t}$ . Similarly to a preference shock, borrowers start supplying more labour and substitute mortgaged housing for rental services. The reason for this shift is the housing preference parameter  $\theta_S$ , which is estimated at 0.63. As Borrowers favour owner-occupied housing, a positive shock to  $\tilde{H}_{S,t}$  triggers are trade-off between mortgaged and rental housing services. The reduction in rental services leads to a decline in the sector for rental housing. Despite the substitution effect, impatient households still want to rent. However, savers cut back on their rental housing supply at a much higher rate than rental services are demanded, such that  $Z_t > H_{r,t}$ . As a result of this, rental prices increase. House prices have to soar in order to offset the direct, positive response of the saver's housing stock  $H_{H,t}$  caused by the housing demand shock. This ensures that the housing supply remains fixed. Households supply now a higher level of labour to entrepreneurs and hence, output increases as a result.



Figure 1.6 shows the mean impulse responses of a positive shock to the borrower's collateral constraint. This type of shock can be interpreted as looser credit checks by banks, where borrowers qualify for a higher amount of loans for a given level of collateral. Hence, a LTV shock indirectly affects the housing choices of impatient households through the lending channel. As already mentioned, a higher LTV ratio implies that borrowers can now qualify for a higher amount of loans, given their current collateral value. Therefore, constrained households are able to increase consumption and accumulate more owner-occupied housing. This results in an expansion of the mortgaged housing sector and the total amount of loans in the economy. As borrowers accumulate more mortgaged housing, they demand less rental services  $Z_t$  which leads to a drop in rental prices. The reduction in rental demand and the accompanied fall in prices causes a decrease in rental income for savers. This gives patient households an incentive to cut down on their accumulation of rental housing. However, without a fall in house prices, the rise in mortgaged housing would be very small due to the high, estimated inertia  $\rho_S$ . For this reason, the drop in house prices helps to stimulate the accumulation of  $H_{S,t}$  and offsets the contraction of the rental housing sector. This also counteracts the income effect triggered by an increase in  $L_{S,t}$  in order to ensure a binding budget constraint. Due to a rise in bank lending, households supply less labour and capital to entrepreneurs which in turn leads to a decline in output.

#### 1.5.2Historical Shock and Variance Decomposition

Table 1.4 shows the conditional variance decomposition, evaluated at the posterior mean, for a set of key variables. As illustrated below, I compute the forecast error variance decomposition for a time horizon of 4 periods and infinity.

Variable	$v_{H,t}, v_{E,t}$ Default	$v_{j,t}$ Housing	$v_{K,t}$ Invest.	$\begin{array}{c} \upsilon_{MH,t}, \upsilon_{ME,t} \\ \mathrm{LTV} \end{array}$	$v_{p,t}$ Pref.	$\begin{array}{c} \upsilon_{z,t}^0 \\ \mathrm{TFP} \end{array}$	$v_{z,t}^4$ TFP	$v_{z,t}^8$ News
4 Periods								
Output Rental prices House prices Price-rent ratio Owner-occupied <sup>a</sup> Rental/homeowner <sup>b</sup> Mortgaged Housing Rental Housing	$\begin{array}{c} 0.23 \\ 0.02 \\ 0.23 \\ 0.28 \\ 0.38 \\ 2.84 \\ 0.61 \\ 2.30 \end{array}$	$\begin{array}{c} 0.01 \\ 17.90 \\ 0.12 \\ 31.06 \\ 0.18 \\ 0.14 \\ 0.21 \\ 0.10 \end{array}$	$58.83 \\ 9.50 \\ 21.20 \\ 4.06 \\ 6.47 \\ 5.67 \\ 4.67 \\ 4.55 \\ \end{cases}$	$\begin{array}{c} 0.52 \\ 4.90 \\ 0.18 \\ 8.86 \\ 20.27 \\ 5.07 \\ 15.41 \\ 14.44 \end{array}$	$\begin{array}{c} 7.70 \\ 13.48 \\ 0.92 \\ 41.92 \\ 23.88 \\ 22.40 \\ 17.38 \\ 18.39 \end{array}$	$\begin{array}{c} 19.91\\ 33.47\\ 30.30\\ 0.44\\ 0.63\\ 0.46\\ 0.56\\ 0.35\end{array}$	$\begin{array}{c} 12.44 \\ 18.84 \\ 36.21 \\ 6.56 \\ 15.80 \\ 22.88 \\ 51.33 \\ 21.90 \end{array}$	$\begin{array}{c} 0.37 \\ 1.90 \\ 10.85 \\ 6.83 \\ 32.39 \\ 41.54 \\ 9.81 \\ 37.96 \end{array}$
∞ Output Rental prices House prices Price-rent ratio Owner-occupied Rental/homeowner Mortgaged Housing Rental Housing	$\begin{array}{c} 0.02\\ 0.01\\ 0.01\\ 0.14\\ 0.28\\ 0.23\\ 0.19\\ 0.22\\ \end{array}$	$\begin{array}{c} 0.00\\ 0.36\\ 0.00\\ 17.60\\ 0.29\\ 0.18\\ 0.16\\ 0.14 \end{array}$	$\begin{array}{r} 26.52 \\ 15.08 \\ 14.59 \\ 23.62 \\ 31.05 \\ 29.28 \\ 25.34 \\ 28.31 \end{array}$	$\begin{array}{c} 0.01 \\ 0.19 \\ 0.02 \\ 10.83 \\ 37.80 \\ 29.76 \\ 24.08 \\ 28.66 \end{array}$	$\begin{array}{c} 0.14\\ 0.23\\ 0.04\\ 22.89\\ 11.22\\ 9.50\\ 7.11\\ 8.28 \end{array}$	$\begin{array}{c} 10.01 \\ 10.94 \\ 10.74 \\ 0.68 \\ 0.15 \\ 0.18 \\ 0.89 \\ 0.21 \end{array}$	$\begin{array}{c} 29.78\\ 34.57\\ 35.01\\ 9.53\\ 9.54\\ 15.88\\ 24.04\\ 17.42 \end{array}$	$\begin{array}{r} 33.52\\ 38.52\\ 39.58\\ 14.70\\ 9.67\\ 14.46\\ 18.15\\ 15.96\end{array}$

Table 1.4: Conditional and Unconditional Variance Decomposition

<sup>a</sup> Represents the owner-occupied housing stock, i.e.  $H_{S,t} + H_{H,t}$ . <sup>b</sup> Stands for the rental to owner-occupied housing ratio, i.e.  $\frac{H_{r,t}}{H_{S,t}+H_{H,t}}$ .

Over both forecast horizons, I find that the investment and TFP innovations are important driving forces behind the variance of GDP. The conditional variance decomposition (1 year horizon) shows that more than 50 percent of the fluctuations in output can be explained by the investment shock. However, the contribution of this shock decreases to 27 percent under an infinite forecast horizon. Despite the decline, investment and productivity disturbances still explain the largest fraction of the output variance and are therefore key contributors of the business cycle. Interestingly, fluctuations in GDP remain almost unaffected by LTV, default and preference shocks. This result holds over both forecast horizons. As the unconditional variance decomposition indicates, TFP news shocks account for more than a half of the variations in output, rental and house prices. These findings are in line with the results of Beaudry and Portier (2006) and Barsky and Sims (2011), who show that productivity news shocks explain more than 50 and 40 percent of the variations in output, respectively. The analysis by Beaudry and Portier (2006) relies on a moving average representation stemming from an estimated vector error correction model (VECM) for stock prices and TFP. The motivation behind this approach is to show how the business cycle is influenced by changes in stock prices in combination with TFP movements. The reason why Beaudry and Portier (2006) focus on stock market information is explained by the view that stock prices are an adequate tool for capturing agents' changes in expectations about their future economic outlook. To explain the findings from the VECM exercise, the authors develop a model in which TFP innovations influence productivity with a delay and demonstrate how this model can easily explain the observed movements in the data. One key result of the study is that business cycles are determined largely by productivity growth that is heavily anticipated by agents. Beaudry and Portier (2006) call this expectation-driven booms. Based on a structural VAR model Barsky and Sims (2011) implement a new identification approach to assess the importance of news shocks are crucial factors in determining output fluctuations at low and medium frequencies. Their model is estimated on a four variable VAR, consisting of macroeconomic variables such as TFP, output, consumption, hours worked. The authors extend this to a seven variable VAR by introducing the observables inflation, stock prices and consumer confidence. Under both scenarios, hours, investment and output drop as a result of a positive news shock but quickly revert after the shock impact. In contrast, consumption increases as a response to the positive news shock. The dynamic responses to news are in line with the implication of many macro models.

Overall, 1.4 table illustrates that the impact of the productivity news shocks keeps increasing for GDP, the price-rent ratio, house and rental prices over the forecast horizon. The preference shock  $v_{p,t}$  and housing demand shock  $v_{j,t}$  explain together over 30 percent of the total variance of rental prices at a one year forecast horizon. In contrast, the variability of house prices remains almost unaffected by the housing demand shock. The picture is significantly different for the rental to owner-occupied housing ratio. Over a length of four periods, more than 40 percent of the home ownership ratio's fluctuations are driven by the LTV and preference shock. The rest of the variations can be attributed to news. The significance of TFP news decreases over time, and as the variance decomposition shows, more than 80 percent of the ratio's variations are determined by  $v_{j,t}$ ,  $v_{p,t}$  and LTV shocks. Home ownership (represented by owner-occupied housing) is significantly driven by bank lending, investment and preferences which account for the largest fraction of the variance of this variable. These results can be observed over both periods. Things look differently for house prices, at horizon infinity, house prices are mainly driven by three innovations: the investment shock with 15 percent, the anticipated TFP components with 74 percent and the unanticipated productivity innovation, which takes up 11 percent.

As shown in table 1.4 the impact of the housing demand shock on house prices is very small. Introducing a rental sector has an offsetting effect on house prices. A positive housing preference shock stimulates the saver's and borrower's demand for housing. The increase in the agents' housing stock combined with a fixed housing supply leads to a rise in the price for homes. However, the existence of a rental sector counteracts this reaction. The growth in demand for owner-occupied housing results in a demand decline for rental housing, which puts downward pressure on house prices. Therefore, the overall house price effect of the housing demand shock is offset by a reduction of the rental housing stock. See figure 2.7 in chapter 2.



Figure 1.7: Shock decomposition of the rental/homeowner ratio, the solid black line depicts the smoothed series.

Turning to the historical shock decomposition of the three endogenous variables, real house prices, real rents and the housing ratio delivers similar results to those obtained from the conditional variance decomposition. As Figure 1.7 illustrates, homeownership is largely determined by two innovations: the investment and LTV shock. This also becomes apparent by looking at table 1.5,<sup>19</sup> as these shocks were the dominant driving forces during the first two decades of the sample. An explanation for the prominent role of LTV shocks between 1985 and 2000 are the efforts by the government to boost homeownership of low-income households. They are better known as the Housing and Community Development Acts of 1987 and 1992. This in turn stimulated residential investment and led to a reduction in resources supplied to the business sector, which is depicted by the negative investment<sup>20</sup> shocks starting in the mid 90s. As figure 1.2 shows, business investment fell dramatically between the beginning of the sample and the negative deviations from its steady state lasted until the late 1990s. Although the magnitude of investment shocks decreases, they still continue to have an impact in the years leading up to the crisis. This trend can be explained by low interest rates and the low quality loan purchases by Fannie Mae and Freddie Mac prior to the crisis, which kept boosting residential

<sup>&</sup>lt;sup>19</sup>For a better visualisation, table 1.5 presents the individual shocks and their contributions to the movements of the observable. Therefore, the figures shown in the table are identical to the shock decomposition illustrated in figure 1.7.

<sup>&</sup>lt;sup>20</sup>In this model a positive investment shock triggers an increase in the capital stock and hence diverts resources away from residential investment. As a result of this, borrowers decrease their housing accumulation. In contrast, a negative investment shock causes an increase in mortgaged housing.

investment. A reason for the noticeable, increasing contribution of news shocks between the mid 90s and early 2000s could be the Great Moderation. They may reflect the reduced business cycle volatility of GDP growth, suggesting a stable and healthy economic outlook. Looking at Figure 1.2, the same observation can be made for the TFP data. Between 1985 and the early 2000s productivity fluctuations were relatively small. This in turn had a positive impact on the housing market. However, the sign of anticipated news changes in the mid 2000s and the impact intensifies with the outbreak of the financial crisis. During the crisis years of 2006 and 2010, default and productivity news are the largest positive driving forces behind the rental/homeowner ratio, whereas LTV and preference shocks have contributed negatively to the movement of the ratio.

The findings above, specifically the ones regarding the importance of economic news, add to the discussion by Mian and Sufi (2015). The authors explain in detail the roots of the housing boom and the cause of the latest recession. Mian and Sufi (2015) identify debt as one of the main sources behind the latest growth of the owner-occupied housing market. As they show, lending to low credit-score households<sup>21</sup> expanded massively in the years between 2002 and 2006. This in turn fuelled the house price bubble in cities where the housing supply was inelastic. As house prices began to fall sharply, the equity brought into a mortgage by borrowers was either dramatically reduced or completely wiped out. The result of this was a wave of defaults and foreclosures, which led to a drastic reduction in aggregate demand. Figure 1.7 confirms this through the contribution of LTV and preference shocks. In contrast to Mian and Sufi (2015), who reject the fundamental view based on empirical findings, I find that news about the economic outlook also mattered in the expansion and contraction of the owner-occupied housing market.

	1985 - 1995	1996 - 2006	2007 - 2010
Default Shocks	0.1160	-0.2888	0.4996
Housing Demand Shock	0.1392	0.3903	0.2361
Investment	-0.2447	-3.1130	0.2979
LTV Shocks	-3.4806	-2.2045	-1.4908
Preference Shock	0.7972	0.6984	-0.5660
Unanticipated TFP Shock	-0.0487	0.0169	-0.0243
Anticipated TFP Shocks	0.9248	-0.0912	0.9322

Table 1.5: Historical Decomposition of the Rental/Homeowner Ratio

<sup>&</sup>lt;sup>21</sup>They are also called marginal borrowers. During the housing boom households qualified for a mortgage who in fact were not eligible (Mian and Sufi 2015).

Figure 1.8 and 1.9 depict the shock decomposition of the yearly house and rental price growth rates. In the literature usually housing demand shocks overwhelmingly determine house price movements. However, this study finds that asset prices have also significantly responded to productivity news. As depicted in figure 1.2, TFP exhibits a dramatic increase from its trend in the years leading up to the crisis and a contraction with the outbreak of the Great Recession. Therefore, positive news about future productivity and the resulting growth in GDP have substantially contributed to the housing boom. Put differently, the positive and negative economic outlook before and after the financial crisis are important driving forces of the boom and bust of the housing market.

These results are related to a branch of the housing literature, which identifies fundamentals as an important driving force behind the sharp pre-crisis increase in house prices. For example, Adam, Kuang, and Marcet (2012) observe that low interest rates after the year 2000 played a central role in the housing boom. The same conclusion reaches Taylor (2007, 2009) and the Bank for International Settlements (2007, 2008) in earlier published research. In contrast, Justiniano, Primiceri, and Tambalotti (2015) find that the main cause of the boom and bust of the housing market was the increased credit supply, which was fuelled by loose lending constraints. These results are based on a model, where agents face a non-binding lending constraint. Besides finding indirect evidence for a housing bubble, the model by Sommer, Sullivan, and Verbrugge (2013) indicates that a combination of low interest rates and relaxed lending criteria results in a substantial increase in house prices. Figure 1.8 illustrates that investment and unanticipated technology innovations are the second and third largest contributors of house price fluctuations. This is in line with the results of Guerrieri and Iacoviello (2017), who find that investment technology shocks have contributed substantially to the house price boom. In contrast, rental price changes have virtually remained unaffected by default. The importance of housing demand shocks on annual rental price changes starts to significantly increase after the year 2003. In addition to this, between 2005 and 2010, preferences and news innovations played a central role in the annual growth of rental prices.



Figure 1.8: Shock decomposition of real house prices



Figure 1.9: Shock decomposition of real rental prices

## **1.6** Identification and Robustness

First of all, identification has been tested by plotting the individual likelihood functions for each parameter. This visualises whether all parameters can be identified given the underlying dataset. A flat likelihood function indicates that there is no information in the data to identify the given parameter. However, this is not the case in the present study. Furthermore, I perform trace plots of the newly introduced parameters to see whether the Metropolis-Hastings draws converge to a stable distribution. As the trace plots do not show any trends or jumps, we can conclude that the chain has converged. After the estimation an univariate convergence check is performed, following Brooks and Gelman (1998). Given 1,000,000 parameter draws and two chains with a burn-in rate of 50 percent, the diagnostics show that both Markov chains have converged to the ergodic distribution.<sup>22</sup>

This study has found that the housing and rental market respond significantly to productivity news. News shocks account for a large fraction of fluctuations in the rental/homeowner ratio and determine the majority of house and rental prices changes. It is therefore vital to test whether these results hold for different prior specifications. Table 1.6 summarises those findings, where column 3 and 4 represent the respective posterior modes and the benchmark column shows the respective posterior means as discussed in section 1.4. Under Specification (1) only the prior mean and standard deviation of the anticipated ( $\sigma_z^4$ ,  $\sigma_z^8$ ) and unanticipated ( $\sigma_z^0$ ) TFP components have been changed. The prior mean for those three shocks is set to 0.10 with a standard deviation of 2. This is line with the study conducted by Born, Peter, and Pfeifer (2013). Specification (2) follows Iacoviello and Neri (2010), where now all standard errors of the shock processes have a prior mean of 0.1 and a standard deviation of 1. Comparing both posterior modes with our benchmark results show, that the estimations findings presented in this paper are robust towards different prior specifications. Especially the standard errors of the technology shocks only vary slightly.

<sup>&</sup>lt;sup>22</sup>Plots of the likelihood, Metropolis-Hastings draws and convergence diagnostics are available in the appendix.

Parameter	Benchmark	Specification $(1)$	Specification $(2)$
$ ho_{be}$	0.9338	0.9381	0.9400
$ ho_{bh}$	0.9514	0.9575	0.9639
$ ho_j$	0.8967	0.9042	0.9097
$ ho_k$	0.9790	0.9808	0.9839
$ ho_{me}$	0.8376	0.8476	0.8755
$ ho_{mh}$	0.9201	0.9225	0.9236
$ ho_p$	0.8728	0.8759	0.8763
$ ho_z$	0.9944	0.9961	0.9956
$\sigma_{be}$	0.0011	0.0010	0.0010
$\sigma_{bh}$	0.0014	0.0013	0.0013
$\sigma_{j}$	0.0103	0.0100	0.0071
$\sigma_k$	0.0737	0.0722	0.0708
$\sigma_{me}$	0.0203	0.0182	0.0187
$\sigma_{mh}$	0.0295	0.0268	0.0244
$\sigma_p$	0.0159	0.0156	0.0148
$\sigma_z^0$	0.0095	0.0091	0.0090
$\sigma_z^4$	0.0171	0.0160	0.0158
$\sigma_z^8$	0.0183	0.0171	0.0168

 Table 1.6:
 Robustness, Shock Processes

Additionally, table 1.7 shows the estimated posterior modes for the underlying parameters, when loan losses are excluded from the model and dataset. Overall, there is only little variation between the benchmark version and the re-estimated values.<sup>23</sup>

 $<sup>^{23}</sup>$ Excluding loan losses form the dataset does only marginally improve the second moments of the model.

Parameter	Posterior Mode	Parameter	Posterior Mode
$\eta$	0.3616	$ ho_j$	0.9062
$\phi_{DB}$	0.2649	$ ho_k$	0.9835
$\phi_{DH}$	0.1014	$ ho_{me}$	0.8632
$\phi_{KE}$	4.5703	$ ho_{mh}$	0.9150
$\phi_{KH}$	3.1468	$ ho_p$	0.9022
$\phi_{EB}$	0.1196	$ ho_z$	0.9959
$\phi_{EE}$	0.1024	$\sigma_j$	0.0098
$\phi_{SB}$	0.2272	$\sigma_k$	0.0734
$\phi_{SS}$	0.5372	$\sigma_{me}$	0.0185
$\kappa_S$	3.8663	$\sigma_{mh}$	0.0251
$\mu$	0.3276	$\sigma_p$	0.0144
ν	0.0125	$\sigma_z^0$	0.0092
$\Omega_r$	0.2756	$\sigma_z^4$	0.0153
$\rho_D$	0.1833	$\sigma_z^8$	0.0163
$ ho_E$	0.6610		
$ ho_S$	0.8126		
$\sigma$	0.5427		
$ heta_S$	0.6085		
$\zeta_E$	0.3459		
$\zeta_H$	0.8336		

Table 1.7: Robustness, Posterior Modes without Loan Losses

# 1.7 Conclusion

The financial crisis has been identified as one of the main reasons behind the latest developments in the U.S. housing sector. There seems to be shift away from owner-occupied housing towards rental housing. So far studies have largely ignored factors such as news and banking frictions, when it comes to analysing the dynamics of the owner-occupied and rental housing sector. Therefore, this paper develops a framework in which a rental market, banking and financial frictions coexist. I also allow for two anticipated components in the TFP shock structure. They are better known as productivity news shocks and measure to what extent agents react to future TFP changes, which ultimately effect GDP. The model shows that the latest increase in the demand for rental housing was mainly driven by a combinations of four innovations: default, productivity news, preferences and LTV. Between 1996 and 2006 shifts in the home ownership structure were largely determined by investment, LTV and preference shocks. A variance decomposition shows that

more than 60 percent of home ownership fluctuations can be explained by investment and LTV innovations.

In contrast to the literature, this study finds that productivity news are important contributors to the growth of house prices. Recent changes in rental prices have significantly responded to preferences, news and housing demand shocks. In line with the results of Sun and Tsang (2017), house prices have remained unaffected by housing demand innovations.

Chapter 1 investigates the developments of the owner-occupied and rental housing markets through the lens of a real business cycle DSGE model. As this part of the thesis focuses also on the impact of news shocks on the housing economy, I abstract from New Keynesian features which usually bring an additional set of shocks with them. Chapter 2 addresses the shortcoming of ignoring how rental and owner-occupied housing react to endogenous interest rates changes. In other words, the model in chapter 1 is not equipped to assess how monetary policy actions have affected the housing market. However, according to Shiller (2007) monetary policy, which influences the level of interest rates and thus the discount factor, is a crucial factor that drives house prices. The U.S. experienced a low interest rate environment during the years leading up to the financial crisis and therefore the question has been asked how this might have contributed to the pre-crisis housing boom. For this reason, the next chapter presents a model that features a central bank which sets interest rates according to a Taylor rule. This enables us to investigate the link between pre-crisis monetary policy measures and the developments of the owner-occupied housing sector.

# 1.A Technical Appendix

#### 1.A.1 Full Model Economy

#### Bankers

Banks play an important role in the model economy as they receive deposits from patient households and issue loans to entrepreneurs and impatient households. Bankers maximise their lifetime utility according to:

$$E_0 \sum_{t=0}^{\infty} \beta_B^t (1 - \eta) \log(C_{B,t} - \eta C_{B,t-1})$$
(1.A.1)

subject to

$$C_{B,t} + R_{H,t-1}D_{t-1} + L_{E,t} + L_{S,t} + ac_{DB,t} + ac_{EB,t} + ac_{SB,t} = D_t + R_{E,t}L_{E,t-1} + R_{S,t-1}L_{S,t-1} - \varepsilon_{E,t} - \varepsilon_{H,t}$$
(1.A.2)

where

$$ac_{DB,t} = \frac{\phi_{DB}}{2} \frac{(D_t - D_{t-1})^2}{D}$$
(1.A.3)

$$ac_{EB,t} = \frac{\phi_{EB}}{2} \frac{(L_{E,t} - L_{E,t-1})^2}{L_E}$$
(1.A.4)

$$ac_{SB,t} = \frac{\phi_{SB}}{2} \frac{(L_{S,t} - L_{S,t-1})^2}{L_S}$$
(1.A.5)

Bankers' private consumption is given by  $C_{B,t}$ ,  $L_{E,t}$  and  $L_{H,t}$  are loans issued to entrepreneurs and borrowers. Liabilities of bankers are given by deposits  $D_t$ . The terms  $ac_{EB,t}$ ,  $ac_{SB,t}$  and  $ac_{DB,t}$  are the respective adjustment costs. The loan losses caused by defaults of households  $\varepsilon_{H,t}$  and entrepreneurs  $\varepsilon_{E,t}$  show up on the expenditure side of the budget constraint. Beside the budget constraint the bank also faces a capital adequacy constraint of the form:

$$L_t - D_t - E_t(\varepsilon_{t+1}) \ge \rho_D [L_{t-1} - D_{t-1} - E_{t-1}(\varepsilon_t)] + (1 - \gamma)(1 - \rho_D) [L_t - E_t(\varepsilon_{t+1})]$$
(1.A.6)

Total assets are given by the sum  $L_t = L_{E,t} + L_{S,t}$  and aggregate loan losses are denoted by  $\varepsilon_t = \varepsilon_{E,t} + \varepsilon_{H,t}$ .

The left hand side of the capital adequacy constraint is the net equity of banks after having accounted for future expected loan losses. This expression has to be greater than last period's equity plus some fraction of bank assets. Furthermore, the capital adequacy constraint ensures that banks can react to those deviations and restore their long-run deposit-to-asset ratio target  $\gamma$  over more than just one period. The non-zero inertia  $\rho_D$  ensures two things. First a partial adjustment of bank capital. Second, a deviation from its capital-to-asset ratio target.

The optimality conditions are:

$$C_{B,t}: \qquad u_{CB,t} = \frac{A_{p,t}(1-\eta)}{C_{B,t} - \eta C_{B,t-1}}$$
(1.A.7)

$$L_{E,t}: \qquad u_{CB,t} \left\{ 1 - \lambda_{B,t} \left[ \rho_D + \gamma_E (1 - \rho_D) \right] + \frac{\partial a c_{EB,t}}{\partial L_{E,t}} \right\} = \beta_B E_t \left[ u_{CB,t+1} (R_{E,t+1} - \lambda_{B,t+1} \rho_D) \right] \quad (1.A.8)$$

$$L_{S,t}: \qquad u_{CB,t}\left\{1-\lambda_{B,t}\left[\rho_D+\gamma_S(1-\rho_D)\right]+\frac{\partial ac_{SB,t}}{\partial L_{S,t}}\right\}=\beta_B E_t\left[u_{CB,t+1}(R_{S,t}-\lambda_{B,t+1}\rho_D)\right] \qquad (1.A.9)$$

$$D_t: \qquad u_{CB,t} \left( 1 - \lambda_{B,t} - \frac{\partial a c_{DB,t}}{\partial D_t} \right) = \beta_B E_t \left[ u_{CB,t+1} (R_{H,t} - \lambda_{B,t+1} \rho_D) \right] \tag{1.A.10}$$

#### Entrepreneurs

The entrepreneur's problem is symmetrical to the one of the impatient household. Entrepreneurs maximise their lifetime utility according to:

$$\sum_{t=0}^{\infty} \beta_E^t (1 - \eta) \log(C_{E,t} - \eta C_{E,t-1})$$
(1.A.11)

subject to the following budget constraint:

$$C_{E,t} + \frac{K_{E,t}}{A_{K,t}} + q_t H_{E,t} + R_{E,t} L_{E,t-1} + W_{H,t} N_{H,t} + W_{S,t} N_{S,t} + R_{M,t} z_{KH,t} K_{H,t-1} + ac_{KE,t} + ac_{EE,t} = Y_t + \frac{1 - \delta_{KE,t}}{A_{K,t}} K_{E,t-1} + q_t H_{E,t-1} + L_{E,t} + \varepsilon_{E,t}$$

$$(1.A.12)$$

where

$$ac_{KE,t} = \frac{\phi_{KE}}{2} \frac{(K_{E,t} - K_{E,t-1})^2}{E_H}$$
(1.A.13)

$$ac_{EE,t} = \frac{\phi_{EE}}{2} \frac{(L_{E,t} - L_{E,t-1})^2}{L_E}$$
(1.A.14)

and the depreciation function of capital is given by:

$$\delta_{KE,t} = \delta_{KE} + b_{KE} \left[ 0.5 \,\zeta'_H z_{KE,t}^2 + (1 - \zeta'_E) z_{KE,t} + (0.5 \,\zeta'_E - 1) \right] \tag{1.A.15}$$

To ensure a steady state utilisation rate of one,  $b_{KE}$  has to be equal to  $\frac{1}{\beta_H} [1 - \lambda_E (1 - \rho_E) m_K] - (1 - \delta_{KE})$ . Similar to the borrower's problem, entrepreneurs face a collateral constraint of the form:

$$L_{E,t} \le \rho_E L_{E,t-1} + (1-\rho_E) A_{ME,t} E_t \left[ m_H \frac{q_{t+1}}{R_{E,t+1}} H_{E,t} + m_K K_{E,t} - m_N (W_{H,t} N_{H,t} + W_{S,t} N_{S,t}) \right]$$
(1.A.16)

Entrepreneurs produce the final good by using labour and capital as inputs. As in the case of the borrower,  $\varepsilon_{E,t}$  denotes the redistribution shock of the entrepreneur. The terms  $ac_{KE,t}$  and  $ac_{EE,t}$  represent the payable capital and loan adjustment costs. The final good is produced according to the following production function:

$$Y_t = A_{Z,t} (z_{KH,t} K_{H,t-1})^{\alpha(1-\mu)} (z_{KE,t} K_{E,t-1})^{\alpha\mu} H_{E,t-1}^{\nu} N_{H,t}^{(1-\alpha-\nu)(1-\sigma)} N_{S,t}^{(1-\alpha-\nu)\sigma}$$
(1.A.17)

here  $A_{Z,t}$  stands for a technology shock and the respective utilisation rates for capital are denoted by  $z_{KH,t}$  and  $z_{KE,t}$ . The entrepreneur's borrowing constraint drives a wedge between the demand for labour and capital. For example, a high labour demand decreases substantially the borrowing capacity of the entrepreneur, whereas a large capital stock has a positive effect on the amount of loans borrowed. This explains the two types of capital stocks in the economy. Note that  $\mu$  represents the capital share in the production function of the final and hence the total capital stock in the economy is represented by  $K_{H,t}$  and  $K_{E,t}$ . As already discussed, the variable  $A_{ME,t}$  represents a positive shock to the collateral value of the entrepreneur. The depreciation function of capital takes the following form:

$$\delta_{KE,t} = \delta_{KE} + b_{KE} \left[ 0.5 \,\zeta'_E z_{KE,t}^2 + (1 - \zeta'_E) z_{KE,t} + (0.5 \,\zeta'_E - 1) \right] \tag{1.A.18}$$

The first order conditions are:

$$C_{E,t}: \qquad u_{CE,t} = \frac{A_{p,t}(1-\eta)}{C_{E,t}-\eta C_{E,t-1}}$$
(1.A.19)

$$L_{E,t}: \qquad u_{CE,t} \left( 1 - \lambda_{E,t} - \frac{\partial a c_{EE,t}}{\partial L_{E,t}} \right) = \beta_E E_t [u_{CE,t+1} (R_{E,t} - \rho_E \lambda_{E,t+1})] \tag{1.A.20}$$

$$H_{E,t}: \qquad u_{CE,t} \left[ q_t - \lambda_{E,t} (1 - \rho_E) m_H A_{ME,t} E_t \left( \frac{q_{t+1}}{R_{E,t}} \right) \right] = \beta_E E_t \left[ u_{CE,t+1} q_{t+1} (1 + R_{V,t+1}) \right] \qquad (1.A.21)$$

$$K_{E,t}: \qquad \beta_E E_t \Big[ u_{CE,t+1} (1 - \delta_{KE,t+1} + R_{K,t+1} z_{KE,t+1}) \Big] = u_{CE,t} \Big[ 1 + \frac{\partial a_{CKE,t}}{\partial K_{E,t}} - \lambda_{E,t} m_k (1 - \rho_E) A_{ME,t} \Big]$$
(1.A.22)

$$N_{H,t}: \qquad Y_t(1-\alpha-\nu)(1-\sigma) = N_{H,t}W_{H,t} \left[ 1 + (1-\rho_E)\lambda_{E,t}A_{ME,t}m_N \right]$$
(1.A.23)

$$N_{S,t}: \qquad Y_t \left(1 - \alpha - \nu\right) \sigma = N_{S,t} W_{S,t} \left[1 + (1 - \rho_E) \lambda_{E,t} A_{ME,t} m_N\right]$$
(1.A.24)

$$z_{KE,t}: \qquad R_{K,t} = \frac{\partial \delta_{KE,t}}{\partial z_{KE,t}} = b_{KE}(\zeta_E' z_{KE,t} + 1 - \zeta_E') \tag{1.A.25}$$

#### 1.A.2 Market Clearing

The market clearing conditions of the model economy are given by the following expressions:

$$H_{H,t} + H_{S,t} + H_{E,t} + H_{R,t} = 1 (1.A.26)$$

$$C_t + \frac{I_t}{A_{K,t}} = Y_t - AC_t \tag{1.A.27}$$

The first equation is the housing market clearing condition, where the supply of housing has been normalised to one. The second equation represents the clearing in the goods market, where  $C_t = C_{H,t} + C_{S,t} + C_{B,t} + C_{E,t}$ and  $I_t = K_{H,t} - (1 - \delta_{KH,t})K_{H,t-1} + K_{E,t} - (1 - \delta_{KE,t})K_{E,t-1}$ .  $AC_t$  represents the sum of the respective convex, capital adjustment costs.

# 1.A.3 Steady State conditions

$$\lambda_B = \frac{1 - \beta_B R_H}{1 - \beta_B \rho_D} \tag{1.A.28}$$

$$\lambda_E = \frac{1 - \beta_E R_E}{1 - \beta_E \rho_E} \tag{1.A.29}$$

$$\lambda_S = \frac{1 - \beta_S R_S}{1 - \beta_S \rho_S} \tag{1.A.30}$$

$$R_H = \frac{1}{\beta_H} \tag{1.A.31}$$

$$R_{V} = \frac{1}{\beta_{E}} - 1 - \lambda_{E} (1 - \rho_{E}) m_{H} \frac{1}{\beta_{E} R_{E}}$$
(1.A.32)

$$R_{K} = \frac{1}{\beta_{E}} - \frac{\lambda_{E}(1 - \rho_{E})m_{K}}{\beta_{E}} - (1 - \delta)$$
(1.A.33)

$$R_{S} = \frac{1}{\beta_{B}} - \lambda_{B} \frac{\rho_{D}(1 - \beta_{B}) + \gamma_{S}(1 - \rho_{S})}{\beta_{B}}$$
(1.A.34)

$$R_{E} = \frac{1}{\beta_{B}} - \lambda_{B} \frac{\rho_{D}(1 - \beta_{B}) + \gamma_{E}(1 - \rho_{S})}{\beta_{B}}$$
(1.A.35)

$$R_K = b_{KE}(\zeta'_E z_{KE} + 1 - \zeta'_E)$$
(1.A.36)

$$R_M = \frac{1}{\beta_H} - (1 - \delta)$$
 (1.A.37)

$$Z = \Omega_r H_r \tag{1.A.38}$$

$$W_H = C_H \, \frac{\tau}{1 - N_H} \tag{1.A.39}$$

$$C_H = (R_M - \delta)K_H + (R_H - 1)D + W_H N_H + q_r \Omega_r H_r$$
(1.A.40)

$$C_{S} = (1 - R_{S})L_{S} + W_{S}N_{S} - q_{r}Z$$
(1.A.41)  

$$C_{S} = (1 - R_{S})L_{S} + W_{S}N_{S} - q_{r}\Omega_{r}H_{r}$$

$$C_E = Y - \delta K_E + L_E (R_E - 1) - W_H N_H - W_S N_S - R_M K_H$$
(1.A.42)

$$C_B = D(1 - R_H) + L_E(R_E - 1) + L_S(R_S - 1)$$
(1.A.43)

$$q H_H = \frac{j}{1 - \beta_H} C_H \tag{1.A.44}$$

$$z_{KH} = z_{KE} = 1$$
 (1.A.45)

$$q\left(1-\beta_H\right) = q_r \,\Omega_r \tag{1.A.46}$$

$$W_S = C_S \frac{\tau_S}{1 - N_S} \tag{1.A.47}$$

$$W_H = C_H \frac{\tau_H}{1 - N_H} \tag{1.A.48}$$

$$L_S = m_S \frac{q}{R_S} H_S \tag{1.A.49}$$

$$L_E = m_H \frac{q}{R_E} H_E + m_K K_E - m_N (W_H N_H + W_S N_S)$$
(1.A.50)

$$\widetilde{H}_{S} = \left[\theta_{S}^{1/\kappa_{s}}(H_{S})^{\frac{\kappa_{s}-1}{\kappa_{s}}} + (1-\theta_{S})^{1/\kappa_{s}}(Z)^{\frac{\kappa_{s}-1}{\kappa_{s}}}\right]^{\frac{\kappa_{s}}{\kappa_{s}-1}}$$
(1.A.51)

$$C_{S} \frac{j}{q\tilde{H}_{S}} \left(\frac{\theta_{S}\tilde{H}_{S}}{H_{S}}\right)^{1/\kappa_{S}} = 1 - \beta_{S} - \lambda_{S}(1 - \rho_{S})m_{S}\frac{1}{R_{S}}$$

$$q \tilde{H}_{S} \left(\frac{H_{S}}{\theta_{S}\tilde{H}_{S}}\right)^{1/\kappa_{S}} = C_{S} \frac{j}{1 - \beta_{S} - \lambda_{S}(1 - \rho_{S})m_{S}\frac{1}{R_{S}}}$$

$$(1.A.52)$$

$$\frac{j}{\widetilde{H}_{S,t}} \left( \frac{(1-\theta_S)\widetilde{H}_S}{Z} \right)^{1/\kappa_S} = q_r \frac{1}{C_S}$$

$$C_S \frac{j}{q_r \widetilde{H}_S} \left( \frac{(1-\theta_S)\widetilde{H}_S}{Z} \right)^{1/\kappa_S} = 1$$
(1.A.53)

$$D = \gamma_E L_E + \gamma_S L_S \tag{1.A.54}$$

$$q H_E = Y \frac{\nu}{R_V} \tag{1.A.55}$$

$$K_E = Y \, \frac{\alpha \, \mu}{R_K} \tag{1.A.56}$$

$$K_H = Y \,\frac{\alpha(1-\mu)}{R_M} \tag{1.A.57}$$

$$N_H W_H = Y (1 - \alpha - \nu) (1 - \sigma)$$
 (1.A.58)

$$N_S W_S = Y \left(1 - \alpha - \nu\right) \sigma \tag{1.A.59}$$

$$Y(1 - \alpha - \nu)(1 - \sigma) = N_H W_H [1 + (1 - \rho_E)\lambda_E m_N]$$
(1.A.60)

$$Y(1 - \alpha - \nu)\sigma = N_S W_S[1 + (1 - \rho_E)\lambda_E m_N]$$
(1.A.61)

$$Y = (K_H)^{\alpha(1-\mu)} (K_E)^{\alpha\mu} K_E^{\nu} N_H^{(1-\alpha-\nu)(1-\sigma)} N_S^{(1-\alpha-\nu)\sigma}$$
(1.A.62)

#### 1.A.4 Derivation of the Steady State Variables

First we start deriving the rental housing share  $H_r$  in terms of  $H_S$ . For this reason we rewrite condition (1.A.52) such that:

$$u_{HS} = \frac{j}{\tilde{H}_S} \left(\frac{H_S}{\theta_S \tilde{H}_S}\right)^{1/\kappa_S} = C_S^{-1} q \left[1 - \beta_S - \lambda_S (1 - \rho_S) m_S \frac{1}{R_S}\right]$$
(1.A.63)

Recall that equation (1.A.53) is equal to

$$u_{ZS} = \frac{j}{\widetilde{H}_{S,t}} \left(\frac{(1-\theta_S)\widetilde{H}_S}{Z}\right)^{1/\kappa_S} = q_r C_S^{-1}$$
(1.A.64)

Dividing equation (1.A.63) by equation (1.A.64) yields

$$\frac{u_{HS}}{u_{ZS}} = \left[\frac{\theta_S}{(1-\theta_S)}\frac{Z}{H_S}\right]^{1/\kappa_S} = \frac{q}{q_r}\left[1-\beta_S-\lambda_S(1-\rho_S)m_S\frac{1}{R_S}\right]$$
(1.A.65)

Using the fact that  $Z = \Omega_r H_r$ , equation (1.A.65) can be rewritten:

$$\left[\frac{H_r}{H_S}\right]^{1/\kappa_S} = \frac{q}{q_r} \left(\frac{1-\theta_S}{\theta_S}\right)^{1/\kappa_S} \left[1-\beta_S - \lambda_S(1-\rho_S)m_S\frac{1}{R_S}\right]$$
(1.A.66)

Condition (1.A.46) provides us with the steady state price-rent ratio of the form  $\frac{q}{q_r} = \frac{\Omega_r}{1-\beta_H}$ . Using this result and substituting it into (1.A.65) yields:

$$\frac{H_r}{H_S} = \frac{1 - \theta_S}{\Omega_r \theta_S} \left(\frac{\Omega_r}{1 - \beta_H}\right)^{\kappa_S} \left[1 - \beta_S - \lambda_S (1 - \rho_S) m_S \frac{1}{R_S}\right]^{\kappa_S} = \Gamma^*$$
(1.A.67)

and hence we end up with the steady state relationship between rental and mortgaged housing:

$$H_r = H_S \,\Gamma^* \tag{1.A.68}$$

The next step involves deriving the borrower's steady state consumption  $C_S$ . Using the result stated by equation (1.A.68), (1.A.46) and (1.A.49) we can rewrite the constraint given by (1.A.41)

$$C_{S} = (1 - R_{S})L_{S} + W_{S}N_{S} - q_{r} \Omega_{r}H_{r}$$
  
=  $(1 - R_{S})L_{S} + W_{S}N_{S} - q_{r} \Omega_{r}H_{S} \Gamma^{*}$   
=  $(1 - R_{S})m_{S}\frac{q}{R_{S}}H_{S} + W_{S}N_{S} - (1 - \beta_{H})qH_{S} \Gamma^{*}$  (1.A.69)

We are now able to factor out  $H_S q$ , which leaves us with:

$$C_{S} = W_{S}N_{S} - q H_{S} \left[ \left(1 - \frac{1}{R_{S}}\right) m_{S} + \left(1 - \beta_{H}\right) \Gamma^{*} \right]$$
(1.A.70)

However, we still do not know the exact expression for  $C_S$ . In order to pin it down we have to return to condition (1.A.52). Recall that  $Z = \Omega_r H_r = \Omega_r H_S \Gamma^*$ , we can then write

$$C_{S} \frac{j}{q\widetilde{H}_{S}} \left(\frac{\theta_{S}\widetilde{H}_{S}}{H_{S}}\right)^{1/\kappa_{S}} = \underbrace{1 - \beta_{S} - \lambda_{S}(1 - \rho_{S})m_{S}\frac{1}{R_{S}}}_{= T_{1}}$$

$$\Rightarrow C_{S} \frac{j}{q} \left(\frac{\theta_{S}}{H_{S}}\right)^{1/\kappa_{S}} \widetilde{H}_{S}^{\frac{-(\kappa_{S}-1)}{\kappa_{S}}} = T_{1}$$

$$\Rightarrow C_{S} \frac{j}{q} \left(\frac{\theta_{S}}{H_{S}}\right)^{1/\kappa_{S}} \frac{1}{\theta_{S}^{1/\kappa_{S}} H_{S}^{\frac{(\kappa_{S}-1)}{\kappa_{S}}} + (1 - \theta_{S})^{1/\kappa_{S}} (\Omega_{r} H_{S} \Gamma^{*})^{\frac{(\kappa_{S}-1)}{\kappa_{S}}}} = T_{1}$$

$$(1.A.71)$$

Condition (1.A.71) can be further simplified by combining  $H_S^{-1/\kappa_S}$  with the denominator of the fraction. We can collect terms in  $H_S$  which yields the result:

$$\frac{q H_S}{C_S} = \underbrace{\frac{j \theta_S^{1/\kappa_S}}{T1 \left[ \theta_S^{1/\kappa_S} + (1 - \theta_S)^{1/\kappa_S} \left(\Omega_r \, \Gamma^*\right)^{\frac{(\kappa_S - 1)}{\kappa_S}} \right]}_{= T_2}}_{(1.A.72)$$

$$\Rightarrow q H_S = T_2 C_S$$

We are now able to derive the borrower's steady state consumption. Using the earlier derived result in (1.A.70) and combining it with (1.A.72):

$$C_{S} = W_{S}N_{S} - T_{2}C_{S}\left[\left(1 - \frac{1}{R_{S}}\right)m_{S} + (1 - \beta_{H})\Gamma^{*}\right]$$
  

$$\Rightarrow C_{S} = \underbrace{\frac{1}{1 + T_{2}\left[\left(1 - \frac{1}{R_{S}}\right)m_{S} + (1 - \beta_{H})\Gamma^{*}\right]}_{= T_{3}}W_{S}N_{S}$$
(1.A.73)  

$$\Rightarrow C_{S} = T_{3}W_{S}N_{S}$$

In a similar fashion we can derive  $C_H$ ,  $C_E$  and  $C_B$ . In order to find  $C_H$ , we can combine (1.A.49), (1.A.50), (1.A.54) with the saver's budget constraint (1.A.40). This yields:

$$C_{H} = (R_{M} - \delta)K_{H} + (R_{H} - 1)\left\{\gamma_{E}\left[m_{H}\frac{q}{R_{E}}H_{E} + m_{K}K_{E} - m_{N}(W_{H}N_{H} + W_{S}N_{S})\right] + \gamma_{S}m_{S}\frac{q}{R_{S}}H_{S}\right\} + W_{H}N_{H} + q_{r}\Omega_{r}H_{r}$$
(1.A.74)

Using the earlier computed results we can rewrite (1.A.74):

$$C_{H} = \underbrace{(R_{M} - \delta)}_{= oo6} K_{H} + (R_{H} - 1)\gamma_{E} \left[ m_{H} \frac{q}{R_{E}} H_{E} + m_{K} K_{E} - m_{N} (W_{H} N_{H} + W_{S} N_{S}) \right] + T_{4} W_{S} N_{S} + W_{H} N_{H}$$
(1.A.75)

where

$$T_4 = T_2 T_3 \left[ \gamma_S (R_H - 1) m_S \frac{1}{R_S} + \Gamma^* (1 - \beta_H) \right].$$

Note that the steady state expressions represented ranging from  $oo_1$  to  $oo_8$  are just functions of the underlying model parameters and hence are constants. In order to pin down  $C_H$  we have to use the steady expressions for  $q H_E$ ,  $K_E$ ,  $N_H W_H$  and  $N_S W_S$ . Equation (1.A.55) provides us with the steady state condition for  $qH_E$ and (1.A.56) describes the steady state capital stock of the entrepreneur. Before we can plug those results into (1.A.75) we need to define  $N_H W_H$  and  $N_S W_S$ . Rearranging condition (1.A.60) and (1.A.61) yields:

$$\Rightarrow N_H W_H = \underbrace{Y \frac{(1 - \alpha - \nu)(1 - \sigma)}{[1 + (1 - \rho_E)\lambda_E m_N]}}_{= oo_7} = oo_7 Y$$
(1.A.76)

$$\Rightarrow N_S W_S = Y \frac{(1 - \alpha - \nu)(1 - \sigma)}{[1 + (1 - \rho_E)\lambda_E m_N]}$$
(1.A.77)

And the sum of both leaves us with:

$$\Rightarrow N_H W_H + N_S W_S = Y \frac{(1 - \alpha - \nu)(1 - \sigma)}{[1 + (1 - \rho_E)\lambda_E m_N]}$$
(1.A.78)

Using these results from above we can now rewrite  $C_H$ :

$$C_{H} = oo6K_{H} + Y \underbrace{(R_{H} - 1)\gamma_{E} \left[ m_{H} \frac{v}{R_{E}R_{V}} + \frac{m_{K}\alpha\mu}{R_{K}} - \frac{m_{N}(1 - \alpha - \mu)}{1 + \lambda_{E}m_{N}(1 - \rho_{E})} \right]}_{= oo4} + T_{4} W_{S}N_{S} + W_{H}N_{H}$$
(1.A.79)

$$\Rightarrow C_H = oo6K_H + oo_4Y + T_4W_SN_S + W_HN_H \tag{1.A.80}$$

(1.A.76) can be rearranged such that:  $Y = \frac{N_H W_H}{oo_7}$ . Therefore,  $C_H$  becomes:

$$C_H = oo_6 K_H + W_H N_H \left(1 + \frac{oo_4}{oo_7}\right) + T_4 W_S N_S$$
(1.A.81)

The next steps involves replacing  $K_H$  in (1.A.81) by using (1.A.57) and (1.A.76):

$$K_H = Y \underbrace{\frac{\alpha(1-\mu)}{R_M}}_{oo_8} = oo_8 Y = \frac{oo_8}{oo_7} W_H N_H$$
(1.A.82)

Dividing (1.A.58) by (1.A.59) yields:

$$\frac{1-\sigma}{\sigma} = \frac{W_H N_H}{W_S N_S} \Rightarrow W_S N_S = \frac{\sigma}{1-\sigma} W_H N_H \tag{1.A.83}$$

Hence, we are now able rewrite (1.A.81) and factor out  $W_H N_H\colon$ 

$$C_H = oo_6 \frac{oo_8}{oo_7} W_H N_H + W_H N_H \left(1 + \frac{oo_4}{oo_7}\right) + T_4 \frac{\sigma}{1 - \sigma} W_H N_H$$
(1.A.84)

$$C_{H} = W_{H}N_{H}\underbrace{\left(oo_{6}\frac{oo_{8}}{oo_{7}} + \frac{oo_{4}}{oo_{7}} + T_{4}\frac{\sigma}{1-\sigma} + 1\right)}_{z_{1}} = W_{H}N_{H}z_{1}$$
(1.A.85)

We want to use this result and find an expression for the steady state labour supply  $N_H$  and  $N_S$ . Combining condition (1.A.48) with the previous expression for  $C_H$  leaves us with

$$1 = \frac{\tau_H}{1 - N_H} N_H z_1 \Rightarrow \frac{\tau_H}{1 - N_H} = \frac{1}{N_H z_1}$$
(1.A.86)

and hence we obtain the steady state solution for the labour supply  $N_H$ :

$$N_H = \frac{1}{1 + \tau_H \, z_1} \tag{1.A.87}$$

Now we substitute (1.A.73) into (1.A.47) to find

$$\frac{1}{T_3 N_S} = \frac{\tau_S}{1 - N_S} \tag{1.A.88}$$

where the solution of  ${\cal N}_S$  takes the following form:

$$N_S = \frac{1}{1 + \tau_S T_3} \tag{1.A.89}$$

In order to work out  $H_S, H_H$  and  $H_E$  we compute the consumption-output-ratios:

$$c_{y_S} = \frac{C_S}{Y} = \frac{T_3 W_S N_S}{N_S W_S [1 + (1 - \rho_E) \lambda_E m_N]} (1 - \alpha - \nu) \sigma = \frac{T_3 (1 - \alpha - \nu) \sigma}{1 + (1 - \rho_E) \lambda_E m_N}$$
(1.A.90)

$$c_{y_H} = \frac{C_H}{Y} = \frac{z_1 W_H N_H}{W_H N_H} oo_7 = z_1 oo_7$$
(1.A.91)

Hence, steady state housing is determined by the following conditions:

$$qH_H = \underbrace{\frac{j}{1-\beta_H}}_{oo_1} C_H = oo1c_{y_H}Y$$
(1.A.92)

$$qH_S = T_2 c_{y_S} Y \tag{1.A.93}$$

$$qH_S = \frac{\nu}{R_V} \tag{1.A.94}$$

$$H_r = H_S \, \Gamma^* \tag{1.A.95}$$

$$H_H + H_S + H_r + H_E = 1 (1.A.96)$$

To work out  $H_H$  we divide (1.A.92) by (1.A.93):

$$H_H = H_S \, \frac{oo_1 \, c_{y_H}}{T_2 c_{y_S}} \tag{1.A.97}$$

$$H_E = H_S \, \frac{\nu}{R_V \, T_2 \, c_{y_S}} \tag{1.A.98}$$

The market clearing condition (1.A.96) provides us with the steady state solution for for the individual housing demands:

$$H_S = \frac{T_2 c_{y_S}}{oo_1 c_{y_H} + T_2 c_{y_S} (1 + \Gamma^*) + \frac{\nu}{R_V}}$$
(1.A.99)

$$H_H = \frac{oo_1 c_{y_H}}{oo_1 c_{y_H} + T_2 c_{y_S} (1 + \Gamma^*) + \frac{\nu}{R_V}}$$
(1.A.100)

$$H_E = \frac{\frac{\nu}{R_V}}{oo_1 c_{y_H} + T_2 c_{y_S} (1 + \Gamma^*) + \frac{\nu}{R_V}}$$
(1.A.101)

$$H_r = \frac{T_2 \Gamma^* c_{y_S}}{oo_1 c_{y_H} + T_2 c_{y_S} (1 + \Gamma^*) + \frac{\nu}{R_V}}$$
(1.A.102)

Deriving loans to borrowers  $L_S$  and entrepreneurs  $L_E$ :

$$L_S = m_S \frac{q}{R_S} H_S = \frac{m_S}{R_S} T_2 C_S = \frac{m_S}{R_S} T_2 T_3 W_S N_S$$
(1.A.103)

$$L_{E} = m_{H} \frac{q}{R_{E}} H_{E} + m_{K} K_{E} - m_{N} (W_{H} N_{H} + W_{S} N_{S})$$
  
$$= m_{H} \frac{q}{R_{E}} H_{E} + m_{K} K_{E} - m_{N} \frac{1 - \alpha - \nu}{1 + \lambda_{E} m_{N} (1 - \rho_{E})}$$
(1.A.104)

Having obtained these steady state values, it is straight forward to solve for the remaining variables.

#### 1.A.5 Plots of the Posterior Modes

This section shows the mode plots of the constructed log-likelihood kernel (orange) and log-posterior (blue) functions. A shift in the posterior indicates the effect of the prior distribution. Identical functions suggest that the prior information has no impact on the posterior, after adding it to the likelihood. The x-axis represents the parameter space and the y-axis stands for the value of the log-likelihood kernel. The vertical line has to coincide with the mode of the posterior, otherwise the MCMC starts at the wrong point for the parameter space.



**Figure 1.10:** Mode Plots: Upper panel:  $\sigma_{be}$ ,  $\sigma_{bh}$ ,  $\sigma_j$ . Middle panel:  $\sigma_k$ ,  $\sigma_{ME}$ ,  $\sigma_{MH}$ . Lower Panel:  $\sigma_p$ ,  $\sigma_z^0$ ,  $\sigma_z^4$ .



Figure 1.11: Mode Plots: Upper panel:  $\sigma_z^8$ ,  $\eta$ ,  $\phi_{DB}$ . Middle panel:  $\phi_{DH}$ ,  $\phi_{KE}$ ,  $\phi_{KH}$ . Lower Panel:  $\phi_{EB}$ ,  $\phi_{EE}$ ,  $\phi_{SB}$ .



**Figure 1.12:** Mode Plots: Upper panel:  $\phi_{SS}$ ,  $\kappa_S$ ,  $\Omega_r$ . Middle panel:  $\mu$ ,  $\nu$ ,  $\rho_D$ . Lower Panel:  $\rho_E$ ,  $\rho_S$ ,  $\sigma$ .



**Figure 1.13:** Mode Plots: Upper panel:  $\theta_S$ ,  $\zeta_E$ ,  $\zeta_H$ . Middle panel:  $\rho_{be}$ ,  $\rho_{bh}$ ,  $\rho_j$ . Lower Panel:  $\rho_k$ ,  $\rho_{me}$ ,  $\rho_{mh}$ .



Figure 1.14: Mode Plots: Upper panel:  $\rho_p$ ,  $\rho_z$ .

#### 1.A.6 Convergence Results

The Brooks and Gelman (1998) univariate convergence diagnostics are illustrated below. The first column of the figure represents the convergence results of the 80% interval, according to section 3, in Brooks and Gelman (1998). The red line shows the mean interval space depending on the draws of the individual sequences. In contrast, the blue line depicts the pooled draws of each sequence at 80% interval. The columns m2 and m3 report an estimate of the squared and cubed absolute deviations from the pooled within-sample mean. In other words, it delivers an estimate of the second and third central moment. To see whether the parameters have converged, we need to observe two things from the graphs. First, the red and blue lines have to stabilise horizontally. Second, both lines have to be close to each other.



Figure 1.15: MCMC Convergence: Upper panel:  $\sigma_{be}$ . Middle panel:  $\sigma_{bh}$ . Lower Panel:  $\sigma_j$ .



**Figure 1.16:** MCMC Convergence: Upper panel:  $\sigma_k$ . Middle panel:  $\sigma_{me}$ . Lower Panel:  $\sigma_{mh}$ .



**Figure 1.17:** MCMC Convergence: Upper panel:  $\sigma_p$ . Middle panel:  $\sigma_z^0$ . Lower Panel:  $\sigma_z^4$ .


Figure 1.18: MCMC Convergence: Upper panel:  $\sigma_z^8$ . Middle panel:  $\eta$ . Lower Panel:  $\phi_{DB}$ .



**Figure 1.19:** MCMC Convergence: Upper panel:  $\phi_{DH}$ . Middle panel:  $\phi_{KE}$ . Lower Panel:  $\phi_{KH}$ .



Figure 1.20: MCMC Convergence: Upper panel:  $\phi_{EB}$ . Middle panel:  $\phi_{EE}$ . Lower Panel:  $\phi_{SB}$ .



**Figure 1.21:** MCMC Convergence: Upper panel:  $\phi_{SS}$ . Middle panel:  $\kappa_S$ . Lower Panel:  $\Omega_r$ .



Figure 1.22: MCMC Convergence: Upper panel:  $\mu$ . Middle panel:  $\nu$ . Lower Panel:  $\rho_D$ .



**Figure 1.23:** MCMC Convergence: Upper panel:  $\rho_E$ . Middle panel:  $\rho_S$ . Lower Panel:  $\sigma$ .



**Figure 1.24:** MCMC Convergence: Upper panel:  $\theta_S$ . Middle panel:  $\zeta_E$ . Lower Panel:  $\zeta_H$ .



Figure 1.25: MCMC Convergence: Upper panel:  $\rho_{be}$ . Middle panel:  $\rho_{bh}$ . Lower Panel:  $\rho_j$ .



**Figure 1.26:** MCMC Convergence: Upper panel:  $\rho_k$ . Middle panel:  $rho_{me}$ . Lower Panel:  $\rho_{mh}$ .



Figure 1.27: MCMC Convergence: Upper panel:  $\rho_p$ . Middle panel:  $\rho_z$ .  $\sigma_j$ .

## 1.A.7 Trace Plots of Housing Parameters

This section plots the iterations of the first and second Markov chain (gray) and the 200 period moving average (black). As we can see from the figures the trace plots exhibit no trend behaviour and can therefore be considered stable. This in turn indicates parameter convergence of the newly introduced housing parameters.



Figure 1.28: Trace plot of chain 1, parameter  $\kappa_S$ .



**Figure 1.29:** Trace plot of chain 2, parameter  $\kappa_S$ .



Figure 1.30: Trace plot of chain 1, parameter  $\theta_S$ .



Figure 1.31: Trace plot of chain 2, parameter  $\theta_S$ .



**Figure 1.32:** Trace plot of chain 1, parameter  $\Omega_r$ .



**Figure 1.33:** Trace plot of chain 2, parameter  $\Omega_r$ .

Chapter 2

# The Credit Boom Revisited - A DSGE Analysis

## 2.1 Introduction

In this chapter I revisit the question, whether expansionary monetary policy by the Federal Reserve is to blame for the latest housing boom and bust, as pointed out by Taylor (2007, 2009) and the Bank for International Settlements (2007, 2008). They argue that the low interest rates prior to the financial crisis stimulated the demand for housing and triggered a sharp increase in house prices, household credit and homeownership. Due to the ambiguous results in the literature, I shed new light on this topic with the help of an estimated DSGE model.



The figure above depicts the pre-crisis developments of household loans,<sup>24</sup> measured in percentage deviations from its quadratic trend, and the Federal Funds rate. As we can see from the top figure, the largest positive deviation of household loans occurs in the mid 2000s which is accompanied by increased homeownership rates. In fact, during 2004 and 2005, homeownership reached historical highs and exceeded 69 percent twice. Overall, homeownership remained at a very high level until the end of 2006 before it started to decline,<sup>25</sup> as illustrated in figure 2.2. These numbers can be obtained from the U.S. Bureau of the Census database. Interest rates exhibit an overall downward trend, with a sharp decline between 2000 and 2003 where they fell

 $<sup>^{24}</sup>$ The data corresponds to the sum of XL15HOM5 + HCCSDODNS. The series is log transformed and in real terms. XL15HOM5: Households and nonprofit organisations; home mortgages. HCCSDODNS: Households and nonprofit organisations; consumer credit. It is worth to mention that XL15HOM5 takes up on average more than 75 percent of total household loans. Between the years 2003 and 2006, home mortgages grew on average much faster (3.1 percent) than consumer credit (1.3 percent).

<sup>&</sup>lt;sup>25</sup>The homeownership rate declined rapidly during the post-crisis years and has reached a value of 63.7 in the second quarter of 2017. This is equivalent to rates in the mid 80s and early 90s.

from around 6 percent down to 1 percent. The policy rate remained at a very low level and did not exceed 2 percent until the first quarter of 2005. Therefore, the question arises whether loose monetary policy has contributed to the sharp increase in loans and thus boosted homeownership.



Figure 2.2: Homeownership Rate

The contribution of this chapter is to provide new evidence of the role of monetary policy during the buildup of the financial crisis. The foundation of today's DSGE models with housing and financial frictions was laid long before the financial crisis by Kiyotaki and Moore (1997). The authors were the first to introduce a borrowing constraint on the supply side of the economy, where land is used as a collateral. As the chapter shows, the implementation of such a collateral constraint generates an acceleration effect of the shock transmission. The mechanism was updated by Iacoviello (2005) and land was replaced by housing. The latest financial crisis has sparked a new wave of research, focussing on housing markets and their effect on the real economy. The most famous study in this area is the paper by Iacoviello and Neri (2010). They develop and estimate a DSGE model of the U.S., in order to analyse the spillover effects of the housing sector. One of their key results shows that housing market spillovers to the broader economy are non-negligible and increase in importance over time.

The underlying framework is a general equilibrium model, similar to those presented in Iacoviello (2015) and Iacoviello and Neri (2010). The economy is inhabited by three agents: households, entrepreneurs and banks. There is heterogeneity across households, which is represented by an impatient and patient agent. They can be also referred to as borrowers and savers. The difference between both household types is their discount factor. Hence, impatient agents discount the future more heavily than patient households which creates an incentive to borrow from banks. Savers supply deposits to banks and provide borrowers with rental services. Impatient households are credit constrained and decide between renting or owning a home. The supply side of the economy consists of two sectors: consumption and housing. As borrowers, entrepreneurs face a liquidity constraint and produce the final good and new housing. A central bank sets the interest rates at which banks collect deposits. Therefore changes in the deposit rates either contract or loosen the credit channel. Banks are included in this model for three reasons. First, a Bayesian comparison performed by Iacoviello (2015) shows that a model with banks is preferred to one with traditional financial frictions.<sup>26</sup> Second, in contrast to a conventional financial frictions framework, the same study finds that banking frictions amplify the responses of house prices to shocks. Third, as we know from the recent financial crisis, banks were one of the key players of the latest economic downturn. Note that our analysis abstracts from factors such as unemployment, income distributions, education and other socio-economic variables which also influence an individual's ability to buy a home.

The estimated model presented in this paper, is able to replicate the trade-off between monetary policy and homeownership. The results indicate that the impact of a monetary policy shock on owner-occupied housing is rather small, however it is its persistence which severely determines the housing status (i.e. either renting or owning) of households. This adds to the findings of Painter and Redfearn (2002), who conclude that interests rates have only little impact on movements of the homeownership rate. Banks play a crucial role in this analysis as they control the loan supply subject to interest rate changes. Monetary policy shocks drive 12 and 30 percent of the variance of household loans and mortgaged housing, respectively. Similarly, monetary disturbances only account for a small share of house price movements. This study also finds that loose monetary policy before the crisis is not to blame for the dramatic expansion in household loans and house price growth. However, the main driving force behind loan fluctuations in the past were LTV shocks. They pick up on the Housing and Community Development Act established in the 80s and early 90s and capture irresponsible lending and risk taking by banks before the crisis. Dell'Ariccia, Igan, and Laeven (2008) provide robust evidence regarding the lending standards in the run-up to 2007. They show that areas with a faster credit expansion also exhibited lower loan denials and lenders were less concerned about the loan-to-income ratio of borrowers. Overall, the quality of loans deteriorated monotonically between 2001 and 2007, as Demyanyk and Van Hemert (2009) find.

There is an extensive literature, investigating the link between monetary policy and the recent financial crisis. A small list of notable contributions are studies conducted by Jarocinski and Smets (2008), Dokko et al.

 $<sup>^{26}\</sup>mathrm{Household}$  savers act as lenders.

(2011), Eickmeier and Hofmann (2013), Bordo, Landon-Lane, et al. (2014) and Cesa-Bianchi and Rebucci (2017). However, the results in the literature are mixed. While some papers find that loose monetary policy contributed significantly to the recent crisis, other research projects suggest that low interest rates prior to the Great Recession were not the key contributor. In other words, the link between interest rates and the housing market is too weak.

Jarocinski and Smets (2008) analyse the link between monetary policy and the U.S. housing market with an estimated Bayesian VAR model. The authors find evidence that monetary policy significantly influences house prices and residential investment. Furthermore, the results show that loose monetary policy has contributed to the pre-crisis housing boom in 2004 and 2005. The research project by Eickmeier and Hofmann (2013) confirms these findings. Based on the outcome of a factor augmented VAR model, the authors reach two important conclusions. First, changes in the policy rate have a long-lasting impact on private sector debt, real estate wealth and house prices. Second, the model results also show that pre-crisis monetary policy was a crucial driving force behind the dangerous developments of the U.S. credit and housing markets. Bordo, Landon-Lane, et al. (2014) take a more general stance. In their paper they evaluate the effect of monetary policy on asset price booms. The authors therefore look at data from 18 OECD economies from 1920 to 2011, which contains information about commodity, stock market and house price booms. Using a panel data regression approach, the robust estimation results illustrate that expansionary monetary policy does positively influence asset prices. This link becomes increasingly strong in times of fast asset price growth, followed by a correction period.

The findings discussed above stand in contrast to those of Dokko et al. (2011). The output of their estimated and unrestricted VAR framework indicates that monetary policy was not the main cause behind the U.S. housing boom. In other words, monetary policy shocks have only a small effect on house prices. Moreover the authors find that interest rates before the crisis were adequate and therefore monetary policy was not too loose, as argued above. This is in line with the findings of Cesa-Bianchi and Rebucci (2017). The study constructs a model which features occasionally binding borrowing constraints and rigidities in the bank lending rate. Apart from analysing the interplay of monetary and macro-prudential policy, Cesa-Bianchi and Rebucci (2017) use their framework to discuss the latest housing boom and the role of the Fed. The model results suggest that the unfolding housing boom could not have been prevented through monetary policy actions alone, without putting economic stability at risk. As the findings demonstrate, regulation should have been used along with monetary policy's stabilisation measures between 2000 and 2004.

Shortly after the crisis a new explanation for the low long-term interest rates emerged. This is better known

as the "global savings glut" and was first mentioned by Bernanke et al. (2005). The hypothesis says that world savings increased sharply during the early and mid 2000s, which led to a large inflow of capital into the U.S. and drove down long-term interest rates (Bernanke 2010). Hence, the argument is that the low policy rates prior to the crisis simply reflected this decline and the Fed did follow the correct procedure by reducing interest rates. Authors such as Obstfeld and Rogoff (2009) support the savings glut hypothesis. Again, research in this area has delivered ambiguous results. The findings by Warnock and Warnock (2009) show that long-term Treasury yields would be 80 basis points higher without the foreign purchases of U.S. government bonds. However, Taylor (2009) argues that the concept of a global saving glut does not hold when looking at the data. He finds that between 2002 and 2004 world saving rates are in fact smaller than in the 1980s and 1990s. Taylor (2009) also highlights that during this time the U.S. was in fact running a current account deficit (i.e. savings are smaller than investments). Research output by Borio and Disyatat (2011) shows that the global excess saving hypothesis was not the main driving force behind the credit boom and hence the financial crisis. Besides the literature mentioned above, articles by Rötheli (2010), and Sá, Towbin, and Wieladek (2011) conclude that accommodative monetary policy contributed significantly to the latest housing boom. These findings are therefore in contrast to the global saving glut theory.<sup>27</sup>

This study provides new evidence on this topic by using a DSGE model which explicitly accommodates a banking and owner-occupied housing sector as well as nominal rigidities. The remainder of the paper is organised as follows. Section 2.2 outlines the model economy with its respective agents. Sections 2.3 and 2.4 discuss the calibrated parameters and data used for the estimation exercise. The empirical results are presented in sections 2.5 and 2.6. Section 2.7 performs a robustness check and section 2.8 concludes.

# 2.2 The Model

The model economy is related to those outlined in Iacoviello (2015), Iacoviello and Neri (2010) and Sun and Tsang (2017). However, this chapter relaxes the assumption of a constant housing supply and introduces a banking channel. Furthermore, nominal price rigidities are introduced at the retail level and a central bank sets interest rates according to a Taylor rule. The model accommodates three different types of agents: households, banks and entrepreneurs. Patient households transform their owner-occupied housing units into rental housing services and lease them to impatient households. Each economic agent is represented by a continuum of measure one.

<sup>&</sup>lt;sup>27</sup>Economists such as Summers (2013) have argued that the low pre-crisis interest rates should have caused an overheating of the economy. Hence, inflation should have increased dramatically which it failed to do.

#### 2.2.1 Patient Households

Savers discount at rate  $\beta_H$  and choose consumption  $C_{H,t}$ , housing  $H_{H,t}$  and derive disutility from working.  $N_{H,t}^c$  and  $N_{H,t}^h$  are the hours supplied to the consumption and construction sector.

$$E_{0} \sum_{t=0}^{\infty} \beta_{H}^{t} \left\{ A_{p,t}(1-\eta) \log(C_{H,t} - \eta C_{H,t-1}) + j A_{j,t} A_{p,t} \log(H_{H,t}) - \frac{\tau}{1+\chi^{H}} \left[ (N_{H,t}^{c})^{1+\kappa_{H}^{N}} + (N_{H,t}^{h})^{1+\kappa_{H}^{N}} \right]^{\frac{1+\chi^{H}}{1+\kappa_{H}^{N}}} \right\}$$
(2.2.1)

Subject to the following budget constraint:

$$C_{H,t} + \frac{K_{H,t}^{c}}{A_{K,t}} + K_{H,t}^{h} + D_{t} + q_{t} \left\{ [H_{H,t} - (1 - \delta_{HH})H_{H,t-1}] + [H_{r,t} - (1 - \delta_{Hr})H_{r,t-1}] \right\} + ac_{KH,t}^{c} + ac_{KH,t}^{h} + ac_{DH,t} = \left( R_{M,t}^{c} z_{KH,t}^{c} + \frac{1 - \delta_{KH,t}^{c}}{A_{K,t}} \right) K_{H,t-1}^{c} + (R_{M,t}^{h} z_{KH,t}^{h} + 1 - \delta_{KH,t}^{h}) K_{H,t-1}^{h} + \frac{R_{H,t-1}D_{t-1}}{\pi_{t}} + W_{H,t}^{c} N_{H,t}^{c} + W_{H,t}^{h} N_{H,t}^{h} + q_{r,t} \Omega_{r} H_{r,t} + DIV_{t}.$$

$$(2.2.2)$$

External habit formation in consumption is represented by the parameter  $\eta$ . Two shocks enter the utility function of the patient household: the preference shock  $A_{p,t}$  and the housing demand shock  $A_{j,t}$ . The aggregate spending shock simultaneously effects the saver's choices of consumption and housing. i determines the preference share in housing and  $\tau$  stands for the labour supply parameter. The way the disutility of labour is defined ( $\kappa_H^N, \chi^H \ge 0$ ) allows for less than perfect mobility between sectors. Turning to the budget constraint, savers deposit  $D_t$  and receive a gross return of  $R_{H,t}$ . Patient households accumulate owneroccupied  $H_{H,t}$  and rental housing  $H_{r,t}$  priced at  $q_t$ . The term  $DIV_t$  refers to the lump-sum dividends paid by retailers. Unconstrained households rent capital to entrepreneurs, which they use to produce the final good and new homes.  $K_{H,t}^c$  and  $K_{H,t}^h$  represent therefore the capital stock of the consumption and construction sector with their respective utilisation rates of  $z_{KH,t}^c$  and  $z_{KH,t}^h$ .  $A_{K,t}$  is an investment-specific capital shock. Patient agents receive a rental rate of capital denoted by  $R_{M,t}^c$  and  $R_{M,t}^h$ . Savers convert their rental property into rental services  $Z_t$ , which they then let to borrowers. This transformation process is captured by the production function  $Z_t = \Omega_r H_{r,t}$ . The parameter  $\Omega_r$  measures the inefficiency in converting rental homes into rental services. Patient households receive rental income according to  $q_{r,t} \Omega_r H_{r,t}$  at a rental rate  $q_{r,t}$ . The terms  $ac_{KH,t}^c$ ,  $ac_{KH,t}^h$  and  $ac_{DH,t}$  are the respective (quadratic and convex) external adjustment costs for capital and deposits. As habits, adjustment costs are assumed to be external. Owner-occupied and rental housing depreciate at rate  $\delta_{HH}$  and  $\delta_{Hr}$ . The capital depreciation functions are given by  $\delta_{KH,t}^c$  and  $\delta^h_{KH,t}$ . The exact specification of adjustment costs, capital depreciation functions, marginal utilities and the resulting first order conditions can be found in the appendix.

#### 2.2.2 Impatient Households

Borrowers are credit constrained and discount the future at a rate  $\beta_S < \beta_H$ . This assumption ensures that for small shocks the collateral constraint binds in the neighbourhood of the steady state. As impatient households have access to the loan market they use their current mortgaged housing stock  $H_{S,t}$  as collateral. Hence, those types of households are liquidity constrained. The borrower's utility function is given by:

$$E_{0} \sum_{t=0}^{\infty} \beta_{S}^{t} \left\{ A_{p,t}(1-\eta) \log(C_{S,t}-\eta C_{S,t-1}) + j A_{j,t} A_{p,t} \log(\widetilde{H}_{S,t}) - \frac{\tau}{1+\chi^{S}} \left[ (N_{S,t}^{c})^{1+\kappa_{S}^{N}} + (N_{S,t}^{h})^{1+\kappa_{S}^{N}} \right]^{\frac{1+\chi^{S}}{1+\kappa_{S}^{N}}} \right\}$$
(2.2.3)

where

$$\widetilde{H}_{S,t} = \left[\theta_S^{1/\kappa_s}(H_{S,t})^{\frac{\kappa_s-1}{\kappa_s}} + (1-\theta_S)^{1/\kappa_s}(Z_t)^{\frac{\kappa_s-1}{\kappa_s}}\right]^{\frac{\kappa_s}{\kappa_s-1}}$$

subject to

$$C_{S,t} + q_{r,t}Z_t + q_t[H_{S,t} - (1 - \delta_{HS})H_{S,t-1}] + \frac{R_{S,t-1}L_{S,t-1}}{\pi_t} - \varepsilon_{H,t} + ac_{SS,t} = L_{S,t} + W_{S,t}^c N_{S,t}^c + W_{S,t}^h N_{S,t}^h.$$

$$(2.2.4)$$

The CES housing aggregator  $H_{S,t}$  in the borrower's utility function captures the assumption that owneroccupied and rental homes are substitutes. In other words, the impatient agent's demand for housing is a composite index consisting of owner-occupied and rental housing. The constant elasticity of substitution between both housing types is represented by the parameter  $\kappa_S$ .  $\theta_S$  is the preference share of mortgaged housing and  $1 - \theta_S$  the weight on rental services. The expenditure side of the budget constraint includes consumption  $C_{S,t}$ , the accumulation of mortgaged housing  $H_{S,t}$ , payments for rental services  $Z_t$  priced at  $q_{r,t}$  and loan payments  $L_{S,t}$  at a gross interest rate  $R_{S,t}$ . Mortgaged housing depreciates at rate  $\delta_{HS}$ . The term  $ac_{SS,t}$  reflects the loan adjustment costs of the impatient household. As described in Iacoviello (2015), the positive wealth redistribution shock  $\varepsilon_{H,t}$  occurs when constrained households default on their loan obligations. This shock shows up on banks' balance sheets as loan losses, as borrowers are unable to pay back their debt. The default shock  $\varepsilon_{H,t}$  therefore transfers wealth from banks to constrained households.

The collateral constraint (2.2.5) shows that impatient agents borrow against a fraction of the expected future

value of their homes. The inertia  $\rho_S$  accounts for a slow adjustment of the constraint and  $m_S$  represents the loan-to-value ratio. This specification of the borrowing constraint is consistent with the empirical evidence that aggregate debt measures tend to lag changes in house prices.  $A_{MH,t}$  stands for a positive shock to the borrowing capacity of constrained households. An interpretation of this shock are for example laxer credit-screening standards, which require a smaller down payment.

$$L_{S,t} \le \rho_S L_{S,t-1} + (1-\rho_S) m_S A_{MH,t} E_t \bigg[ \frac{\pi_{t+1}}{R_{S,t}} (1-\delta_{HS}) q_{t+1} H_{S,t} \bigg].$$
(2.2.5)

Note that the above formulation of the impatient agent's housing choice does not imply that borrowers live simultaneously in a mortgaged and rented house. Instead, I assume that some fraction large borrower-type household chooses to live in a rental house and the rest in a owner-occupied home. For this reason, the composite index  $\tilde{H}_{S,t}$  represents the aggregate preferences of all household members with respect to each type of housing services. This is equivalent to the "within a family" approach of Gertler and Karadi (2011). As before the borrower's adjustment costs, marginal utilities and equilibrium conditions can be found in the appendix.

#### 2.2.3 Bankers

Bankers play an important role in the economy as they collect deposits from patient households for which they pay the interest rate  $R_{H,t}$  set by the central bank. In addition to this, bankers issue loans to entrepreneurs, denoted by  $L_{E,t}$  and to impatient households  $L_{S,t}$ . Bankers maximise their lifetime utility according to:

$$E_0 \sum_{t=0}^{\infty} \beta_B^t (1-\eta) \log(C_{B,t} - \eta C_{B,t-1})$$
(2.2.6)

subject to the budget constraint:

$$C_{B,t} + \frac{R_{H,t-1}D_{t-1}}{\pi_t} + L_{E,t} + L_{S,t} + ac_{DB,t} + ac_{EB,t} + ac_{SB,t} = D_t + \frac{R_{E,t}L_{E,t-1}}{\pi_t} + \frac{R_{S,t-1}L_{S,t-1}}{\pi_t} - \varepsilon_{E,t} - \varepsilon_{H,t}.$$
(2.2.7)

Bankers consume  $C_{B,t}$  and hold assets and liabilities in the form of deposits and loans. The terms  $\varepsilon_{H,t}$  and  $\varepsilon_{E,t}$  are loan losses of households and entrepreneurs caused by default. The quadratic adjustment costs for deposits  $(D_t)$  and loans  $(L_{S,t}, L_{E,t})$  take the same form as before. Beside the budget constraint, bankers face a capital adequacy constraint, which is defined as:

$$L_t - D_t - E_t(\varepsilon_{t+1}) \ge \rho_D \big[ L_{t-1} - D_{t-1} - E_{t-1}(\varepsilon_t) \big] + (1 - \gamma)(1 - \rho_D) \big[ L_t - E_t(\varepsilon_{t+1}) \big]$$
(2.2.8)

The total level of assets is given by the sum  $L_t = L_{E,t} + L_{S,t}$  and aggregate loan losses are denoted by  $\varepsilon_t = \varepsilon_{E,t} + \varepsilon_{H,t}$ . The left hand side of the capital adequacy constraint shows the net equity of banks after having accounted for future expected loan losses. This expression has to be equal or greater than last period's equity plus some fraction of bank assets. The non-zero inertia  $\rho_D$  ensures two things. First, a partial adjustment of bank capital. Second, a deviation from its deposit-to-asset ratio (long-run) target  $\gamma$ .

#### 2.2.4 Entrepreneurs

Entrepreneurs produce the final good  $Y_t$  and new homes  $IH_t$ . The factors of input are labour and capital supplied by households, land  $\ell_t$ , intermediate inputs  $K_{B,t}$  and capital  $K_{E,t}$  produced by entrepreneurs themselves. They solve:

$$\sum_{t=0}^{\infty} \beta_E^t (1-\eta) \log(C_{E,t} - \eta C_{E,t-1})$$
(2.2.9)

subject to the entrepreneur's budget constraint:

$$C_{E,t} + \frac{K_{E,t}}{A_{K,t}} + \frac{R_{E,t}L_{E,t-1}}{\pi_t} + K_{B,t} + \sum_{i=c,h} W^i_{H,t}N^i_{H,t} + \sum_{i=c,h} W^i_{S,t}N^i_{S,t} + p_{\ell,t}(\ell_t - \ell_{t-1}) + R^c_{M,t}z^c_{KH,t}K^c_{H,t-1} + R^h_{M,t}z^h_{KH,t}K^h_{H,t-1} + ac_{KE,t} + ac_{EE,t} = \frac{Y_t}{X_t} + q_t IH_t + \frac{1 - \delta_{KE,t}}{A_{K,t}}K_{E,t-1} + (2.2.10) + L_{E,t} + \varepsilon_{E,t},$$

and a borrowing constraint of the form:

$$L_{E,t} \le \rho_E L_{E,t-1} + (1-\rho_E) A_{ME,t} E_t \Big[ m_K K_{E,t} - m_N \Big( \sum_{i=c,h} W^i_{H,t} N^i_{H,t} + \sum_{i=c,h} W^i_{S,t} N^i_{S,t} \Big) \Big].$$
(2.2.11)

As we can see from the budget constraint, entrepreneurs pay households the sector specific real wages  $W_{H,t}^c$ ,  $W_{H,t}^h$ ,  $W_{S,t}^c$  and  $W_{S,t}^h$ . Inflation in the consumption sector is denoted by  $\pi_t$  and  $p_{\ell,t}$  is the price of land. The terms  $ac_{KE,t}$  and  $ac_{EE,t}$  are the respective adjustment costs for capital and loans. Retailers purchase consumption goods from entrepreneurs and sell them at markup  $X_t$ . As impatient households, entrepreneurs are subject to loan losses which are captured by  $\varepsilon_{E,t}$  and face a borrowing constraint. Agents borrow against a fraction of their capital and have to pay their workers upfront.  $\rho_E$  is the inertia in the entrepreneurs liquidity constraint and  $A_{ME,t}$  represents a LTV shock.<sup>28</sup> The production functions of the consumption and construction sector are:

$$Y_t = A_{Z,t} (z_{KH,t}^c K_{H,t-1}^c)^{\alpha(1-\mu_c)} (z_{KE,t} K_{E,t-1})^{\alpha\mu_c} (N_{H,t}^c)^{(1-\alpha)(1-\sigma)} (N_{S,t}^c)^{(1-\alpha)\sigma},$$
(2.2.12)

$$IH_{t} = A_{H,t} (z_{KH,t}^{h} K_{H,t-1}^{h})^{\mu_{h}} (N_{H,t}^{h})^{(1-\mu_{h}-\mu_{b}-\mu_{l})(1-\sigma)} (N_{S,t}^{h})^{(1-\mu_{h}-\mu_{b}-\mu_{l})\sigma} K_{B,t}^{\mu_{b}} \ell_{t-1}^{\mu_{l}}$$
(2.2.13)

#### 2.2.5 Nominal Rigidities and Monetary Policy

The existence of retailers, who operate under monopolistic competition, allows for sticky prices in the consumption sector. Nominal price adjustments in the retail sector entail implicit costs, which follow Calvo-style contracts (see Calvo (1983)). Consistent with the literature I assume that house prices are flexible.<sup>29</sup> Patient households own retailers and receive dividends in the form of  $DIV_t = \frac{X_t - 1}{X_t}Y_t$ . The resulting Phillips curves takes the form:

$$\frac{\pi_t}{\pi_{t-1}^{\iota_{\pi}}} = \left(\frac{\pi_{t+1}}{\pi_t^{\iota_{\pi}}}\right)^{\beta_H} \left(\frac{X_t}{X}\right)^{-\frac{(1-\Theta_\pi)(1-\beta_H,\Theta_\pi)}{\Theta_\pi}} v_\pi, \tag{2.2.14}$$

As described in Smets and Wouters (2003), equation (2.2.14) implies partial indexation to lagged inflation of prices which cannot be reoptimised. Therefore, setting the elasticity  $\iota$  equal to zero, leaves us with the standard forward looking Phillips curve. Each period a fraction of retailers  $\Theta_{\pi}$  cannot reset their prices optimally and  $v_{\pi}$  is an identically and independently distributed cost-push shocks with zero mean and variance  $\sigma_{\pi}^2$ . In order to close the model, I assume that the central bank sets interest rates  $R_{H,t}$  according to the following Taylor rule:

$$R_{H,t} = (R_{H,t-1})^{\Psi_R} \left(\frac{1}{\beta_H}\right)^{(1-\Psi_R)} (\pi_t)^{(1-\Psi_R)\Psi_\pi} \left(\frac{GDP_t}{GDP_{t-1}}\right)^{(1-\Psi_R)\Psi_Y} \frac{\upsilon_{R,t}}{A_{S,t}},$$
(2.2.15)

where interest rates react to inflation and GDP growth.  $\frac{1}{\beta_H}$  is the steady state real interest rate on deposits;  $v_{R,t}$  stands for an identically and independently distributed monetary policy shock with zero mean and variance  $\sigma_{r,t}^2$ ;  $A_{S,t}$  is a persistent AR(1) shock process, which measures long lasting inflation deviations from its steady state level. This could be due to changes in the central bank's inflation target.

<sup>&</sup>lt;sup>28</sup>In the models presented in chapter 1 and 2 it is assumed that the LTV shocks of borrower and entrepreneur are different. First of all, this gives us the isolated response to the borrowing ability of entrepreneurs. As the shock increases (decreases) the loan amount of the supply side, the dynamics will be different to the  $A_{MH,t}$  responses of the demand side. Second, looking at the data (see figure 2.3) reveals that loans to entrepreneurs and loan losses of entrepreneurs exhibit a different pattern, compared to the household time series. However, more empirical research is necessary to explore this further.

 $<sup>^{29}\</sup>mathrm{See}$  for example the discussion by Barsky, House, and Kimball (2007).

#### 2.2.6 Market Clearing

The central clearing conditions of the goods and housing market are:

$$C_t + \frac{IK_{c,t}}{A_{K,t}} + IK_{h,t} + K_{B,t} = Y_t - AC_t, \qquad (2.2.16)$$

$$IH_t = H_{H,t} - (1 - \delta_{HH})H_{H,t-1} + H_{S,t} - (1 - \delta_{HS})H_{S,t-1} + H_{r,t} - (1 - \delta_{Hr})H_{r,t-1}, \qquad (2.2.17)$$

where the goods sector produces (aggregate) consumption  $C_t = C_{H,t} + C_{S,t} + C_{B,t} + C_{E,t}$ , business investment  $IK_{c,t} = K_{H,t}^c - (1 - \delta_{KH,t}^c)K_{H,t-1}^c + K_{E,t} - (1 - \delta_{KE,t})K_{E,t-1}$ , residential investment  $IK_{h,t} = K_{H,t}^h - (1 - \delta_{KH,t}^h)K_{H,t-1}$  and intermediate inputs  $K_{B,t}$ .  $AC_t$  represents the sum of the respective convex, capital adjustment costs. In this study land is fixed and normalised to one.<sup>30</sup> The housing sector constructs new homes  $IH_t$  as shown in condition (2.2.17).

#### 2.2.7 Shock Processes

There are in total ten structural shocks, which are: the default shock of entrepreneurs  $\varepsilon_{E,t}$  and impatient households  $\varepsilon_{H,t}$ , the housing preference shock  $A_{j,t}$ , the capital shock  $A_{K,t}$ , the LTV ratio shock of entrepreneurs  $A_{ME,t}$  and impatient households  $A_{MH,t}$ , the aggregate spending shock  $A_{p,t}$ , the technology shock in the consumption sector  $A_{Z,t}$  and housing sector  $A_{H,t}$  and the monetary policy shock  $A_{S,t}$ .

$$\varepsilon_{E,t} = \rho_{be} \varepsilon_{E,t-1} + \upsilon_{E,t} \qquad \upsilon_E \sim N(0, \sigma_{be}) \tag{2.2.18}$$

$$\varepsilon_{H,t} = \rho_{bh} \varepsilon_{H,t-1} + \upsilon_{H,t} \qquad \upsilon_H \sim N(0,\sigma_{bh}) \tag{2.2.19}$$

$$\log A_{j,t} = \rho_j \log A_{j,t-1} + v_{j,t} \qquad v_{j,t} \sim N(0,\sigma_j)$$
(2.2.20)

$$\log A_{K,t} = \rho_j \log A_{K,t-1} + v_{K,t} \qquad v_{K,t} \sim N(0,\sigma_k)$$
(2.2.21)

$$\log A_{ME,t} = \rho_{me} \log A_{ME,t-1} + v_{ME,t} \qquad v_{ME,t} \sim N(0,\sigma_{ME})$$
(2.2.22)

$$\log A_{MH,t} = \rho_{mh} \log A_{MH,t-1} + v_{MH,t} \qquad v_{MH,t} \sim N(0,\sigma_{MH})$$
(2.2.23)

$$\log A_{p,t} = \rho_p \log A_{p,t-1} + v_{p,t} \qquad v_{p,t} \sim N(0,\sigma_p)$$
(2.2.24)

<sup>&</sup>lt;sup>30</sup>Even though land is a production input, it plays only a secondary role in this study.

$$\log A_{Z,t} = \rho_{zc} \log A_{Z,t-1} + v_{z,t} \qquad v_{z,t} \sim N(0,\sigma_{zc})$$
(2.2.25)

$$\log A_{H,t} = \rho_{zh} \log A_{H,t-1} + v_{h,t} \qquad v_{h,t} \sim N(0,\sigma_{zh})$$
(2.2.26)

$$\log A_{S,t} = \rho_s \log A_{S,t-1} + v_{s,t} \qquad v_{s,t} \sim N(0,\sigma_s)$$
(2.2.27)

# 2.3 Calibration

Table 2.1 summarises the calibrated parameters. Fixing the discount factor  $\beta_H$  at 0.9925 results in a 3 percent annual steady state return on deposits.<sup>31</sup> This value is close to its empirical counterpart in the data. The other discount factor  $\beta_B$  and  $\beta_S$  are set at 0.945 and 0.94 respectively, implying a 5 percent annual steady state return on loans. I choose  $m_N = 1$ , which assumes that all labour of both sectors has to be paid in advance. The steady state inflation rate is zero, which implies a gross steady state inflation rate  $\pi$  of 1. Rental housing depreciates faster than owner-occupied housing; the reason for this is that rental housing is subject to moral hazard, as discussed in Chambers, Garriga, and Schlagenhauf (2009). Consistent with the data, the calibrated parameters show that the owner-occupied housing stock is substantially larger than the rental housing stock.

 $<sup>\</sup>overline{{}^{31}}$ This can be easily shown by using the following transformation:  $R_H^{annual} = 400 \cdot (R_H^{quarterly} - 1).$ 

Parameter		Value
Discount factor Saver (S)	$\beta_H$	0.9925
Discount factor Borrower (B)	$\beta_S$	0.94
Discount factor Banker	$\beta_B$	0.945
Discount factor Entrepreneur (E)	$\beta_E$	0.94
Total capital share in production	α	0.35
Housing LTV ratio, B	$m_S$	0.9
Capital LTV ratio, E	$m_K$	0.9
Wage bill paid in advance	$m_N$	1
Bankers' liabilities to assets ratios	$\gamma_E,  \gamma_S$	0.9
Housing preference share	j	0.075
Capital depreciation rates consump. sector	$\delta_{KE},  \delta^c_{KH}$	0.025
Capital depreciation rates housing sector	$\delta^h_{KH}$	0.030
Depreciation owner-occupied housing	$\delta_{HH},  \delta_{HS}$	0.008
Depreciation rental housing	$\delta_{Hr}$	0.016
Labour supply parameter	au	2
Input share parameters	$\mu_h,\mu_b,\mu_\ell$	0.10
Markup	X	1.15
Persistence of monetary policy shock	$ ho_s$	0.95

Table 2.1: Calibrated Parameters

The calibrated parameters above produce a housing investment share  ${}^{qIH}/{GDP}$  of 4 percent, total housing wealth  ${}^{qH}/{}^{(4 \times GDP)}$  wealth of 1.17 and a share of business capital in housing the sector  $K_{H}^{h}/{}^{(4 \times GDP)}$  of 0.03. The steady state markup X of the consumption sector is set at 1.15. This value is consistent with the recent literature.<sup>32</sup>

## 2.4 Data

I estimate the model on U.S. quarterly data ranging from 1985Q1 - 2008Q3. Due to the zero lower bound, I do not include post-crisis years. This is in line with the results of Binning and Maih (2016), who show that the zero lower bound (ZLB) regime only becomes active at the beginning of 2009.<sup>33</sup> Consistent with my dataset, their sample starts in 1985Q1 and ends in 2015Q2. Policy analysis in a zero interest rate environment is not the aim of this chapter and hence the model is not built to capture this fact. The dataset consists of

 $<sup>^{32}</sup>$ See for example Corsetti et al. (2013).

<sup>&</sup>lt;sup>33</sup>Binning and Maih (2016) plot in figure 6 (p. 22) the developments of the fed funds rate and the estimated probability of being in a ZLB regime. The chart illustrates that the likelihood of being in a state of zero interest rates increases sharply in 2009Q1 and thus jumps to one. Before that period the estimated probability is zero.

14 macroeconomic variables: loan losses of businesses, loan losses of households, loans to businesses, loans to households, real consumption, real business investment, real residential investment, real house prices, real housing rents, rental to owner-occupied housing ratio, nominal interest rates, inflation and hours in the housing and consumption sector. The data on housing rents can be obtained from the Bureau of Labor statistics and the data source of the owner-occupied housing ratio is provided by the U.S. Census Bureau. I match the latter to the corresponding model variable  $\frac{H_{r,t}}{H_{H,t}+H_{S,t}}$ . The rest of the data is identical to Iacoviello (2015). Since the model is defined in stationary form, we have to detrend the respective data counterparts. Therefore, each time series is quadratically detrended apart from loan losses, inflation, the nominal interest rate and hours, which are all demeaned. Thus, all corresponding model observables have a mean of zero. Figure 2.3 depicts the time series used for the estimation process in percentage deviation from their steady states.<sup>34</sup>



Figure 2.3: Data used for estimation

*Notes:* Consumption, investment (residential/non-residential), loans (HH/E), the rental to homeowner housing ratio and house and rental prices are displayed in percentage deviation from their quadratic trend. Loan losses (HH/E) are shown as a percentage share of GDP and are demeaned. Finally, the observables inflation, interest rates and hours are plotted in percentage deviation from their steady state.

# 2.5 Prior and Posterior Distributions

As outlined in An and Schorfheide (2007), I estimate the model using Bayesian techniques. The posterior distribution is constructed with the help of the Random Walk Metropolis-Hastings algorithm. Table 2.2 and

 $<sup>^{34}</sup>$ As in the previous chapter, the estimation is performed with the data in absolute deviations. This means that the observables are not multiplied by the factor 100.

2.3 show the prior and simulated posterior distributions of the underlying structural parameters and shock processes. They are based on 2,000,000 draws with a burn-in rate of 50 percent.

Parameter		Prior Distribution		Posterior Distribution			
		Density	Mean	Std	10%	Mean	90%
Elasticity of hours, S	$\chi_H$	Gamma	0.5	0.1	0.8989	1.0732	1.2517
Elasticity of hours, B	$\chi_S$	Gamma	0.5	0.1	0.6383	0.8854	1.1245
Habit in consumption	$\eta$	Beta	0.5	0.15	0.1417	0.2190	0.2990
Deposit adj. cost, Banks	$\phi_{DB}$	Gamma	0.25	0.1	0.0506	0.2113	0.3672
Deposit adj. cost, S	$\phi_{DH}$	Gamma	0.25	0.1	0.1522	0.2425	0.3384
Capital adj. cost consum. sector, E	$\phi_{KE}$	Gamma	0.25	0.1	0.1548	0.2827	0.4066
Capital adj. cost consum. sector, S	$\phi_{KC}$	Gamma	0.25	0.1	0.1320	0.2243	0.3139
Capital adj. cost housing sector, S	$\phi_{KH}$	Gamma	0.25	0.1	0.1130	0.2958	0.4740
Loans to E adj. cost, Banks	$\phi_{EB}$	Gamma	0.25	0.1	0.0373	0.1261	0.2130
Loans to E adj. cost, E	$\phi_{EE}$	Gamma	0.25	0.1	0.2377	0.3852	0.5349
Loans to B adj. cost, Banks	$\phi_{SB}$	Gamma	0.25	0.1	0.0974	0.3409	0.5851
Loans to B adj. cost, B	$\phi_{SS}$	Gamma	0.25	0.1	0.4420	0.6904	0.9395
Inflation indexation	ι	Beta	0.5	0.2	0.0157	0.2715	0.5310
Elast. of substitution housing	$\kappa_S$	Normal	2	0.5	2.4300	2.9203	3.3987
Inverse elast. of subst. across hours, S	$\kappa_H^N$	Normal	1	0.5	1.4345	1.9609	2.4924
Inverse elast. of subst. across hours, B	$\kappa_S^N$	Normal	1	0.5	0.5794	1.3156	2.0332
Capital share of E	$\mu_c$	Beta	0.5	0.1	0.1362	0.1639	0.1906
Taylor rule, interest rate parameter	$\Psi_R$	Beta	0.75	0.1	0.2405	0.3581	0.4751
Taylor rule, inflation parameter	$\Psi_{\pi}$	Normal	1.5	0.1	1.4029	1.5524	1.7071
Taylor rule, output parameter	$\Psi_Y$	Normal	0	0.1	0.0091	0.1474	0.2664
Efficiency rental housing services	$\Omega_r$	Beta	0.5	0.2	0.2914	0.4475	0.5957
Inertia in capital adequacy constraint	$ ho_D$	Beta	0.25	0.1	0.0525	0.1906	0.3236
Inertia in borrowing constraint, E	$ ho_E$	Beta	0.25	0.1	0.0364	0.1108	0.1819
Inertia in borrowing constraint, B	$ ho_S$	Beta	0.25	0.1	0.9045	0.9149	0.9247
Wage share, B	$\sigma$	Beta	0.3	0.1	0.1346	0.1678	0.2003
Weight owner-occup. housing	$ heta_S$	Beta	0.5	0.2	0.5060	0.6994	0.8928
Calvo, retailer share	$\Theta_{\pi}$	Beta	0.667	0.05	0.3125	0.3498	0.3861
Curvature for utilization function, E	$\zeta_E$	Beta	0.2	0.1	0.0625	0.2431	0.4211
Curvature for utilization function, B	$\zeta_H$	Beta	0.2	0.1	0.0043	0.0308	0.0570

 Table 2.2:
 Prior and Posterior Distributions, Structural Parameters

Most of the prior distributions are adopted from Iacoviello (2015) and Iacoviello and Neri (2010). The

housing parameters  $\theta_S$  and  $\Omega_r^{35}$  have a very informative beta prior distribution with mean 0.5 and standard deviation 0.2. The elasticity of substitution between rental and mortgaged housing  $\kappa_S$  follows a normal distribution with mean 2 and a standard deviation of 0.5. The choice of the prior mean is based on the study shown in Mora-Sanguinetti and Rubio (2014).

Given the new data, the share of constrained households  $\sigma$  is found to be 0.17. This value is consistent with the estimation results discussed in Jappelli (1990), who finds that 20 percent of the US population is credit constrained. Since our sample ends in 2008 and does therefore not include more post-crisis years, this share parameter is understated.<sup>36</sup> The preference weight  $\theta_S$  of impatient households towards owneroccupied housing is estimated at 0.7, which is close to the estimate obtained by Sun and Tsang (2017).  $\Omega_r$ , the housing efficiency parameter, is estimated to be 0.45 and is therefore not far away from its prior mean of 0.5. The estimate of the elasticity of substitution between owner-occupied and rental housing ( $\kappa_S = 2.9$ ) is considerably larger than originally assumed by Mora-Sanguinetti and Rubio (2014). As both labour supply parameters  $\kappa_N^H$  and  $\kappa_N^S$  are different from zero and positive, we can conclude that hours in both sectors are imperfect substitutes. The labour elasticities  $\chi_H$  and  $\chi_S$  are 1.07 and 0.89 respectively and are not far off from their prior mean of 0.5.

<sup>&</sup>lt;sup>35</sup>Note that I interpret  $\Omega_r$  as a pure efficiency parameter. This means it is restricted to take values greater than unity, which is different to Ortega, Rubio, and Thomas (2011) and Mora-Sanguinetti and Rubio (2014). They allow the efficiency parameter  $\Omega_r$  to exceed 1.

<sup>&</sup>lt;sup>36</sup>See for example Iacoviello (2015) or Guerrieri and Iacoviello (2017).

Parameter		Prior Distribution		Posterior Distribution			
		Density	Mean	Std	10%	Mean	90%
Autocor. E default shock	$ ho_{be}$	Beta	0.8	0.1	0.8676	0.9077	0.9500
Autocor. B default shock	$ ho_{bh}$	Beta	0.8	0.1	0.7585	0.8154	0.8761
Autocor. housing demand shock	$ ho_j$	Beta	0.8	0.1	0.8337	0.8621	0.8910
Autocor. investment shock	$ ho_k$	Beta	0.8	0.1	0.9683	0.9781	0.9880
Autocor. LTV shock, E	$\rho_{me}$	Beta	0.8	0.1	0.9245	0.9372	0.9500
Autocor. LTV shock, B	$\rho_{mh}$	Beta	0.8	0.1	0.9198	0.9480	0.9760
Autocor. preference shock	$ ho_p$	Beta	0.8	0.1	0.8746	0.8941	0.9135
Autocor. techn. shock, consum.	$\rho_{zc}$	Beta	0.8	0.1	0.9460	0.9600	0.9746
Autocor. techn. shock, housing	$\rho_{zh}$	Beta	0.8	0.1	0.8749	0.9012	0.9279
Std default shock, E	$\sigma_{be}$	Inv.gamma	0.0025	0.025	0.0008	0.0009	0.0011
Std default shock, B	$\sigma_{bh}$	Inv.gamma	0.0025	0.025	0.0009	0.0011	0.0013
Std housing demand shock	$\sigma_{j}$	Inv.gamma	0.05	0.05	0.0092	0.0106	0.0120
Std investment shock	$\sigma_k$	Inv.gamma	0.005	0.025	0.0106	0.0133	0.0158
Std LTV shock, E	$\sigma_{me}$	Inv.gamma	0.0025	0.025	0.0225	0.0272	0.0318
Std LTV shock, B	$\sigma_{mh}$	Inv.gamma	0.0025	0.025	0.0501	0.0613	0.0726
Std preference shock	$\sigma_p$	Inv.gamma	0.005	0.025	0.0142	0.0163	0.0183
Std techn. shock, consum.	$\sigma_{zc}$	Inv.gamma	0.005	0.025	0.0078	0.0090	0.0103
Std techn. shock, housing	$\sigma_{zh}$	Inv.gamma	0.005	0.025	0.0180	0.0211	0.0243
Std monetary policy shock, (iid)	$\sigma_r$	Inv.gamma	0.0025	0.025	0.0172	0.0220	0.0267
Std monetary policy shock	$\sigma_s$	Inv.gamma	0.0025	0.025	0.0022	0.0030	0.0038
Std cost-push shock, (iid)	$\sigma_{\pi}$	Inv.gamma	0.0025	0.025	0.0105	0.0142	0.0178
Std measurement error	$\sigma_{NC}$	Inv.gamma	0.001	0.01	0.0118	0.0143	0.0168
Std measurement error	$\sigma_{NH}$	Inv.gamma	0.001	0.01	0.0817	0.0928	0.1040

Table 2.3: Prior and Posterior Distributions, Shock Processes

The estimate of  $\eta$  indicates a moderate degree of habit formation across agents. The fraction of retailers who do not reoptimise prices is 0.35. This estimate is consistent with the results described in Bils and Klenow (2004), who find that the probability of not changing over a quarter is 0.34. Hence, prices are set every one to two quarters. The estimated Taylor rule parameters are in line with the literature. The estimate of the capital share ( $\mu_c = 0.16$ ) is smaller than its prior mean of 0.5. Turning to the shock processes, the estimation results show a high level of persistence for all AR(1) shocks ranging from 0.81 to 0.98. Overall, the largest standard deviation exhibits the LTV shock to the household's borrowing constraint of 0.061.

## 2.6 Results

This section presents the estimated mean impulse response functions at a 90 percent confidence interval (dotted curves) and performs a shock analysis. However, we first have a look at the performance of the estimated DSGE model.

#### 2.6.1 Standard Deviation Comparison of Data and Model Variables

In order to assess the fit of the model, I compare the theoretical moments with the respective data counterparts. The solution of the DSGE model can be written in a linear state space form, which allows us to compute the endogenous moments (Hamilton 1994). Table 2.4 shows the model and data standard deviations.

Data	Model
0.0262	0.0767
0.0608	0.0735
0.0146	0.0778
0.1063	0.4334
0.1436	0.0864
0.0210	0.0165
0.0321	0.0564
0.1020	0.0999
	Data 0.0262 0.0608 0.0146 0.1063 0.1436 0.0210 0.0321 0.1020

 Table 2.4:
 Theoretical Moments vs.
 Data

As the comparison indicates, the model produces slightly higher fluctuations for the observables business investment and rental prices. However, based on the results shown in the table above, the framework is able to replicate the cyclical properties of the data and therefore exhibits an overall good fit. Furthermore, the match of the data and model has improved by allowing for rigidities and a responsive housing supply.

### 2.6.2 Impulse Response Functions

All IRFs of the key variables described in this section are computed in percentage deviations from their respective steady states.



Figure 2.4: Impulse response to a one standard error housing technology shock.

A positive housing technology shock, as shown in figure 2.4, leads to a rise in real residential investment and the construction increase of new homes causes an expansion of owner-occupied and rental housing. House prices drop due to decreasing construction costs. The rise in the supply of new homes and the decline in house prices causes a shrinkage of the collateral value, which triggers a reduction in borrowing of households. Rental prices fall due to the fact that the supply of rental homes is higher than the demand for rental services, i.e.  $H_{r,t} > Z_t$ . Output of the consumption sector drops which stems from a contraction in the supply of resources by households. Inflation falls due to the output drop in the consumption sector. As a result interest rates fall, even tough only marginally.

The impact of a positive aggregate preference shock is illustrated in figure 2.5. As a result of this, households demand more housing and consumption, which materialises in an increase in mortgaged homes  $H_{S,t}$  and a rise in output of the consumption sector  $Y_t$ . Simultaneously, loans issued to households rise due to the increased demand for mortgaged homes. Overall, owner-occupied housing expands as result of the shock. The sharp initial decline in rental housing combined with a higher output in the construction sector in the first periods, leads to a drop in house prices. A shortage in rental homes causes rental prices to go up, as  $H_{r,t} < Z_t$ .


Figure 2.5: Impulse response to a one standard error aggregate spending shock.



Figure 2.6: Monetary Policy Shock, independently and identically distributed.

Figure 2.6 depicts the response of an independently and identically distributed monetary policy shock. A rise in the nominal interest rate increases costs for banks and reduces the spread between the deposit and lending rate. This leads to a contraction of bank lending and a drop in the demand for mortgaged housing. Here, interest rates rise by 70 basis points (280 basis points per annum) on impact and drop due to the decline in economic activity represented by the output of the consumption and housing sector. Impatient agents are therefore forced to opt for rental homes, which results in a reduction of mortgaged housing. In contrast, patient households reduce their supply of capital and labour to entrepreneurs. This diversion of

resources materialises in an expansion of the saver's owner-occupied housing stock  $H_{H,t}$ , which offsets the decline in mortgaged housing. Therefore the aggregate effect of a monetary policy shock on owner-occupied housing turns out to be small. House and rental prices decline in the short-run as a direct effect of the shock. Investment in both sectors decreases which results in a production decline of the consumption good and new housing. Note, expansionary monetary policy triggers the opposite response. It boosts homeownership and mortgaged housing, combined with an increase in household loans.

#### 2.6.3 Comparison of Model Responses

The graphs below depict the shock responses of house prices to a positive housing demand, preference and LTV shock. In order to visualise the differences between models, each graph shows four different scenarios. The black graph illustrates the house price responses of the Iacoviello (2015) model. I compare this to a model with just rental housing as in chapter 1 (red graph), rental housing and price rigidities (green graph)<sup>37</sup> and the model presented in chapter 2 (blue graph). We can see that there is a supply effect which shifts the blue curve up and therefore offsets the negative impact on house prices originating from the rental housing market.



Figure 2.7: Model comparison based on impulse responses

 $<sup>^{37}</sup>$ It is simply the model presented in chapter 1 with the feature of price rigidities in the consumption section.

#### 2.6.4 Variance and Historical Shock Decomposition

This section presents the historical and unconditional variance forecast decomposition. Having solved and simulated the model we can then find the contribution of each shock to the forecast error variance, as shown in table 2.5. The innovations are grouped in four categories: macroeconomic, preference, financial and monetary policy shocks. The first column shows the total contribution of the TFP, investment and cost-push shocks. Preference shocks contain the aggregate spending and housing demand shocks. Financial shocks are represented by the LTV and default shocks. As table 2.5 indicates, most of the variables are driven by macroeconomic shocks. However, more than half of the fluctuations in loans, mortgaged and rental housing are driven by financial shocks. Household LTV shocks take up the largest fraction of this share. Monetary policy shocks drive more than one quarter of the variance of mortgaged housing and 12 percent of the fluctuations in loans. Movements in rental housing are equally affected with a contribution of 15 percent. Monetary policy shocks take up the largest share of the variance of nominal interest rates with 83 percent. In contrast, house prices remain unaffected by monetary policy shocks. As already pointed out in chapter 1, the existence of a rental sector has an offsetting impact on house prices. The fact that housing supply is no longer fixed introduces a second effect into the model. For example, a positive aggregate spending shock leads to a rise in the demand for owner-occupied homes and causes house prices to increase. At the same time, rental housing declines which puts downward pressure on house prices. The second effect comes from the supply side. Entrepreneurs react to the higher demand for owner-occupied housing and expand their supply of homes. Therefore, these two features have an offsetting effect on house price responses. See figure 2.7 in the appendix.

	Macro Shocks	Preference Shocks	Financial Shocks	Monetary Policy Shocks
GDP	78.77	10.56	2.75	7.39
Consumption	84.63	11.13	0.83	3.36
Investment	89.79	1.77	2.66	4.82
House prices	97.32	1.24	0.29	1.13
Rental prices	88.50	9.99	0.29	1.20
Loans to households	4.94	0.54	82.13	12.13
Mortgaged housing	15.54	1.69	51.51	29.96
Rental housing	28.98	3.08	52.62	14.70
Nominal interest rate	11.43	0.29	5.42	82.62

Table 2.5: Variance Decomposition

With the help of the Kalman smoother we can decompose the historical data on loans and measure the contribution of each shocks to the series' deviation from its implied steady state. As we can see from figure 2.8, most of the loans to households movements are driven by household LTV and monetary policy shocks. The model picks up on the Housing and Community Development Acts of 1987 and 1992, which should help to boost homeownership especially for low and moderate-income households. This can be the reason for the large contribution of LTV shocks in the 80s and 90s. The negative LTV shocks can be explained by the Savings and Loan Crisis, which lasted until the early 90s. Between 1986 and 1995, over 1,000 Savings and  $Loans^{38}$  failed with a total asset value of \$500 billion (Curry and Shibut 2000). However, the crisis is persistent and it takes the loan market until 1998 to start reverting back to its steady state. Lending behaviour changes in the mid 2000s with the beginning of the housing boom and contributed significantly to the rise in household loans. This can for example be explained by excessive risk taking and looser credit checks of financial institutions. As we know today, many borrowers were never able to pay back their debt which became evident with the end of the housing boom. Another contributing factor, to some extent, were the low quality loan purchases performed by Fannie Mae and Freddie Mac.<sup>39</sup> The origins go back to the year 1996, when the Housing and Urban Development (HUD) department decided that 42 percent of the mortgage purchases of Fannie Mae and Freddie Mac had to be supplied to low-income households. This target rose to 52 percent in 2005 (Schwartz 2009). As we can see from the shock decomposition, monetary policy was not the main driving force behind the steep increase in household loans before the crisis. This contradicts the findings of Taylor (2009) and confirms the results outlined in Nelson, Pinter, and Theodoridis (2018). The same outcome holds when we look at the historical decomposition of house prices. Monetary policy shocks only drive a small fraction of house price movements. To verify this results, I perform a robustness exercise in the next section.

<sup>&</sup>lt;sup>38</sup>Savings and Loans are specialised banks with the objective of offer affordable mortgages to low-income households in order to boost home ownership.

<sup>&</sup>lt;sup>39</sup>For a critical discussion of the role of Fannie Mae and Freddie Mac before the financial crisis, see Stiglitz (2010), Schwartz (2009) or Taylor (2011).



Figure 2.8: Shock decomposition of loans to households



Figure 2.9: Shock decomposition of loans to households

# 2.7 Robustness Tests

In this section I perform robustness exercises in order to find out whether the results change, if we allow for a different treatment of the data. Therefore, the data are filtered by applying a one-sided HP and a first-difference filter. The next step involves performing a shock decomposition on house prices at the estimated posterior mode. The outcome is illustrated by figure 2.10 and 2.11. As we can see from both charts, monetary policy shocks are not the main driving forces behind the movement of house prices. Macro shocks still determine the largest fraction of house price fluctuations. These results confirm the findings in the previous section.



Figure 2.10: Shock decomposition of house prices based on first-differenced data



Figure 2.11: Shock decomposition of house prices based one-sided HP filtered data.

The datasets contain the same 14 macroeconomic variables as before: loan losses of businesses, loan losses of households, loans to businesses, loans to households, real consumption, real business investment, real residential investment, real house prices, real housing rents, rental to owner-occupied housing ratio, nominal interest rates, inflation and hours in the housing and consumption sector. Figure 2.12 shows the data when a first-difference filter is applied to the non-stationary time series residential investment, consumption, business investment, business and household loans, house prices, rental rates and the rental to owner-occupied housing ratio. Hence, the y-axis depicts the quarterly percentage change of these observables. In contrast, figure 2.13 uses a one-sided HP-filter to stationarise the data. As before, the y-axis of these variables represents the percentage deviation from their HP filtered trend. The remaining observables (i.e. interest rates, inflation, hours consumption and housing sector, loan losses of entrepreneurs and households) have been demeaned and are expressed in percentage deviations from their respective means.



Figure 2.12: First-difference filtered data used for the construction of the posterior mode



Figure 2.13: One-sided HP filtered data used for the construction of the posterior mode

As outlined in chapter 1 I exclude loan losses from the dataset and re-estimate the model. The tables below report the structural parameters and the model fit at the posterior mode. Overall, the results are robust when loan losses are omitted from the estimation. Furthermore, the fit of the model has only improved marginally. This is evident by comparing table 2.6 with tables 2.2/2.3 and table 2.7 with table 2.4.

Parameter	Posterior Mode	Parameter	Posterior Mode
$\chi_H$	1.3018	$ ho_j$	0.8538
$\chi_S$	0.5652	$ ho_k$	0.9797
$\eta$	0.2136	$ ho_{me}$	0.9407
$\phi_{DB}$	0.1289	$ ho_{mh}$	0.9403
$\phi_{DH}$	0.2693	$ ho_p$	0.9139
$\phi_{KE}$	0.3245	$\rho_{zc}$	0.9692
$\phi_{KC}$	0.2248	$ ho_{zh}$	0.9030
$\phi_{KH}$	0.2189	$\sigma_j$	0.0110
$\phi_{EB}$	0.1128	$\sigma_k$	0.0129
$\phi_{EE}$	0.4462	$\sigma_{me}$	0.0264
$\phi_{SB}$	0.1997	$\sigma_{mh}$	0.0509
$\phi_{SS}$	0.6360	$\sigma_p$	0.0150
ι	0.2376	$\sigma_{zc}$	0.0079
$\kappa_S$	2.9065	$\sigma_{zh}$	0.0207
$\kappa_H^N$	1.9676	$\sigma_r$	0.0209
$\kappa^N_S$	1.2846	$\sigma_s$	0.0030
$\mu_c$	0.1511	$\sigma_{\pi}$	0.0149
$\Psi_R$	0.3830	$\sigma_{NC}$	0.0128
$\Psi_{\pi}$	1.5457	$\sigma_{NH}$	0.0891
$\Psi_Y$	0.0812		
$\Omega_r$	0.4563		
$ ho_D$	0.1954		
$ ho_E$	0.1793		
$ ho_S$	0.9049		
σ	0.0574		
$\theta_S$	0.7747		
$\Theta_{\pi}$	0.3319		
$\zeta_E$	0.2720		
$\zeta_H$	0.0275		

 Table 2.6:
 Robustness, Posterior Modes without Loan Losses

	Data	Model
Consumption	0.0262	0.0866
House prices	0.0608	0.0795
Rental prices	0.0146	0.0836
Business investment	0.1063	0.4631
Residential investment	0.1436	0.0858
Interest rates	0.0210	0.0164
Hours, consumption	0.0321	0.0558
Hours, housing	0.1020	0.0916

Table 2.7: Theoretical Moments vs. Data (Excluding Loan Losses)

### 2.8 Conclusion

This study has developed a DSGE model which accounts for four important features: rental and owneroccupied housing, endogenous housing supply, nominal rigidities and a banking channel. Allowing for these important variables enables us to study in detail the role of monetary policy and its impact on lending and owner-occupied housing. Taylor (2007, 2009) and the Bank for International Settlements (2007, 2008) are famous advocates of the view that low interest rates before the crisis were one of the main causes of the most recent recession. However, the literature on this topic has produced mixed findings about the importance of monetary policy. I shed new light on this issue through the lens of an estimated DSGE model with banking frictions. The model results show that more than 25 percent of the variance of mortgaged homes is driven by monetary policy shocks. The largest contributor of household loan fluctuations are financial disturbances. 12 percent of household debt can be attributed to monetary policy shocks. House prices remain almost unaffected by monetary policy. This study also reveals that loose pre-crisis monetary policy played only a minor role in the rise of house prices and household loans. Bank lending behaviour takes up the largest share of fluctuations in household debt. During the mid 80s and 90s this can be explained by the Housing and Community Development Acts, established in 1982 and 1995. Excessive lending behaviour of banks combined with the low quality loan purchases by Fannie Mae and Freddie Mac are one of the reasons for the dominant role of LTV shocks in the years leading up to financial crisis. As household loans, house prices are only effected to a minor degree by monetary policy shocks. For this reason, accommodative monetary policy did not contribute to the housing boom. Based on these results the next chapter discusses important policy implications which involve the use of supply side measures.

# 2.A Technical Appendix

## 2.A.1 Adjustment Costs, Capital Utilisation and Marginal Utilities

#### Patient Households

The adjustment costs of both capital types and deposits are defined as follows:

$$ac_{KH,t}^{c} = \frac{\phi_{KC}}{2} \frac{(K_{H,t}^{c} - K_{H,t-1}^{c})^{2}}{K_{H}^{c}},$$
(2.A.1)

$$ac_{KH,t}^{h} = \frac{\phi_{KH}}{2} \frac{(K_{H,t}^{h} - K_{H,t-1}^{h})^{2}}{K_{H}^{h}},$$
(2.A.2)

$$ac_{DH,t} = \frac{\phi_{DH}}{2} \frac{(D_t - D_{t-1})^2}{D}.$$
 (2.A.3)

 $K_{H}^{c}$ ,  $K_{H}^{h}$  and  $D_{H}$  are the respective steady state expressions for capital and deposits. The depreciation functions  $\delta_{KH,t}^{c}$  and  $\delta_{KH,t}^{h}$  take the following form:

$$\delta_{KH,t}^{c} = \delta_{KH}^{c} + b_{KH} \left[ 0.5 \,\zeta_{H}^{\prime} (z_{KH,t}^{c})^{2} + (1 - \zeta_{H}^{\prime}) z_{KH,t}^{c} + (0.5 \,\zeta_{H}^{\prime} - 1) \right], \tag{2.A.4}$$

$$\delta^{h}_{KH,t} = \delta^{h}_{KH} + b_{KH} \big[ 0.5 \, \zeta'_{H} (z^{h}_{KH,t})^{2} + (1 - \zeta'_{H}) z^{h}_{KH,t} + (0.5 \, \zeta'_{H} - 1) \big].$$
(2.A.5)

The curvature of the depreciation function is determined by  $\zeta'_H = \frac{\zeta_H}{1-\zeta_H}$ . Defining  $b^c_{KH} = \frac{1}{\beta_H} + 1 - \delta_{KH}$  implies a steady state utilization rate  $z^c_{KH}$  of one. Symmetrically, this result also holds for  $z^h_{KH}$ . Finally, let the marginal utilities of housing and labour be:

$$u_{HH,t} = \frac{jA_{j,t}A_{p,t}}{H_{H,t}},$$
$$u_{NH,t}^{c} = \tau \left[ \left( (N_{H,t}^{c})^{1+\kappa_{H}^{N}} + (N_{H,t}^{h})^{1+\kappa_{H}^{N}} \right)^{\frac{\chi^{H}-\kappa_{H}^{N}}{1+\kappa_{H}^{N}}} \right] (N_{H,t}^{c})^{\kappa_{H}^{N}},$$
$$u_{NH,t}^{h} = \tau \left[ \left( (N_{H,t}^{c})^{1+\kappa_{H}^{N}} + (N_{H,t}^{h})^{1+\kappa_{H}^{N}} \right)^{\frac{\chi^{H}-\kappa_{H}^{N}}{1+\kappa_{H}^{N}}} \right] (N_{H,t}^{h})^{\kappa_{H}^{N}}.$$

The resulting equilibrium conditions of the patient household are:

$$C_{H,t}: \qquad u_{CH,t} = \frac{A_{p,t}(1-\eta)}{C_{H,t} - \eta C_{H,t-1}},$$
(2.A.6)

$$D_t: \qquad u_{CH,t} \left( 1 + \frac{\partial a c_{DH,t}}{\partial D_t} \right) = \beta_H E_t \left( u_{CH,t+1} \frac{R_{H,t}}{\pi_{t+1}} \right), \tag{2.A.7}$$

$$N_{H,t}^c: \qquad u_{CH,t}W_{H,t}^c = u_{NH,t}^c, \tag{2.A.8}$$

$$N_{H,t}^h: \qquad u_{CH,t}W_{H,t}^h = u_{NH,t}^h, \tag{2.A.9}$$

$$K_{H,t}^{c}: \qquad \beta_{H} E_{t} \Big[ u_{CH,t+1} \bigg( R_{M,t+1}^{c} z_{KH,t+1}^{c} + \frac{1 - \delta_{KH,t+1}^{c}}{A_{K,t+1}} \bigg) \Big] = u_{CH,t} \bigg( \frac{1}{A_{K,t}} + \frac{\partial a c_{KH,t}^{c}}{\partial K_{H,t}^{c}} \bigg), \qquad (2.A.10)$$

$$K_{H,t}^{h}: \qquad \beta_{H} E_{t} \Big[ u_{CH,t+1} \Big( R_{M,t+1}^{h} z_{KH,t+1}^{h} + 1 - \delta_{KH,t+1}^{h} \Big) \Big] = u_{CH,t} \bigg( 1 + \frac{\partial a c_{KH,t}^{h}}{\partial K_{H,t}^{h}} \bigg), \qquad (2.A.11)$$

$$H_{H,t}: \qquad q_t u_{CH,t} = u_{HH,t} + (1 - \delta_{HH}) \,\beta_H E_t(q_{t+1} u_{CH,t+1}), \tag{2.A.12}$$

$$H_{r,t}: \qquad (1-\delta_{Hr})\,\beta_H E_t(u_{CH,t+1}q_{t+1}) = u_{CH,t}(q_t - q_{r,t}\,\Omega_r), \tag{2.A.13}$$

$$z_{KH,t}^c: \qquad R_{M,t}^c = \frac{1}{A_{K,t}} \frac{\partial \delta_{KH,t}^c}{\partial z_{KH,t}^c} = \frac{\partial \delta_{KH,t}^c}{\partial z_{KH,t}^c}, \qquad (2.A.14)$$

$$z_{KH,t}^{h}: \qquad R_{M,t}^{h} = \frac{\partial \delta_{KH,t}^{h}}{\partial z_{KH,t}^{h}}.$$
(2.A.15)

#### **Impatient Households**

The loan adjustment costs of loans take the same functional form as above and can be written as:

$$ac_{SS,t} = \frac{\phi_{SS}}{2} \frac{(L_{S,t} - L_{S,t-1})^2}{L_S}.$$
 (2.A.16)

Let the borrower's marginal utilities of housing and labour be:

$$u_{ZS,t} = A_{j,t}A_{p,t}\frac{j}{\tilde{H}_{S,t}} \left[\frac{(1-\theta_S)\tilde{H}_{S,t}}{Z_t}\right]^{\frac{1}{\kappa_S}},$$
$$u_{HS,t} = A_{j,t}A_{p,t}\frac{j}{\tilde{H}_{S,t}} \left[\frac{\theta_S\tilde{H}_{S,t}}{H_{S,t}}\right]^{\frac{1}{\kappa_S}},$$

$$\begin{split} u_{NS,t}^{c} &= \tau \bigg[ \bigg( (N_{S,t}^{c})^{1+\kappa_{S}^{N}} + (N_{S,t}^{h})^{1+\kappa_{S}^{N}} \bigg)^{\frac{\chi^{S}-\kappa_{S}^{N}}{1+\kappa_{S}^{N}}} \bigg] (N_{S,t}^{c})^{\kappa_{S}^{N}} \ ,\\ u_{NS,t}^{h} &= \tau \bigg[ \bigg( (N_{S,t}^{c})^{1+\kappa_{S}^{N}} + (N_{S,t}^{h})^{1+\kappa_{S}^{N}} \bigg)^{\frac{\chi^{S}-\kappa_{S}^{N}}{1+\kappa_{S}^{N}}} \bigg] (N_{S,t}^{h})^{\kappa_{S}^{N}} \ . \end{split}$$

Then the first order conditions are:

$$C_{S,t}: \qquad u_{CS,t} = \frac{A_{p,t}(1-\eta)}{C_{S,t} - \eta C_{S,t-1}},$$
(2.A.17)

$$L_{S,t}: \qquad u_{CS,t}\left(1-\lambda_{S,t}-\frac{\partial ac_{SS,t}}{\partial L_{S,t}}\right) = \beta_S E_t \left[u_{CS,t+1}\left(\frac{R_{S,t}}{\pi_{t+1}}-\rho_S,\lambda_{S,t+1}\right)\right],\tag{2.A.18}$$

$$N_{S,t}: \qquad u_{CS,t}W_{S,t} = \frac{\tau}{1 - N_{S,t}},$$
(2.A.19)

$$H_{S,t}: \qquad u_{HS,t} + \beta_S E_t(u_{CS,t+1}q_{t+1}) = u_{CS,t} \Big[ q_t - \lambda_{S,t} (1-\rho_S) m_S A_{MH,t} E_t \left( \frac{q_{t+1}}{R_{S,t}} \right) \Big], \qquad (2.A.20)$$

$$Z_t: u_{ZS,t} = q_{r,t} u_{CS,t}. (2.A.21)$$

#### Bankers

The banker's adjustment costs of deposits, household and corporate loans are summarised below:

$$ac_{DB,t} = \frac{\phi_{DB}}{2} \frac{(D_t - D_{t-1})^2}{D},$$
 (2.A.22)

$$ac_{EB,t} = \frac{\phi_{EB}}{2} \frac{(L_{E,t} - L_{E,t-1})^2}{L_E},$$
(2.A.23)

$$ac_{SB,t} = \frac{\phi_{SB}}{2} \frac{(L_{S,t} - L_{S,t-1})^2}{L_S}.$$
(2.A.24)

The optimality conditions of the banker's problem are:

$$C_{B,t}: \qquad u_{CB,t} = \frac{A_{p,t}(1-\eta)}{C_{B,t} - \eta C_{B,t-1}},$$
(2.A.25)

$$L_{E,t}: \qquad u_{CB,t} \left\{ 1 - \lambda_{B,t} \left[ \rho_D + \gamma_E (1 - \rho_D) \right] + \frac{\partial a c_{EB,t}}{\partial L_{E,t}} \right\} = \beta_B E_t \left[ u_{CB,t+1} \left( \frac{R_{E,t+1}}{\pi_{t+1}} - \lambda_{B,t+1} \rho_D \right) \right], \quad (2.A.26)$$

$$L_{S,t}: \qquad u_{CB,t} \left\{ 1 - \lambda_{B,t} \left[ \rho_D + \gamma_S (1 - \rho_D) \right] + \frac{\partial a c_{SB,t}}{\partial L_{S,t}} \right\} = \beta_B E_t \left[ u_{CB,t+1} \left( \frac{R_{S,t}}{\pi_{t+1}} - \lambda_{B,t+1} \rho_D \right) \right], \quad (2.A.27)$$

$$D_t: \qquad u_{CB,t} \left( 1 - \lambda_{B,t} - \frac{\partial a c_{DB,t}}{\partial D_t} \right) = \beta_B E_t \left[ u_{CB,t+1} \left( \frac{R_{H,t}}{\pi_{t+1}} - \lambda_{B,t+1} \rho_D \right) \right]. \tag{2.A.28}$$

# Entrepreneurs

The respective adjustment costs of capital and loans are:

$$ac_{KE,t} = \frac{\phi_{KE}}{2} \frac{(K_{E,t} - K_{E,t-1})^2}{K_E},$$
(2.A.29)

$$ac_{EE,t} = \frac{\phi_{EE}}{2} \frac{(L_{E,t} - L_{E,t-1})^2}{L_E}.$$
(2.A.30)

The first order conditions of the entrepreneur's problem are:

where 
$$u_{HE,t} = j_E \frac{1}{H_{E,t}},$$
 (2.A.31)

$$C_{E,t}: \qquad \lambda_{E,t}^* = u_{CE,t} = \frac{A_{p,t}(1-\eta)}{C_{E,t} - \eta C_{E,t-1}},$$
(2.A.32)

$$L_{E,t}: \qquad u_{CE,t} \left( 1 - \lambda_{E,t} - \frac{\partial a c_{EE,t}}{\partial L_{E,t}} \right) = \beta_E E_t \left[ u_{CE,t+1} \left( \frac{R_{E,t}}{\pi_{t+1}} - \rho_E \lambda_{E,t+1} \right) \right], \tag{2.A.33}$$

$$K_{E,t}: \qquad \beta_E E_t \Big[ u_{CE,t+1} (1 - \delta_{KE,t+1} + R_{K,t+1} z_{KE,t+1}) \Big] = u_{CE,t} \Big[ \frac{1}{A_{K,t}} + \frac{\partial a c_{KE,t}}{\partial K_{E,t}} - \lambda_{E,t} m_k (1 - \rho_E) A_{ME,t} \Big],$$
(2.A.34)

$$K_{H,t}^h: \qquad \mu_h q_t I H_t = R_{M,t}^h z_{KH,t}^h K_{H,t-1}^h, \qquad (2.A.35)$$

$$K_{H,t}^c: \qquad \alpha (1-\mu_c) \frac{Y_t}{X_t} = R_{M,t}^c z_{KH,t}^c K_{H,t-1}^c, \qquad (2.A.36)$$

$$N_{H,t}^c: \qquad \frac{Y_t}{X_t}(1-\alpha)(1-\sigma) = N_{H,t}^c W_{H,t}^c \left[1 + (1-\rho_E)\lambda_{E,t} A_{ME,t} m_N\right], \tag{2.A.37}$$

$$N_{S,t}^{c}: \qquad \frac{Y_{t}}{X_{t}} \left(1-\alpha\right)\sigma = N_{S,t}^{c} W_{S,t}^{c} \left[1+(1-\rho_{E})\lambda_{E,t} A_{ME,t} m_{N}\right], \qquad (2.A.38)$$

$$N_{H,t}^{h}: \qquad q_t IH_t \left(1 - \mu_h - \mu_b - \mu_l\right)(1 - \sigma) = N_{H,t}^{h} W_{H,t}^{h} \left[1 + (1 - \rho_E)\lambda_{E,t} A_{ME,t} m_N\right], \qquad (2.A.39)$$

$$N_{S,t}^{h}: \qquad q_t IH_t \left(1 - \mu_h - \mu_b - \mu_l\right) \sigma = N_{S,t}^{h} W_{S,t}^{h} \left[1 + (1 - \rho_E) \lambda_{E,t} A_{ME,t} m_N\right], \tag{2.A.40}$$

$$K_{B,t}: \qquad K_{B,t} = \mu_b q_t I H_t, \tag{2.A.41}$$

$$\ell_t: \qquad u_{CE,t} p_{\ell,t} = \beta_E E_t \bigg[ u_{CE,t+1} \Big( \mu_c \frac{IH_{t+1}}{\ell_t} q_{t+1} + p_{\ell,t+1} \Big) \bigg], \tag{2.A.42}$$

$$\ell_t \text{ normalised to 1:} \quad u_{CE,t} p_{\ell,t} = \beta_E E_t \bigg[ u_{CE,t+1} \Big( \mu_c I H_{t+1} q_{t+1} + p_{\ell,t+1}, \Big) \bigg]$$
(2.A.43)

combining it with profit cond. 
$$u_{CE,t}p_{\ell,t} = \beta_E E_t \left[ u_{CE,t+1}p_{\ell,t+1} \left( 1 + R_{\ell,t+1}, \right) \right]$$
(2.A.44)

$$z_{KE,t}: \qquad R_{K,t} = \frac{\partial \delta_{KE,t}}{\partial z_{KE,t}} = b_{KE}(\zeta_E' z_{KE,t} + 1 - \zeta_E'). \tag{2.A.45}$$

## 2.A.2 Steady State Derivations

In this section I derive the steady state of the economy. Due to the complexity of the model I only show the key steps and results of this exercise. Before we can start to derive the central expressions, we first have to compute the steady state equations for the respective interest rates and multipliers. Based on the first order conditions of the agents, we end up with:

$$R_H = \frac{1}{\beta_H} \tag{2.A.46}$$

$$R_E = \frac{1}{\beta_B} - \frac{\gamma_E (1 - \rho_D) + (1 - \beta_B)\rho_D}{\beta_B} \frac{1 - \beta_B R_H}{1 - \beta_B \rho_B},$$
(2.A.47)

$$R_{S} = \frac{1}{\beta_{B}} - \frac{\gamma_{S}(1-\rho_{D}) + (1-\beta_{B})\rho_{D}}{\beta_{B}} \frac{1-\beta_{B}R_{H}}{1-\beta_{B}\rho_{B}},$$
(2.A.48)

$$R_M^c = \frac{1}{\beta_H} - (1 - \delta_{KH}^c), \qquad (2.A.49)$$

$$R_M^h = \frac{1}{\beta_H} - (1 - \delta_{KH}^h), \qquad (2.A.50)$$

$$R_K = \frac{1}{\beta_E} [1 - \lambda_E (1 - \rho_E) m_K] - (1 - \delta_{KE}), \qquad (2.A.51)$$

$$\lambda_B = \frac{1 - \beta_B R_H}{1 - \beta_B \rho_B},\tag{2.A.52}$$

$$\lambda_E = \frac{1 - \beta_E R_E}{1 - \beta_E \rho_E},\tag{2.A.53}$$

$$\lambda_E = \frac{1 - \beta_S R_S}{1 - \beta_S \rho_S}.\tag{2.A.54}$$

The next step involves to derive the housing-consumption, price-rent and housing ratio. From the saver's problem we obtain the first consumption ratio and the price-rent ratio:

$$\frac{qH_H}{C_H} = \frac{j}{1 - (1 - \delta_{HH})\beta_H} = oo_3, \qquad (2.A.55)$$

$$\frac{q_r}{q} = \frac{1 - (1 - \delta_{Hr})\beta_H}{\Omega_r} = oo_6.$$
 (2.A.56)

From the borrower's problem we can determine the ratio  $\frac{H_r}{H_s}$ , which later helps us to work out the housingconsumption ratio of the impatient household. The housing ratio takes the form:

$$\frac{H_S}{H_r} = \Omega_r \left[ \frac{1 - (1 - \delta_{Hr})\beta_H}{\Omega_r} \right]^{\kappa_S} \left( \frac{\theta_S}{1 - \theta_S} \right) \left[ 1 - (1 - \delta_{HS})\beta_S - \lambda_S (1 - \rho_S)m_S (1 - \delta_{HS})\frac{1}{R_S} \right]^{-\kappa_S} = \Gamma^*.$$
(2.A.57)

Using this result, we are able to define the housing-consumption ratio of the borrower:

$$\frac{qH_S}{C_S} = \frac{j}{1 + \left(\frac{1-\theta_S}{\theta_S}\right)^{\frac{1}{\kappa_S}} \left(\Omega_r \frac{1}{\Gamma^*}\right)^{\frac{\kappa_S - 1}{\kappa_S}}} \left[1 - (1 - \delta_{HS})\beta_S - \lambda_S (1 - \rho_S)m_S (1 - \delta_{HS})\frac{1}{R_S}\right]^{-1} = oo_4. \quad (2.A.58)$$

Similarly we can obtain the output ratios from the entrepreneurs side. I summarise below all important results, which are crucial for the next steps.

$$K_{H}^{c} = Y \frac{\alpha(1-\mu_{c})}{XR_{M}^{c}} = Yoo_{1},$$
 (2.A.59)

$$K_H^h = qIH \frac{\mu_h}{R_M^h} = qIHoo_2, \qquad (2.A.60)$$

$$\frac{qH_H}{C_H} = oo_3 \Rightarrow qH_H = oo_3C_H, \qquad (2.A.61)$$

$$\frac{qH_S}{C_S} = oo_4 \Rightarrow qH_S = oo_4C_S, \tag{2.A.62}$$

$$\frac{qH_r}{C_S} = \frac{qH_S}{\Gamma^*C_S} = \frac{1}{\Gamma^*} \quad \frac{qH_S}{C_S} = \frac{1}{\Gamma^*}oo_4 = oo_5 \Rightarrow qH_r = oo_5C_S, \tag{2.A.63}$$

$$\frac{q_r}{q} = oo_6, \tag{2.A.64}$$

$$K_E = Y \frac{\alpha \mu_c}{XR_K} = Yoo_7, \tag{2.A.65}$$

$$K_B = \mu_b q I H, \tag{2.A.66}$$

$$N_{H}^{c}W_{H}^{c} = Y \frac{(1-\alpha)(1-\sigma)}{X[1+(1-\rho_{E})\lambda_{E}m_{N}]},$$
(2.A.67)

$$N_{S}^{c}W_{S}^{c} = Y \frac{(1-\alpha)\sigma}{X[1+(1-\rho_{E})\lambda_{E}m_{N}]},$$
(2.A.68)

$$N_{H}^{h}W_{H}^{h} = qIH\frac{(1-\mu_{h}-\mu_{b}-\mu_{\ell})(1-\sigma)}{1+(1-\rho_{E})\lambda_{E}m_{N}},$$
(2.A.69)

$$N_{S}^{h}W_{S}^{h} = qIH\frac{(1-\mu_{h}-\mu_{b}-\mu_{\ell})\sigma}{1+(1-\rho_{E})\lambda_{E}m_{N}}.$$
(2.A.70)

The collateral constraints of the borrower and entrepreneur deliver:

$$L_S = m_S (1 - \delta_{HS}) q H_S \frac{1}{R_S},$$
(2.A.71)

$$L_E = m_K K_E - m_N (N_H^c W_H^c + N_H^h W_H^h + N_S^c W_S^c N_S^h W_S^h).$$
(2.A.72)

In addition to this, we can rewrite the housing market clearing condition:

$$qIH = \delta_{HH}qH_H + \delta_{HS}qH_S + \delta_{Hr}qH_r$$
  
=  $\delta_{HH}oo_3C_H + \delta_{HS}oo_4C_S + \delta_{Hr}oo_5C_S$  (2.A.73)  
=  $\delta_{HH}oo_3C_H + C_S(\delta_{HS}oo_4 + \delta_{Hr}oo_5).$ 

And let

$$oo_8 = X[1 + (1 - \rho_E)\lambda_E m_N],$$
 (2.A.74)

$$oo_9 = 1 + (1 - \rho_E)\lambda_E m_N.$$
 (2.A.75)

Since labour enters the utility function via a CES aggregator, we have to work with consumption-output ratios. This implies we have to rewrite the budget constraint of the entrepreneur and both household types, using the ratios derived above. Starting with the patient agent, we find that the budget constraint can be written as:

The expressions between the curly brackets are simply constants and therefore we can write:

$$C_H T_1 + C_S T_2 = Y T_3 \Rightarrow \frac{C_H}{Y} T_1 + \frac{C_S}{Y} T_2 = T_3.$$
 (2.A.77)

In the same fashion we can write the borrower's budget constraint as:

$$C_{S}\left[1 + oo_{5}oo_{6}\Omega_{r} + \delta_{HS}oo_{4} - (1 - R_{H})m_{S}(1 - \delta_{HS})\frac{1}{R_{S}}oo_{4} - (\delta_{HS}oo_{4} + \delta_{Hr}oo_{5})\frac{(1 - \mu_{h} - \mu_{b} - \mu_{\ell})\sigma}{oo_{8}}\right] = Y\frac{1 - \alpha)\sigma}{oo_{8}} + C_{H}oo_{3}\delta_{HH}\frac{(1 - \mu_{h} - \mu_{b} - \mu_{\ell})\sigma}{oo_{8}},$$

$$(2.A.78)$$

$$\Rightarrow C_S T_4 = Y T_5 + C_H T_6 \Rightarrow \frac{C_S}{Y} T_4 = T_5 + \frac{C_H}{Y} T_6.$$
(2.A.79)

Similarly the entrepreneur's budget constraint becomes:

$$C_{E} + Y \left\{ \delta_{KE}oo_{7} + (R_{E} - 1) \left[ m_{K}00_{7} - m_{N} \frac{(1 - \alpha)}{oo_{8}} \right] + \frac{(1 - \alpha)}{oo_{8}} + R_{M}^{c}oo_{1} - \frac{1}{X} \right\} = C_{H}\delta_{HH}oo_{3} \left[ 1 - R_{M}^{h}oo_{2} - \frac{(1 - \mu_{h} - \mu_{b} - \mu_{\ell})}{oo_{9}} - \mu_{b} + m_{N}(R_{E} - 1) \frac{(1 - \mu_{h} - \mu_{b} - \mu_{\ell})}{oo_{9}} \right] + C_{S}(\delta_{HS}oo_{4} + \delta_{Hr}oo_{5}) \left[ 1 - R_{M}^{h}oo_{2} - \mu_{b} + m_{N}(R_{E} - 1) \frac{(1 - \mu_{h} - \mu_{b} - \mu_{\ell})}{oo_{8}} \right],$$

$$(2.A.80)$$

$$\Rightarrow C_E + YT_7 = C_H T_8 + C_S T_9 \Rightarrow \frac{C_E}{Y} + T_7 = \frac{C_H}{Y} T_8 + \frac{C_S}{Y} T_9.$$
(2.A.81)

What we have just derived is a system of three equations and three unknowns. They are summarised below:

$$\frac{C_H}{Y}T_1 + \frac{C_S}{Y}T_2 = T_3,$$
(2.A.82)

$$\frac{C_S}{Y}T_4 = T_5 + \frac{C_H}{Y}T_6,$$
(2.A.83)

$$\frac{C_E}{Y} + T_7 = \frac{C_H}{Y}T_8 + \frac{C_S}{Y}T_9.$$
(2.A.84)

We now solve for  $\frac{C_H}{Y}$ ,  $\frac{C_S}{Y}$  and  $\frac{C_E}{Y}$ . The final result for the three ratios is:

$$\frac{C_S}{Y} = \frac{T_6 T_3 + T_1 T_5}{T_1 T_4 + T_6 T_2},$$
(2.A.85)

$$\frac{C_H}{Y} = \frac{C_S}{Y} \frac{T_4}{T_6} - \frac{T_5}{T_6},$$
(2.A.86)

$$\frac{C_E}{Y} = \frac{C_H}{Y} T_8 \frac{C_S}{Y} T_9 - T_7.$$
(2.A.87)

We can again rewrite the housing market clearing condition and find:

$$\frac{qIH}{Y} = \delta_{HH}oo_3\frac{C_H}{Y} + \frac{C_S}{Y}(\delta_{HS}oo_4 + \delta_{Hr}oo_5).$$
(2.A.88)

In order to derive the steady state in levels from the ratios, we now have to work out Y. This means we have to pin down  $N_H^c$  and  $N_S^c$ . Along the way we are also able to derive the steady state for  $N_H^h$  and  $N_S^h$ . Algebraic rearrangement of the four optimality conditions involving savers' and borrowers' labour choices yields:

$$N_{H}^{c} = \left\{ \frac{\frac{Y}{C_{H}} \frac{(1-\alpha)(1-\sigma)}{oo_{8}}}{\tau \left[ 1 + \frac{qIH}{Y} \frac{(1-\mu_{h}-\mu_{b}-\mu_{\ell})}{1-\alpha} \right]^{\frac{\chi_{S}-\kappa_{H}^{N}}{1+\kappa_{H}^{N}}}} \right\}^{\frac{1}{1+\chi_{H}}},$$
(2.A.89)

and

$$N_{H}^{h} = N_{H}^{c} \frac{N_{H}^{h}}{N_{H}^{c}}, (2.A.90)$$

where

$$\frac{N_{H}^{h}}{N_{H}^{c}} = \left[\frac{qIH}{Y}\frac{X(1-\mu_{h}-\mu_{b}-\mu_{\ell})}{1-\alpha}\right]^{\frac{1}{1+\kappa_{H}^{N}}}$$
(2.A.91)

Symmetrically, we can find the same result for the borrower's labour choice:

$$N_{S}^{c} = \left\{ \frac{\frac{Y}{C_{S}} \frac{(1-\alpha)\sigma}{oo_{8}}}{\tau \left[ 1 + \frac{qIH}{Y} \frac{(1-\mu_{h}-\mu_{b}-\mu_{\ell})}{1-\alpha} \right]^{\frac{\chi_{S}-\kappa_{S}^{N}}{1+\kappa_{S}^{N}}}} \right\}^{\frac{1}{1+\chi_{S}}}, \qquad (2.A.92)$$

$$N_{S}^{h} = N_{S}^{c} \frac{N_{S}^{h}}{N_{S}^{c}},$$
(2.A.93)

where

$$\frac{N_S^h}{N_S^c} = \left[\frac{qIH}{Y} \frac{X(1-\mu_h - \mu_b - \mu_\ell)}{1-\alpha}\right]^{\frac{1}{1+\kappa_S^N}}.$$
(2.A.94)

Finally we can pin down the level of output in the steady state:

$$Y = (K_{H}^{c})^{\alpha(1-\mu_{c})} (K_{E})^{\alpha\mu_{c}} (N_{H}^{c})^{(1-\alpha)(1-\sigma)} (N_{S}^{c})^{(1-\alpha)\sigma}$$
  
$$= Y^{\alpha} (oo_{1})^{\alpha(1-\mu_{c})} (oo_{7})^{\alpha\mu_{c}} (N_{H}^{c})^{(1-\alpha)(1-\sigma)} (N_{S}^{c})^{(1-\alpha)\sigma}$$
  
$$Y = \left[ (oo_{1})^{\alpha(1-\mu_{c})} (oo_{7})^{\alpha\mu_{c}} (N_{H}^{c})^{(1-\alpha)(1-\sigma)} (N_{S}^{c})^{(1-\alpha)\sigma} \right]^{\frac{1}{1-\alpha}}.$$
  
(2.A.95)

Having derived the level of output, we then can then move on to define the level of consumption, residential investment and the different types of capital stocks:

$$K_H^c = oo_1 Y, \tag{2.A.96}$$

$$K_H^h = oo_2 Y \frac{qIH}{Y},\tag{2.A.97}$$

$$qIH = Y\frac{qIH}{Y},\tag{2.A.98}$$

$$K_B = \mu_b q I H, \tag{2.A.99}$$

$$C_H = Y \frac{C_H}{Y},\tag{2.A.100}$$

$$C_S = Y \frac{C_S}{Y},\tag{2.A.101}$$

$$C_E = Y \frac{C_E}{Y},\tag{2.A.102}$$

$$IH = \left(K_H^h\right)^{\mu_h} \left(N_H^h\right)^{(1-\mu_h-\mu_b-\mu_\ell)(1-\sigma)} \left(N_S^h\right)^{(1-\mu_h-\mu_b-\mu_\ell)\sigma} K_B^{\mu_b}.$$
 (2.A.103)

House and rental prices are defined according to the following conditions:

$$q = \frac{qIH}{q},\tag{2.A.104}$$

$$qr = qoo_6.$$
 (2.A.105)

The individual housing stocks can be computed from the market clearing condition of the housing sector.

$$IH = \delta_{HH}H_H + \delta_{HS}H_S + \delta_{Hr}H_r$$
  

$$\Rightarrow \frac{IH}{H_H} = \delta_{HH} + \delta_{HS}\frac{H_S}{H_H} + \delta_{Hr}\frac{H_r}{H_H},$$
(2.A.106)

where we need the following housing ratios:

$$\frac{H_S}{H_H} = \frac{oo_4 C_S}{oo_3 C_H},\tag{2.A.107}$$

$$\frac{H_r}{H_H} = \frac{oo_5 C_S}{oo_3 C_H},$$
(2.A.108)

in order to work out  $H_H$ ,  $H_S$  and  $H_r$ :

$$H_H = \frac{IH}{\delta_{HH} + \delta_{HS} \frac{oo_4 C_S}{oo_3 C_H} + \delta_{Hr} \frac{oo_5 C_S}{oo_3 C_H}},$$
(2.A.109)

$$H_H = H_H \frac{H_S}{H_H},\tag{2.A.110}$$

$$H_r = H_H \frac{H_r}{H_H}.$$
(2.A.111)

Based on these results it is straightforward to solve for the other steady states values.

### 2.A.3 Plots of the Posterior Modes

As in the appendix of chapter 1, this section plots the mode finding results of the individual parameters.



**Figure 2.14:** Mode Plots: Upper panel:  $\sigma_{be}$ ,  $\sigma_{bh}$ ,  $\sigma_j$ . Middle panel:  $\sigma_k$ ,  $\sigma_{ME}$ ,  $\sigma_{MH}$ . Lower Panel:  $\sigma_p$ ,  $\sigma_{zc}$ ,  $\sigma_{zh}$ .



**Figure 2.15:** Mode Plots: Upper panel:  $\sigma_r$ ,  $\sigma_s$ ,  $\sigma_{\pi}$ . Middle panel:  $\sigma_{NC}$ ,  $\sigma_{NH}$ ,  $\chi_H$ . Lower Panel:  $\chi_S$ ,  $\eta$ ,  $\phi_{DB}$ .



**Figure 2.16:** Mode Plots: Upper panel:  $\phi_{DH}$ ,  $\phi_{KE}$ ,  $\phi_{KC}$ . Middle panel:  $\phi_{KH}$ ,  $\phi_{EB}$ ,  $\phi_{EE}$ . Lower Panel:  $\phi_{SB}$ ,  $\phi_{SS}$ ,  $\iota$ .



**Figure 2.17:** Mode Plots: Upper panel:  $\kappa_S$ ,  $\kappa_H^N$ ,  $\kappa_S^N$ . Middle panel:  $\Omega_r$ ,  $\mu_c$ ,  $\psi_R$ . Lower Panel:  $\psi_{\pi}$ ,  $\psi_Y$ ,  $\rho_D$ .







**Figure 2.19:** Mode Plots: Upper panel:  $\rho_j$ ,  $\rho_k$ ,  $\rho_{me}$ . Middle panel:  $\rho_{mh}$ ,  $\rho_p$ ,  $\rho_{zc}$ . Lower Panel:  $\rho_{zc}$ .

Chapter 3

**Policy Implications** 

## 3.1 Introduction

Motivated by the results in chapter 2, this section critically discusses the use of macroprudential and housing supply side policies. The previous chapter has shown that a flexible housing supply counteracts the house price increase resulting from a positive demand shock. A supply-demand mismatch can therefore lead to rising house prices. Macroprudential policies, aimed towards the housing market, have the goal to prevent an overheating of the housing economy during good times and to cushion the economic damage after a collapse. In other words, sharply increasing and falling house prices during a housing boom and bust are offset by these types of prudential policies. However, a simulation exercise illustrates that a model with an elastic housing supply implies a better stabilisation of house prices than a framework with a prudential LTV rule and fixed supply of homes. Section 3.2 and 3.4 discuss the different prudential and supply side policies available to policy makers and authorities. Section 3.3 presents an IRF based model comparison.

# 3.2 Macroprudential Policy

Empirical evidence provided by Gilchrist, Yankov, and Zakrajšek (2009), Adrian and Shin (2010) and Ciccarelli, Maddaloni, and Peydró (2015) shows that the accessibility of credit played a central role in the years leading up to 2007 and in the aftermath of the financial crisis. The studies confirm that lax lending standards in numerous advanced economies fuelled the sharp increase of many macroeconomic variables, such as consumption, household debt or house prices. One important indicator, which reflects either loose or tight credit conditions, is the LTV ratio. Figure 3.1 depicts the average LTV ratio for mortgaged and all homeowners. In the early 1990s LTV ratios of both homeowner types increased above their historical averages and even rose more dramatically after 2005.



Figure 3.1: Average Mortgage LTV ratios: Mortgaged Homeowner vs. All Homeowners, 1970Q1 - 2011Q4; Source: Taken from the presentation by Bullard (2012)

A high LTV ratio implies a low down payment for a given amount of loan. However, this causes a greater economic damage to the lender in the case of default. Hence, high LTV ratios usually also come with a higher interest rate and significantly raise the rate of default (Deng et al. 1996). During the years before the financial crisis, LTV ratios increased to 0.8 and even exceeded 1.0.<sup>40</sup> This experience has triggered a fast growing literature on the use and effectiveness of a time varying LTV rule as a possible macroprudential tool. The mechanism of a countercyclical LTV rule is as follows: during a boom phase of the economy the rule contracts, requiring a high down payment. Therefore fewer applicants are able to qualify for a loan. Similarly, when the economy is in a recession, the LTV rule loosens up and the down payment declines. This can counteract a potential credit crunch during an economic downturn, like the one in the wake of the financial crisis.

Apart from monetary policy and a countercyclical LTV rule, there is a large set of macroprudential tools for authorities to choose from. The following paragraph is based on the discussion by Elliott (2011) and gives an overview of the different preventive measures to avoid an overheating of the credit market.<sup>41</sup> These instruments include:

• Limit to the leverage of asset purchases. Caps are introduced on the amount of leverage for different <sup>40</sup>See Bullard (2012), Ferreira, Gyourko, and Tracy (2010), Demyanyk and Van Hemert (2009) and Kaplan and Sommers (2009) <sup>41</sup>For a comprehensive discussion of different macroprudential instruments, see also Galati and Moessner (2013). transaction categories, in contrast to regulating the total leverage at various types of financial institutions. However, this is only effective if a significant quantity of borrowing is connected to asset purchases. In most countries transactions linked to real estate and security acquisition take up a large share of the credit market.

- *Reserve requirements.* As the name suggests, financial institutions have to hold a minimum fraction of their deposit liabilities as reserves at the central bank. In previous years, the U.S. and many other advanced economies altered their reserve requirements in order to stimulate bank lending.
- Administrative limits on aggregate lending. Authorities place a limit on the total amount of lending by financial institutions. However, this policy instrument is usually only implemented in less developed countries where the financial sector consists largely of banks and state intervention is more prevalent. This instrument enables regulators to directly adjust the flow of credit. The disadvantage of this interventionist approach is that the government decides over the credit volumes rather than market forces. Furthermore, the larger the size and the higher the complexity of the financial sector, the harder it is to enforce such a lending limit.
- Countercyclical capital requirements. This policy measure has been subject to a lot of critical debate and experienced the widest acceptance amongst authorities.<sup>42</sup> The idea behind this macroprudential instrument is simple. Financial institutions are required to hold more capital during a boom phase, which is likely to end in a sharp contraction of economic activity. First, this creates a financial cushion for institutions and therefore avoids a possible credit crunch during the bust phase. Second, it prevents excessive lending behaviour in pre-crisis periods.
- Dynamic loan loss provisioning. Similar to the policy measure described above. Financial institutions are required to hold more reserves during a boom-phase in order to cover a large quantity of loan losses in the following bust-phase. There are two different ways how this can be implemented. First, the aim of this macroprudential tool is to counteract the procyclical aspects of traditional loan loss reserving. Reserves are prone to decline during times of an economic upswing. This is especially dangerous when the fall in reserves is fuelled by over-optimism about the economic outlook. Conventional loan provisioning procedures make banks estimate their loan losses based on a relatively recent time frame. However, during a boom phase this recent time period will suggest a very low amount of loan losses, resulting in a fall in reserves. In contrast, dynamic loan loss provisioning acts in a countercyclical manner and aims to build up loss provisions for an upcoming recession. The second approach is to

<sup>&</sup>lt;sup>42</sup>These authorities involve the Basel Committee on Banking Supervision and the Financial Stability Board. For further details, see Elliott (2011).

introduce quasi capital reserves, which exceed the best estimate of potential, future loan losses. This can be achieved by looking at loan losses during periods of severe financial distress, or by accounting for an error margin.<sup>43</sup> A famous example is Spain, which implemented dynamic loan loss provisioning as a macroprudential tool.

- Countercyclical liquidity requirements. Under this scenario more and more financial institutions need to hold a minimum of safe, short-term or highly liquid assets in order to counterbalance a cash outflow during a bank run or a contraction of credit markets (e.g. interbank lending). The set of liquidity and capital rules are summarised under the Basel III framework. Higher liquidity requirements during economic boom phases have the same intention as an increase in capital buffers.
- Minimum margins/haircuts on secured lending. In past years, a significant share of financial transactions performed by large institutions were conducted via different forms of secured lending, e.g. repurchase agreements (repos). Repos have played a very important role in a specific part of the financial sector. It is often referred to as the "shadow banking" sector. These types of banks have been subject to less prudential regulations than other financial institutions and also have less access to reliable sources of funds or insured deposits. Therefore authorities proposed that haircuts<sup>44</sup> and margins should be regulated and capped at a minimum. The financial crisis was intensified by sharp increases in haircuts and margins. They occurred because lenders responded to the negative developments of financial markets, such as the bankruptcy of Lehman Brothers. This in turn led to fire sales and fuelled the downward spiral of security prices. At the same time lenders kept increasing their haircuts and margins, resulting in a vicious cycle. Therefore the idea of this policy instrument is to incrementally rise the level of minimum haircuts during economic upturns, in order to prevent swift jumps during a recession and avoid resulting fire sales.
- Limits on loan-to-income ratio (LTI). This ratio gives insight into whether a borrower is able to pay back her mortgage and lenders are therefore not solely reliant on the collateral value. Proposing a cap on the loan-to-income ratio can diminish the risk of an excessive growth in homeowner mortgages. However, there are two problematic factors with this approach. First of all, in some U.S. states it is impossible for lenders to receive financial compensation from the borrower's assets or income, in the case of a mortgage default. This means when the home value falls below the outstanding debt and

<sup>&</sup>lt;sup>43</sup>For a detailed discussion and empirical evidence on dynamic loan loss provisioning, see also Wezel, Chan Lau, and Columba (2012).

<sup>&</sup>lt;sup>44</sup>Haircut refers to the difference between an asset used as loan collateral at its market price and the actual loan amount. The haircut itself mirrors the risk of loss due to drop in the asset value or an immediate sale. Thus, the higher the risk the higher the haircut. For example, consider the following repo transaction. The haircut of the trade is 5% and the seller offers collateral at a market value \$1 million, then the buyer is only going to pay \$950,000.

the borrower decides to default, then the lender has only the collateral value as a protection against the borrower's insolvency. Thus, in these states the LTI ratio is only of minor significance. Second, income is subject to fluctuations and tied to the economic outlook. For example, at the time of the loan application the LTI ratio of a borrower can be very good. This can quickly change during times of economic distress and the borrower, who once had a good LTI score, defaults now on her loan obligations.

- Taxation. Specific taxes, which for example target sounder liquidity management, are an alternative method to alter incentives of banks and financial institutions. Most of the tools involving a maximum or minimum limit can be replaced by tax violations of these levels, instead of absolutely forbidding them. If taxes have the purpose to dampen the level of risk in the financial sector, rather than increasing government revenue, then alterations in tax policies can be a tool to counteract booms and busts. A significant difference between taxation and implementing safety limits (e.g. capital buffers) is that the former does not directly improve robustness of the system, instead it can weaken it through an outflow of resources. In contrast, increased capital buffers have an effect on incentives (e.g. stop overlending during a boom phase) and prepare the system for a period of severe losses. However, taxation raises funds for the government which can be used to combat pre-crisis developments and to strengthen the economy in the aftermath of the crisis.
- Constraints on currency mismatches. A significant portion of a country's credit transactions are undertaken in a foreign currency. During the financial crisis, global exchange rates have experienced sharp drifts (Fratzscher 2009). This in turn is an important risk factor during a boom phase. Therefore, in a countercyclical manner, limits should be relaxed in times of economic distress and tightened during a boom period.
- *Capital controls.* Capital flows to less advanced economies are an important reason for their credit cycles, which exhibits a strong pro-cyclical pattern. In other words, these economies experience a severe inflow and outflow of resources during good and bad economic times. For this reason, countries have started to use capital controls in a macroprudential fashion. Capital flow requirements have been subject to a vivid debate, whether they are suitable as a countercyclical policy tool. The literature on this topic suggests that regulation on capital flows can have serious consequences. However, one would have to also consider the improvements in financial stability which outweigh these "costs".

Having intensively reviewed the different macroprudential tools, the question arises which of those instruments are actually used by authorities? A study conducted by Claessens (2015) sheds light on this issue. The analysis is based on a total sample of 42 countries, consisting of 28 emerging and 14 developing economies. The results show that more than a half of the investigated countries have implemented the time varying LTV approach at least once. Regarding the duration and relative overall use, the LTV ratio is again the most often implemented policy measure.

As described above, many authorities favour LTV ratios as an instrument of macroprudential policy. For example, countries like Hong Kong or Canada have already adopted such an approach. In fact, LTV policies in Hong Kong have been established for a relatively long time in order to cool down an overheating of the property markets. Between 1990 and 2010 the Hong Kong Monetary authority stepped in and adjusted the LTV limits on several occasions. For example, during the global crisis periods 2008 and 2009, LTV ratios of higher priced properties were lowered by 10 percent<sup>45</sup> in order to bring house prices down (Funke and Paetz 2012).

Canada is another famous example of using the LTV ratio in a macroprudential fashion. First of all it is important to mention that loans with LTV ratios greater than 80 percent have to be insured. Mortgage insurance is provided by the government-owned Canadian Mortgage and Housing Corporation (CMHC) and two private companies. However, CMHC is by far the largest insurer with a market share of three quarters. The mortgage insurance applies to all governmentally regulated lenders and covers the entire Canadian banking sector. Banks are responsible for the majority of mortgage lending. In 2013, 74 percent of the mortgage supply originated from banks (Krznar and Morsink 2014). In the past and very recent years, Canadian authorities have adjusted LTV ratios in a countercyclical way. Due to the recession in 1991, and to stimulate residential investment, maximum LTV ratios of mortgages were raised in 1992 from 90 to 95 percent. This pilot project was specifically introduced for first-time home buyers. Regulations changed in 1998, which meant that mortgages with a LTV ratio of 95 percent could now be given to all home buyers within the regional price boundaries. In the years before the global financial crisis unfolded, macroprudential tools were substantially loosened. In 2006 it was decided that limits on LTV ratios were allowed to climb up to 100 percent before they were changed back to 95 percent in 2008 with the outbreak of the crisis. Therefore, Canadian authorities decreased LTV ratios and tightened the access to mortgages in response to the onset of the global financial crisis (Allen et al. 2017).

<sup>&</sup>lt;sup>45</sup>During that time, the LTV ratio was decreased from 60 to 50 percent for properties with a market value  $\geq$  HK\$ 12 million and declined from 70 to 60 percent for properties with values of HK\$ 12 million > HK\$ 8 million. For more details on the history see Funke and Paetz (2012) or Wong et al. (2011).

# 3.3 LTV Rule vs. Endogenous Housing Supply

In this section I compare the responses of house prices to a positive preference and monetary policy shock under a framework with flexible housing versus a model with a prudential LTV ratio. The aim of this exercise is to illustrate that a flexible housing supply is equally capable of stabilising house prices than a countercyclical LTV rule. For this reason, I compare three models. The first scenario is the benchmark setup, where housing supply is fixed and nominal rigidities have been introduced into the economy. The second model extends this frameworks by allowing for a countercyclical LTV rule of the form:

$$m_{S,t} = m_S \left(\frac{L_{S,t}}{L_S}\right)^{-\Psi_{m_S}},\tag{3.3.1}$$

where  $\Psi_{ms}$ ,  $\Psi_q = 2$ . The value has been chosen according to the studies by Bruneau, Christensen, and Meh (2016) and Funke and Paetz (2012). The third and last scenario is described by the model outlined in chapter 2, which endogenises the supply of homes. As already discussed, I assume that the central bank follows at the same time the benchmark Taylor rule. The LTV ratio now reacts to household debt deviations from its steady state. Thus, in good times the LTV ratio contracts, implying a higher down payment. The opposite happens during a recession, where the down payment becomes relatively small. The resulting IRFs are depicted in figure 3.2. All shock responses are expressed in percentage deviations from their respective steady states.




As we can see from the comparison above, the flexible housing supply (blue curve) implies a better price stabilisation effect than the countercyclical LTV rule (green curve). Even though the LTV rule is able to cushion the impact of both shocks, figure 3.2 illustrates the importance of a responsive housing supply side. In fact, it makes the use of prudential LTV measures redundant. The price responses under the flexible supply framework are the smallest, showing the economic significance of an elastic construction sector. Furthermore, the mechanisms of the two approaches are different. The LTV rule targets the borrowing ability of households and artificially restricts the amount of loans in the economy. This stands in contrast to the supply side approach. An elastic construction sector is able to react to demand swings and stabilises the price of housing by reducing the supply/demand mismatch. For completeness the same exercise has been performed again but now a macroprudential LTV rule was added to the third model represented by the blue graph. It turns out including the rule has not much impact on the responses. A possible explanation for this can be found in the overpowering supply effect originating from the housing sector. The next section discusses the different housing supply side policies to improve the responsiveness of the local construction sector.

## 3.4 Supply Side Policies

The previous section has provided evidence that a flexible housing supply yields better results than resorting to prudential LTV actions. This finding entails important implications for regulators and policy makers. Instead of focussing on macroprudential instruments, such as the LTV rule which restricts the borrowing ability of loan applicants, authorities also have to put more emphasis on policies that support the supply of housing. This for example includes the removal and reduction of inefficient regulations concerning the housing market. The reason for this is that housing markets are substantially affected by regulatory actions. In fact, most studies have found that regulations bring down construction activity and decrease the housing supply elasticity. Furthermore, they lead to an increase in house prices (Gyourko and Molloy 2015).

One important area for local governments is the regulation of land use. This involves topics such as zoning and growth controls. Research by Mayer and Somerville (2000) studies the link between new residential construction and the use of land regulations. Based on a panel data exercise, which involves 44 U.S. metro areas between 1985 and 1996, the authors find that land use regulations result in two negative effects. First, they reduce the local housing supply responsiveness to shocks and second, they decrease the steady state level of new construction. Additionally, the study finds that cities with a higher level of regulation exhibit price elasticities that are more than 20 percent lower than in metro areas with less regulation. The same conclusion reach Green, Malpezzi, and Mayo (2005) after having estimated different housing supply elasticities for 45 U.S. metro areas. Heavily regulated areas always showed low estimates of housing supply elasticities. Similarly, Glaeser, Gyourko, and Saks (2005) point out that the housing supply can become inelastic due to restrictive zoning and other land use regulations.

Regulations also matter for labour demand in connection with the housing stock. As pointed out by Saks (2008), housing supply differences create significant fluctuations in house prices across the U.S. Since migration is affected by house prices, the housing supply elasticity also has substantial implications for local labour markets. An expansion in the demand for labour causes an increase in wages and less employment in places with an insufficient supply of new homes. Saks (2008) therefore identifies metropolitan areas with an inelastic housing supply by gathering evidence on regulations concerning the construction of homes. He finds that in areas with fewer construction regulations, a rise in housing demand results in a substantial number of new housing units and a moderate increase in house prices. For the same housing demand shock, places with more construction barriers exhibit double the rise in house prices and a 17 percent smaller growth of their housing stock. Saks (2008) also concludes that local labour markets are significantly affected by the regulations connected to the residential construction sector. The results show that the long-run level of employment rises by 1 percent, following a 1 percent increase in the demand for labour. However, in areas where construction is highly constrained, employment only responds with less than 0.8 percent to the labour demand increase.

Caldera and Johansson (2013) investigate the different supply conditions for 21 OECD countries by estimating the elasticity of new housing supply. Whereas the supply responses are very slow in countries such as Switzerland, Austria and the Netherlands, housing supply reacts strongly in some Nordic Countries and North America. The study also concludes that in the long-run a more elastic housing supply is preferable, as it ensures a better adjustment of housing construction to the swings in demand. Caldera and Johansson (2013) also argue that the housing supply can be made more flexible through policy reforms which include taxation and housing regulations. They argue for a more efficient use of land-use policies and regulations, to guarantee a more effective utilisation of land in countries where rising house prices are driven by land scarcity. Additionally, optimising lengthy licensing processes also help in some countries to improve their housing supply elasticity. Caldera and Johansson (2013) suggest taxes on vacant or insufficiently used land that targets landowner. This helps to stimulate residential development in countries with a land shortage for construction activity. The incentive to build on vacant land can be increased by linking the evaluation of property value for tax purposes to the market value.<sup>46</sup> Another important factor mentioned by the study

 $<sup>^{46}\</sup>mathrm{See}$  Johansson et al. (2008).

is competition. Therefore, the implementation of competition policies is crucial because they improve the flexibility of the housing supply in countries with only a few large constructions businesses.

As above, DiPasquale (1999) argue that the housing supply can be heavily influenced by the federal tax policy through changing the pretax return for investors in rental housing. The tax policy defines the share of taxable rental income, determines the taxable rate of capital gains originating from the property, sets the tax life (i.e. the depreciation period of the asset) and defines the tax approach at which housing assets can be depreciated. DiPasquale and Wheaton (1992) show empirically that a one percentage point increase in the cost of capital to investors in rental housing is followed by a 14 percent decline in rental housing construction. The study by Bramley (2007) discusses the causes behind housing supply restrictions in the UK. Therefore, an inelastic housing supply depends on three main factors. First, planning contributes to this inelasticity through the insufficient allocation of land for new housing projects. This process also involves procedural delays which include the approval of specific developments or the production of plans. Second, the housing building industry itself contributes to the low supply responsiveness. The reason for this can be weak (local) competition, risk aversion or the internal corporate strategy. Additionally, these factors can be intensified by mixing them with technological conservatism and labour skill shortages. Third, low public sector investment, which goes directly into housing or indirectly via infrastructure to support developments, negatively effects the housing supply elasticity.

Having discussed the importance of a flexible housing supply, the question remains to what extend macroprudential policy affects welfare. For this reason, the next section analyses the implied welfare gains and losses of having a countercyclical LTV rule in place. Additionally, we are going to see how permanent changes in the LTV ratio and capital-asset requirement trigger welfare changes for the economic agents.

## 3.5 Welfare Analysis

In this section I perform a welfare analysis which studies two scenarios. First, I examine the welfare implications of introducing a countercyclical LTV rule into the model economy. Second, what are the implied welfare changes if there is a permanent change in the LTV ratio  $m_S$  and the capital-to-asset requirement  $\gamma$  (where  $\gamma = \gamma_E, \gamma_S$ ). I follow Levine, McAdam, and Pearlman (2008) and compute the welfare change expressed as the equivalent steady state consumption gains or losses. The analysis in this section relies on a second-order approximation of the welfare function  $W_t$ :

$$W_t = \beta W_{t+1} + (1-\beta) U_t.$$

The term  $U_t$  represents the individual utility functions of each agent in the economy (i.e. equation 2.2.1, 2.2.3, 2.2.6 and 2.2.9). Hence, the expression above yields in total four measures which capture the welfare of savers, borrowers, bankers and entrepreneurs. I simulate the benchmark model described in chapter 2 and compute the equivalent steady state level of consumption  $C_0$ , such that  $U(C_0, ...) = W_{t,0}$ . Once a change to the macroprudential parameters is made, we can then simulate the model again and a new steady state level of consumption is computed such that  $U(C_1, ...) = W_{t,1}$ . Finally, we can calculate the percentage change from  $C_0$  to  $C_1$ .

	Consumption Equivalent Gain/Loss		
Saver, $c_H^{gain}$	0.084%		
Borrower, $c_S^{loss}$	-0.199%		
Banker, $c_B^{gain}$	0.078%		
Entrepreneur, $c_E^{loss}$	-0.053%		

Table 3.1: Welfare Effects of Applying a LTV rule

Table 3.1 illustrates the welfare implications of using a time-varying LTV rule. The introduction of the macroprudential policy measure leads to a consumption equivalent loss for borrowers (-0.199%) and entrepreneurs (-0.053%). This is not surprising, as these agents rely on borrowing which ultimately affects their level of consumption. In contrast, savers and bankers experience a consumption equivalent gain of 0.084% and 0.078%, respectively. As discussed above, the studies by Rubio and Carrasco-Gallego (2014) and Campbell and Hercowitz (2009) show that there is a welfare trade-off when allowing for a macroprudential adjustment of the LTV requirement. However, their findings suggest that a high LTV ratio negatively effects borrowers' welfare, while savers gain from the rise. As we will see, this stands in contrast to the output presented in table 3.2.

**Table 3.2:** Welfare Effects of a Permanent Change of  $m_s$  and  $\gamma$ 

	$m_{S} = 0.85$	$m_{S} = 0.95$	$\gamma=0.85$	$\gamma=0.95$
Saver, $c_H^{gain/loss}$	0.031%	-0.033%	-0.025%	0.040%
Borrower, $c_S^{gain/loss}$	-0.077%	0.078%	-0.457%	1.308%
Banker, $c_B^{gain/loss}$	0.028%	-0.030%	-0.459%	1.483%
Entrepreneur, $c_E^{gain/loss}$	-0.047%	0.049%	0.241%	-1.380%

Table 3.2 depicts the welfare implications for a permanent change in the LTV ratio  $m_S$  and the capital-asset

ratio  $\gamma$ . I assume that both prudential policy parameters are adjusted by  $\pm 5\%$ . Therefore the first column shows the effect of a 5% permanent decrease of the LTV requirement. The agents who rely on borrowing (impatient household, entrepreneur) experience both a consumption equivalent loss of -0.124% in total. The opposite is the case for the saver and banker who are responsible for the loan supply in the economy. Both see a consumption equivalent gain of 0.031% and 0.028%, respectively. Increasing  $m_S$  to 0.95 reverts the signs and turns the previous gains (losses) into losses (gains). Note that the welfare implications are not symmetric. The increase in  $m_S$  has a slightly larger effect.

Turning to the permanent change in the capital-asset ratio  $\gamma$ , represented by the last two columns of table 3.2, we can see that a decrease of 5% implies a consumption equivalent loss for savers (-0.025%), borrowers (-0.457%) and bankers (-0.459%). This stands in contrast to an increase in the ratio which delivers welfare gains for borrowers and bankers. Only entrepreneurs face a substantial consumption equivalent loss of - 1.380% induced by the rise of the capital-adequacy requirement. These results add to the findings of Rubio and Carrasco-Gallego (2016). The study evaluates welfare under the Basel I, II and III regulatory framework. The results show that the imposed capital requirements do not automatically translate into higher welfare. However, the authors find that a countercycical capital buffer, as a part of the Basel III regulations, improves welfare significantly. Furthermore, they demonstrate that the macroprudential policy creates a welfare trade-off between savers and borrowers. The former benefits from the policy, whereas the latter is made worse off due to a reduction in borrowing of banks caused by increasing capital requirements.

### 3.6 Conclusion

Research has shown that the access to credit has significantly contributed to the latest boom and bust. Specifically lax lending standards boosted the dangerous expansion of household debt and house prices in the years leading up to the financial crisis. A well known indicator of either lax or tight credit conditions is the LTV ratio. A high ratio implies a lower down payment and hence requires less capital provided by the loan applicant. Pre-crisis LTV ratios reached record highs and were ranging between 0.9 and 1. The latter implies that no cash down payment is necessary in order to obtain a loan, which in turn entails a very high risk for the lender. Governments and authorities have recognised the potential of LTV ratios in their role as macroprudential instruments. Down payments are therefore adjusted in a countercyclical manner and the mechanism is as follows: during a boom phase of the economy the LTV ratio would remain low, opposed to a recession where ratios are adjusted upwards. This helps to prevent excess credit growth and a possible credit crunch during the years of economic distress.

Apart from LTV ratios, authorities have a large set of different macroprudential policies they can choose from. The most famous are countercyclical capital and liquidity requirements, dynamic loan loss provisioning and caps on LTI ratios. However, research shows that LTV ratios are the most used policy instruments amongst authorities. Hong Kong and Canada have a long history of adjusting mortgage down payments in order to combat rising house prices and sharp increases in residential investment. As chapter 2 and the simulation exercise performed in the above section have shown, a model with a flexible housing supply delivers a better stabilisation effect of house prices than a framework equipped with a countercyclical LTV rule and a fixed supply of new homes. Furthermore, the literature on this topic has shown that an elastic housing supply is able to respond better to changes in demand. This in turn has an offsetting effect on house prices. One way to improve the supply elasticity of the construction sector is to either reduce or improve inefficient regulations. Reviewing restrictive land-use and zoning requirements are examples of such regulations. Furthermore, promoting competition in the construction sector and introducing specific housings taxes help to increase the responsiveness of the housing supply. Hence, authorities have to focus on improving the responsiveness of their local housing supplies. Furthermore, this chapter has shown that macroprudential policies cause a welfare trade-off. Savers experience a welfare gain through a countercyclical LTV rule, whereas borrowers suffer a consumption equivalent loss. This also holds for a permanent, negative change in the LTV ratio. This is effect reversed for a downward adjustment of the bank's capital-asset ratio.

This chapter has focussed on discussing macroprudential and housing supply side policies. However, more research on this topic is necessary in order to determine the effectiveness of both policy approaches during boom and bust developments. This is especially important when interest rates are at their zero lower bound. I leave this question open for future research.

# **Concluding Remarks**

The empirical work presented in this thesis has led to two main findings. News about future productivity have significantly contributed to the U.S. boom and bust behaviour of house prices and also played a role in the latest shift towards rental housing, besides other factors such as loan defaults and changes in preferences and bank lending. This set of findings is obtained from an estimated DSGE model which accommodates a rental market and a banking sector, as outlined in chapter 1. The second main finding concerns the role of monetary policy and its contribution to the pre-crisis build-up of household credit. The second chapter therefore introduces nominal rigidities into the model and relaxes the assumption of a fixed housing supply. This framework is then re-estimated on a modified dataset. The outcome of the estimation shows that monetary policy was not the main driving force behind the latest housing booms which contradicts the by Taylor (2007, 2009) or the Bank for International Settlements (2007, 2008).

As already mentioned above, at the heart of this dissertation lie two estimated DSGE models. Chapter 1 studies the pre and post-crisis dynamics of the owner-occupied and rental housing markets. I introduce a market for both housing types into the Iacoviello (2015) framework, where household borrowers are able to choose between renting or owning. Allowing for this feature is crucial to study the interplay and dynamics of the rental and owner-occupied housing sectors. As presented in chapter 2, in order to analyse the effects of monetary policy on household debt and the production of new homes, I relax the assumptions of a constant housing supply and flexible prices in the consumption sector. The modelling strategy of these features follows the approach described in Iacoviello and Neri (2010).

The methodology outlined in the first chapter differs from the literature, as it allows for banking frictions and the existence of a rental market. The work most closely related to chapter 1 is the paper by Sun and Tsang (2017). They estimate the Iacoviello and Neri (2010) framework, equipped with a rental sector, on U.S. data which also includes the crisis years 2007 and 2008. Despite including data on the financial crisis, the authors abstracts from loan defaults and banking frictions. The combination of banking frictions, housing choices and an endogenous construction sector of new homes is a distinct feature of chapter 2, in contrast to the existing literature. Furthermore, both models developed in this dissertation are estimated on U.S. quarterly data with the help of Bayesian techniques. This allows us to empirically evaluate the underlying structural parameters, as many results of the rental and policy DSGE literature rely on calibrated models. 3 offers a critical discussion about macroprudential and housing supply side policies. Furthermore, it looks at the welfare implications of such prudential measures.

The limitations of this dissertation lie in the socio-economic factors, which influence the decision making process of agents to either buy a home or rent a flat. They can be difficult or even impossible to model under the DSGE framework. Examples are demographics, social status of households, spatial differences or simply the employment status of individuals. Furthermore, this dissertation has focused on the owner-occupied and rental housing markets before the outbreak of the financial crisis. Therefore, investigating the dynamics of both housing types during the post-crisis years, which were for example characterised by zero interest rates, is avenue for further research.

# Bibliography

- Adam, Klaus, Pei Kuang, and Albert Marcet (2012). "House price booms and the current account". NBER Macroeconomics Annual 26.1, pp. 77–122.
- Adrian, Tobias and Hyun Song Shin (2010). "Financial intermediaries and monetary economics". Handbook of Monetary Economics. Vol. 3. Elsevier, pp. 601–650.
- Allen, Jason et al. (2017). "The impact of macroprudential housing finance tools in Canada". Journal of Financial Intermediation 1-14.
- An, Sungbae and Frank Schorfheide (2007). "Bayesian analysis of DSGE models". *Econometric Reviews* 26.2-4, pp. 113–172.
- Arezki, Rabah, Valerie A Ramey, and Liugang Sheng (2017). "News shocks in open economies: Evidence from giant oil discoveries". The Quarterly Journal of Economics 132.1, pp. 103–155.
- Bank for International Settlements (2007). 77th Annual Report. Accessible under https://www.bis.org/publ/arpdf/ar2007e.pdf.
- (2008). 78th Annual Report. Accessible under https://www.bis.org/publ/arpdf/ar2008e.pdf.
- Barsky, Robert B, Christopher L House, and Miles S Kimball (2007). "Sticky-price models and durable goods". *The American Economic Review* 97.3, pp. 984–998.
- Barsky, Robert B and Eric R Sims (2011). "News shocks and business cycles". Journal of Monetary Economics 58.3, pp. 273–289.
- Baxter, Marianne (1996). "Are consumer durables important for business cycles?" The Review of Economics and Statistics, pp. 147–155.
- Beaudry, Paul and Franck Portier (2006). "Stock prices, news, and economic fluctuations". The American Economic Review 96.4, pp. 1293–1307.
- Bernanke, Ben (2010). "Economic challenges: Past, present and future". Speech given at the Dallas Regional Chamber, Dallas, Texas on April 07, 2010.

- Bernanke, Ben S et al. (2005). "The global saving glut and the US current account deficit". Presentation given at the Sandridge Lecture, Virginia Association of Economists, Richmond, Virginia, on March 10, 2005.
- Bernanke, Ben and Mark Gertler (1989). "Agency costs, net worth, and business fluctuations". The American Economic Review, pp. 14–31.
- Bils, Mark and Peter J Klenow (2004). "Some evidence on the importance of sticky prices". Journal of Political Economy 112.5, pp. 947–985.
- Binning, Andrew and Junior Maih (2016). "Implementing the zero lower bound in an estimated regimeswitching DSGE model". Norges Bank Working Paper 03/2016.
- Bordo, Michael D, John Landon-Lane, et al. (2014). "Does expansionary monetary policy cause asset price booms? Some historical and empirical evidence". Central Banking, Analysis, and Economic Policies Book Series 19, pp. 61–116.
- Borio, Claudio EV and Piti Disyatat (2011). "Global imbalances and the financial crisis: Link or no link?" BIS Working Paper No. 346.
- Born, Benjamin, Alexandra Peter, and Johannes Pfeifer (2013). "Fiscal news and macroeconomic volatility". Journal of Economic Dynamics and Control 37.12, pp. 2582–2601.
- Bramley, Glen (2007). "The sudden rediscovery of housing supply as a key policy challenge". *Housing Studies* 22.2, pp. 221–241.
- Brooks, Stephen P and Andrew Gelman (1998). "General methods for monitoring convergence of iterative simulations". *Journal of Computational and Graphical Statistics* 7.4, pp. 434–455.
- Bruneau, Gabriel, Ian Christensen, and Césaire Assah Meh (2016). "Housing market dynamics and macroprudential policy". Bank of Canada Staff Working Paper.
- Bullard, James (2012). The Aftermath of the Housing Bubble. https://www.stlouisfed.org/~/media/ Files/PDFs/Bullard/remarks/BullardBipartisanPolicyCenter5June2012Final.pdf. Online; accessed 13-October-2017.
- Caldera, Aida and Åsa Johansson (2013). "The price responsiveness of housing supply in OECD countries". Journal of Housing Economics 22.3, pp. 231–249.
- Calvo, Guillermo A (1983). "Staggered prices in a utility-maximizing framework". Journal of Monetary Economics 12.3, pp. 383–398.
- Campbell, Jeffrey R and Zvi Hercowitz (2009). "Welfare implications of the transition to high household debt". Journal of Monetary Economics 56.1, pp. 1–16.
- Cesa-Bianchi, Ambrogio and Alessandro Rebucci (2017). "Does easing monetary policy increase financial instability?" Journal of Financial Stability 30, pp. 111–125.

- Chambers, Matthew, Carlos Garriga, and Don E Schlagenhauf (2009). "Housing policy and the progressivity of income taxation". *Journal of Monetary Economics* 56.8, pp. 1116–1134.
- Chang, Yongsung (2000). "Comovement, excess volatility, and home production". Journal of Monetary Economics 46.2, pp. 385–396.
- Chib, Siddhartha and Edward Greenberg (1995). "Understanding the metropolis-hastings algorithm". *The* American Statistician 49.4, pp. 327–335.
- Ciccarelli, Matteo, Angela Maddaloni, and José-Luis Peydró (2015). "Trusting the bankers: A new look at the credit channel of monetary policy". *Review of Economic Dynamics* 18.4, pp. 979–1002.
- Claessens, Stijn (2015). "An overview of macroprudential policy tools". Annual Review of Financial Economics 7, pp. 397–422.
- Corsetti, Giancarlo et al. (2013). "Sovereign risk, fiscal policy, and macroeconomic stability". *The Economic Journal* 123.566.
- Curry, Timothy and Lynn Shibut (2000). "The cost of the savings and loan crisis: truth and consequences". *FDIC Banking Rev.* 13, p. 26.
- Davis, Morris A and Jonathan Heathcote (2005). "Housing and the business cycle". International Economic Review 46.3, pp. 751–784.
- Dell'Ariccia, Giovanni, Deniz Igan, and Luc Laeven (2008). Credit booms and lending standards: Evidence from the subprime mortgage market. 2008-2106. International Monetary Fund.
- Demyanyk, Yuliya and Otto Van Hemert (2009). "Understanding the subprime mortgage crisis". *The Review* of Financial Studies 24.6, pp. 1848–1880.
- Deng, Yongheng et al. (1996). "Mortgage default and low downpayment loans: the costs of public subsidy". Regional Science and Urban Economics 26.3, pp. 263–285.
- DiPasquale, Denise (1999). "Why don't we know more about housing supply?" The Journal of Real Estate Finance and Economics 18.1, pp. 9–23.
- DiPasquale, Denise and William C Wheaton (1992). "The cost of capital, tax reform, and the future of the rental housing market". *Journal of Urban Economics* 31.3, pp. 337–359.
- Dokko, Jane et al. (2011). "Monetary policy and house prices". Economic Policy 26.66, pp. 237–287.
- Eickmeier, Sandra and Boris Hofmann (2013). "Monetary policy, housing booms, and financial (im) balances". Macroeconomic Dynamics 17.4, pp. 830–860.
- Elliott, Douglas J (2011). "Choosing among macroprudential tools". The Brookings Institution. Mimeo, June.
- Fairchild, Joseph, Jun Ma, and Shu Wu (2015). "Understanding housing market volatility". Journal of Money, Credit and Banking 47.7, pp. 1309–1337.

- Favilukis, Jack, Sydney C Ludvigson, and Stijn Van Nieuwerburgh (2017). "The macroeconomic effects of housing wealth, housing finance, and limited risk sharing in general equilibrium". Journal of Political Economy 125.1, pp. 140–223.
- Fernández-Villaverde, Jesús (2010). "The econometrics of DSGE models". SERIEs 1.1-2, pp. 3–49.
- Fernández-Villaverde, Jesús and Juan Francisco Rubio-Ramírez (2004). "Comparing dynamic equilibrium models to data: a Bayesian approach". *Journal of Econometrics* 123.1, pp. 153–187.
- Ferreira, Fernando, Joseph Gyourko, and Joseph Tracy (2010). "Housing busts and household mobility". Journal of Urban Economics 68.1, pp. 34–45.
- Forlati, Chiara and Luisa Lambertini (2011). "Risky mortgages in a DSGE model". International Journal of Central Banking, Center for Fiscal Policy Working Paper Series, Working Paper 02-2010.
- Fratzscher, Marcel (2009). "What explains global exchange rate movements during the financial crisis?" Journal of International Money and Finance 28.8, pp. 1390–1407.
- Funke, Michael and Michael Paetz (2012). "A DSGE-based assessment of nonlinear loan-to-value policies: Evidence from Hong Kong". BOFIT Discussion Paper No. 11/2012.
- Galati, Gabriele and Richhild Moessner (2013). "Macroprudential policy-a literature review". Journal of Economic Surveys 27.5, pp. 846–878.
- Gertler, Mark and Peter Karadi (2011). "A model of unconventional monetary policy". Journal of Monetary Economics 58.1, pp. 17–34.
- Gilchrist, Simon, Vladimir Yankov, and Egon Zakrajšek (2009). "Credit market shocks and economic fluctuations: Evidence from corporate bond and stock markets". Journal of Monetary Economics 56.4, pp. 471– 493.
- Glaeser, Edward L, Joseph Gyourko, and Raven E Saks (2005). "Urban growth and housing supply". Journal of Economic Geography 6.1, pp. 71–89.
- Green, Richard K, Stephen Malpezzi, and Stephen K Mayo (2005). "Metropolitan-specific estimates of the price elasticity of supply of housing, and their sources". *The American Economic Review* 95.2, pp. 334– 339.
- Greenwood, Jeremy and Zvi Hercowitz (1991). "The allocation of capital and time over the business cycle". Journal of Political Economy 99.6, pp. 1188–1214.
- Guerrieri, Luca and Matteo Iacoviello (2017). "Collateral constraints and macroeconomic asymmetries". Journal of Monetary Economics 90, pp. 28–49.
- Gyourko, Joseph and Raven Molloy (2015). "Regulation and housing supply". Handbook of Regional and Urban Economics. Vol. 5. Elsevier, pp. 1289–1337.
- Hamilton, James Douglas (1994). Time series analysis. Vol. 2. Princeton University Press.

- Iacoviello, Matteo (2005). "House prices, borrowing constraints, and monetary policy in the business cycle". The American Economic Review 95.3, pp. 739–764.
- (2010). "Housing in DSGE models: Findings and new directions". Housing Markets in Europe: A Macroeconomic Perspective. Springer-Verlag Berlin.
- (2015). "Financial business cycles". Review of Economic Dynamics 18.1, pp. 140–163.
- Iacoviello, Matteo and Stefano Neri (2010). "Housing market spillovers: evidence from an estimated DSGE model". American Economic Journal: Macroeconomics 2.2, pp. 125–164.
- Jappelli, Tullio (1990). "Who is credit constrained in the US economy?" The Quarterly Journal of Economics 105.1, pp. 219–234.
- Jarocinski, Marek and Frank Smets (2008). "House prices and the stance of monetary policy". ECB Working Paper No. 891.
- Johansson, Åsa et al. (2008). "Taxation and economic growth". OECD Economics Department Working Papers No. 620.
- Joint Center for Housing Studies (2013). "America's rental housing: evolving markets and needs". The Joint Center for Housing Studies of Harvard University.
- Justiniano, Alejandro, Giorgio E Primiceri, and Andrea Tambalotti (2015). "Credit supply and the housing boom". *National Bureau of Economic Research.* (No. w20874).
- Kaplan, David H and Gail G Sommers (2009). "An analysis of the relationship between housing foreclosures, lending practices, and neighborhood ecology: Evidence from a distressed county". The Professional Geographer 61.1, pp. 101–120.
- Kiyotaki, Nobuhiro and John Moore (1997). "Credit cycles". Journal of Political Economy 105.2, pp. 211– 248.
- Koop, Gary (2003). Bayesian Econometrics. John Wiley & Sons Ltd.
- Krznar, Mr Ivo and James Morsink (2014). With Great Power Comes Great Responsibility: Macroprudential Tools at Work in Canada. 14-83. International Monetary Fund.
- Lambertini, Luisa, Caterina Mendicino, and Maria Teresa Punzi (2017). "Expectations-driven cycles in the housing market". *Economic Modelling* 60, pp. 297–312.
- Lambertini, Luisa, Victoria Nuguer, and Pinar Uysal (2017). "Mortgage default in an estimated model of the US housing market". Journal of Economic Dynamics and Control 76, pp. 171–201.
- Levine, Paul, Peter McAdam, and Joseph Pearlman (2008). "Quantifying and sustaining welfare gains from monetary commitment". Journal of Monetary Economics 55.7, pp. 1253–1276.
- Matsuyama, Kiminori (1990). "Residential investment and the current account". Journal of International Economics 28.1-2, pp. 137–153.

- Mayer, Christopher J and C Tsuriel Somerville (2000). "Land use regulation and new construction". *Regional Science and Urban Economics* 30.6, pp. 639–662.
- Mian, Atif and Amir Sufi (2015). House of debt: How they (and you) caused the Great Recession, and how we can prevent it from happening again. University of Chicago Press.
- Miao, Jianjun, Pengfei Wang, and Tao Zha (2014). "Liquidity premia, price-rent dynamics, and business cycles". *National Bureau of Economic Research* (No. w20377).
- Monacelli, Tommaso (2009). "New Keynesian models, durable goods, and collateral constraints". Journal of Monetary Economics 56.2, pp. 242–254.
- Mora-Sanguinetti, Juan S and Margarita Rubio (2014). "Recent reforms in Spanish housing markets: An evaluation using a DSGE model". *Economic Modelling* 44, S42–S49.
- Nelson, Benjamin, Gabor Pinter, and Konstantinos Theodoridis (2018). "Do contractionary monetary policy shocks expand shadow banking?" Journal of Applied Econometrics 33.2, pp. 198–211.
- Obstfeld, Maurice and Kenneth Rogoff (2009). "Global imbalances and the financial crisis: products of common causes". *CEPR Discussion Paper No. DP7606.*
- Ortega, Eva, Margarita Rubio, and Carlos Thomas (2011). "House purchase versus rental in Spain". Banco de España Working Paper (No. 1108).
- Paccagnini, Alessia (2017). "Dealing with Misspecification in DSGE Models: A Survey". MPRA Paper 82914.
- Painter, Gary and Christian L Redfearn (2002). "The role of interest rates in influencing long-run homeownership rates". The Journal of Real Estate Finance and Economics 25.2, pp. 243–267.
- Rötheli, Tobias F (2010). "Causes of the financial crisis: Risk misperception, policy mistakes, and banks" bounded rationality". The Journal of Socio-Economics 39.2, pp. 119–126.
- Rubio, Margarita (2014). "Rented vs. owner-occupied housing and monetary policy". National Bank of Poland Working Paper No. 180.
- Rubio, Margarita and José A Carrasco-Gallego (2014). "Macroprudential and monetary policies: Implications for financial stability and welfare". Journal of Banking & Finance 49, pp. 326–336.
- (2016). "The new financial regulation in Basel III and monetary policy: A macroprudential approach". Journal of Financial Stability 26, pp. 294–305.
- Sá, Filipa, Pascal Towbin, and Tomasz Wieladek (2011). "Low interest rates and housing booms: the role of capital inflows, monetary policy and financial innovation". Bank of England Working Paper No. 411.
- Saks, Raven E (2008). "Job creation and housing construction: Constraints on metropolitan area employment growth". Journal of Urban Economics 64.1, pp. 178–195.
- Schmitt-Grohé, Stephanie and Martin Uribe (2012). "What's news in business cycles". Econometrica 80.6, pp. 2733–2764.

Schwartz, Anna J (2009). "Origins of the financial market crisis of 2008". Cato J. 29, p. 19.

- Shiller, Robert J (2007). "Understanding recent trends in house prices and home ownership". *National Bureau* of Economic Research (No. w13553).
- Smets, Frank and Raf Wouters (2003). "An estimated dynamic stochastic general equilibrium model of the euro area". Journal of the European economic association 1.5, pp. 1123–1175.
- Sommer, Kamila, Paul Sullivan, and Randal Verbrugge (2013). "The equilibrium effect of fundamentals on house prices and rents". *Journal of Monetary Economics* 60.7, pp. 854–870.
- Stiglitz, Joseph E (2010). "Interpreting the Causes of the Great Recession of 2008". Financial System and Macroeconomic Resilience: Revisited. Bank for International Settlements.
- Summers, Larry (2013). "Speech at IMF 14th Annual Research Conference in Honor Of Stanley Fisher". International Monetary Fund 8.
- Sun, Xiaojin and Kwok Ping Tsang (2017). "What Drives the Owner-Occupied and Rental Housing Markets? Evidence from an Estimated DSGE Model". Journal of Money, Credit and Banking 49.2-3, pp. 443–468.
- (2018). "The impact of monetary policy on local housing markets: Do regulations matter?" Empirical Economics 54.3, pp. 989–1015.
- Taylor, John B (2007). "Housing and monetary policy". National Bureau of Economic Research (No. w13682).
- (2009). "Economic policy and the financial crisis: an empirical analysis of what went wrong". Critical Review 21.2-3, pp. 341–364.
- (2011). "Macroeconomic lessons from the Great Deviation". NBER Macroeconomics Annual 25.1, pp. 387– 395.
- Townsend, Robert M (1979). "Optimal contracts and competitive markets with costly state verification". Journal of Economic Theory 21.2, pp. 265–293.
- Walsh, Carl E (1993). "What caused the 1990-1991 recession?" Economic Review-Federal Reserve Bank of San Francisco 2, p. 33.
- Warnock, Francis E and Veronica Cacdac Warnock (2009). "International capital flows and US interest rates". Journal of International Money and Finance 28.6, pp. 903–919.
- Wezel, Torsten, Jorge A Chan Lau, and Francesco Columba (2012). "Dynamic loan loss provisioning: simulations on effectiveness and guide to implementation". International Monetary Fund, WP/12/110.
- Wong, TC et al. (2011). "Loan-to-value ratio as a macroprudential tool-Hong Kong's experience and crosscountry evidence". Hong Kong Monetary Authority, Working Paper 01/2011.