Mortgage Default, Financial Disintermediation and Macroprudential Policies

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Abstract

The recent global financial crisis has highlighted the spillover effects of shocks originating in the housing and financial markets on the real economy. This paper embeds endogenous mortgage default into a New Keynesian model that features housing and non-trivial banking sectors. In particular, loan origination is subject to capital requirements. We study shocks to the variance of an idiosyncratic housing shock (housing risk shocks) and to the penalty on capital regulation (risk premium shocks). A large adverse housing risk shock results in higher mortgage default, which in turn raises the mortgage spreads. It also generates losses to banks, which subsequently constrains their lending activity. Capital regulation and housing adjustment costs are shown to be important for propagating the effects of a shock and explaining the substantial decline in GDP. A risk premium shock, meanwhile, raises mortgage and business loan interest rates. This has negative effects on aggregate demand. We later introduce three macroprudential measures to explore whether they improve economic stability and welfare. These include caps on loan-to-value (LTV) ratio, countercyclical capital buffers and a state-contingent LTV ratio. The results support the use of the first two measures, while the latter may exacerbate a decline in the welfare of mortgage borrowers.

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1 Introduction

The recent global financial crisis has highlighted the spillover effects of shocks originating in the housing and financial markets on the real economy. Prior to the crisis, banks granted easier access to funds for subprime mortgage borrowers, supported by a number of factors including continuously-rising house prices, excess liquidity, securitisation activity, and so on. Households enjoyed increased possession of houses, while ultimate investors/lenders received high returns with a low perceived risk from mortgage-backed securities (MBS). However, the situation reversed. The housing bubble collapsed, triggering a widespread default on mortgages. Financial intermediaries inevitably faced immense losses, which were further exacerbated by a decline in the market value of those MBS. As bank capital eroded, they encountered the need to deleverage to satisfy the capital adequacy regulation. Being aware of counterparty risks, they were also reluctant to lend to one another, giving rise to liquidity problems. A credit crunch occurred and put pressures on both domestic and global economy.

Policymakers around the world have then provided unprecedented amounts of economic stimuli. At the same time, macroprudential regulation measures were introduced to prevent systemic risks and improve the resilience of the overall financial system. Drawing on the precedent crisis, the paper therefore aims to embed mortgage default into a New Keynesian (NK) model that features housing and non-trivial banking sectors. To replicate the crisis event, we see mortgage default as a necessary ingredient in generating shocks and the presence of the banking sector as a sufficient ingredient to bring about a meaningful financial accelerator. We are then interested in whether macroprudential regulation can help promote economic stability and welfare.[1]

Examining the composition of household debt and bank assets may offer an idea of why problems in the mortgage market can precipitate into financial and economic crises. It also underscores the necessity to introduce the housing sector and mortgages into the model, if one seeks to understand macroeconomic fluctuations. The data from the US flow of funds accounts (Table 7 in the Appendix) have shown that mortgages constitute a large part of the balance sheet for both households and commercial banks. On household liabilities, home mortgages constitute 65.38 percent of total liabilities at the end of 2015. This figure is far greater than consumer credits

[1] See Brunnermeier (2008) for a brief description of the causes and consequences of the global financial crisis.

which is the second biggest component. Mortgages also form 16 percent of total liabilities of non-financial businesses.[2]

At the same time, on the asset side of bank balance sheet, 39.74 percent of total financial assets are mortgage related. They can be in the form of either individual mortgage loans or MBS. In terms of the latter, even though they are backed by an agency and government-sponsored enterprises, banks may still suffer from the deterioration of their value, particularly when asset fire-sales occur. Banks, as well as non-bank financial institutions, recorded considerable losses from investment in both mortgages and MBS during the past crisis. Therefore, studying behaviors of households and banks without taking mortgage origination into consideration would lead to an incomplete picture of the modern financial economy. In addition, without the mortgage market the recent crisis cannot be assessed properly.

Our benchmark model builds on Gerali et al. (2010), who embed the housing and banking sectors in the NK framework. Two households differing in their discount rates derive utility from both consumption goods and housing services. Patient households save in equilibrium while impatient households acquire mortgages from banks using the houses as collateral. Their model is suitable for an analysis of mortgage default and macroprudential regulation. The existence of housing and mortgages makes it straightforward to extend and include the possibility of default. We follow the approach by Bernanke et al. (1999) (hereinafter called BGG) and Forlati and Lambertini (2011) in modeling it. In particular, mortgage borrowers can choose to default on loan obligation and have their collateral seized by banks, whenever the ex-post value of the collateral falls below debt outstanding. Their model also includes banks that face capital requirements. This feature generates interactions between the real and financial sectors, as an erosion in bank net worth can trigger a credit crunch. The model with such Basel-II-type capital regulation will serve as our benchmark economy where only microprudential regulation is in place. We then extend this model to incorporate several macroprudential tools. Moreover, to allow for the role of investment in macroeconomic fluctuations, the model includes another agent, the entrepreneur who owns the economy's capital. We will show both with empirical evidence as well as model simulations that a slump in investment

[2] We do not focus on commercial mortgages in this paper. See Iacoviello (2005) for the model including both residential and commercial mortgages. The data from the Federal Reserve Board suggests that the majority of the real estate loans (53.48 percent) is of residential type (excluding multifamily property, but including both revolving home equity loans and closed end residential loans). In addition, MBS backed by the government are mostly those collateralised by a pool of residential mortgages. These justify the importance of studying residential mortgages.

is the key factor that decreased Gross Domestic Product (GDP) during the recent crisis.

Empirical evidence in section 3 shows an acceleration of mortgage default and increased credit spreads during the crisis, which coincide with a deep and persistent economic recession. We study two main shocks to explain what have happened. First, a shock to the variance of idiosyncratic housing shocks is introduced to capture a trigger that generates a rise in mortgage default. We model this similarly to that introduced in Christiano et al. (2014) in the case of entrepreneurial loans. We show that adverse housing risk shocks depress economic activities. An unanticipated rise in default generates losses to banks and lowers their capital ratios. The latter leads banks to reduce new loans, particularly mortgages which become riskier. Entrepreneurs also receive less funding, which negatively affects their investment. Banks also anticipate a persistent rise in mortgage default and thus charge higher mortgage spreads. Given fewer mortgages, impatient households cut both durable and non-durable consumption. We show that capital regulation and housing adjustment costs are crucial in propagating the effects of a shock and explaining the substantial decline in GDP. Second, a capital regulation penalty shock aims to capture rising credit spreads. As in Gilchrist and Zakrajšek (2012), we consider that the evolution of credit spreads partly reflects changes in bank risk-bearing capacity, which deteriorated immensely during the recent crisis. We show that this shock can also contribute to significant economic downturns. Banks raise the premia on both mortgages and business loans, prompting impatient households and entrepreneurs to reduce consumption and investment.

We then assess three macroprudential regulations to analyse their effectiveness in stabilising the effects of these two shocks. These include caps on the loan-to-value (LTV) ratio, countercyclical capital buffers and a state-contingent LTV ratio, which responds to the ratio of mortgages to GDP. We report four key results. First, imposing LTV caps benefits mortgage borrowers in the steady state. This may sound counterintuitive as the policy should constrain mortgage lending in the first place. However, it also brings down the steady-state probability of default. Due to a lower default risk, impatient households face a lower mortgage spread and are able to obtain more mortgages for consumption and housing accumulation. Therefore, their welfare improves, while the banking system becomes safer. Second, LTV caps are effective in limiting a surge in mortgage default in the face of housing risk shocks. The decline in mortgages and aggregate demand becomes much more muted. However, the level of the caps needs to be sufficiently stringent for impatient households to reap the welfare benefits. When risk premium shocks occur, the measure again limits a fall in mortgages, which in turn improves the welfare of impatient households.

Third, countercyclical capital buffers that react to the credit-to-GDP ratio may improve allocations and the welfare of both impatient households and entrepreneurs. As the effects of both shocks are transmitted through the banking sector, policies that ease the constraint faced by banks are effective in resolving the problems. In the face of housing risk shocks, the buffers also yield large macroeconomic stabilisation benefits when LTV caps are not available. However, financial regulators have to be aware that the credit-to-GDP ratio may send a false signal in certain circumstances which can destabilise the economy. This happens when the economy faces risk premium shocks and already has a LTV constraint in place. Last, our results do not support the use of state-contingent LTV caps when the economy faces housing risk shocks. The measure helps relax impatient households borrowing constraint during the crisis period. However, it exacerbates default and eventually reduces their welfare. This last result disagrees with the literature most of which supports state-contingent LTV ratios. For example, see Lambertini et al. (2013) and Rubio and Carrasco-Gallego (2014).

The rest of the paper is organised as follows. Section 2 reviews the existing literature in the area. Section 3 offers empirical evidence for the US during the crisis. We also offer a vector autoregression (VAR) analysis to motivate empirical relevance of the two shocks. Sections 4 and 5 describe the benchmark model and macroprudential regulation, respectively. Calibration of the model parameters is discussed in Section 6. Section 7 provides the simulation results, showing the responses of the economy with respect to the proposed shocks. In Section 8, we analyse the effectiveness of macroprudential measures in improving economic stability and welfare. The thesis ends with concluding remarks and potential extensions of future work.

2 Literature Review

This paper relates to literature that incorporates financial friction a la Kiyotaki and Moore (1997) in the dynamic stochastic general equilibrium (DSGE) model with housing. Iacoviello (2005) assumes that impatient households face borrowing constraints linked to the expected value of houses. Such constraints produce a financial accelerator in the face of demand shocks. Furthermore, Iacoviello and Neri (2010) further model the supply side of the housing market. Changes in house prices in their model impact both the collateral constraint of households and the profitability of the housing production sector. They show that shocks originating from the housing market, namely housing demand and housing technology shocks, have a significant contribution on economic fluctuations. In this respect, our paper follows Iacoviello (2005) in assuming fixed supply of houses, in order to exclusively focus on shock amplification through the demand side. Meanwhile, Monacelli (2009) exploits such borrowing constraints to capture the comovement of the durable and non-durable sectors in response to monetary policy shocks–an empirical finding established in Erceg and Levin (2006). In response to the Great Recession, Gerali et al. (2010) further imposed monopolistically competitive banks and capital regulation into the DSGE model with housing. They study the feedback loop between the real and financial sectors that magnifies the effects of productivity and monetary policy shocks. Moreover, they find considerable effects of a negative shock to bank capital on the real economy. Our model relies on the framework of the latter, however we introduce the possibility of mortgage default and utilise such framework to study the effectiveness of macroprudential tools.

Since the recent crisis, economists have become interested in embedding mortgage default into the DSGE framework. The literature relies on the modelling device introduced in BGG by introducing idiosyncratic shocks to the housing value. Mortgage borrowers default whenever the realised value of the collateral turns out to be lower than their debt. Forlati and Lambertini (2011) were the first to do so. They find that the real effects of mortgage default are amplified in highly-leveraged economy, while sluggish response of monetary policy can result in deeper recession. Similarly to BGG, they assume adjustable mortgage interest rates to satisfy the ex-post participation constraint of lenders, implying that borrowers absorb all the losses from aggregate risk. This seems an unrealistic assumption since during the crisis lenders suffered from extensive mortgage default. More importantly, their model does not include financial intermediaries. Hence, it is not possible to study the interactions between the banking and real sectors, which were instrumental during the Great Recession.

Quint and Rabanal (2014) instead assume a predetermined mortgage interest rate so as to permit loss-sharing between lenders and borrowers. Working with a two-economy model with financial intermediaries, they study the effectiveness of macroprudential regulation in improving economic stability and welfare within the context of the Euro Area. They find the measures to be useful when the economy faces housing market, rather than productivity, shocks. However, the key drawback of the paper is that the introduction of macroprudential regulation is fundamentally ad hoc. They assume that only a certain proportion of deposits is available as loanable funds, and that financial regulators adjust this proportion to implement macroprudential policies. Moreover, domestic financial intermediaries, being risk-neutral, have a naive and rather mechanical role in the economy. In our paper, the non-trivial role arises from the existence of capital requirements that link the size and composition of the banks balance sheet to their capital. Clerc et al. (2015) introduce three layers of default (deposits, mortgages and entrepreneurial loans) to study the interplay between the net worth of the borrowing agents and examine the effectiveness of the countercyclical capital buffers. Deposits default gives a special role to the net worth of financial intermediaries in determining loans supply conditions. However, the paper does not put any particular emphasis on mortgage default.[3]

Ferrante (2015) is the closest precursor to our paper, as the paper seeks to explain a slump in investment and output during the crisis through financial disintermediation. Housing risk and MBS collateral shocks affect banks' net worth, which subsequently widens an interest rate spread required on both mortgages and business loans. However, the key difference is that the banking friction in our model arises from the capital regulation as in Gerali et al. (2010), while that in Ferrante (2015) is generated by the moral hazard incentive as banks can divert away assets from depositors, an idea originated in Gertler and Karadi (2011). The framework of the latter is suitable for studying unconventional measures. In terms of policy implications, his focus is therefore not on macroprudential regulation but on credit policies that were recently employed during the crisis.

A handful of papers attempt to model mortgage default in dynamic general equilibrium model with finite periods, finite states and incomplete market. Campbell and Cocco (2015) model mortgage default that is driven not only by home equity consideration but the tightness of the borrowing constraint. They also emphasise mechanisms how increases in the LTV ratio and loan-to-income (LTI) ratio raise default probability. Goodhart et al. (2011) and Goodhart et al. (2013) have an endowment-economy model with heterogeneous households and banks, cash-in-advance constraint, housing and mortgage default. The latter further introduces shadow banks and securitisation to emphasise risks and consequences of asset fire sales. They study multiple financial regulations and show that the economy can benefit from their right combi-

[3]Capital regulations are imposed strictly in their model, while in ours banks optimally weigh benefits and costs of complying with the regulations. The capital adequacy ratio can then be time-varying. In addition, borrowers again have to satisfy lenders participation constraint ex-ante. We instead opt for Quint and Rabanal (2014)'s approach where loans pricing is done through the market.

nation (for example, using countercyclical capital buffers in conjunction with margin requirements).

This paper is also related to literature exploring the effectiveness of macroprudential regulation. This strand of the literature can be split into two groups. The first group conducts a normative analysis seeking to identify distortions that result in inefficient allocation and examines how regulation improves the outcomes. Bianchi (2011), for example, constructs an international model featuring an occasionally binding borrowing constraint. During normal time, the failure of the agents to internalise the effects of their borrowing decisions on collateral prices gives rise to the so-called "pecuniary" externalities and hence the problem of "overborrowing". This raises the probability and severity of the crisis, driven by the Fisherian debt-deflation dynamics. He concludes that taxes on debt can yield welfare improvements. In a related framework, two-period setting, Jeanne and Korinek (2010) argue that imposing Pigouvian taxes on capital inflows during the boom periods can reduce the probability of sudden stops. Bianchi and Mendoza (2010), on the other hand, consider a closed economy where the borrowing constraint is tied with the price of assets (i.e. land) rather than goods. They show that taxes on debt and dividends can help a decentralised economy obtain constrained Pareto allocations.

Our work belongs to the second group, which features a positive approach. In particular, we take the existence of macro-prudential measures for granted and examine whether regulation reduces macroeconomic fluctuations and improves welfare. Angelini et al. (2014), using the model of Gerali et al. (2010), examine the effectiveness of countercyclical capital buffers and find that the measure helps promote economic stability when it is used to counterweigh financial shocks, namely shocks to bank capital. They also stress the importance of the cooperation between monetary and macroprudential authorities. Angelini et al. (2015) use wide ranges of DSGE models and tend to support countercyclical capital buffers as tools to dampen output volatility. Bean et al. (2010) modify the framework of Gertler and Karadi (2011) to study the effects of lump-sum levy or subsidy on the banking sector. They also support the use of macroprudential regulation and suggest that policymakers coordinate to avoid "push-me, pull-you" outcome, particularly when facing inflation shocks. Like Angelini et al. (2014), Kannan et al. (2012) suggest that using a macroprudential tool that responds to credit growth can improve welfare in the face of credit spread and housing demand shocks, as opposed to productivity shocks. However, their model lacks microfoundation on the determination of credit spreads, which are ad-hocly assumed to depend on the LTV ratio, macroprudential regulation and exogenous shocks.

One of the key contributions of our paper is with respect to the effects of the LTV regulation on mortgage default. A handful of articles have assessed the effectiveness of state and non-state contingent LTV caps in the model with housing. However, none of them includes mortgage default, which is the key aspect of the global financial crisis and the, subsequent, Great Recession. DSGE papers with mortgage default above are yet to consider LTV regulations which should be the most relevant to housing market fluctuations. Lambertini et al. (2013) model mortgage boom-bust cycles driven by news shocks. They find that countercyclical LTV and interest rates that respond to credit growth are socially optimal. They also stress the impact of heterogeneity on welfare across borrowers and savers. Gelain et al. (2013) deviate from rational expectations and assume that a subset of agents instead adopt a simple moving average forecast rule. This helps explain excessive volatility in debt and house prices. They find that a debt-to-income type constraint is more effective than LTV caps in terms of dampening excess volatility, while interest rates that respond to financial indicators can result in higher inflation volatility.[4] In addition, more restrictive LTVs makes impatient households worse off at the steady state. This result differs from ours. Finally, Rubio and Carrasco-Gallego (2014) suggest that the optimal LTV rule which responds to credit growth improves both macroeconomic stability and welfare. However, they support non-cooperation between the central bank and financial regulators. Our paper will show that state-contingent LTV caps may potentially be undesirable in the face of housing risk shocks. Meanwhile, countercyclical capital buffers, in certain circumstances, may destabilise the economy when encountering risk premium shocks.

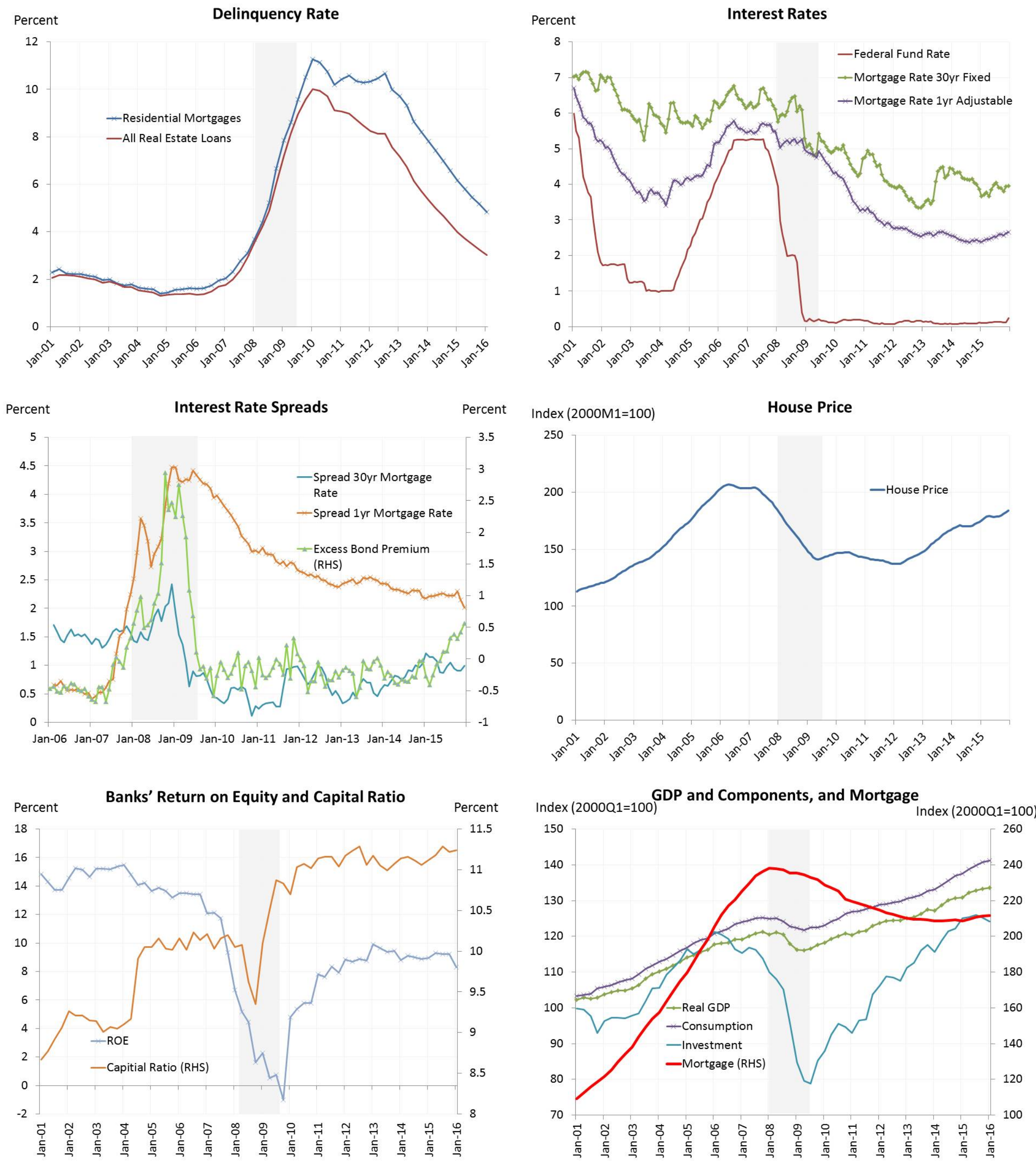
3 Empirical Evidence

This section briefly examines empirical evidence on how the housing, banking and real sectors interacted during the Great Recession. We offer a VAR analysis, where the model's two key shocks, namely housing risk shocks and risk premium shocks, are identified using standard Cholesky decomposition, to explore whether they are empirically relevant in explaining the housing and financial crises.

We consider that the trigger to such a deep and prolonged recession was the rise in mortgage default and a reduction in bank risk-bearing capacity, the latter reflected in increasing credit spreads. In figure 1, we present evidence from the US and

[4] However, the paper considers only standard macroeconomic shocks as a source of disturbances.

Figure 1: Empirical Evidence



Note: see data description in the Appendix.

highlight the data during the economic recession period in grey. The delinquency rate on real-estate loans rose from below 2 percent before 2007 to its peak at 10 percent in the first quarter of 2010, and then gradually declined. Far worse was the delinquency rate on residential mortgages, the only type of mortgages considered in this model, which climbed above 11 percent and stood higher than 10 percent for almost three years. The trend of mortgage interest rates closely follows that of the federal funds rate. We can observe that from 2007 interest rates are declining to ward off recession. Nevertheless, mortgage spreads seem to reflect heightened default risk and tight credit supply conditions. The spread between 30-year mortgages and government bonds of the same maturity stood at around 1.5 percent pre-crisis. The spread is even lower for 1-year mortgages. However, both began rising in 2007 to reach the maximum at the end of 2008 at 2.42 and 4.13 percent, respectively.[5] Gilchrist and Zakrajšek (2012) construct a credit spread index from the corporate bond market, namely the excess bond premium (EBP), to reflect banks risk-bearing capacity and hence credit supply conditions. They show that EBP is a powerful predictor for future economic activity. From the figure, we see EBP skyrocketing during the crisis.

S&P/Case-Shiller house price index began falling from the second quarter of 2007. The index only stabilised in 2009 and started to increase again in 2012. Return on average equity, a measure of bank profitability, for all US banks fell sharply in 2007-2008 from above 13 percent, and reached its bottom at -1.03 percent during the last quarter of 2009. A period of decline in house prices and bank profits is consistent with the timing of a surge in mortgage default. Bank capital-to-asset ratios exhibited an upward trend for decades. The crisis interrupted this trend during the second half of 2008. Data on bank profitability and capitalisation all signal financial fragility. Based on the data from the US flow of funds accounts, the stock of household mortgages delivered a consistent picture, despite the decline that took place later in 2008. This may be due to the fact that borrowers can still exercise credit lines (in particular from home-equity borrowing), although new loans can already become constrained. However, the decline is persistent and reached its trough in 2014.

As far as real economic variables are concerned, we can observe a fall in real GDP from the third quarter of 2008 until the second quarter of 2009. Subsequently, the figure rebounded and has already surpassed its pre-crisis level in 2011. Real consumption and non-residential investment exhibited the same pattern, but the

[5] It can be observed from 1987 that there are three episodes where mortgage default soared, and they all coincide with widening mortgage spreads.

decline in investment is much deeper and more persistent, highlighting the need to consider and model the slump in capital investment.[6]

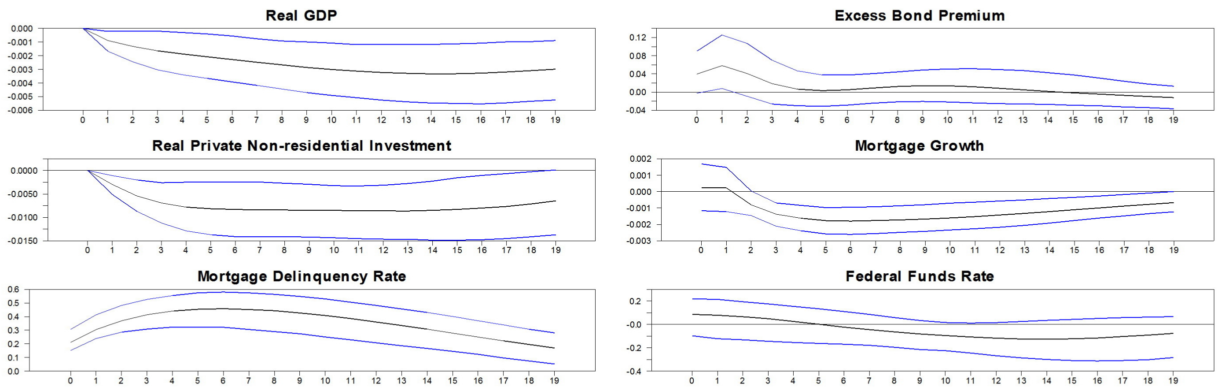
Next we examine VAR evidence to observe macroeconomic effects of the two shocks of interest in the theoretical model. Our 2-lag quarterly US VAR model consists of seven variables, namely log of real GDP, log of real private non-residential investment, log of GDP deflator, the delinquency rate of loans secured by real estate (also known as mortgage default), EBP, growth of mortgages and the federal funds rate. We use an orthogonalised shock to mortgage default and EBP, identified with Cholesky decomposition, to trace the effects of theoretical housing risk and risk premium shocks, respectively. Mortgage growth is ordered below mortgage default and EBP, because we consider that a shock to the latter variables may exert immediate pressure on lending activity but not vice versa. Altering the order of the three variables does not qualitatively change the results. The estimation period covers the first quarter of 1987 to the second quarter of 2008, based on the availability of delinquency data. The confidence interval is based on 90-percent bootstrapped band.[7]

Figure 2 shows that a positive shock to mortgage default and EBP causes adverse effects on real GDP, investment and lending activity. In the upper panel, a positive impulse to mortgage default leads to a fall in bank risk-bearing capacity, as implied by a rise in EBP. Banks tighten their loans supply and hence extend fewer mortgages. We hasten to add that mortgage growth declines significantly three quarters after the shock. The results show no significant responses during the initial periods. This is consistent with the stylized fact described above that mortgages began declining in 2008 (or one year after default rose). The responses of EBP to mortgage default shock is crucial as we view bank financial condition as an important amplifier and propagator of shocks. Consistent with credit contraction, real economic activities experience a downturn. Real GDP, real private non-residential investment and prices fall, taking certain amount of time to reach their trough. The Federal Reserve responds by lowering its policy interest rate. However, the responses only become significant after two years. This may signal that, before the Great Recession, the Central Bank did not react promptly to shocks that originated in the housing

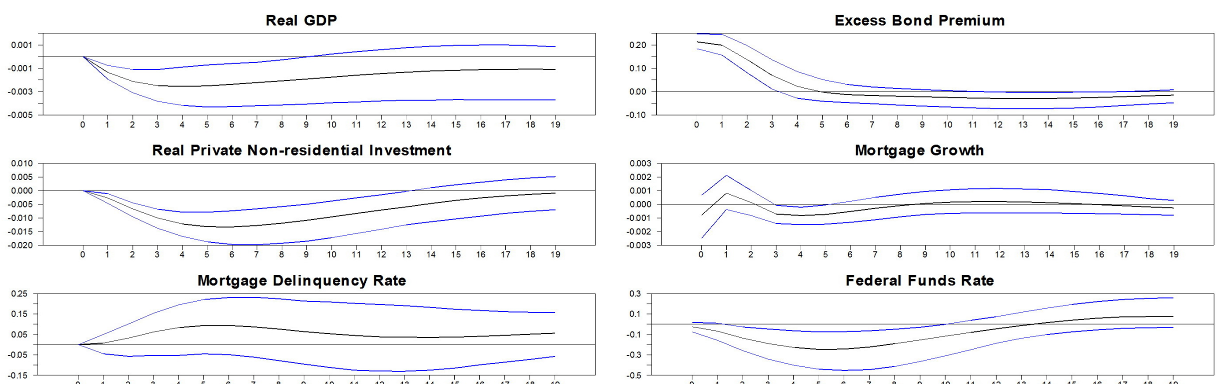
[6]Not being described in the figure, the residential fixed investment manifests an even sharper decline and has not yet returned to the pre-crisis level. However, we did not model such a type of investment in this paper. This may be an interesting extension, but for now, given that housing investment is a small portion of the overall investment and GDP, the theoretical results should not change significantly without it.

[7]Serial correlation LM test shows that the model does not reject the null hypothesis of no serial correlation among VAR residuals at 10 percent significant level.

Figure 2: VAR Evidence



(a) Mortgage Default Shock



(b) EBP Shock

Note: the blue lines show 5- and 95-percentile responses from bootstrapping. The black line shows median responses.

markets, and tended to wait and see until they had materially large impacts on the real economy. In sum, the responses to mortgage default shocks can explain very well the economic variables during the Great Recession.

The lower panel of figure 2 shows the economy's responses to a positive EBP shock, which signals a tightening of credit supply conditions. Such a shock causes a decline in mortgages, which again takes effect after three quarters, but the decline is not as persistent as the responses under a default shock.[8] Mortgage delinquency rate rises, but is not significant. We suspect that a decline in mortgage extension as well as economic activity puts downward pressure on house prices and leads to higher default. A rise in default can in turn cause banks to be more vigilant in lending, resulting in an adverse feedback loop. Real GDP and investment falls, while the Federal Reserve promptly reacts to a shock. An EBP shock is, therefore, another potential candidate to explain the crisis event. Overall, the VAR evidence shows that shocks that we are interested in identifying in our model in the next section, despite originating in financial sector, have significant effects on real economic activities. Importantly, their identified responses do match the behavior of both real and financial data during 2008-2009 global financial crisis.

4 The Benchmark Model

The benchmark model follows Gerali et al. (2010), who embed housing and the banking sector in the NK framework. The economy consists of two types of households, patient and impatient households, which fundamentally differ in their discount rate and flow of income. Heterogeneity of the discount rates generates positive flows of borrowing and lending in equilibrium. The two agents derive utility from consuming both non-durable and durable goods. The former are standard consumption goods whereas the latter are houses, which can also be used as collateral in acquiring mortgages. Having lower discount rate, patient households become lenders in equilibrium and, hence, deposit their savings with banks. The latter, taking into account capital adequacy regulation, make loans to impatient households and entrepreneurs in terms of mortgages and business loans, respectively. Entrepreneurs invest in the economy's physical capital and rent it to firms for the production of consumption goods. The existence of capital allows us to model non-residential

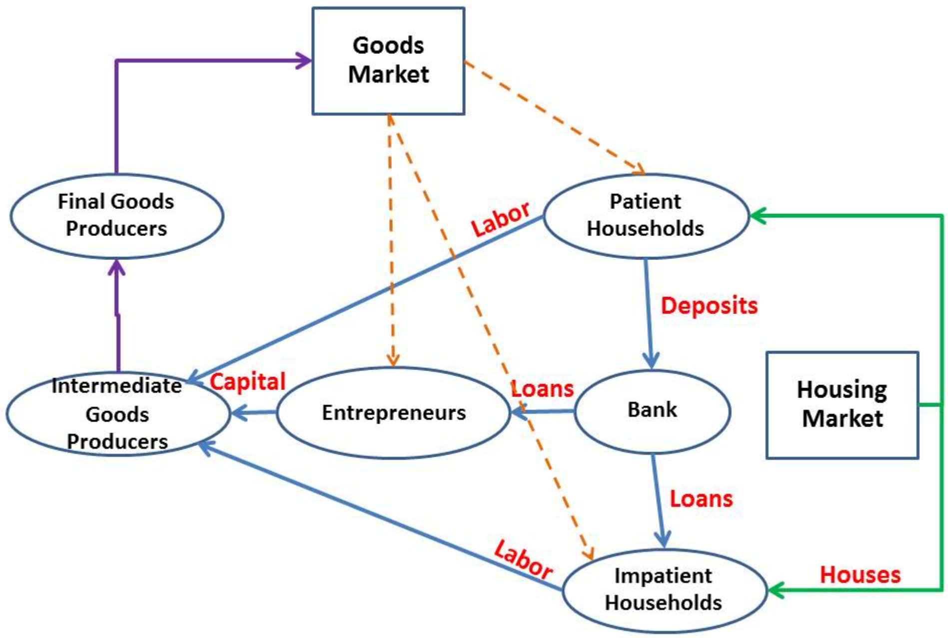
[8]One may suspect that the model is subject to an identification problem, as higher growth of mortgages may result in contemporaneous rise in EBP. This creates an attenuation bias such that we do not observe a significant decline in mortgages immediately after the shock. However, as stated above, changing the order of these variables does not alter the results.

investment, whose fluctuations have a large contribution to the slowdown in the US economy during the Great Recession. Two agents are involved in producing consumption goods: monopolistically-competitive intermediate goods producers and perfectly-competitive final goods producers. As is standard in the literature, the existence of the former is to model price stickiness that gives rise to demand-driven macroeconomic fluctuations. They hire households labor and rent entrepreneurial capital to produce heterogeneous intermediate goods and set their prices subject to Calvo (1983) lottery. Final goods producers, on the other hand, combine intermediate goods into homogenous consumption goods. As in Christiano et al. (2005) and Smets and Wouters (2007), the economy features several real frictions, which are crucial in generating persistent responses of the economy in the face of shocks. Figure 3 summarises the structure of the economy.

The crucial new feature of the model is the possibility of endogenous default on mortgages. In particular, impatient households can choose to default on their loan obligation and have their collateral foreclosed by banks. In Gerali et al. (2010) and Iacoviello (2005), a pledge of collateral rules out any default possibility. In particular, the exogenously-assumed loan-to-value (LTV) constraint ensures that the value of the houses, which can be affected by economy-wide shocks, is always larger than outstanding debt. Lenders therefore anticipate full repayment at all circumstances. This is, however, inconsistent with evidence during the Great Recession where problems in the mortgage market, particularly the increase in default, are claimed to be a major source of shocks. In this model, triggered by idiosyncratic shocks to the value of the houses owned by individual household members, mortgage default occurs and generates losses to the banking sector. Unlike the two articles cited above, the LTV ratio results from the optimisation problems of borrowers and lenders and will matter for future mortgage default probability. Banks charge premium on mortgage interest rates to compensate for any anticipated net-of-collateral losses. In the extended model introduced in section 5, we impose an exogenous LTV constraint on mortgage borrowing in order to study the effects of macroprudential regulation. Business loans, on the other hand, are always subject to an exogenous borrowing constraint such that their default possibility is zero.[9]

[9]In this paper, banks are assumed to be perfectly competitive. In Gerali et al. (2010), they are monopolistically competitive and subject to interest rate adjustment costs. These assumptions allow the authors to assess differential responses of various interest rates to monetary policy shocks, which is not the focus of this paper.

Figure 3: The Structure of the Economy



4.1 Patient Households

There is a continuum of patient households of measure one. They supply labor, consume, accumulate housing, while saving the rest of their income with banks in order to smooth consumption. They also own banks and intermediate goods firms which return them dividends and profits, respectively. A lifetime utility function of the representative patient household i is given by:

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1 - a_P) \ln \left(c_t^P (i) - a_P c_{t-1}^P \right) + j \ln h_t^P (i) - \frac{\left(l_t^{P,s} (i) \right)^{\eta}}{\eta} \right]$$

where, β_P denotes the discount rate, c_t^P is non-durable goods consumption, h_t^P is housing accumulated, j measures the housing weight in the utility function, $l_t^{P,s}$ is the amount of labor supplied, and η represents a labor disutility parameter. We assume that both types of households face an external and group-specific habit formation in consumption, where $a_H :\ H \in \{P, I\}$ measures the degree of habit formation. The representative patient household maximises its objective function above given the budget constraint:

$$\begin{aligned} & c_t^P(i) + q_t^h \triangle h_t^P(i) + d_t^P(i) + \phi_h \left(\tfrac{h_t^P(i) - h_{t-1}^P(i)}{h_{t-1}^P(i)} \right)^2 \tfrac{q_t^h h_{t-1}^P(i)}{2} \\ & = \tfrac{r_{t-1} d_{t-1}^P(i)}{\pi_t} + w_t^P l_t^{P,s}(i) + div_t(i) + F_t(i) + t_t^P(i) \end{aligned} \quad . \tag{1}$$

The household deposits its savings d_t^P with banks, who promise to pay interests at the nominal interest rate r_t. It therefore receives deposits repayment in real term equivalent to $\frac{r_t d_t^P}{\pi_{t+1}}$. $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate, where P_t is the price of consumption goods. q_t^h and w_t^P denote real house price and real labor wage, respectively. div_t are dividends from banks, while F_t are profits from intermediate goods producers. As in Iacoviello (2005), both types of households face a pecuniary cost whenever they adjust their housing demand. ϕ_h represents a housing adjustment cost parameter. Since we do not model the house production sector or introduce other frictions associated with housing, we will show that this friction is sufficient in generating significant real economic impacts from shocks originating within the housing market. t_t^P is the income from monitoring activities that shall be explained later.

Each patient household optimally chooses c_t^P, h_t^P, d_t^P and $l_t^{P,s}$. Assuming a symmetric equilibrium, we obtain the following first order conditions (λ_t^P is the Lagrange multiplier with respect to the budget constraint):

$$\lambda_t^P = \frac{1 - a_P}{c_t^P - a_P c_{t-1}^P} \tag{2}$$

$$\lambda_t^P = \beta_P E_t \left[\frac{r_t}{\pi_{t+1}} \lambda_{t+1}^P \right] \tag{3}$$

$$\begin{aligned} & q_t^h \lambda_t^P \left(1 + \phi_h \left(\tfrac{h_t^P - h_{t-1}^P}{h_{t-1}^P} \right) \right) \\ & = \tfrac{j}{h_t^P} + \beta_P E_t \left[q_{t+1}^h \lambda_{t+1}^P \left(1 + \tfrac{\phi_h}{2} \left(\tfrac{h_{t+1}^P - h_t^P}{h_t^P} \right) \left(\tfrac{h_{t+1}^P + h_t^P}{h_t^P} \right) \right) \right] \end{aligned} \tag{4}$$

$$w_t^P \lambda_t^P = \left(l_t^{P,s} \right)^{\eta - 1} \quad . \tag{5}$$

Equation (2)-(5) are the shadow price of wealth, the Euler equation for consumption, housing demand equation and labor supply equation, respectively. From equation (4), neglecting the adjustment costs, housing accumulation yields two distinct benefits to the households: utility from housing services in period t and additional wealth from reselling it in period $t+1$.

4.2 Impatient Households

There is a continuum of impatient households of measure one. Like their patient counterparts, they supply labor, consume and accumulate housing. However, having higher discount rate, i.e. $\beta_I < \beta_P$, they have incentive to borrow to spend. Houses serve as collateral in acquiring loans from banks. The representative impatient household i maximises a lifetime utility function given by:

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \left[(1 - a_I) \ln \left(c_t^I (i) - a_I c_{t-1}^I \right) + j \ln h_t^I (i) - \frac{\left(l_t^{I,s} (i) \right)^\eta}{\eta} \right]$$

subject to the following budget constraint:

$$\begin{gathered} c_t^I (i) + q_t^h h_t^I (i) + (1 - F_t (\bar{\omega}_t (i))) \frac{r_{t-1}^I b_{t-1}^I (i)}{\pi_t} + \phi_h \left(\frac{h_t^I (i) - h_{t-1}^I (i)}{h_{t-1}^I (i)} \right)^2 \frac{q_t^h h_{t-1}^I (i)}{2} \\ = b_t^I (i) + w_t^I l_t^{I,s} (i) + (1 - G_t (\bar{\omega}_t (i))) q_t^h h_{t-1}^I (i) \end{gathered} . \quad (6)$$

The definition of each variable parallels with the case of patient households. $F_t (\bar{\omega}_t)$ denotes the probability of mortgage default, while $G_t (\bar{\omega}_t)$ measures the proportion of houses seized by banks in case of mortgage default. To model mortgage default, we follow the approach of Forlati and Lambertini (2011). Each impatient household consists of a continuum of members j. Of the total housing demand $h_t^I (i)$, it allocates houses equally to each member $h_t^I (i, j)$, where $\int h_t^I (i, j) \, dj = h_t^I (i)$. It also orders each member to be liable for repaying equal amount of loans $b_t^I (i, j)$, where $\int b_t^I (i, j) \, dj = b_t^I (i)$. $b_t^I (i)$ hence denotes total mortgages obtained from banks. Each mortgage contract faces the same mortgage interest rate r_t^I, and so the amount of $r_t^I b_t^I (i, j)$ has to be repaid next period by each member. The total amount of debts owed to the banks (in nominal term) is therefore $r_t^I b_t^I (i)$. We can compute the LTV ratio at the household level as follows,

$$m_t^I (i) = E_t \left[\frac{r_t^I b_t^I (i)}{q_{t+1}^h h_t^I (i) \pi_{t+1}} \right] . \quad (7)$$

Ex post (i.e. in the following period), we assume that there is an idiosyncratic housing risk such that the housing value for each household member becomes $\omega_{t+1} (i, j) \, q_{t+1}^h h_t^I (i, j)$. $\omega_{t+1} (i, j)$ represents an idiosyncratic shock, which is independently and identically distributed across members, justifying a homogenous mortgage interest rate. We also assume that $E_t (\omega_{t+1} (i, j)) = 1$ so that $E_t \left(\omega_{t+1} (i, j) \, q_{t+1}^h h_t^I (i, j) \right) = q_{t+1}^h h_t^I (i)$. This assumption implies that such idiosyncratic risk does not have consequences on the aggregate housing value and keeps the model tractable. In practice, the shock may capture the risk associated with housing investment. Alternatively, Quint and Rabanal (2014) view ω as housing quality shock.

Given the realised value of $\omega_{t+1}(i,j)$, for each mortgage contract, the household member has choices of whether (1) to conform to loan obligation by fully repaying debts or (2) to default and face seizure of the houses. Rational household members will tend to default on mortgages with low realisation of $\omega_{t+1}(i,j)$ since the houses yield low resale value, making paying back debt a more expensive option. Therefore, at the household level, mortgage default decision amounts to choosing the cut-off point $\bar{\omega}_{t+1}(i)$, such that its members default on the contracts with $\omega_{t+1}(i,j)$ lower than $\bar{\omega}_{t+1}(i)$. Denoted with $f(\omega)$ the density function of ω. We can compute the cumulative distribution function of $\bar{\omega}$, $F(\bar{\omega})$, and the expected value of ω conditional on $\omega < \bar{\omega}$, $G(\bar{\omega})$, as follow:

$$F(\bar{\omega}) = \int_0^{\bar{\omega}} f(\omega)\, d\omega \tag{8}$$

$$G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)\, d\omega\,. \tag{9}$$

Given the formulae above, each impatient household defaults by the total amount of $\int_0^{\bar{\omega}_t(i)} \frac{r^I_{t-1} b^I_{t-1}(i,j)}{\pi_t} f_t(\omega_t(i,j))\, d\omega = F_t(\bar{\omega}_t(i)) \frac{r^I_{t-1} b^I_{t-1}(i)}{\pi_t}$ in real term. The total value of the houses seized by banks is equal to $\int_0^{\bar{\omega}_t(i)} \omega_t(i,j)\, q^h_t h^I_{t-1}(i,j)\, f_t(\omega_t(i,j))\, d\omega = G_t(\bar{\omega}_t(i))\, q^h_t h^I_{t-1}(i)$. These two terms appear in the above budget constraint.

Denote with λ^I_t the Lagrange multiplier of the budget constraint. Each impatient household chooses c^I_t, h^I_t, b^I_t, $l^{I,s}_t$ and $\bar{\omega}_t$, which yields the following first order conditions, given a symmetric equilibrium:

$$\lambda^I_t = \frac{1 - a_I}{c^I_t - a_I c^I_{t-1}} \tag{10}$$

$$\lambda^I_t = \beta_I E_t \left[\left(1 - F_{t+1}(\bar{\omega}_{t+1}) + \frac{G_{t+1}(\bar{\omega}_{t+1})}{m^I_t} \right) \frac{r^I_t}{\pi_{t+1}} \lambda^I_{t+1} \right] \tag{11}$$

$$\begin{aligned} & q^h_t \lambda^I_t \left(1 + \phi_h \left(\tfrac{h^I_t - h^I_{t-1}}{h^I_{t-1}} \right) \right) \\ = & \tfrac{j}{h^I_t} + \beta_I E_t \left[q^h_{t+1} \lambda^I_{t+1} \left(1 + \tfrac{\phi_h}{2} \left(\tfrac{h^I_{t+1} - h^I_t}{h^I_t} \right) \left(\tfrac{h^I_{t+1} + h^I_t}{h^I_t} \right) \right) \right] \end{aligned} \tag{12}$$

$$w^I_t \lambda^I_t = \left(l^{I,s}_t \right)^{\eta - 1} \tag{13}$$

$$\frac{b^I_{t-1} r^I_{t-1}}{\pi_t} = \bar{\omega}_t q^h_t h^I_{t-1}\,. \tag{14}$$

Equations (10)-(13) are the shadow value of wealth, the Euler equation for consumption, housing demand equation and labor supply equation, respectively. With mortgage default, the Euler equation becomes nonstandard. The effective repayment rate takes into account the possibility that the households decide not to fully repay their debts and face asset foreclosure. Equation (14), namely the on-the-verge condition, shows the first order condition with respect to the mortgage default decision. It suggests that the household defaults on the mortgage contracts where the ex-post housing value falls below real debt outstanding. This condition is exogenously imposed in most articles featuring mortgage default, whereas our paper derives it endogenously from the households optimisation problem. As mentioned in section 2, Campbell and Cocco (2015) find that mortgage borrowers do not default immediately as the house value plunges below debts, but their default decision also depends on the tightness of the borrowing constraint. Therefore, we believe it is theoretically consistent to derive such a condition from agent optimisation, rather than assuming it in an ad hoc manner.

Mortgage Default Probability

As in BGG and Forlati and Lambertini (2011), we assume the distribution of an idiosyncratic housing shock to be log-normal: $\log(\omega_t) \sim N(\mu_{\omega,t}, \sigma^2_{\omega,t})$. In addition, $E_t[\omega_{t+1}(i)] = 1$ requires that $\mu_{\omega,t} = -\frac{\sigma^2_{\omega,t}}{2}$. To model a trigger for an increase in mortgage default, we assume that the variance of an idiosyncratic housing shock is time-varying and follows an autoregressive process subject to random shocks:

$$ln(\sigma_{\omega,t}) = \rho_\omega ln(\sigma_{\omega,t-1}) + (1-\rho_\omega)\, ln(\sigma_\omega) + \varepsilon_{\omega,t} \tag{15}$$

where $\varepsilon_\omega \sim N(0, \vartheta_\omega)$.

We can then deduce factors determining the "default probability" of mortgages from the cumulative distribution function $F_t(\bar{\omega}_t)$ and the "on-the-verge" condition:

$$\bar{\omega}_t = \frac{b^I_{t-1} r^I_{t-1}}{q^h_t h^I_{t-1} \pi_t} \frac{E_{t-1}\left[q^h_t \pi_t\right]}{E_{t-1}\left[q^h_t \pi_t\right]} = m^I_{t-1} \frac{E_{t-1}\left[q^h_t \pi_t\right]}{q^h_t \pi_t}\,.$$

In the benchmark model, the probability of default is driven by three factors, the variance of an idiosyncratic housing shock, the LTV ratio and a deviation of nominal house price from expectation. From equation (8), and assuming $\mu_{\omega,t} = -\frac{\sigma^2_{\omega,t}}{2}$, we can show that the default probability increases with the housing shock variance

$(\sigma^2_{\omega,t})$ and the cut-off level $(\bar{\omega}_t)$.[10] The on-the-verge condition (14) suggests that the cut-off level rises with the LTV ratio, but declines whenever nominal house prices unexpectedly rise. Consequently, the default probability increases when the LTV ratio is higher or when unexpected shocks drive nominal house prices down. It is to note that default in this paper arises from strategic considerations as well as from that due to "ill-fortune". It is caused by ill fortune in the sense that adverse shocks cause a deterioration in the house value, thus increasing the incentive to default. It also arises strategically due to an implicit assumption that the mortgage contract is non-recourse. Certainly, impatient household members could rely on other sources of income to repay debts, but this possibility is ruled out in this framework, without loss of generality.

4.3 Entrepreneurs

Similarly, there is a continuum of entrepreneurs of measure one. They possess the economy's physical capital and rent it to intermediate goods producers. Given that $\beta_E < \beta_P$, they also have an incentive to borrow from banks. Using loans and rental income, they make consumption-investment decisions. Collateral is required to acquire business loans (b^E_t), such that there exists a borrowing limit based upon the expected undepreciated capital value:

$$r^E_t b^E_t \leq m^E E_t \left[(1-\delta) q^k_{t+1} k_t \pi_{t+1}\right] \tag{16}$$

where, r^E_t is business loan interest rate, m^E is an exogenous cap on the LTV ratio set by financial regulators, and k_t is capital demanded which will be available for rent next period. δ measures the depreciation rate of capital, while q^k_t denotes real capital price. The representative entrepreneur maximises a lifetime utility function given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t_E \left[(1-a_E)\, ln\left(c^E_t(i) - a_E c^E_{t-1}\right)\right]$$

subject to the above borrowing constraint and the following flow of fund constraint:

$$\begin{array}{c} c^E_t(i) + \frac{r^E_{t-1} b^E_{t-1}(i)}{\pi_t} + q^k_t \left(k_t(i) - (1-\delta) k_{t-1}(i)\right) + \Psi(u_t) k_{t-1}(i) \\ = r^k_t u_t(i) k_{t-1}(i) + b^E_t(i) \end{array} . \tag{17}$$

[10] $F(\bar{\omega}_t) = \int_0^{\bar{\omega}_t} f_t(\omega_t)\, d\omega = \frac{1}{2} + \frac{1}{2} erf\left[\frac{\ln(\bar{\omega}_t) - \mu_{\omega,t}}{\sqrt{2}\sigma_{\omega,t}}\right] = \Phi\left(\frac{\ln(\bar{\omega}_t) - \mu_{\omega,t}}{\sigma_{\omega,t}}\right)$, where Φ represents cumulative distribution function of the standard normal distribution.

In each period, each entrepreneur chooses the utilisation rate of capital (u_t), i.e. the proportion of owned capital to be rented to production firms. There exists a cost of capital utilisation $\Psi(u_t) = \varepsilon_{k,1}(u_t - 1) + \frac{\varepsilon_{k,2}}{2}(u_t - 1)^2$.

The entrepreneur chooses c_t^E, b_t^E, k_t and u_t to maximise its objective function. Assuming a symmetric equilibrium, we obtain the following first order conditions (λ_t^E and ξ_t^E are the Lagrange multiplier with respect to the budget constraint and the tightness of the borrowing constraint, respectively):

$$\lambda_t^E = \frac{1 - a_E}{c_t^E - a_E c_{t-1}^E} \tag{18}$$

$$\lambda_t^E = \beta_E E_t \left[\frac{r_t^E}{\pi_{t+1}} \lambda_{t+1}^E \right] + \xi_t^E r_t^E \tag{19}$$

$$\lambda_t^E q_t^k = \begin{array}{c} \beta_E E_t \left[\lambda_{t+1}^E \left(r_{t+1}^k u_{t+1} + (1-\delta) q_{t+1}^k - \Psi(u_{t+1}) \right) \right] \\ + \xi_t^E m^E E_t \left[(1-\delta) q_{t+1}^k \pi_{t+1} \right] \end{array} \tag{20}$$

$$r_t^k = \Psi'(u_t) = \varepsilon_{k,1} + \varepsilon_{k,2}(u_t - 1)\ . \tag{21}$$

Equations (18)-(21) are the shadow value of wealth, the Euler equation for consumption, capital demand equation and capital utilisation equation, respectively.

4.4 Capital Producers

The existence of capital producers is to model asset prices that matter for the tightness of the entrepreneurs borrowing constraint as well as the cost of capital investment. Perfectly-competitive capital producers purchase undepreciated capital $(1-\delta)k_{t-1}$ at the price q_t^k from entrepreneurs and consumption goods i_t from final goods producers. They combine both components into new capital k_t, using the production function:

$$k_t = (1-\delta)k_{t-1} + i_t \left(1 - \frac{k_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right)\ . \tag{22}$$

The production of capital goods is subject to investment adjustment costs, where k_i represents a cost parameter. They sell new capital back to entrepreneurs at the price q_t^k.

Capital producers maximise their lifetime utility function $E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^E \left[q_t^k (k_t - (1-\delta)k_{t-1}) - i_t \right]$ with the stochastic discount factor $\Lambda_{t,k}^E = \beta_E^k \left(\frac{\lambda_{t+k}^E}{\lambda_t^E} \right)$, subject to the above production function. This yields the following capital price equation:

$$1 = \begin{array}{c} q_t^k\left(1-\frac{k_i}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2-k_i\left(\frac{i_t}{i_{t-1}}-1\right)\frac{i_t}{i_{t-1}}\right) \\ +\beta_E E_t\left[\frac{\lambda_{t+1}^E}{\lambda_t^E}q_{t+1}^k k_i\left(\frac{i_{t+1}}{i_t}-1\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right] \end{array}. \tag{23}$$

4.5 Commercial Banks

Perfectly-competitive risk-neutral commercial banks channel funds from savers to two borrowers: impatient households and entrepreneurs. They use deposits obtained from patient households in conjunction with retained earnings (e_t^B) to fund lending activities. Loan origination is subject to capital adequacy regulations, as financial regulators specify capital adequacy ratio ($\bar{k}$) to which banks have to conform. Bank capital adequacy ratio (k_t^B) is measured as the ratio of the bank equity capital to risk-weighted assets (rwa_t):

$$k_t^B = \frac{e_t^B}{rwa_t} \tag{24}$$

where,

$$rwa_t = rw_t^I b_t^I + rw^E b_t^E\,. \tag{25}$$

rw_t^I and rw^E are the risk weight on mortgages and business loans, respectively. We assume the latter to be time-invariant given that the borrowing constraint has already ruled out default possibility for business loans. Meanwhile, consistent with the Basel Accord, risk weights on mortgages are an increasing function of the default probability:

$$rw_t^I = rw^I + \Upsilon E_t\left[F_{t+1}\left(\bar{\omega}_{t+1}\right) - F\left(\bar{\omega}\right)\right] \tag{26}$$

where, Υ measures the sensitivity of risk weights to the expected probability of mortgage default, rw^I denotes the steady-state risk weight on mortgages, and $F\left(\bar{\omega}\right)$ is the steady-state mortgage default frequency. In each period, banks receive net-of-default gross profits:

$$\Pi_t^B = \left(1-F_t\left(\bar{\omega}_t\right)\right)\frac{r_{t-1}^I b_{t-1}^I}{\pi_t} + \left(1-\Theta\right)G_t\left(\bar{\omega}_t\right)q_t^h h_{t-1}^I + \frac{r_{t-1}^E b_{t-1}^E}{\pi_t} - \frac{r_{t-1}d_{t-1}^P}{\pi_t}\,. \tag{27}$$

For those mortgage contracts that impatient household members decide to default, we assume that banks have to bear an additional cost proportional to the value of the houses seized from impatient households, $\Theta G_t\left(\bar{\omega}_t\right) q_t^h h_{t-1}^I$. Such a cost may represent cost of state verification, asset liquidation (or fire-sale) cost, or even legal and accounting costs. In this paper, we follow BGG and assume that asymmetric information requires banks to pay monitoring (or state-verification) costs to observe the true value of the houses.[11] Banks allocate part of their profits as dividends (div_t) to their shareholders, the patient households, and retain the rest as retained earnings. After dividend payments, their equity capital is given by:

$$e_t^B = (1-\delta_B)\frac{e_{t-1}^B}{\pi_t} + (1-\gamma_B)\left(\Pi_t^B - \frac{e_{t-1}^B}{\pi_t}\right) \tag{28}$$

where, δ_B and γ_B are dividend payout parameters. Bank dividends thus equal $\delta_B\frac{e_{t-1}^B}{\pi_t} + \gamma_B\left(\Pi_t^B - \frac{e_{t-1}^B}{\pi_t}\right)$.

Each bank maximises its objective function:

$$E_0\sum_{t=0}^{\infty}\Lambda_{0,t}^P\left[\Pi_t^B + \phi_t^k\left(\frac{\left(\frac{k_t^B}{k}\right)^{1-\sigma_B}-1}{1-\sigma_B}\right)\right]$$

subject to the balance sheet constraint:

$$b_t^I + b_t^E \quad = d_t^P + e_t^B \tag{29}$$

where, $\Lambda_{t,k}^P = \beta_P^k\left(\frac{\lambda_{t+k}^P}{\lambda_t^P}\right)$ is the relevant stochastic discount factor. Capital adequacy regulations are modelled as non-pecuniary cost (gain) in terms of utility, whenever the capital adequacy ratio is lower (higher) than capital requirements.[12] It is important to note that the functional form of the penalty above implies increasing marginal cost of failure to comply with the regulations and diminishing marginal benefits from satisfying the regulatory requirements. This non-linearity is crucial to why downside deviations from the requirements can create a significant credit supply contraction. $\sigma_B > 1$ and ϕ_t^k denote capital regulation penalty parameters. The former captures this non-linearity feature, while the latter measures the weight of such penalty in the utility function, which is assumed to be time-varying. We obtain the following first

[11] This mechanism also obliges impatient household members to truthfully reveal their identity.

[12] Gerali et al. (2010) model capital regulations as pecuniary costs to deviations of the capital ratio from the regulatory required level. So, banks are penalised whenever their capital ratio deviates from the target. With such a functional form, there is possibility that loan interest rates fall below the deposit interest rate when the capital ratio is sufficiently high. Such possibility is even more likely in the perfectly-competitive banking sector.

order conditions (λ_t^B represents the Lagrange multiplier with respect to the balance sheet constraint):

$$\lambda_t^B = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t}{\pi_{t+1}} \right] \tag{30}$$

$$\begin{aligned} & \lambda_t^B + \phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \left(\frac{rw_t^I}{rwa_t} \right) \\ = \beta_P E_t & \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \left(1 - F_{t+1}\left(\bar{\omega}_{t+1} \right) + (1-\Theta) \frac{G_{t+1}(\bar{\omega}_{t+1})}{m_t^I} \right) \frac{r_t^I}{\pi_{t+1}} \right] \end{aligned} \tag{31}$$

$$\lambda_t^B + \phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \left(\frac{rw^E}{rwa_t} \right) = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t^E}{\pi_{t+1}} \right]. \tag{32}$$

Equations (30) to (32) describe the first order conditions with respect to deposits, mortgages and business loans, respectively.

Interest Rate Spreads

Interest rate spreads are an important indicator of the loans supply conditions as they directly affect borrowers cost of consumption and investment. We can combine the first order conditions (30)-(32) above to study factors affecting spreads between loan and deposit interest rate:

$$\phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \frac{rw_t^I}{rwa_t} = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{\left(1 - F_{t+1}\left(\bar{\omega}_{t+1} \right) + (1-\Theta) \frac{G_{t+1}(\bar{\omega}_{t+1})}{m_t^I} \right) r_t^I - r_t}{\pi_{t+1}} \right]$$

$$\phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \frac{rw^E}{rwa_t} = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t^E - r_t}{\pi_{t+1}} \right].$$

The first equation show, on the one hand, how banks price into the mortgage interest rate any anticipated losses from mortgage default, which include (1) the amount of unrepaid loans less the value of the seized collateral and (2) the additional default cost from state verification. Capital adequacy regulation, on the other hand, affects both credit spreads, as it makes loan origination costly. When banks extend additional loans, their capital ratio declines. Consequently, this depresses their utility and induces them to raise spreads to reap more profits in return. The size of spreads depends critically on: first, the size of a deviation of the capital adequacy ratio from the regulatory required level, second, the risk weight on loans, and third, the weight of capital regulation penalty in the utility function. First, given non-linear penalties, banks are penalised more from loan origination whenever the capital ratio is low. Banks thus demand a higher compensation. The sensitivity of the spreads to the capital ratio depends on the size of σ_B. Second, a higher risk weight leads to a larger increase in the risk-weighted assets and a greater decrease in bank capital ratio from making loans. Banks therefore widen interest rate spreads to a larger extent to compensate for the resulting utility loss. In this paper, we put emphasis on the last factor, namely stochastic variations of the parameter ϕ_t^k, as another source of shocks that explain widening credit spreads during the Great Recession. We assume it to follow an autoregressive process:

$$\ln(\phi_t^k) = \rho_k \ln(\phi_{t-1}^k) + (1 - \rho_k) \ln(\phi^k) + \varepsilon_{k,t} \tag{33}$$

where, $\varepsilon_k \sim N(0, \sigma_k^2)$. A rise in ϕ_t^k implies greater importance of capital regulation penalty in the bank utility function, making loan origination more costly, thus resulting in a surge in interest rate spreads. The time-varying property of such parameter could reflect changes in the strictness of financial regulators in enforcing the regulation or changes in the market perception towards it. Alternatively, we exploit this parameter to reflect exogenous variations in lenders risk-bearing capacity, which matters for credit supply conditions. Gilchrist and Zakrajšek (2012) show that excess bond premium, a component of corporate bond spreads unexplained by default risk, rose considerably during the crisis. The authors attribute such a rise to a reduction in financial intermediaries risk-bearing capacity. We also believe that the crisis greatly impaired individual banks balance sheet and reduced their risk tolerance. This led them to tighten their lending standards to an extent that is difficult to be explained with increased default risk and their capitalisation condition only.

4.6 Final Good Producers

Perfectly-competitive final goods producers combine intermediate goods into homogenous final consumption goods using the production function:

$$Y_t = \left(\int_0^1 Y_t^{\frac{\varepsilon-1}{\varepsilon}} (j)\, dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

where, ε measures the elasticity of substitution. They purchase intermediate goods $Y_t(j)$ from intermediate goods firm j at price $P_t(j)$ and sell final products at price P_t. They maximise profits $P_t Y_t - \int_0^1 Y_t(j) P_t(j)\, dj$ subject to the production function above, taking both prices as given. The input demand function derived from this optimisation problem is:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon} Y_t \ \forall j$$

where, the price index $P_t = \left(\int_0^1 P_t^{1-\varepsilon}(j)\, dj\right)^{\frac{1}{1-\varepsilon}}$.

4.7 Intermediate Good Producers

There is a continuum of monopolistically-competitive intermediate goods producers. Each producer j possesses the following technology $Y_t(j) = A_t(k_{t-1}(j))^{\mu}\left(l_t^{P,d}(j)\right)^{\alpha(1-\mu)}\left(l_t^{I,d}(j)\right)^{(1-\alpha)(1-\mu)}$ where, A_t is the productivity level and is assumed to follow an autoregressive process: $\ln A_t = \rho_A \ln A_{t-1} + (1-\rho_A)\ln A + \varepsilon_A$, μ denotes the share of capital income, and α denotes the share of labor income paid to patient households. The producers rent physical capital $k_{t-1}(j)$ from entrepreneurs, while hiring labor $l_t^{P,d}(j)$ and $l_t^{I,d}(j)$, to produce intermediate goods $Y_t(j)$. They then sell those intermediate goods to final goods firms.

Given their monopolistic power, intermediate goods producers set the product price $P_t(j)$ with markup over nominal marginal cost $MC_t(j)$ of producing one unit of goods. To obtain an expression for the marginal cost, each firm rents $l_t^{P,d}(j)$, $l_t^{I,d}(j)$ and $k_{t-1}(j)$ in the perfectly-competitive factor markets in order to minimise real marginal cost $mc_t(j) = \frac{MC_t(j)}{P_t}$:

$$r_t^k k_{t-1}(j) + w_t^P l_t^{P,d}(j) + w_t^I l_t^{I,d}(j)$$

subject to the production function above. Therefore, we obtain the following first order conditions:

$$w_t^P = \frac{(1-\mu)\alpha}{\mu}\frac{r_t^k k_{t-1}(j)}{l_t^{P,d}(j)} \tag{34}$$

$$w_t^I = \frac{(1-\mu)(1-\alpha)}{\mu}\frac{r_t^k k_{t-1}(j)}{l_t^{I,d}(j)}. \tag{35}$$

We can then compute real marginal cost as follow:

$$mc_t(j) = mc_t = \frac{\left(r_t^k\right)^{\mu}\left(w_t^P\right)^{(1-\mu)\alpha}\left(w_t^I\right)^{(1-\mu)(1-\alpha)}}{(\mu)^{\mu}\left((1-\mu)\alpha\right)^{(1-\mu)\alpha}\left((1-\mu)(1-\alpha)\right)^{(1-\mu)(1-\alpha)}}\frac{1}{A_t}. \tag{36}$$

Given an expression for real marginal cost, each producer then chooses intermediate goods price that maximises discounted real lifetime profits. However, in each period, due to Calvo (1983) lottery, only a fraction θ of firms are allowed to reoptimise their prices. Those who have chances to reoptimise will therefore choose the price $P_t^*(j)$, considering the possibility that this price will remain effective in later periods. All other firms keep their price the same as in the previous period. Subject to the demand from final goods producers, the problem of each intermediate goods firm is then to maximise the following objective function:

$$E_t \sum_{k=0}^{\infty} \theta^k \left[\Lambda_{t,k}^P \left(\frac{P_t^*(j)}{P_{t+k}} Y_{t+k}^*(j) - mc_{t+k} Y_{t+k}^*(j) \right) \right]$$

where, $\Lambda_{t,k}^P$ is the relevant stochastic discount factor and $Y_{t+k}^*(j) = \left(\frac{P_t^*(j)}{P_{t+k}} \right) Y_{t+k}$. Assuming a symmetric equilibrium, we obtain the following first order condition:

$$E_t \sum_{k=0}^{\infty} (\beta_P \theta)^k \left[\lambda_{t+k}^P \left((1-\varepsilon) \left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}} \right)^{1-\varepsilon} \frac{P_t^*}{P_t} + \varepsilon \left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}} \right)^{-\varepsilon} mc_{t+k} \right) Y_{t+k} \right] = 0\,. \tag{37}$$

The condition suggests that intermediate goods producers set their product price by considering both present and expected future nominal marginal cost. The producers rebate their profits, $F_t = (1 - mc_t) Y_t$, back to patient households.

We can now express the aggregate price index (P_t) above in terms of optimal prices (P_t^*):

$$1 = \theta \left(\frac{1}{\pi_t} \right)^{1-\varepsilon} + (1-\theta) (\pi_t^*)^{1-\varepsilon} \tag{38}$$

where, $\pi_t^* = \frac{P_t^*}{P_t}$. Log-linearising and combining equations (37) and (38) yield standard New Keynesian Phillips Curve (NKPC).

4.8 Aggregation and Market Clearing Conditions

Aggregate demand is made up from agents consumption, investment, capital utilisation cost, housing adjustment cost and state-verification cost following mortgage default:

$$Y_t = c_t^P + c_t^I + c_t^E + i_t + \Psi(u_t) + \phi_h(.) + (1 - rec)\Theta G_t(\bar{\omega}_t) q_t^h h_{t-1}^I \tag{39}$$

In this paper, we introduce the recovery rate, rec, being the proportion of monitoring cost that is returned as profits to patient households. This may result from the fact that they own companies specialising in monitoring activities. Consequently, we can define $t_t^P = rec\Theta G_t(\bar{\omega}_t) q_t^h h_{t-1}^I$. The treatment of default cost differs among articles featuring mortgage default. Quint and Rabanal (2014) assume that such cost is paid back to patient households as profits from debt-collection agency (rec=1). On the other hand, following BGG, Clerc et al. (2015) assume that the monitoring cost causes deadweight losses to the economy (rec=0).[13] Ferrante (2015) examines both cases. Our paper adopts an intermediate approach by setting $0 < rec < 1$.

Based upon market clearing conditions of the labor and capital markets, (1) $\int_0^1 l_t^{P,d}(j)\,dj = l_t^{P,s} = l_t^P$ (2) $\int_0^1 l_t^{I,d}(j)\,dj = l_t^{I,s} = l_t^I$ and (3) $\int_0^1 k_{t-1}(j)\,dj = u_t k_{t-1}$, and intermediate goods demand function, we can aggregate up the production function of intermediate good firms, which yields the following expression:

$$A_t(u_t k_{t-1})^{\mu} \left(l_t^P\right)^{\alpha(1-\mu)} \left(l_t^I\right)^{(1-\alpha)(1-\mu)} = Y_t \int_0^1 \left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon} dj\,. \tag{40}$$

The supply of houses is assumed to be fixed:

$$h_t^P + h_t^I = H\,. \tag{41}$$

4.9 The Central Bank

The central bank controls the deposit interest rate based on a simple rule, which links the interest rate to deviations of current inflation from the steady state and GDP growth:

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{r_R} \left(\left(\frac{\pi_t}{\pi}\right)^{1+r_\pi} \left(\frac{GDP_t}{GDP_{t-1}}\right)^{r_Y}\right)^{1-r_R} \tag{42}$$

where, r is the steady-state deposit interest rate. r_π and r_Y measure the sensitivity of the policy interest rate to inflation deviations and GDP growth, respectively. Meanwhile, r_R denotes the degree of interest rate stickiness. GDP, or Gross Domestic Product, is defined as the sum of consumption and investment:

$$GDP_t = c_t^P + c_t^I + c_t^E + k_t - (1-\delta)\,k_{t-1}\,. \tag{43}$$

Recall that $k_t - (1-\delta)\,k_{t-1} \neq i_t$ due to the existence of investment adjustment costs. It properly measures effective investment that can be used for production

[13] Forlati and Lambertini (2011) adopt a different approach by assuming that this monitoring cost results in the destruction of the housing stock. However, this results in a rise in housing construction immediately after adverse housing risk shocks that is counterfactual.

next period.

5 Macroprudential Regulations

The benchmark model includes only one banking regulation, namely capital adequacy regulation. The regulation ensures that individual banks accumulate sufficiently large buffers to face unexpected losses. It also has side benefits of putting more skin-in-the-game to prevent excessive risk-taking and over-leveraging. Nevertheless, the Great Recession has proven that microprudential regulation alone, which promotes the soundness of individual financial institutions, is not adequate to cope with systemic risks. Policymakers and academics therefore have greatly supported the use of macroprudential tools to address such risks and to reduce the probability and severity of the financial crisis. In this paper, we focus on three different macroprudential regulations and assess whether they help promote economic stability and welfare in the face of large adverse shocks.

Caps on Loan to Value Ratio

Caps on LTV ratio have been popular in such Asian countries as Singapore, Hong Kong and Korea to prevent house price bubbles and mortgage booms. According to the IMF's Global Macroprudential Policy Instruments (GMPI) database, Jacome and Mitra (2015) suggest that 47 countries imposed limits on LTVs during the year 2000-2013. Cerutti et al. (2015); Claessens et al. (2013); Crowe et al. (2013); Kuttner and Shim (2016) have provided empirical cross-country evidence to support that caps on LTV ratio are effective in mitigating boom in the real estate market and stabilising growth in bank assets and leverage. In this model, we introduce such regulations as a constraint on mortgages demand, as in Iacoviello (2005). In particular, mortgage borrowing cannot exceed the maximum LTV ratio times the value of the collateral provided,

$$r_t^I b_t^I \leq \widetilde{m}^I q_t^h h_t^I \,. \tag{44}$$

We assume that the collateral is valued at current real house prices in contrast with previous articles that often assume valuation at expected future prices. We will show that this assumption allows changes in asset prices to influence the default probability. In addition, our approach is consistent with actual practices. Impatient households now maximise their objective function taking into account both the budget constraint (6) and the borrowing constraint (44). The first order conditions with respect to loans and housing demand become (ξ_t^I is the Lagrange multiplier with respect to the borrowing constraint):

$$\lambda_t^I = \beta_I E_t \left[\left(1 - F_{t+1}\left(\bar{\omega}_{t+1}\right) + \frac{G_{t+1}\left(\bar{\omega}_{t+1}\right) q_{t+1}^h \pi_{t+1}}{\widetilde{m}^I q_t^h} \right) \frac{r_t^I}{\pi_{t+1}} \lambda_{t+1}^I \right] + \xi_t^I r_t^I \tag{45}$$

$$\begin{aligned} & q_t^h \lambda_t^I \left(1 + \phi_h \left(\tfrac{h_t^I - h_{t-1}^I}{h_{t-1}^I}\right)\right) \\ = & \tfrac{j}{h_t^I} + \beta_I E_t \left[q_{t+1}^h \lambda_{t+1}^I \left(1 + \tfrac{\phi_h}{2}\left(\tfrac{h_{t+1}^I - h_t^I}{h_t^I}\right)\left(\tfrac{h_{t+1}^I + h_t^I}{h_t^I}\right)\right)\right] + \xi_t^I \widetilde{m}^I q_t^h \end{aligned} . \tag{46}$$

As is standard in the literature, the LTV constraint disturbs consumption smoothing incentive of the agent, as shown in equation (45). Moreover, from equation (46), the shadow value of housing includes not only utility derived from housing services and gains from reselling houses in the following period but also the benefits from relaxing the borrowing constraint. Introducing LTV regulations has important impacts on mortgage default, since we earlier show that default probability depends on the LTV ratio. From the "on-the-verge" condition, it follows that

$$\bar{\omega}_t = \frac{b_{t-1}^I r_{t-1}^I}{q_t^h h_{t-1}^I \pi_t} \frac{q_{t-1}^h}{q_{t-1}^h} = \widetilde{m}^I \frac{q_{t-1}^h}{q_t^h \pi_t} .$$

Caps on LTV ratio fix the equilibrium LTV ratio as well as the steady-state mortgage default probability. In equilibrium, the probability of default is determined by the variance of an idiosyncratic housing shock and the quarterly growth rate of nominal house prices. Rising nominal house prices from the previous quarter contribute to a lower default frequency. The assumption that assets are evaluated at the current price also affects how banks determine the interest rate spread between mortgages and deposits; i.e.,

$$\phi_t^k \left(\frac{k_t^B}{\bar{k}}\right)^{1-\sigma_B} \left(\frac{rw_t^I}{rwa_t}\right) = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{\left(1 - F_{t+1}\left(\bar{\omega}_{t+1}\right) + (1-\Theta)\frac{G_{t+1}(\bar{\omega}_{t+1}) q_{t+1}^h \pi_{t+1}}{\widetilde{m}^I q_t^h}\right) r_t^I - r_t}{\pi_{t+1}} \right] .$$

Expected changes in asset prices now matter for mortgage loan pricing. If the value of the houses is anticipated to rise, banks will charge a lower mortgage spread, as they can resale foreclosed assets at higher prices.

It is straightforward to prove that the borrowing constraint binds at the steady state. To ensure that the constraint always binds in equilibrium, Iacoviello (2005) assumes that the size of shocks is sufficiently small. However, in this paper, we are interested in large shocks that trigger a significant rise in mortgage default. Therefore, it is possible that, in response to shocks, impatient households demand fewer mortgages than the restricted amount and, therefore, the constraint does not bind. One alternative is to solve the model with occasionally binding constraints. Otherwise, one may introduce LTV caps as an equality constraint. We, nevertheless, proceed by ensuring that the constraint is initially binding with a sufficiently high shadow value of borrowing (ξ^I). Specifically, in the model with LTV caps, we purposely decrease impatient households discount factor (β_I) so that they have greater incentive to borrow. This will result in tighter borrowing constraints at the steady state (higher ξ^I) and they will keep binding in equilibrium despite the economy facing large shocks. Nonetheless, this comes with a drawback. We need to be cautious that the impulse responses from the benchmark model and the model with LTV caps cannot be legitimately compared as β_I differs across these two models. Therefore, for the sake of consistency, when we analyse the effectiveness of this regulation, we rely on the framework with caps on LTV ratio and focus on the effects from imposing more stringent LTV caps (by varying $\widetilde{m}^I$).

Countercyclical Capital Buffers

The Basel III regulatory framework proposes countercyclical capital buffers with the aim to prevent excessive credit growth and risk accumulation during the boom periods. This reduces the probability of crisis in the first place. The buffers also ensure that the banking sector has sufficient capital whenever the crisis occurs. In particular, whenever the ratio of credit to GDP has risen above its trend beyond certain threshold, banks are required to hold additional capital. The opposite does not hold over the period of credit crunch as the credit-to-GDP ratio moves below its trend. However, we take a different approach here by allowing minimum capital adequacy ratio to adjust over the boom-bust cycles. Therefore, we allow this macroprudential regulation to actively serve as a crisis-resolution tool. This ensures that capital regulation, while incentivising banks to hold enough buffers in normal times, does not constrain their lending activity in adverse times, especially when they are in need to deplete such buffers. We assume that the minimum capital adequacy ratio adjusts according to the following formula:

$$\bar{k}_t = \rho_{\bar{k}}\bar{k}_{t-1} + (1-\rho_{\bar{k}})\left[\bar{k} + \Phi_k\left(\frac{b_t^I + b_t^E}{GDP_t} - \frac{b^I + b^E}{GDP}\right)\right]. \tag{47}$$

Capital requirements are adjusted upward (downward) whenever the ratio of credit to GDP is higher (lower) than the steady state value. Φ_k measures the sensitivity of the capital ratio to deviations of the credit-to-GDP ratio from the steady state.

Indeed, from 2016, several countries have already made this regulation operational. More precisely, Hong Kong, Sweden and Norway authorities already require banks to hold additional capital. However, the implementation does not rely on an analytical framework that evaluates its effectiveness. Empirical researchers, meanwhile, have relied on counterfactual analysis and yield inconsistent results. Repullo and Saurina (2011) find that the buffers can even exacerbate procyclicality because the credit-to-GDP ratio tends to be negatively correlated with GDP growth, causing capital requirements to decline in the boom period. On the other hand, Drehmann et al. (2011) and Drehmann and Gambacorta (2012) show that the measure helps dampen credit cycles and support the use of the ratio of credit to GDP as a signaling indicator due to its ability to predict recession.

State-contingent Caps on Loan to Value Ratio

State-contingent LTV caps, though not formally proposed by regulatory institutions, have been introduced in a number of theoretical articles to improve cyclical properties of the economy. Indeed, Jacome and Mitra (2015) point out that around 27 countries have adjusted LTV caps over time to reduce systemic risks and promote the resilience of the financial sector. In this paper, we assume that they vary systematically over the cycle in response to mortgages supply condition, according to the following formula:

$$\hat{m}_t^I = \rho_m \hat{m}_{t-1}^I + (1-\rho_m)\left[\hat{m}^I - \Phi_m\left(\frac{b_t^I}{GDP_t} - \frac{b^I}{GDP}\right)\right]. \qquad (48)$$

LTV caps are adjusted upward (downward) whenever the mortgage-to-GDP ratio is lower (higher) than the steady state value. In the bust period where mortgage extension is constrained, higher LTV limits enable borrowers to obtain more loans given the same collateral value. Consequently, this should allow them to boost consumption and housing accumulation. Φ_m measures the sensitivity of LTV caps to deviations of the mortgage-to-GDP ratio from its steady state.

6 Parameter Calibration

The calibration aims to target the steady state value of some of the model's endogenous variables at certain level consistent with historical US data. We set patient households discount factor at 0.991 to target the steady-state deposit rate at 3.67 percent annually. Following Monacelli (2009), the steady-state LTV ratio is targeted at 70 percent, which in turn determines the steady-state cut-off level of idiosyncratic housing shocks ($\bar{\omega}$). Forlati and Lambertini (2011) suggest that the average US LTV ratio between 1973 and 2008 is 75.7 percentage points. The delinquency rate on single-family residential mortgages during pre-crisis averaged at 2 percent. Therefore, we set the steady-state variance of idiosyncratic housing shocks at 0.167 to ensure the steady-state value of mortgage default probability close to such figure. Monitoring cost (Θ) is set at 16 percent, the intermediate value of the range of 12 and 20 percent calibrated by other articles.[14] We work with a relatively high steady-state annualised mortgage interest rate of 6.80 percent, implying a spread with deposit rate of 3.13 percent. In the data, the spread between 30-year conventional mortgage rate and the Treasury constant maturity rate averaged at 1.59 percent during ten years run up to the crisis. However, we note that the average value of the 30-year conventional mortgage rate itself is almost 8.00 percent during 1990s, while it is close to 6.80 percent in a few years prior to the crisis. The discount rate of impatient households can be implied by equation (11).

[14] Forlati and Lambertini (2011) suggest that the median foreclosure price in California in 2006 was 12 percent lower than the median market price of home sold without having previously been foreclosed. Meanwhile, Ferrante (2015) picks 20 percent in line with the average foreclosure losses.

Table 1: Parameters

	Description	Value		Description	Value
β_P	Patient household's discount rate	0.991	σ^2_ω	Variance of idiosyncratic housing shocks	0.167
β_I	Impatient household's discount rate	0.984	Θ	Cost of state verification	0.160
β_E	Entrepreneur's discount rate	0.980	rec	Recovery rate	0.500
j	Housing weight	0.200	m^E	Business loans LTV caps	0.200
η	Labor supply aversion	2.000	$\bar{k}$	Minimum capital adequacy ratio	0.080
δ	Depreciation rate of capital	0.025	rw^E	Risk weight on business loans	1.000
μ	Share of capital income	0.330	rw^I	Risk weight on mortgages	0.350
α	Patient household's wage share	0.640	Υ	Sensitivity of risk weight	7.473
A	Steady-state productivity level	1.000	ϕ^k	Capital regulation penalty	0.044
$\frac{\varepsilon}{(\varepsilon-1)}$	Mark up in the goods market	1.100	σ_B		6.000
θ	Probability of fixed price	0.750	δ_B	Dividend payout rate	0.135
H	Fixed supply of houses	33.27	γ_B		0.010
ϕ_h	Housing adjustment cost	0.330	a_P	Habit coefficient	0.500
r_R	Taylor-rule coefficient on r_{t-1}	0.800	a_I		
r_Y	Taylor-rule coefficient on GDP_t	0.50/4	a_E		
r_π	Taylor-rule coefficient on π_t	0.500	k_i	Investment adjustment cost	0.200
ρ	persistence of shocks	0.900	$\varepsilon_{k,1}$	Capital utilisation cost	0.0452
			$\varepsilon_{k,2}$		0.0452

We turn to banking parameters. Before the crisis, qualified residential real estate exposures receive a flat risk weight of 35 percent. Under the December-2015 proposed revision by the Basel Committee, risk weight will be determined based upon the exposure's LTV ratio. If the LTV ratio falls within the range of 60-80 percent, risk weight of 35 percent is applied. However, the proposed revision also considers the scenario of non-recourse debt where mortgage repayment is only dependent on cash flows generated by property. Such exposure, which is more relevant in the context of subprime crisis, faces 90-percent risk weight. Despite the non-recourse nature of debt, we however apply a steady-state risk weight of 35 percent with moderate sensitivity to the expected default risk, so as to be consistent with the pre-crisis context. Risk weights for corporate exposure vary with external credit ratings of the counterparty. The values range between 20 and 150 percent. Despite the fact that default on business loans is ruled out in equilibrium, we choose intermediate risk weights of 100 percent, the figure applied to BB+ to BB- companies. Given risk weights, we can compute the steady-state business loan spread equivalent to 4.06 percent. The spread between bank prime loan rate and 1-year Treasury constant maturity rate (or effective federal funds rate) in the data is roughly 3 percent annually. For the initial conditions to be characterised as financial stability, we assume the bank capital ratio to be at the regulatory level at 8 percent. The dividend payment rates (δ_B and γ_B) are calibrated to ensure this. We can now obtain implied steady-state capital regulation penalty weight ϕ^k.

As is standard in the literature, the depreciation rate of capital equals 2.50 percent quarterly. The capital share of income is at 33 percent. The rest of the income is split among the two households; we set α at 0.64, as estimated in Iacoviello (2005). The discount rate of entrepreneurs is set at 0.98. Entrepreneurs face the borrowing constraint, with caps on LTV ratio set at 20 percent. The value is much lower than that calibrated in Gerali et al. (2010) in the case of Euro Area (35 percent). However, it matters for the steady-state proportion of business loans on banks portfolio. As discussed in the introduction, it is crucial to ensure that mortgages constitute the largest proportion of bank assets. Frisch elasticity of labor supply is assumed at 1. Housing weight equals 0.20, implying the steady-state ratio of mortgages to quarterly output at 170 percent. We assume the steady-state markup in the goods market to be 10 percent. Probability of fixed price equals 0.75. The steady-state productivity level is normalised at 1. Fixing real house price at 1, we can obtain the implied (fixed) supply of houses. Real frictions, including habit formation, capital utilisation costs and investment adjustment costs, are necessary to generate persistent responses of the economy to shocks. Rigidities are kept as low as possible to generate persistence. We use a conventional value for the Taylor rule coefficients, with r_R, r_Y and r_π equal 0.80, 0.13 and 0.50, correspondingly. The important rates and ratios at the steady state are summarised in table 2.

We are left with a few more parameters. As σ_B affects the sensitivity of interest rate spreads to the capital adequacy ratio, it will be calibrated to match cyclical property of the data. In particular, in the data, 1-year mortgage spread rose by approximately 4 percentage points annually during the crisis. We set the housing adjustment cost parameter (ϕ_h) at 0.33. Both parameters will be shown to have important impacts on the dynamics of the economy with respect to adverse housing risk shocks.

7 Model Properties

This section presents simulation results from the benchmark model. The model is log-linearised around the steady state. We firstly examine responses with respect to standard macroeconomic shocks to see whether the model, after including endogenous mortgage default, still produces reasonable results. To capture key aspects of

Table 2: Important Rates and Ratios at the Steady State

	Description	Value
$F(\omega)$	Mortgage default probability	2.007 %
m^I	Loan-to-value ratio	70.00 %
r	Deposit interest rate (p.a.)	3.673 %
r^I	Mortgage interest rate (p.a.)	6.800 %
r^E	Business loan interest rate (p.a.)	7.736 %
$\frac{b^I}{b^I+b^E}$	Proportion of mortgages	57.26 %
$\frac{b^I}{Y}$	Mortgages to output	170.1 %
$\frac{b^E}{Y}$	Business loans to output	127.0 %
$\frac{c^P}{Y}$	Patient household consumption to output	52.96 %
$\frac{c^I}{Y}$	Impatient household consumption to output	19.24 %
$\frac{c^E}{Y}$	Entrepreneur consumption to output	10.95 %
$\frac{i}{Y}$	Investment to output	16.59 %
$\frac{\Theta G(\omega) q^h h^I}{Y}$	Monitoring cost to output	0.523 %
$\frac{q^h h^P}{Y}$	Patient household's housing demand to output	1164 %
$\frac{q^h h^I}{Y}$	Impatient household's housing demand to output	247.1%
k^B	Bank capital ratio	8.000 %

the Great Recession, we then introduce two shocks originating from the financial market, namely shocks to the variance of an idiosyncratic housing shock (in short, housing risk shock) and shocks to the capital regulation penalty (in short, risk premium shock). These shocks explain the unusual surge in mortgage default and credit spreads that is observed in the US data. We explore the responses of the economy to large adverse shocks, emphasising the role of the banking sector friction in the shock propagation. In the next section, we examine whether the implementation of the three macroprudential tools improves economic stability and welfare of the agents.

7.1 Responses to Standard Macroeconomic Shocks

We begin by exploring whether the benchmark model possesses good properties in terms of identifying the effects of standard macroeconomic shocks. In particular, we focus on three shocks, explored in Gerali et al. (2010), namely monetary policy, productivity and bank capital shocks. The latter is introduced as one-off losses to bank profits. We also assess how mortgage default and bank capitalisation evolve in response to these shocks. The impulse responses are shown in figure 4.

With nominal rigidities, a contractionary monetary policy shock exerts a negative effect on real economic activities and prices. An increase in borrowing costs causes all components of GDP to suffer a persistent drop. Both mortgages and business loans fall. The dynamics of mortgage default can be important to the economy's dynamics. Contemporaneously, a fall in both house prices and consumption good prices triggers more mortgage defaults. Default remains persistently higher than the steady state over the horizon considered as the LTV ratio has increased. Despite less mortgage origination, an increase in the LTV ratio can be explained by the fact that nominal house prices plunge while mortgage interest rates pick up. Anticipated increases in default widen mortgage spread, which in turn adversely affects demand from impatient households, thereby generating a financial accelerator. Meanwhile, the banking sector's capital deteriorates, prompting banks to raise both loan spreads. As in the literature, real house prices fall and gradually return to the steady state. The calibrated size of the policy tightening results in an increase in annualised deposit interest rate of 50 basis points, precipitating 0.81-percent contemporaneous decline in GDP.

A one-percent positive productivity shock generates hump-shaped responses of GDP and household consumption. Inflation falls as marginal cost of producing goods is reduced, prompting the central bank to lower its policy interest rate. However, the model fails to predict immediate increases in investment and GDP. This may result from the fact that higher consumption discourages households incentive to supply labor due to the labor-leisure trade-off. In the financial sector, banks grant more mortgages and business loans to support higher demand for consumption. Mortgage default declines due to an unexpected surge in house prices, but soars up above the steady state in the subsequent periods as the equilibrium LTV ratio rises. However, the magnitude of the changes is relatively small and therefore should not significantly affect the economy's dynamics. In the short run, lower mortgage default improves banks' capital adequacy ratio, allowing them to ease lending standards.

Last, we show that one-off negative bank capital shock may have long-lasting impacts on the economy.[15] The size of the shock is calibrated to generate 5-percent drop in bank profits. Banks' capital ratio therefore diminishes, causing them to raise credit spreads. This has adverse consequences on lending activities and aggregate demand. Total bank assets shrink. The capital ratio remains below the steady state for certain periods since spreads do not sufficiently rise to boost profits to counter the contraction of the banks balance sheet. This results in a persistent rise in the spreads, which continues to drag the economy down for certain periods. These results are

[15] We assume that bank capital losses are transferred to patient households. The shock, in this case, is more or less a "dividend-like" transfer from banks to patient households.

important to understanding why unanticipated increase in mortgage default, which depresses bank capital, can generate significant effects on the real economy.

7.2 Responses to Shocks to the Variance of an Idiosyncratic Housing Shock

A housing risk shock is the main focus in this paper as it was arguably the main reason of the Great Recession. We precisely analyse the transmission mechanisms of a large adverse housing risk shock to the banking sector and the real economy. The black solid lines in figures 5 and 6 show the responses of the benchmark model.

The first-order impact of an adverse housing risk shock (or an unexpected increase in the variance of an idiosyncratic housing shock) is to raise the mortgage default probability. That is, an increasing number of impatient household members decide to default on their loan obligations. Banks face losses from reduced mortgage repayment and an additional cost of state verification. Consequently, their profits and hence equity capital deteriorate. This in turn prompts them to begin tightening credit extension. The size of shocks is calibrated to trigger a 2.5-percentage-point surge in the probability of mortgage default on impact. We note that the default probability rises by more than 8 percentage points during the crisis. Gross bank profits consequently decline by 5.54 percent.

Given the persistence of a housing risk shock, the default probability stays above the steady state for certain periods, despite the fact that the equilibrium LTV ratio is below the steady state by more than 1 percentage point for 3 years following the shock. Banks anticipate a higher future default risk and, therefore, charge a default premium on mortgage interest rates. Increased default risk also makes the overall bank portfolio riskier, as reflected by larger risk-weighted assets. This becomes another factor that worsens their capital adequacy ratio, causing a persistent rise in credit spreads. In the figures, the capital ratio declines by 1.45 percentage point. At the outset, annualised mortgages and business loans spread increase by 3.56 and 3.20 percentage points, respectively. The mortgage spread remains above the steady state during the horizons considered, while that of business loans recovers within a year. Mortgages exhibit a hump-shaped decline, with a maximum reduction of 8.06 percent one year after shocks. Business loans drop 0.57 percent at most on impact, but rebound immediately afterwards.

Facing rising mortgage interest rate, impatient households demand fewer consumption goods and houses. Lower demand from households, along with tighter credit conditions, discourages investment in capital. Meanwhile, entrepreneurs consumption is also adversely affected by reduced rental income. The model correctly predicts a substantial decline in investment, which accounts for large portion of the GDP downfall. However, it fails to match its persistence, as investment picks up within a year. When the shock occurs, impatient households consumption, entrepreneurial investment and GDP fall by 1.10, 4.77 and 1.03 percent, respectively. Inflation decreases below the steady state, but to a small extent. The central bank reacts by slashing its policy interest rate.[16] In sum, our results suggest that negative shocks originating in the housing market contribute towards a significant output contraction, led by a slump in investment.[17]

The Role of Asset Prices

The interactions between mortgage default, house prices and credit supply conditions could be a potential financial accelerator that lies behind a significant economic downturn. The decline in impatient households demand for housing depresses house prices, which according to the on-the-verge condition, raises default probabilities further. The latter worsens banks' capitalisation, thus forcing them to reduce mortgages even more. Their capital is also affected by losses from a deterioration of the value of the seized collateral. With fewer mortgages, demand for housing is further eroded with knock-on effects on asset prices and so on and so forth. Moreover, on the loans demand side, since housing is utilised as collateral in acquiring mortgages, lower housing accumulation by impatient households directly implies that they can obtain less funding. This is exacerbated by falling future nominal house prices. However, like Forlati and Lambertini (2011), we find that real house prices quickly rebound, which is counterfactual. Also, the magnitude of their decline in the impact period is

[16] Declining deposit interest rate induces patient households to increase their expenditure. Deposits fall is compatible with banks need to deleverage. The adverse housing risk shock reallocates welfare from those who demand funding to savers. The latter also benefit from revenue from the monitoring activity.

[17] To illustrate the sensitivity of the results with respect to the assumption on the recovery of the monitoring costs, Figure 7 shows impulse responses under two extreme cases: (1) $rec = 1$ and (2) $rec = 0$. We observe that varying the recovery rate does not affect much the dynamics of real GDP. However, there are certain allocative differences. When the monitoring costs are paid back to patient households, their consumption unsurprisingly does not decline as much as in the case where such costs become deadweight losses. Nevertheless, inflation falls by less in the latter case. Since monitoring costs form part of aggregate demand, they exert upward pressure on inflation. Deposit interest rate, therefore, does not decline as much. In addition, investment is raised to support aggregate demand, making up for the greater decline in household consumption.

small. These findings weaken the role of asset prices in explaining the downturn.[18]

Capital Regulation and Housing Adjustment Costs

The model simulations instead identify two frictions that are crucial in contributing to deep and persistent recessions, namely capital regulation and housing adjustment costs. The red dashed line in figure 5 shows the impulse responses of the economy without bank capital frictions. In particular, we assume the component of both credit spreads driven by capital regulation to be time-invariant. The effects of an adverse housing risk shock on GDP and inflation are considerably smaller, with GDP falling by merely 0.23 percent on impact. The direct effect of an increase of the expected default probability on mortgage interest rate remains. However, by assumption, banks do not tighten credit standards in response to lower capital adequacy ratio. Business loan spread and hence investment barely change from their steady state as compared with the benchmark case. The responses of consumption and housing demand by both households are less pronounced but remain significant. In particular, impatient households consumption shrinks by 0.76 percent on impact. The bank capital ratio gradually recovers towards the steady-state level. Their assets fall by a lesser extent, as they do not face a constraint to deleverage from capital regulation.

The interplay between housing adjustment costs and capital regulation is another factor that leads to pronounced responses of the economy. Figure 6 compares the responses of the benchmark economy against (1) the economy without the adjustment costs and (2) the economy with even higher costs. The key differences, when the housing adjustment cost disappears, are that mortgages plunge considerably more, by around 18.3 percent on impact. The LTV ratio declines by almost 4 percentage points. Impatient households housing demand tumbles to a much larger extent. However, this allows them to afford higher level of consumption. Their non-durable consumption falls by 0.54 percent at most. Furthermore, declining LTV ratio implies a decrease in the future mortgage default probability. Banks thus charge lower mortgage spreads. Moreover, an abrupt fall in mortgages during the times that their risk weight is high mitigates a decrease in their capital ratio. They, therefore, face less pressure to deleverage. Investment and GDP, on impact, fall by merely 1.98 and 0.42 percent, respectively. On the other hand, in the case of high adjustment cost,

[18] In Ferrante (2015), he simulates housing market shocks to replicate a persistent house prices fall. His model assumes that only the impatient households consume housing services. Consequently, there is no demand from patient households to pick up the slack.

the slump in GDP and inflation is even more pronounced. In reality, households may not be able to adjust housing demand abruptly due to several reasons ranging from habit formation to difficulty in reselling houses (and searching for new residence). Such inflexibility could explain why the recent crisis has been so severe.

7.3 Responses to Capital Regulation Penalty Shocks

As explained earlier, risk premium shocks aim at capturing exogenous changes in bank risk-bearing capacity, which in turn influences loan pricing. This section focuses on the effects of a large adverse shock to capital regulation penalty (higher ϕ_t^k), providing us another potential source of widening interest rate spreads during the crisis.

The first-order impacts of such a shock, shown in figure 8, are to increase marginal cost of loan origination. Banks therefore raise premium on both loan interest rates. This results in negative consequences on borrowers. Widening mortgage spreads discourage demand for consumption and housing from impatient households. At the same time, entrepreneurs suffer from a rise in business loan spreads, whereas entrepreneurial consumption and investment both are declining. Investment is also adversely affected by weak aggregate demand. Both GDP and inflation consequently adjust downwards, leading the central bank to cut its policy interest rate. Declining deposit rates induce patient households to raise consumption while reducing deposits to banks, which is consistent with the latter's incentive to deleverage.

We calibrate the size of the shock to generate a surge in annualised business loan spread by 2 percentage points. Since mortgages face lower risk weight, the shock raises their spread to a smaller extent at 0.68 percentage point. Bank assets plunge 0.49 percent on impact. The consequences on the real economy are non-trivial. On impact, impatient households consumption, entrepreneurial consumption, investment and GDP decline by 0.08, 0.54, 3.01 and 0.52 percent, respectively. The effects on both consumption components are highly persistent, thus depressing the welfare of both agents. Due to fewer mortgages, impatient households housing demand also drops, which potentially enhances procyclicality through limited collateral. As anticipated, bank capital ratio improves, achieved by deleveraging and an increase in intermediation margins. The ratio rises by 0.59 percentage point after two quarters. This is one factor that mitigates widening spreads.

Given persistence of a risk premium shock, spreads remain above the steady state level for certain periods. However, mortgage spread can be reduced by lower default probability. Banks restrictive lending practice implies falling LTV ratio, which brings default down. In the first period, impatient households also default less on their mortgage obligations as real house prices rise. Improving mortgage repayment should help ease impaired lending conditions. Nevertheless, its impact may be modest as the default probability only declines by 0.03 percentage point on impact.[19]

8 Analysis of Macroprudential Regulations

Having discussed adverse consequences of housing risk shocks and risk premium shocks, we now explore in this section how the three macroprudential regulations influence the dynamics of the economy. We summarise their effects on macroeconomic stability and agents welfare in subsection 8.4.

8.1 Steady State Effects of LTV Caps

The LTV regulation not only influences cyclical properties of the economy but also affects its non-stochastic steady state.[20] In this exercise, we assume all parameter values, including impatient households discount factor to be the same as in the benchmark model. Caps on LTV ratio impose a limit on the amount of mortgages impatient households can borrow for any given housing value. This may sound unsatisfactory for them. However, in this model which incorporates a time-varying mortgage default probability, this policy tool favours them. The last four columns of table 3 show the steady state of the economy with different levels of regulatory LTV ratio (from 67 percent to 55 percent). The last column reflects the most constrained scenario. Recall that the steady-state LTV ratio for the benchmark economy is 70 percent. So, any LTV limits that are lower than such a level will make the borrowing constraint binding. Positive steady-state value of the tightness of the constraint (ξ^I) confirms this.

As the policy becomes more stringent, we surprisingly observe a rise in impatient households demand for both consumption goods and housing. They also enjoy more leisure. All of these arguments benefit their welfare. Mortgage default plays a

[19] In figures 9 and 10 in the Appendix, I present the responses of the economy to both shocks using second-order approximation. The results explained earlier do not qualitatively alter.

[20] Indeed, all the three measures should affect the steady state if the stochastic version is considered. This is because they all affect the dynamics of the economy and hence its future uncertainty. The latter in turn influences agents decision, given risk-averse preferences.

pivotal role here. At the steady state, $\bar{\omega} = m^I$. Therefore, the LTV ratio is the only determinant of the steady-state probability of default. Decreasing LTV ratio limits chances that idiosyncratic housing shocks will force the collateral value to be lower than the debt outstanding. The default probability consequently declines. In particular, imposing LTV limit at 55 percent almost prevents mortgage default from occurring. This curtails the risk premium charged on mortgage lending and eases impatient household's borrowing costs.

However, the effects on mortgages are non-linear. Due to the reduced default risk, the amount of mortgages rises when LTV caps are initially imposed. Nevertheless, as the caps are reduced to a certain level, mortgages begin to fall as the beneficial effects on default are outweighed by their direct negative ones in constraining borrowing. The steady-state capital adequacy ratio improves slightly since the bank portfolio becomes less risky. Nonetheless, the business loan interest rate rises since banks supply fewer business loans so as to increase mortgage lending. GDP and investment fall, though not to a large extent. This is mainly due to a decline in the consumption of patient households, who lend more to the banking sector. Therefore, there exists trade-off in terms of permanent GDP loss when financial regulators attempt to impose tighter LTV caps. The policy helps reallocate welfare towards impatient households, which prima facie seems counterintuitive.

8.2 The Effects of Shocks to Capital Adequacy Ratio and LTV caps

Before exploring the impacts of countercyclical capital buffers and state-contingent LTV caps, we examine how the economy benefits from relaxation of these two policy tools. We assume that $\Phi_m = \Phi_k = 0.9$. Figure 11 shows the effects of a negative shock to the capital adequacy ratio in both the benchmark model and the extended model with caps on LTV ratio.[21] In the benchmark case, its effects are unsurprisingly close to those resulted from risk premium shocks. A decrease in the regulatory capital ratio exerts expansionary consequences on the economy. Banks charge smaller spreads on both mortgages and business loans. A temporary fall in credit spreads encourages consumption and investment by borrowers. Patient households switch

[21] In the latter model, we now adjust impatient households discount factor to 0.975 to ensure that the borrowing constraint always binds given the size of shocks assumed in the previous section. However, as explained before, given different discount factors, the simulation results for these two models are not suitable for comparison. We show the steady state value of the model with LTV caps in table 8 in the Appendix. We still find that more stringent LTV caps (moving from 67.5 percent to 65 percent) benefit impatient households as default declines.

Table 3: Steady State Effects of the Introduction of LTV Caps

Variable	Benchmark	Case 1	Case 2	Case 3	Case 4
Steady State					
LTV ratio	70.00%	67.00%	65.00%	60.00%	55.00%
Default Probability	2.007%	1.032%	0.628%	0.146%	0.024%
Mortgage Interest Rate	1.700%	1.417%	1.302%	1.167%	1.133%
Business Loan Interest Rate	1.934%	1.943%	1.948%	1.956%	1.961%
Capital Adequacy Ratio	8.000%	8.070%	8.108%	8.173%	8.212%
Percentage Change from the Benchmark Case					
Mortgages		6.523%	8.055%	5.031%	-3.121%
Business Loans		-0.212%	-0.325%	-0.513%	-0.624%
GDP		-0.048%	-0.081%	-0.157%	-0.224%
Patient HH Labor Supply		0.083%	0.148%	0.323%	0.498%
Impatient HH Labor Supply		-0.557%	-0.887%	-1.554%	-2.072%
Capital		-0.204%	-0.311%	-0.491%	-0.597%
Patient HH Consumption		-0.332%	-0.549%	-1.044%	-1.479%
Impatient HH Consumption		0.948%	1.521%	2.709%	3.661%
Entrepreneur Consumption		-0.201%	-0.308%	-0.486%	-0.591%
Investment		-0.204%	-0.311%	-0.491%	-0.597%
Patient HH House Demand		-2.008%	-2.918%	-4.004%	-4.202%
Impatient HH House Demand		8.949%	12.70%	16.96%	17.71%
Change from the Benchmark Case					
Patient HH Welfare		-0.6907	-1.0627	-1.7155	-2.1412
Impatient HH Welfare		1.8595	2.7642	4.1688	4.9377
Entrepreneur Welfare		-0.0504	-0.0771	-0.1216	-0.1477

from consumption to deposits. Welfare is reallocated from them to borrowers who benefit from bank balance sheet expansion. The mortgage default probability rises but not significantly.

The measure has different allocative effects when caps on LTV ratio are in place.[22] Given the same size of shocks as in the benchmark case, their effects on mortgages and hence total bank assets are smaller. As a result, a rise in impatient households consumption, particularly on housing, is less pronounced. LTV regulations also have important implications on the behavior of mortgage default. The caps help anchor the probability of default after the shock. An increase in mortgage default may weaken expansionary effects of lower regulatory capital ratio in the benchmark case, however this is not the case in the model with LTV caps. Consumption decision made by impatient households is another interesting aspect. Despite having more mortgages, their non-durable goods consumption does not immediately rise. They instead spend on housing which yields an extra return since it can also serve as collateral. Overall, the effect on GDP and investment is similar to the benchmark case.

A positive shock to the LTV caps also entails expansionary effects on the economy, as shown in figure 12. The shock relaxes impatient households borrowing constraint. Their consumption and housing demand rise as a result. GDP improves, while investment rises in the medium run. However, there exist trade-offs from elevated mortgage default risk and weakened banks financial condition. Increasing equilibrium LTV ratio leads impatient households to default more on their mortgages. This raises mortgage spread, which in turn partially crowds out the initial positive impact to the economy. In addition, more mortgage origination and higher default risk lessen bank capital ratio. Banks hence need to tighten their lending standards. This has negative short-run consequences on business loans and investment. Surprisingly, impatient households welfare worsens as they end up having to repay higher outstanding debt in the medium run. Therefore, even though the policy improves their short run utility, it is detrimental to their lifetime utility. However, the welfare of both patient households and entrepreneurs increases because they reap the gains from the economic expansion.

[22]Under the model with LTV caps, we henceforth assume that financial regulators set the caps equal to 67.5 percent.

8.3 Can Macroprudential Regulations Stabilise Crisis Shocks?

More Stringent LTV Caps

We now consider how imposing more stringent LTV caps influences the path of the economy with respect to the shocks of interest. Figure 13 compares the responses of the economy facing a large adverse housing risk shock in the model with different levels of LTV caps (67.5 percent versus 65.0 percent).[23] The size of the shock is assumed to be the same as in the previous section. More stringent LTV caps manage to contain an increase in mortgage default probabilities. Mortgage spreads behave accordingly. A fall in mortgages and hence demand from impatient households is more limited. Non-durable consumption even picks up in the short run. Given lower default, banks' capital position improves. This reduces their need to tighten loan standards, benefiting both investment and GDP. Therefore, as financial regulators reduce limits on the LTV ratio, the adverse impacts of a housing risk shock on lending activities and GDP become more limited. According to table 4, both impatient households and entrepreneurs achieve an improvement in their welfare. We also note that the extended model with LTV caps predicts a persistent decline in house prices, which lasts for two years.

We underscore certain qualitative changes in the model dynamics from the benchmark case. The decline in mortgages is substantially lower in the model with LTV caps, partly because bank capitalisation conditions improve. The latter also boosts investment. However, when LTV caps are at 67.5 percent, an increase in mortgage default probabilities and spreads is lower than the benchmark responses only in the short run. In the medium run, the fact that equilibrium LTV ratio significantly falls in the benchmark case helps curb a rise in default. A trade-off then exists in terms of worsening future impatient households consumption, which precipitates into a further decline of their welfare from the benchmark case. A potential solution is that financial regulators tighten LTV caps further. Default and hence mortgage spreads will be more controlled in the medium run. Impatient households can thus be better off from this policy.

Facing a risk premium shock, more stringent LTV caps can help limit a decline in mortgages (see figure 14). Improvement in mortgages is partly attributed by a decline in mortgage spread. Since the steady-state mortgage spread is smaller at lower caps on LTV, the first-order effects of a shock on mortgage spreads become less pro-

[23] The graph is juxtaposed with the responses under the benchmark case. However, comparison across the two models should be made with caution as we have already explained.

nounced. Impatient households can afford higher consumption on both non-durable and durable goods. In the model with LTV limits, demand for consumption goods is even positive in the short run. Meanwhile, mortgage default negligibly deviates from the steady state (except in the first period). The welfare of impatient households hence improves (see table 5). Nonetheless, the measure only benefits mortgage borrowers, without significant spillover effects to other parts of the economy. Investment and GDP fall to the same extent. Entrepreneurs welfare marginally declines because banks substitute away from corporate lending.

Countercyclical Capital Buffers

We next explore whether countercyclical capital buffers can mitigate the adverse impacts of housing risk and risk premium shocks. Hereafter, we set $\Phi_m = \Phi_k = 0$, i.e. allowing the policy tools to only vary with specified financial indicators. In the face of a housing risk shock, declining credit-to-GDP ratio after the shock triggers a decrease in the regulatory capital ratio. This relaxes banks need to deleverage and rebuild capital. From figure 15, which assumes away LTV regulations, their capital ratio falls more, contemporaneously, and only gradually returns to the steady state. Both interest rate spreads increase to a lesser extent, which helps boost lending activities. Impatient households can afford to purchase more consumption goods and housing. Investment also picks up significantly. GDP and inflation therefore are more stabilised. This macroprudential measure significantly improves the welfare of impatient households and entrepreneurs at the expense of patient households.

Figure 17 shows that, when LTV caps are already in place, countercyclical buffers can benefit the economy further. However, such benefits are limited, partly because the existence of LTV regulations has already mitigated a decline in the credit-to-GDP ratio in the first place. We can observe that credit spreads are mildly reduced. The previous subsection also shows that adjusting capital requirements has limited impacts on mortgages in the model with LTV caps. However, borrowers can still reap some benefits from more relaxed lending standards. Impatient households housing demand and entrepreneurial investment significantly improve, resulting in a rise of both agents welfare. Consistent with the results found in the previous subsection, there is evidence that impatient households postpone non-durable goods consumption.

In the face of risk premium shocks, as shown in figure 16, the measure has insignificant effects on GDP, but significant redistributive effects. However, the measure may have destabilising effects on the economy in the short run, as the ratio of credit to GDP does not fall immediately after the shocks. A rise in such ratio results from the fact that investment immensely declines, making the denominator more elastic than the numerator. Banks are thus required to hold even more capital, exacerbating their already-constrained capacity to supply loans. This results in a further decline in GDP, though to a negligible extent. This finding is consistent with that of Repullo and Saurina (2011) who suggest that using the credit-to-GDP ratio as a systemic-risk indicator can destabilise the economy. Nevertheless, both borrowers benefit from more relaxed loans supply conditions in periods after, as banks face less pressure to rebuild capital. They raise goods demand, allowing them to achieve higher welfare. The fact the GDP does not change implies that the measure mainly redistributes resources away from patient households who consume less.

Figure 18 shows the results when caps on LTV ratio are in place. In this case, LTV caps help limit the decline in mortgages. Given less pronounced responses of mortgages, the credit-to-GDP ratio rises more significantly in the short term. The indicator therefore sends a wrong signal to financial regulators. Such ratio, which is expected to decline in the bust periods, thereby suggesting to the regulators to implement more relaxed regulation, does the opposite. Again, capital requirement is raised at the times bank credit is already constrained. Credit spreads expand in the initial periods, prompting borrowers to reduce borrowing. This has destabilising effects on the economy. We can observe a considerable decline in impatient households consumption and housing accumulation. However, the welfare of both impatient households and entrepreneurs still improves since the measure helps ease lending standards in the medium term. This is at the expense of their short-term utilities.

State-contingent LTV caps

We consider implementing state-contingent LTV caps only in the case of housing risk shock, as the measure is sector-specific and so financial regulators may not exploit it to deal with shocks that affect lending across all sectors. The measure, though raising impatient households consumption in the initial periods, tends to lower their welfare as consumption declines in later periods. This is reminiscent of the results obtained when examining shocks to LTV caps themselves. As shown in figure 19, in response to a large adverse housing risk shock, the ratio of mortgages to GDP decreases. Financial regulators respond by raising the LTV caps in order to relax a borrowing constraint for mortgage borrowers. Mortgages massively improve from the responses under time-invariant LTV caps. This allows impatient households to demand more consumption goods and housing. We also observe improvement in both investment and GDP, though only in the short run. The medium- to long-run consequences are complicated due to the increased default and debt. With higher LTV ratio, the mortgage default probability and interest rate spreads constantly accelerate. This means higher debt outstanding that impatient households are obliged to repay in later periods. They therefore reduce consumption in the medium run, which ultimately hurts their welfare. Finally, entrepreneurs benefit from such a policy, given a rise in investment and overall economic activity.

8.4 Implications on Welfare and Volatility

The section summarises welfare and volatility implications from implementing macroprudential regulations. The welfare analysis follows from the previous section by considering welfare changes when the economy faces large adverse impulses. In particular, we consider deviations of each agent's welfare from the steady state at period 0 (i.e. when the shock hits) for each particular set of policies. Such a welfare measure can be referred to as a "conditional" welfare measure, since it is conditional on the same initial non-stochastic steady state of the economy, as well as on the shock being large and one-off. We find that no policies considered Pareto improve the welfare. So, we focus on a set of policies that can improve the welfare of those agents adversely affected by the shocks. In terms of volatility implications, we compute, for each particular set of policies, the volatility of key economic variables given the existence of shocks with variance specified in the table below.[24] The variables include GDP, inflation, investment, and total bank credit.

Tables 4 and 5 show the results for housing risk and risk premium shocks, respectively. In the tables, 'Mon Pol Only' row in the benchmark case assumes away all macroprudential measures. Both shocks cause welfare reallocation to patient households from impatient households and entrepreneurs. For the housing risk shock, the adverse effects on impatient households welfare are much stronger. By imposing LTV caps, the volatilities of both real and financial variables are substantially reduced. However, impatient households welfare worsens, if caps on the LTV ratio

[24]

	Standard Deviations		Standard Deviations
Housing risk shock	0.226	Monetary policy shock	0.002
Risk premium shock	0.520	Bank capital shock	0.020
Productivity shock	0.010		

Table 4: Welfare and Volatility Analysis: Housing Risk Shocks

	Welfare change from the steady state			Volatility as a ratio to the benchmark case			
	Patient h.	Impatient h.	Entrepreneur	GDP	Inflation	Investment	Credit
Benchmark Model							
Mon Pol Only	0.0397	-0.2001	-0.0129	-	-	-	-
with countercyclical capital buffers							
Φ_k=0.375	0.0218	-0.1860	0.0023	0.72	0.84	0.82	0.90
Φ_k=0.75	0.0065	-0.1734	0.0155	0.54	0.71	0.00	0.81
LTV Model							
$\widetilde{m}^I$=0.675	0.0588	-0.2127	-0.0037	0.19	0.51	0.32	0.32
$\widetilde{m}^I$=0.65	0.0391	-0.1352	-0.0022	0.08	0.22	0.14	0.12
with countercyclical capital buffers							
Φ_k=0.375	0.0440	-0.2036	0.0068	0.17	0.52	0.29	0.29
Φ_k=0.75	0.0313	-0.1955	0.0161	0.17	0.53	0.29	0.27
with state-contingent caps on LTV ratio							
Φ_m=0.25	0.0877	-0.2665	-0.0013	0.10	1.49	0.26	0.24
Φ_m=0.5	0.1176	-0.3157	-0.0001	0.09	2.42	0.24	0.21

Note: Welfare is expressed as an absolute deviation from the steady state of each model. Volatility is expressed as a ratio to the benchmark case (i.e., without macro-prudential regulation). We assume $\widetilde{m}^I$=0.675 for the last four rows.

Table 5: Welfare and Volatility Analysis: Risk Premium Shocks

	Welfare change from the steady state			Volatility as a ratio to the benchmark case			
	Patient h.	Impatient h.	Entrepreneur	GDP	Inflation	Investment	Credit
Benchmark Model							
Mon Pol Only	0.0293	-0.0308	-0.0237	-	-	-	-
with countercyclical capital buffers							
Φ_k=1.5	0.0223	-0.0275	-0.0187	0.97	0.98	0.96	0.89
Φ_k=3.0	0.0180	-0.0256	-0.0155	0.96	0.96	0.93	0.79
LTV Model							
$\widetilde{m}^I$=0.675	0.0280	-0.0203	-0.0240	0.96	0.80	1.05	0.61
$\widetilde{m}^I$=0.65	0.0276	-0.0174	-0.0242	0.96	0.77	1.06	0.54
with countercyclical capital buffers							
Φ_k=1.5	0.0223	-0.0172	-0.0205	1.03	0.96	1.04	0.43
Φ_k=3.0	0.0188	-0.0153	-0.0182	1.09	1.10	1.04	0.32

Note: Welfare is expressed as an absolute deviation from the steady state of each model. Volatility is expressed as a ratio to the benchmark case (i.e., without macro-prudential regulations). We assume $\widetilde{m}^I$=0.675 for the last two rows.

are not stringent enough. As shown in the previous section, a properly calibrated value of the caps is required to reduce the mortgage default risk in the medium term. Nevertheless, we must not forget that their steady-state welfare has permanently improved from the benchmark case due to lower default risk. This steady-state effect has turned out to be quite large. Next, countercyclical capital buffers improve the welfare of both impatient households and entrepreneurs. However, they are more effective in terms of stabilisation when financial regulators do not simultaneously impose LTV caps. As opposed to the first two measures, state-contingent LTV caps are undesirable as they exacerbate impatient households welfare. The policy is found to escalate the extent of mortgage default. Thus, new loans are issued with even higher mortgage spread. Impatient households then have larger contractual obligations to fulfill in the future. This property is in stark contrast with countercyclical capital buffers that entail more, but "cheaper", credit. The simulations also identify another adverse consequences as inflation volatility picks up.

In the face of risk premium shocks, none of the policies are successful in taming GDP volatility, since a rise in demand from one agent is offseted by a fall in demand from others. More stringent LTV caps again are effective in reducing volatilities in credit (as well as inflation), while improving impatient households welfare. However, this comes at the expense of entrepreneurial welfare, though to a small extent. Countercyclical capital buffers also curtail fluctuations within the banking sector. The measure is effective in raising the welfare of both agents. But, when LTV caps are in place, the credit-to-GDP ratio may send a wrong signal, which results in higher output and inflation volatilities.

9 Concluding Remarks and Extensions

The paper embeds mortgage default into a New Keynesian model that incorporates housing and the non-trivial banking sector. Banks are subject to capital adequacy regulation, which makes their loan origination tied to the availability of bank capital. We study the spillover effects of shocks originating in the mortgage and financial markets on the real sector. Moreover, we explore whether the use of macroprudential regulation can mitigate the adverse effects of shocks on allocations and welfare.

We establish that adverse housing risk shocks depress lending activities and economic outcomes. Such shocks lead to a rise in mortgage default, which in turn weakens bank balance sheet. The banks charge higher interest rate spreads on both mortgages and business loans. Borrowers therefore lower their consumption and investment. Banking sector friction, namely capital regulation and housing adjustment costs, are found to propagate the effects of shocks. Risk premium shocks, meanwhile, cause tougher lending standards and generate an economic downturn. Banks raise both credit spreads, prompting impatient households and entrepreneurs to reduce their corresponding demand. These two candidate shocks capture, at least qualitatively, the behaviour of real and financial variables during the recent global financial crisis.

Three macroprudential regulations are examined with respect to their effectiveness in stabilising the proposed shocks impact. We provide several new results to the literature on macroprudential regulation. First, imposing LTV caps lowers the steady-state probability of default. This results in reduced mortgage spreads that improve impatient households consumption and welfare. Second, LTV caps helps limit a plunge in mortgages when facing both shocks. This measure also has substantial macroeconomic stabilisation benefits when the economy is facing housing risk shocks. Third, countercyclical capital buffers can improve allocations and welfare further for borrowers. But financial regulators need to be aware of receiving a wrong signal from the credit-to-GDP ratio, which might occur in the case of risk premium shocks. Last, as opposed to the literature, our results do not support state-contingent LTV ratios. In the event of adverse housing risk shocks, the policy exacerbates impatient households welfare.

For future work, the mortgage market and contracts can be extended in a number of ways to be more realistic. First, it is assumed that mortgage debt is non-recourse. In reality, even though mortgages become “underwater”, borrowers can rely on other sources of income to repay debt. Campbell and Cocco (2015) have a model where borrowers do not default immediately after the market value of the houses is lower than debt outstanding. Second, it is important to differentiate between the case of fixed-rate and adjustable-rate mortgages since it can influence default decision and the transmission of shocks. Despite the fact that majority of mortgages in the US is fixed-rate mortgages, this is not true in several countries. Calza et al. (2013) explore how features of mortgage contract affect transmission of monetary policy. Moreover, mortgages are usually long-term, as opposed to a one-period contract assumed in this paper. Assuming mortgages to be long-term would allow us to differentiate between the stock and flow of mortgages. Excessive accumulation of mortgages prior to the crisis makes the balance sheet weaker and susceptible to shocks. Other potential extensions to the model include modelling the production of houses and debt securitisation, as in Goodhart et al. (2012). The latter is crucial to understanding why credit risk is underestimated and, yet, there is abundant liquidity in the mortgage market.

In addition, the paper mainly focuses on policies to mitigate the effects after adverse shocks have occurred (i.e. crisis management). It would be interesting to explore what could have been done prior to the crisis (i.e. crisis prevention) to reduce the probability and magnitude of a potential crisis. That is, if policymakers decided to "lean-against-the-wind" or impose tougher regulatory requirements in the mortgage market, how would the crisis be transmitted to the real economy?

References

Angelini, P., L. Clerc, V. Cúrdia, L. Gambacorta, A. Gerali, A. Locarno, R. Motto, W. Roeger, S. Van den Heuvel, and J. Vlček: 2015, 'Basel III: Long-term Impact on Economic Performance and Fluctuations'. *The Manchester School* **83**(2), 217–251.

Angelini, P., S. Neri, and F. Panetta: 2014, 'The Interaction between Capital Requirements and Monetary Policy'. *Journal of Money, Credit and Banking* **46**(6), 1073–1112.

Bean, C. R., M. Paustian, A. Penalver, and T. Taylor: 2010, 'Monetary policy after the fall'. *Proceedings - Economic Policy Symposium - Jackson Hole* ([object Attr]), 267–328.

Bernanke, B. S., M. Gertler, and S. Gilchrist: 1999, 'The financial accelerator in a quantitative business cycle framework'. Handbook of Macroeconomics, Elsevier.

Bianchi, J.: 2011, 'Overborrowing and Systemic Externalities in the Business Cycle'. *American Economic Review* **101**(7), 3400–3426.

Bianchi, J. and E. G. Mendoza: 2010, 'Overborrowing, financial crises and 'macro-prudential' taxes'. *Proceedings* (Oct).

Brunnermeier, M. K.: 2008, 'Deciphering the Liquidity and Credit Crunch 2007-08'. NBER Working Paper 14612, National Bureau of Economic Research, Inc.

Calvo, G. A.: 1983, 'Staggered prices in a utility-maximizing framework'. *Journal of Monetary Economics* **12**(3), 383–398.

Calza, A., T. Monacelli, and L. Stracca: 2013, 'Housing Finance And Monetary Policy'. *Journal of the European Economic Association* **11**([object Attr]), 101–122.

Campbell, J. Y. and J. F. Cocco: 2015, 'A Model of Mortgage Default'. *The Journal of Finance* **70**(4), 1495–1554.

Cerutti, E. M., S. Claessens, and L. Laeven: 2015, 'The Use and Effectiveness of Macroprudential Policies; New Evidence'. IMF Working Paper 15/61, International Monetary Fund.

Christiano, L. J., M. Eichenbaum, and C. L. Evans: 2005, 'Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy'. *Journal of Political Economy* **113**(1), 1–45.

Christiano, L. J., R. Motto, and M. Rostagno: 2014, 'Risk Shocks'. *American Economic Review* **104**(1), 27–65.

Claessens, S., S. R. Ghosh, and R. Mihet: 2013, 'Macro-prudential policies to mitigate financial system vulnerabilities'. *Journal of International Money and Finance* **39**(C), 153–185.

Clerc, L., A. Derviz, C. Mendicino, S. Moyen, K. Nikolov, L. Stracca, J. Suarez, and A. P. Vardoulakis: 2015, 'Capital Regulation in a Macroeconomic Model with Three Layers of Default'. *International Journal of Central Banking* **11**(3), 9–63.

Crowe, C., G. Dell'Ariccia, D. Igan, and P. Rabanal: 2013, 'How to deal with real estate booms: Lessons from country experiences'. *Journal of Financial Stability* **9**(3), 300–319.

Drehmann, M., C. Borio, and K. Tsatsaronis: 2011, 'Anchoring Countercyclical Capital Buffers: The role of Credit Aggregates'. *International Journal of Central Banking* **7**(4), 189–240.

Drehmann, M. and L. Gambacorta: 2012, 'The effects of countercyclical capital buffers on bank lending'. *Applied Economics Letters* **19**(7), 603–608.

Erceg, C. and A. Levin: 2006, 'Optimal monetary policy with durable consumption goods'. *Journal of Monetary Economics* **53**(7), 1341–1359.

Ferrante, F.: 2015, 'Risky Mortgages, Bank Leverage and Credit Policy'. Finance and Economics Discussion Series 2015-110, Board of Governors of the Federal Reserve System (U.S.).

Forlati, C. and L. Lambertini: 2011, 'Risky Mortgages in a DSGE Model'. *International Journal of Central Banking* **7**(1), 285–335.

Gelain, P., K. J. Lansing, and C. Mendicino: 2013, 'House Prices, Credit Growth, and Excess Volatility: Implications for Monetary and Macroprudential Policy'. *International Journal of Central Banking* **9**(2), 219–276.

Gerali, A., S. Neri, L. Sessa, and F. M. Signoretti: 2010, 'Credit and Banking in a DSGE Model of the Euro Area'. *Journal of Money, Credit and Banking* **42**, 107–141.

Gertler, M. and P. Karadi: 2011, 'A model of unconventional monetary policy'. *Journal of Monetary Economics* **58**(1), 17–34.

Gilchrist, S. and E. Zakrajšek: 2012, 'Credit Spreads and Business Cycle Fluctuations'. *American Economic Review* **102**(4), 1692–1720.

Goodhart, C. A. E., A. K. Kashyap, D. P. Tsomocos, and A. P. Vardoulakis: 2012, 'Financial Regulation in General Equilibrium'. NBER Working Paper 17909, National Bureau of Economic Research, Inc.

Goodhart, C. A. E., A. K. Kashyap, D. P. Tsomocos, and A. P. Vardoulakis: 2013, 'An Integrated Framework for Analyzing Multiple Financial Regulations'. *International Journal of Central Banking* **9**(1), 109–144.

Goodhart, C. A. E., D. P. Tsomocos, and A. P. Vardoulakis: 2011, 'Modeling a Housing and Mortgage Crisis'. Central Banking, Analysis, and Economic Policies Book Series, Central Bank of Chile.

Iacoviello, M.: 2005, 'House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle'. *American Economic Review* **95**(3), 739–764.

Iacoviello, M. and S. Neri: 2010, 'Housing Market Spillovers: Evidence from an Estimated DSGE Model'. *American Economic Journal: Macroeconomics* **2**(2), 125–164.

Jacome, L. I. and S. Mitra: 2015, 'LTV and DTI Limits-Going Granular'. IMF Working Paper 15/154, International Monetary Fund.

Jeanne, O. and A. Korinek: 2010, 'Excessive Volatility in Capital Flows: A Pigouvian Taxation Approach'. *American Economic Review* **100**(2), 403–407.

Kannan, P., P. Rabanal, and A. M. Scott: 2012, 'Monetary and Macroprudential Policy Rules in a Model with House Price Booms'. *The B.E. Journal of Macroeconomics* **12**(1), 1–44.

Kiyotaki, N. and J. Moore: 1997, 'Credit Cycles'. *Journal of Political Economy* **105**(2), 211–248.

Kuttner, K. N. and I. Shim: 2016, 'Can non-interest rate policies stabilize housing markets? Evidence from a panel of 57 economies'. *Journal of Financial Stability* **26**(C), 31–44.

Lambertini, L., C. Mendicino, and M. T. Punzi: 2013, 'Leaning against boom–bust cycles in credit and housing prices'. *Journal of Economic Dynamics and Control* **37**(8), 1500–1522.

Monacelli, T.: 2009, 'New Keynesian models, durable goods, and collateral constraints'. *Journal of Monetary Economics* **56**(2), 242–254.

Quint, D. and P. Rabanal: 2014, 'Monetary and Macroprudential Policy in an Estimated DSGE Model of the Euro Area'. *International Journal of Central Banking* **10**(2), 169–236.

Repullo, R. and J. Saurina: 2011, 'The Countercyclical Capital Buffer of Basel III: A Critical Assessment'. CEPR Discussion Paper 8304, C.E.P.R. Discussion Papers.

Rubio, M. and J. A. Carrasco-Gallego: 2014, 'Macroprudential and monetary policies: Implications for financial stability and welfare'. *Journal of Banking & Finance* **49**(C), 326–336.

Smets, F. and R. Wouters: 2007, 'Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach'. *American Economic Review* **97**(3), 586–606.

10 Appendix

10.1 Data Description

Based on the definition provided in the Federal Reserve website, delinquency loans and leases are those past due thirty days or more and still accruing interest as well as those in nonaccrual status. They are measured as a percentage of end-of-period loans. The excess bond premium is a component of corporate bond credit spreads (accounted for duration bias) that is not directly attributable to expected default risk (see Gilchrist and Zakrajšek (2012)).

10.2 Log-linearised Version of the Benchmark Economy

Let hatted values denote percentage changes from the steady state, and those without subscript denote steady-state values. Assume $\gamma_E = \beta_E \left[(1-\delta) + \frac{\mu Y}{Xk} - m^E (1-\delta) \right] = 1 - \frac{m^E(1-\delta)}{r^E}$ and $\omega = \beta_E \frac{\mu Y}{Xk} = 1 - \frac{m^E(1-\delta)}{r^E} + \beta_E m^E (1-\delta) - \beta_E (1-\delta)$, the model can be reduced to the following linearised system:

Patient Households

$$\hat{\lambda}_t^P = -\frac{1}{1-a_P}\hat{c}_t^P + \frac{a_P}{1-a_P}\hat{c}_{t-1}^P \tag{49}$$

$$\hat{\lambda}_t^P = \hat{\lambda}_{t+1}^P + \hat{r}_t - \hat{\pi}_{t+1} \tag{50}$$

$$\hat{q}_t^h + \hat{\lambda}_t^P = (1-\beta_P)\left(-\hat{h}_t^P\right) + \beta_P\left(\hat{q}_{t+1}^h + \hat{\lambda}_{t+1}^P\right) - \phi_h\left(\Delta\hat{h}_t^P - \beta_P \Delta\hat{h}_{t+1}^P\right) \tag{51}$$

$$\hat{w}_t^P + \hat{\lambda}_t^P = (\eta - 1)\,\hat{l}_t^P \tag{52}$$

Impatient Households

$$\begin{aligned} \tfrac{b^I}{Y}\hat{b}_t^I = \; & \tfrac{c^I}{Y}\hat{c}_t^I + \tfrac{q^h h^I}{Y}\left[\hat{q}_t^h + \hat{h}_t^I\right] + (1-F(\bar{\omega}))\tfrac{r^I b^I}{Y}\left[\hat{r}_{t-1}^I + \hat{b}_{t-1}^I - \hat{\pi}_t\right] - F(\bar{\omega})\tfrac{r^I b^I}{Y}\hat{F}_t(\bar{\omega}_t) \\ & -\tfrac{(1-\mu)(1-\alpha)}{X}\left[\hat{Y}_t - \hat{X}_t\right] - (1-G(\bar{\omega}))\tfrac{q^h h^I}{Y}\left[\hat{q}_t^h + \hat{h}_{t-1}^I\right] + G(\bar{\omega})\tfrac{q^h h^I}{Y}\hat{G}_t(\bar{\omega}_t) \end{aligned} \tag{53}$$

$$\hat{b}_{t-1}^I + \hat{r}_{t-1}^I - \hat{\pi}_t = \hat{\bar{\omega}}_t + \hat{q}_t^h + \hat{h}_{t-1}^I \tag{54}$$

$$\hat{m}_t^I = \hat{r}_t^I + \hat{b}_t^I - \hat{q}_{t+1}^h - \hat{h}_t^I - \hat{\pi}_{t+1} \tag{55}$$

$$\hat{\lambda}_t^I = -\frac{1}{1-a_I}\hat{c}_t^I + \frac{a_I}{1-a_I}\hat{c}_{t-1}^I \tag{56}$$

Table 6: Data Source

Data (US)	Unit	Source
Delinquency Rate on Loans Secured by Real Estate	Percent, SA, end of period	Board of Governors
Delinquency Rate on Single-Family Residential Mortgages		
30-Year Fixed Rate Mortgages	Percent, NSA, monthly average	Freddie Mac
1-Year Adjustable Rate Mortgages		
Effective Federal Funds Rate	Percent, NSA, monthly average	Board of Governors
30-Year Treasury Constant Maturity Rate		
1-Year Treasury Constant Maturity Rate		
Excess Bond Premium	Percent, monthly	Board of Governors
S&P/Case-Shiller 20-City Composite Home Price Index	Index Jan 2000=100, SA, monthly	S&P Dow Jones Indices LLC
Return on Average Equity for all U.S. Banks	Percent, SA, quarterly, end of period	Federal Financial Institutions Examination Council
Total Equity to Total Assets for Banks		
Real Gross Domestic Product	Billions of Chained 2009 Dollars, SAAR, quarterly	US. Bureau of Economic Analysis
Real Personal Consumption Expenditures		
Real Gross Private Domestic Investment: Nonresidential		
Households and Nonprofit Organisations: Home Mortgages	Billions of Dollars, SA, quarterly, end of period	Board of Governors
Implicit Price deflator	Index 2009=100, SA, quarterly average	US. Bureau of Economic Analysis

$$\hat{\lambda}_t^I = \hat{\lambda}_{t+1}^I - \frac{F\left(\bar{\omega}\right)}{\beta_I r^I}\hat{F}_{t+1}\left(\bar{\omega}_{t+1}\right) + \frac{G\left(\bar{\omega}\right)}{\beta_I r^I m^I}\left(\hat{G}_{t+1}\left(\bar{\omega}_{t+1}\right) - \hat{m}_t^I\right) + \hat{r}_t^I - \hat{\pi}_{t+1} \tag{57}$$

$$\hat{q}_t^h + \hat{\lambda}_t^I = \left(1-\beta_I\right)\left(-\hat{h}_t^I\right) + \beta_I\left(\hat{q}_{t+1}^h + \hat{\lambda}_{t+1}^I\right) - \phi_h\left(\Delta\hat{h}_t^I - \beta_I\Delta\hat{h}_{t+1}^I\right) \tag{58}$$

$$\hat{w}_t^I + \hat{\lambda}_t^I = \left(\eta - 1\right)\hat{l}_t^I \tag{59}$$

$$\hat{F}_t\left(\bar{\omega}_t\right) = \frac{1}{F\left(\bar{\omega}\right)\sigma_\omega\sqrt{2\pi}}\exp\left[-\left(\frac{ln(\bar{\omega}) + \frac{\sigma_\omega^2}{2}}{\sqrt{2}\sigma_\omega}\right)^2\right]\left[\hat{\bar{\omega}}_t - \left(ln(\bar{\omega}) - \frac{\sigma_\omega^2}{2}\right)\hat{\sigma}_{\omega,t}\right] \tag{60}$$

$$\hat{G}_t\left(\bar{\omega}_t\right) = \tfrac{1}{G(\bar{\omega})\sigma_\omega\sqrt{2\pi}}\exp\left[-\left(\frac{ln(\bar{\omega}) - \frac{\sigma_\omega^2}{2}}{\sqrt{2}\sigma_\omega}\right)^2\right]\left[\hat{\bar{\omega}}_t - \left(ln(\bar{\omega}) + \tfrac{\sigma_\omega^2}{2}\right)\hat{\sigma}_{\omega,t}\right] \tag{61}$$

Entrepreneurs

$$\frac{b^E}{Y}\hat{b}_t^E = \frac{c^E}{Y}\hat{c}_t^E + \frac{r^E b^E}{Y}\left[\hat{r}_{t-1}^E + \hat{b}_{t-1}^E - \hat{\pi}_t\right] + \frac{i}{Y}\hat{i}_t + \varepsilon_{k,1}\frac{k}{Y}\hat{u}_t - \frac{\mu}{X}\left[\hat{Y}_t - \hat{X}_t\right] \tag{62}$$

$$\hat{r}_t^E + \hat{b}_t^E = \hat{q}_{t+1}^k + \hat{k}_t + \hat{\pi}_{t+1} \tag{63}$$

$$\hat{\lambda}_t^E = -\frac{1}{1-a_E}\hat{c}_t^E + \frac{a_E}{1-a_E}\hat{c}_{t-1}^E \tag{64}$$

$$\gamma_E\hat{\lambda}_t^E + \hat{q}_t^k = \gamma_E\hat{\lambda}_{t+1}^E + \left(1-\omega\right)\hat{q}_{t+1}^k + \omega\left(\hat{Y}_{t+1} - \hat{X}_{t+1} - \hat{k}_t\right) - \left(1-\gamma_E\right)\left(\hat{r}_t^E - \hat{\pi}_{t+1}\right) \tag{65}$$

$$\hat{r}_t^k = \frac{\varepsilon_{k,2}}{\varepsilon_{k,1}}\hat{u}_t \tag{66}$$

$$\hat{k}_t = (1-\delta)\hat{k}_{t-1} + \delta\hat{i}_t \tag{67}$$

$$\hat{q}_t^k = k_i\left(\Delta\hat{i}_t - \beta_E\Delta\hat{i}_{t+1}\right) \tag{68}$$

Commercial Banks

$$\frac{b^I}{Y}\hat{b}_t^I + \frac{b^E}{Y}\hat{b}_t^E = \frac{d^P}{Y}\hat{d}_t^P + \frac{e^B}{Y}\hat{e}_t^B \tag{69}$$

$$\frac{e^B}{Y}\hat{e}_t^B = \left(\gamma_B - \delta_B\right)\frac{e^B}{Y}\left(\hat{e}_{t-1}^B - \hat{\pi}_t\right) + \left(1-\gamma_B\right)\frac{\Pi^B}{Y}\hat{\Pi}_t^B \tag{70}$$

$$\begin{aligned}\frac{\Pi^B}{Y}\hat{\Pi}_t^B = \quad & \left(1-F\left(\bar{\omega}\right)\right)\tfrac{r^I b^I}{Y}\left[\hat{r}_{t-1}^I + \hat{b}_{t-1}^I - \hat{\pi}_t\right] - F\left(\bar{\omega}\right)\tfrac{r^I b^I}{Y}\hat{F}_t\left(\bar{\omega}_t\right) + \tfrac{r^E b^E}{Y}\left[\hat{r}_{t-1}^E + \hat{b}_{t-1}^E - \hat{\pi}_t\right] \\ & + \left(1-\Theta\right)G\left(\bar{\omega}\right)\tfrac{q^h h^I}{Y}\left[\hat{G}_t\left(\bar{\omega}_t\right) + \hat{q}_t^h + \hat{h}_{t-1}^I\right] - r\tfrac{d^P}{Y}\left[\hat{r}_{t-1} + \hat{d}_{t-1}^P - \hat{\pi}_t\right]\end{aligned} \tag{71}$$

$$\hat{k}_t^B = \hat{e}_t^B - r\hat{w}a_t \tag{72}$$

$$\frac{rwa}{Y}r\hat{w}a_t = rw^I\frac{b^I}{Y}\left(r\hat{w}_t^I + \hat{b}_t^I\right) + rw^E\frac{b^E}{Y}\hat{b}_t^E \tag{73}$$

$$r\hat{w}_t^I = \frac{\Upsilon F(\bar{w})}{rw^I} \hat{F}_{t+1}(\bar{\omega}_{t+1}) \tag{74}$$

$$\begin{aligned} \hat{\phi}_t^k + (1-\sigma_B)\left(\hat{k}_t^B\right) + r\hat{w}_t^I - r\hat{w}a_t = \hat{\lambda}_{t+1}^P - \hat{\lambda}_t^P - r\left[\left(1 - F(\bar{\omega}) + (1-\Theta)\tfrac{G(\bar{\omega})}{m^I}\right) r^I - r\right]^{-1} \hat{r}_t \\ + \frac{\left[-F(\bar{\omega}) r^I \hat{F}_{t+1}(\bar{\omega}_{t+1}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I} r^I \left(\hat{G}_{t+1}(\bar{\omega}_{t+1}) - \hat{m}_t^I\right) + \left(1 - F(\bar{\omega}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I}\right) r^I \hat{r}_t^I\right]}{\left(1 - F(\bar{\omega}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I}\right) r^I - r} - \hat{\pi}_{t+1} \end{aligned} \tag{75}$$

$$\hat{\phi}_t^k + (1-\sigma_B)\left(\hat{k}_t^B\right) - r\hat{w}a_t = \hat{\lambda}_{t+1}^P - \hat{\lambda}_t^P + \left[\frac{r^E}{r^E - r}\right] \hat{r}_t^E - \left[\frac{r}{r^E - r}\right] \hat{r}_t - \hat{\pi}_{t+1} \tag{76}$$

Production Sector

$$\hat{Y}_t = \hat{A}_t + \mu\left(\hat{u}_t + \hat{k}_{t-1}\right) + \alpha(1-\mu)\hat{l}_t^P + (1-\alpha)(1-\mu)\hat{l}_t^I \tag{77}$$

$$\hat{w}_t^P = \hat{Y}_t - \hat{X}_t - \hat{l}_t^P \tag{78}$$

$$\hat{w}_t^I = \hat{Y}_t - \hat{X}_t - \hat{l}_t^I \tag{79}$$

$$\hat{r}_t^k = \hat{Y}_t - \hat{X}_t - \hat{u}_t - \hat{k}_{t-1} \tag{80}$$

$$\hat{m}c_t = \mu\hat{r}_t^k + \alpha(1-\mu)\hat{w}_t^P + (1-\alpha)(1-\mu)\hat{w}_t^I - \hat{A}_t \tag{81}$$

$$\hat{\pi}_t = \beta_P \hat{\pi}_{t+1} + \frac{(1-\theta)(1-\beta_P\theta)}{\theta} \hat{m}c_t \tag{82}$$

The Central Bank

$$\hat{r}_t = r_R \hat{r}_{t-1} + (1-r_R)\left((1+r_\pi)\hat{\pi}_t + r_Y\left(G\hat{D}P_t - G\hat{D}P_{t-1}\right)\right) \tag{83}$$

$$\frac{GDP}{Y} G\hat{D}P_t = \frac{c^P}{Y}\hat{c}_t^P + \frac{c^I}{Y}\hat{c}_t^I + \frac{c^E}{Y}\hat{c}_t^E + \frac{i}{Y}\hat{i}_t \tag{84}$$

Market-Clearing Conditions

$$\hat{Y}_t = \frac{c^P}{Y}\hat{c}_t^P + \frac{c^I}{Y}\hat{c}_t^I + \frac{c^E}{Y}\hat{c}_t^E + \frac{i}{Y}\hat{i}_t + \varepsilon_{k,1}\frac{k}{Y}\hat{u}_t + (1-rec)\Theta G(\bar{\omega})\frac{q^h h^I}{Y}\left(\hat{G}_t(\bar{\omega}_t) + \hat{q}_t^h + \hat{h}_{t-1}^I\right) \tag{85}$$

$$\hat{h}_t^P = -\frac{h^I}{h^P}\hat{h}_t^I \tag{86}$$

Shocks

$$\hat{\sigma}_{\omega,t} = \rho_\omega \hat{\sigma}_{\omega,t-1} + \hat{\varepsilon}_t^\omega \tag{87}$$

$$\hat{\phi}_t^k = \rho_A \hat{\phi}_{t-1}^k + \hat{\varepsilon}_t^k \tag{88}$$

$$\hat{A}_t = \rho_A \hat{A}_{t-1} + \hat{\varepsilon}_t^A \tag{89}$$

Steady State

This subsection shows how the steady-state rates and ratios that show up in the log-linearised model above are computed. By targeting the steady-state LTV ratio, we can conveniently compute the steady state of this economy as follow:

$$\bar{\omega} = m^I$$
$$r = \frac{1}{\beta_P}$$
$$r^I = \frac{1}{\beta_I\left(1-F(\bar{\omega})+\frac{G(\bar{\omega})}{m^I}\right)}$$
$$r^E = \left[\left(1-F\left(\bar{\omega}\right)+\left(1-\Theta\right)\frac{G(\bar{\omega})}{m^I}\right)r^I - r\right]\frac{rw^E}{rw^I} + r$$
$$X = \frac{\varepsilon}{\varepsilon-1}$$
$$\frac{k}{Y} = \frac{\beta_E}{\omega}\frac{\mu}{X}$$
$$\frac{i}{Y} = \delta\frac{k}{Y}$$
$$\frac{b^E}{Y} = \frac{m^E(1-\delta)}{r^E}\frac{k}{Y}$$
$$\frac{c^E}{Y} = \frac{\mu}{X} + \left(1-r^E\right)\frac{b^E}{Y} - \frac{i}{Y}$$
$$\frac{c^I}{Y} = \frac{\beta_I r^I}{\beta_I r^I + m^I j}\frac{(1-\alpha)(1-\mu)}{X}$$
$$\frac{q^h h^I}{Y} = \frac{j}{1-\beta_I}\frac{c^I}{Y}$$
$$\frac{b^I}{Y} = \frac{m^I}{r^I}\frac{q^h h^I}{Y}$$
$$\frac{c^P}{Y} = 1 - \frac{c^I}{Y} - \frac{c^E}{Y} - \frac{i}{Y} - \left(1-rec\right)\Theta G\left(\bar{\omega}\right)\frac{q^h h^I}{Y}$$
$$\frac{q^h h^P}{Y} = \frac{j}{1-\beta_P}\frac{c^P}{Y}$$
$$\frac{rwa}{Y} = rw^I\frac{b^I}{Y} + rw^E\frac{b^E}{Y}$$
$$\frac{d^P}{Y} = \frac{\left[(1+\delta_B-\gamma_B)\left(\frac{b^I}{Y}+\frac{b^E}{Y}\right)-(1-\gamma_B)((1-F(\bar{\omega}))\frac{r^I b^I}{Y}+(1-\Theta)G(\bar{\omega})\frac{q^h h^I}{Y}+\frac{r^E b^E}{Y})\right]}{[1+\delta_B-\gamma_B-(1-\gamma_B)r]}$$
$$\frac{\Pi^B}{Y} = \left(1-F\left(\bar{\omega}\right)\right)\frac{r^I b^I}{Y} + \left(1-\Theta\right)G\left(\bar{\omega}\right)\frac{q^h h^I}{Y} + \frac{r^E b^E}{Y} - r\frac{d^P}{Y}$$
$$\frac{e^B}{Y} = \frac{b^I}{Y} + \frac{b^E}{Y} - \frac{d^P}{Y}$$
$$k^B = \frac{e^B}{Y}/\frac{rwa}{Y}$$

10.3 Tables

Table 7: Household and Bank Balance Sheet (end of 2015)

Household liabilities			Private Depository Institutions Assets		
	Amount	Percent		Amount	Percent
Total	14,520		Total	17,372.7	
Debt Securities	218	1.50%	Vault Cash	74.2	0.43%
Loans	14,012.1	96.50%	Reserves at Federal Reserve	1,977.2	11.38%
- Home Mortgages	9,493.8	65.38%	Federal Funds and Repo	428.4	2.47%
- Consumer Credit	3,534.6	24.34%	Debt Securities	3,865.4	22.25%
- Depository Institution Loans	325.8	2.24%	- GSE- Backed Securities	2,125.2	12.23%
- Other Loans and Advances	437.4	3.01%	Loans	9,755.5	56.15%
- Commercial Mortgages	220.5	1.52%	- Depository Institution Loans	3,206.4	18.46%
Trade Payables	259.4	1.79%	- Mortgages	4,779.1	27.51%
Deferred and Unpaid Life Insurance Premiums	30.6	0.21%	- Consumer Credit	1,770.1	10.19%
			Corporate Equities	100	0.58%
			Mutual Fund Shares	56.8	0.33%
			Life Insurance Reserves	156.2	0.90%
			Direct Investment Abroad	241.8	1.39%
			Miscellaneous Assets	717.3	4.13%

Unit: billion USD
Source: US Flow of Funds Accounts

Table 8: Important Rates and Ratios at the Steady State

Variable	Description	Benchmark Model	LTV Model	
			$\widetilde{m}^I$=0.675	$\widetilde{m}^I$=0.65
GDP	Gross Domestic Product	2.349	2.347	2.346
$F(\omega)$	Mortgage default probability	2.007 %	1.160 %	0.628 %
m^I	Loan-to-value ratio	70.00 %	67.50 %	65.00 %
r	Deposit interest rate	3.673 %	3.673 %	3.673 %
r^I	Mortgage interest rate	6.800 %	5.826 %	5.216 %
r^E	Business loan interest rate	7.736 %	7.800 %	7.825 %
$\frac{b^I}{b^I+b^E}$	Proportion of mortgages	57.26 %	54.44 %	54.48 %
$\frac{b^I}{Y}$	Mortgages to output	170.1 %	151.6 %	151.7 %
$\frac{b^E}{Y}$	Business loans to output	127.0 %	126.9 %	126.8 %
$\frac{c^P}{Y}$	PH's consumption to output	52.96 %	52.52 %	52.41 %
$\frac{c^I}{Y}$	IH's consumption to output	19.24 %	19.82 %	20.00 %
$\frac{c^E}{Y}$	Entrepreneur's consumption to output	10.95 %	10.95 %	10.94 %
$\frac{i}{Y}$	Investment to output	16.59 %	16.58 %	16.58 %
$\frac{\Theta G(\omega) q^h h^I}{Y}$	Monitoring cost to output	0.523 %	0.270 %	0.147 %
$\frac{q^h h^P}{Y}$	PH's housing demand to output	1164 %	1154 %	1152 %
$\frac{q^h h^I}{Y}$	IH's housing demand to output	247.1%	227.8 %	236.5 %
k^B	Bank capital ratio	8.000 %	8.126 %	8.177 %

Note: $\beta_I = 0.984$ in the benchmark model while $\beta_I = 0.975$ in all models with LTV caps

10.4 Figures

The impulse responses of inflation, mortgage default probability, deposit interest rate, mortgage spread, business loan spread, capital adequacy ratio, credit to GDP ratio and mortgages to GDP ratio are expressed in terms of absolute deviations from the steady state. The rest is expressed in terms of percentage deviations.

Figure 4: Response of the Benchmark Economy to Standard Macroeconomic Shocks

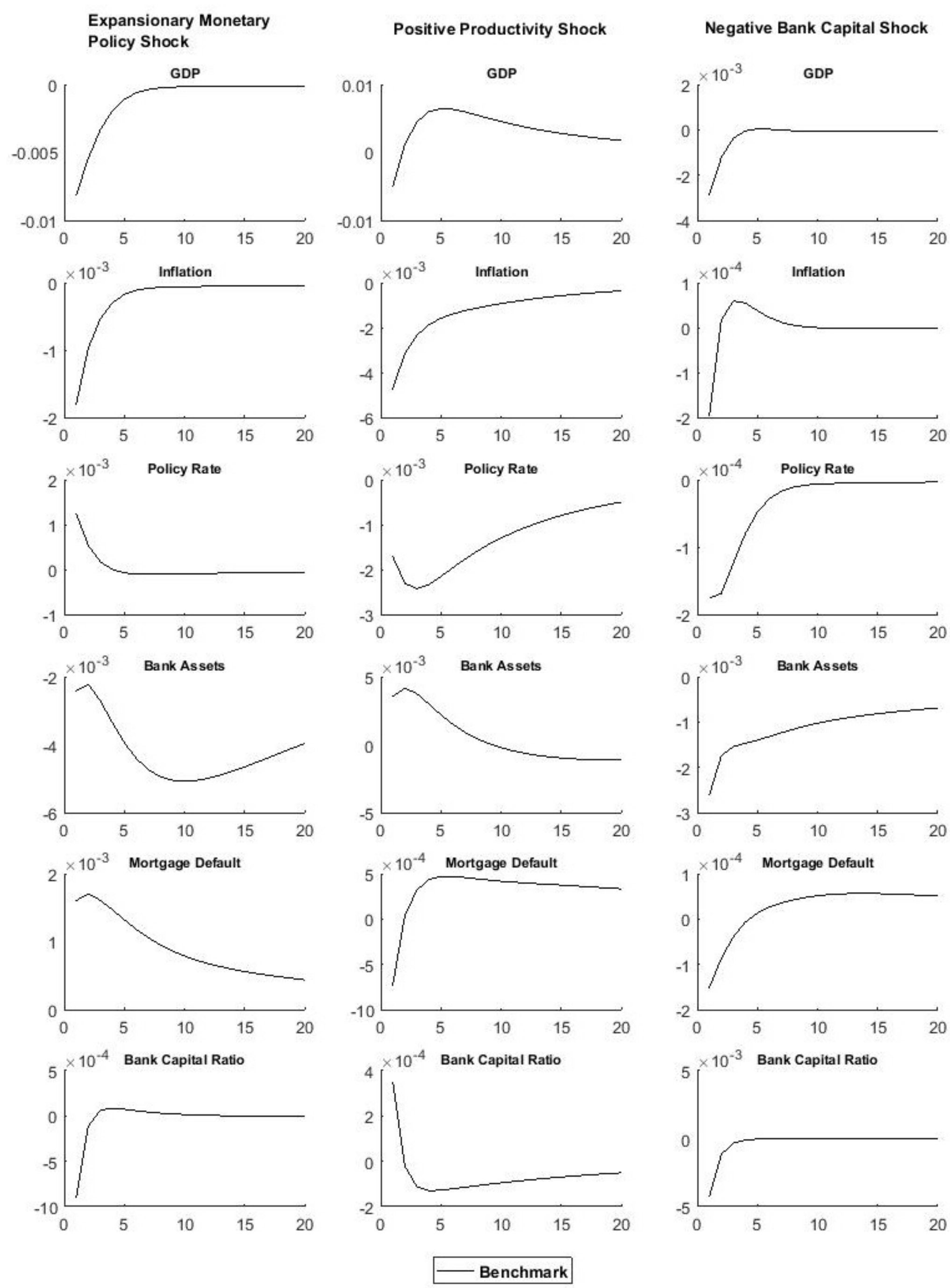
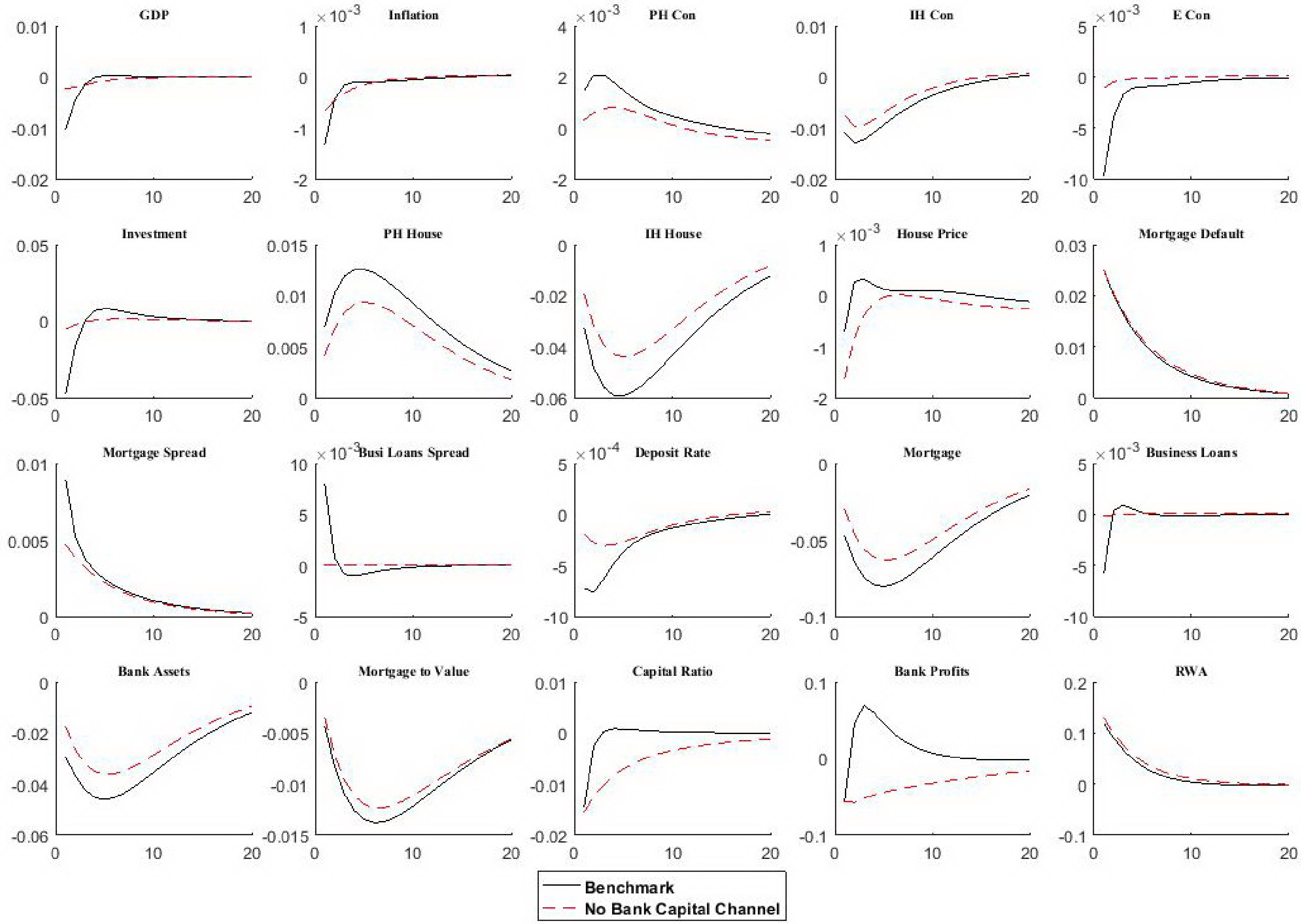
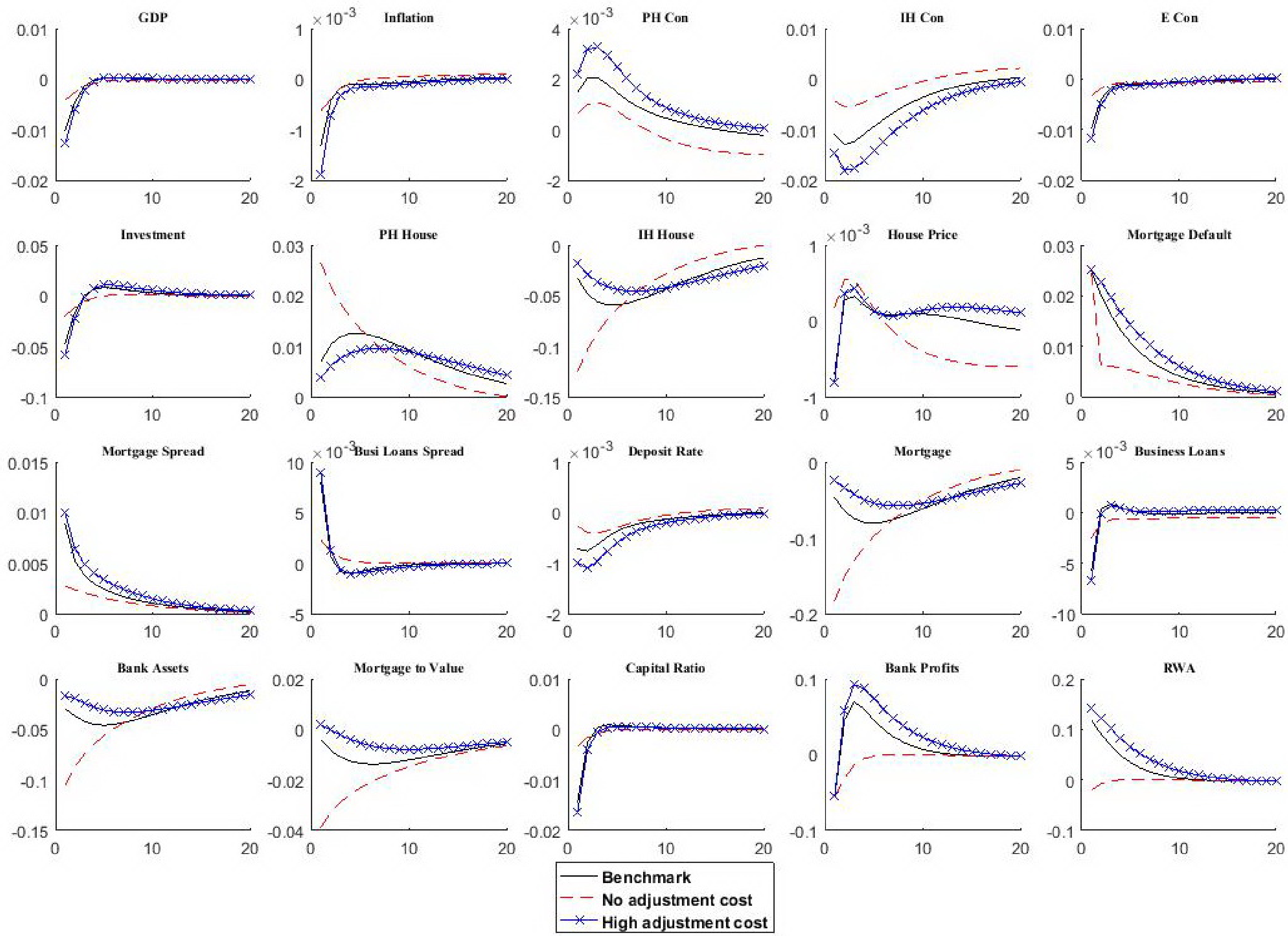


Figure 5: Response of the Economy to Housing Risk Shocks (1)



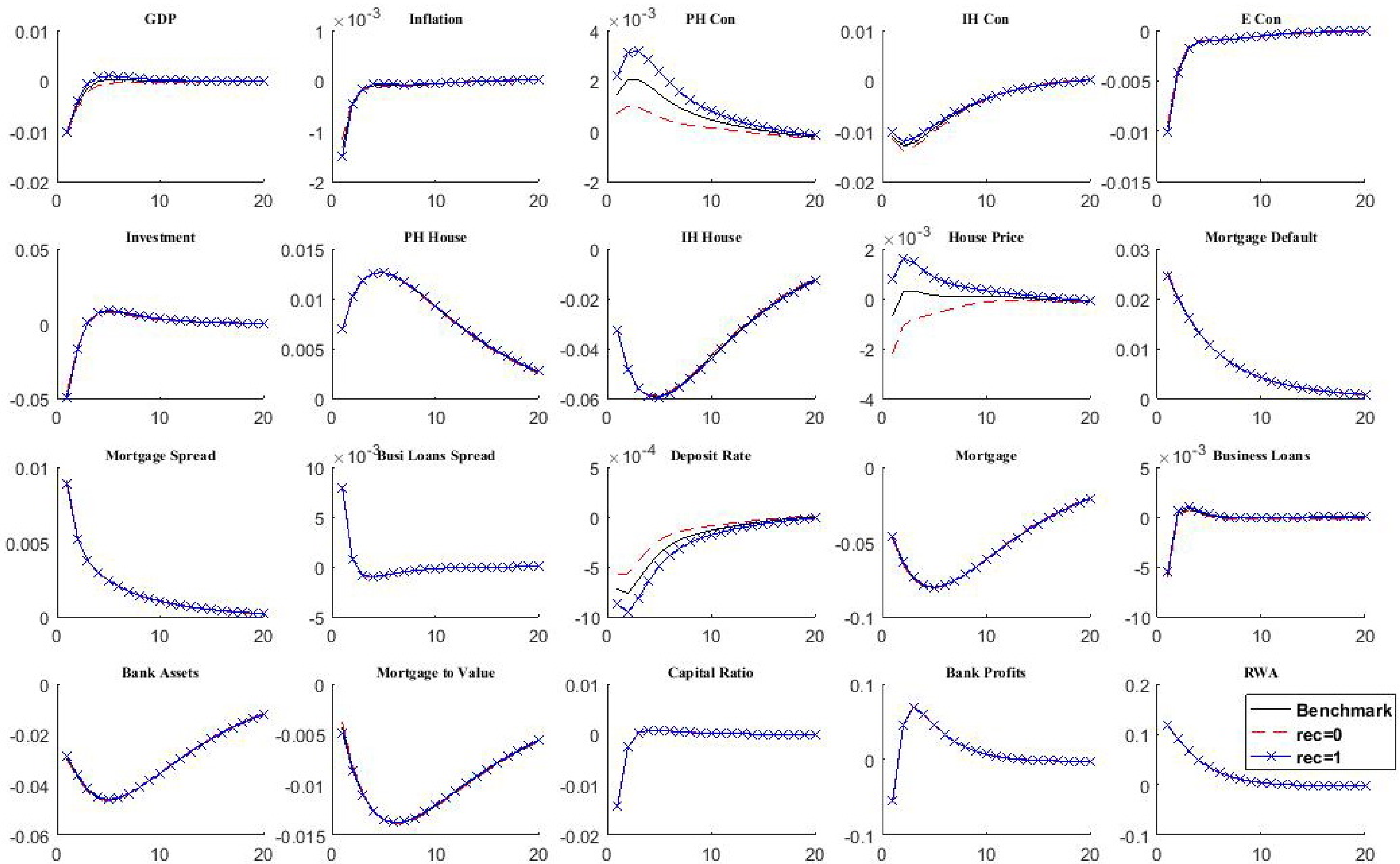
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy assuming no impact of capital regulations on interest rate spreads.

Figure 6: Response of the Economy to Housing Risk Shocks (2)



Note: the black solid line shows the response of the benchmark economy ($\phi_h = 0.5$). The red dashed line shows the response of the economy assuming no housing adjustment cost ($\phi_h = 0$). The crossed blue line shows the response of the economy assuming high adjustment cost ($\phi_h = 1$).

Figure 7: Response of the Economy to Housing Risk Shocks (3)



Note: the black solid line shows the response of the benchmark economy ($rec = 0.5$). The red dashed line shows the response of the economy assuming zero recovery of the monitoring cost ($rec = 0$). The crossed blue line shows the response of the economy assuming full recovery ($rec = 1$).

Figure 8: Response of the Benchmark Economy to Risk Premium Shocks

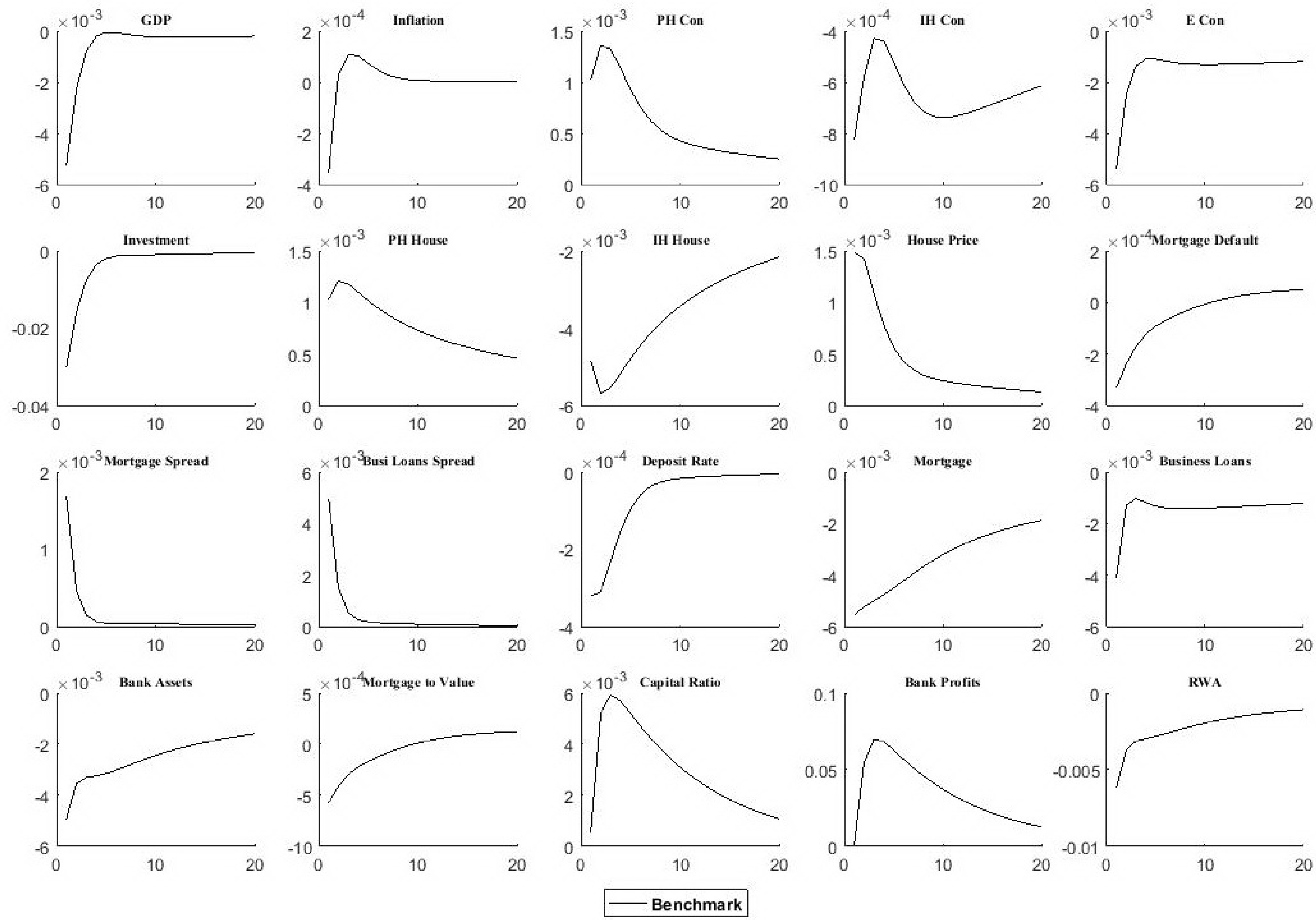
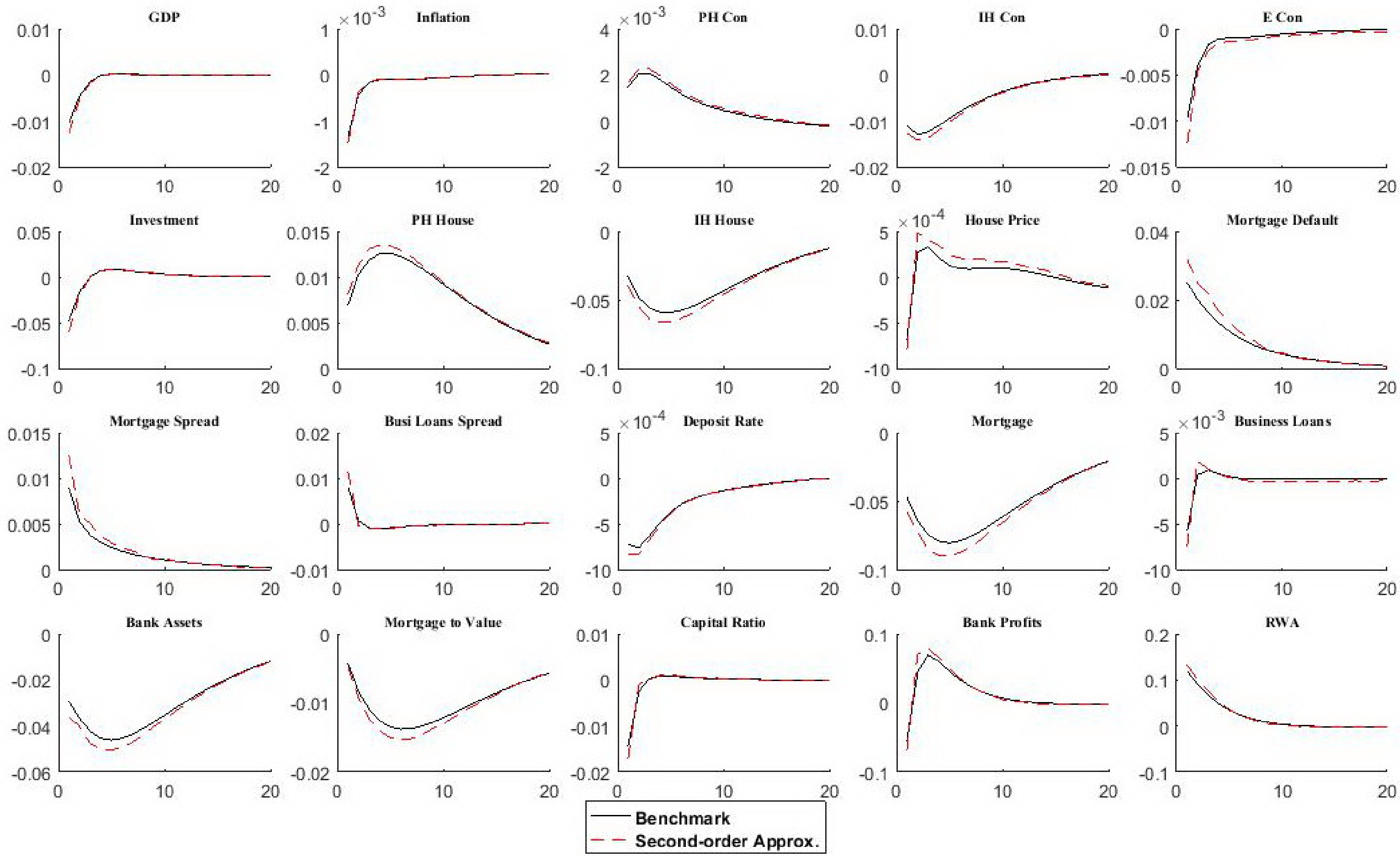
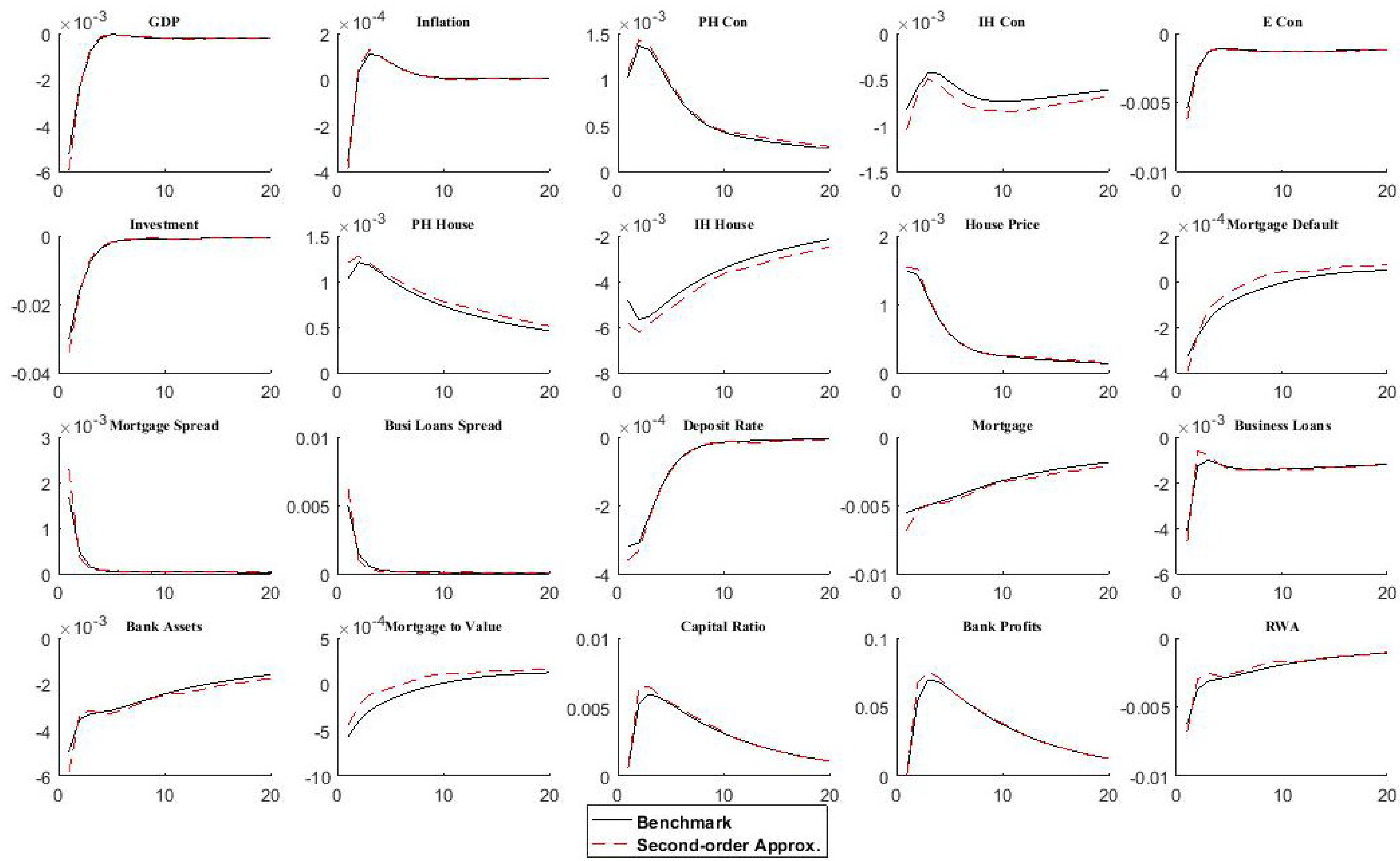


Figure 9: Response of the Economy to Housing Risk Shocks (4)



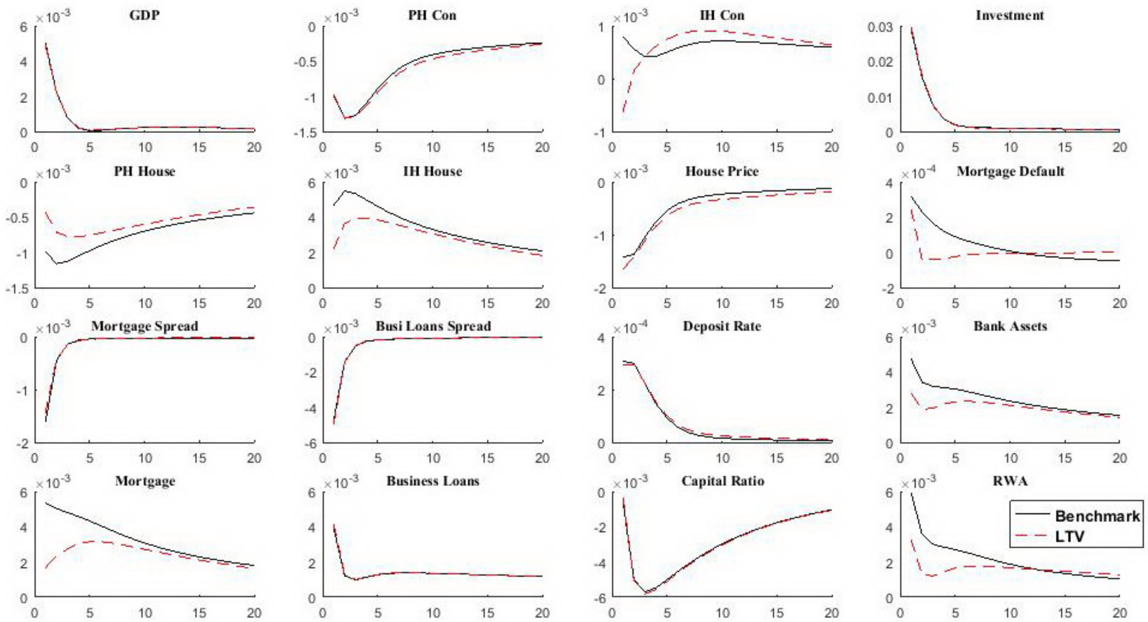
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy using second-order approximation.

Figure 10: Response of the Benchmark Economy to Risk Premium Shocks



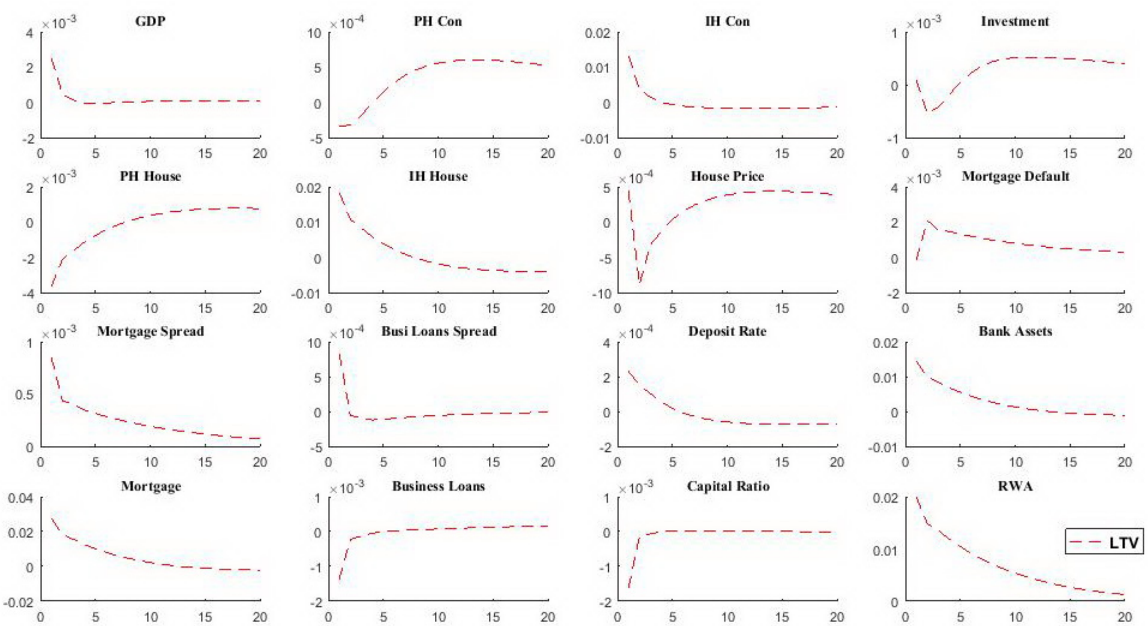
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy using second-order approximation.

Figure 11: Response of the Economy to Capital Adequacy Ratio Shocks (Benchmark VS LTV)



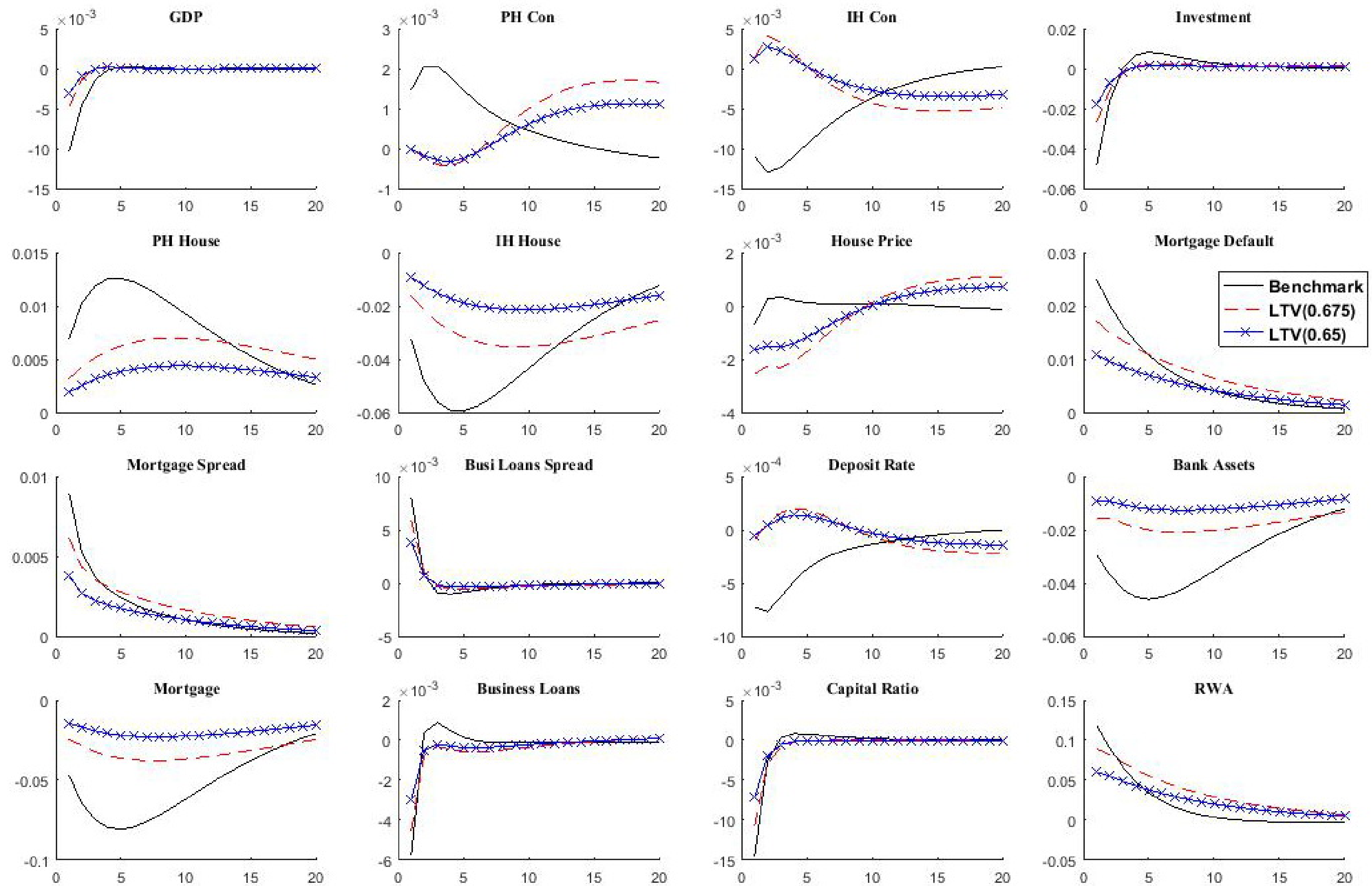
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy with LTV caps.

Figure 12: Response of the Economy to LTV Caps Shocks



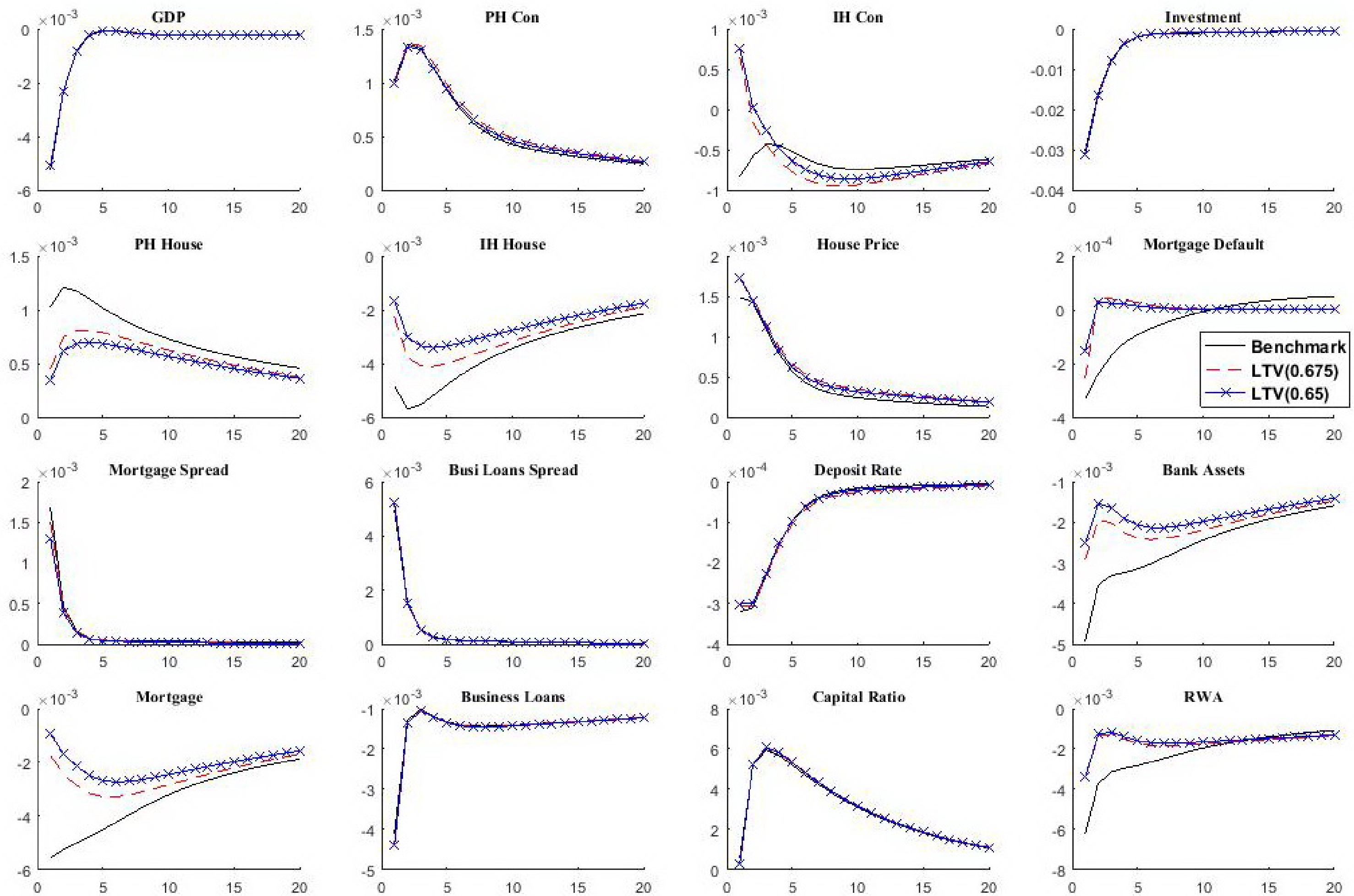
Note: the red dashed line shows the response of the economy with LTV caps.

Figure 13: Response of the Economy to Housing Risk Shocks (Benchmark VS LTV)



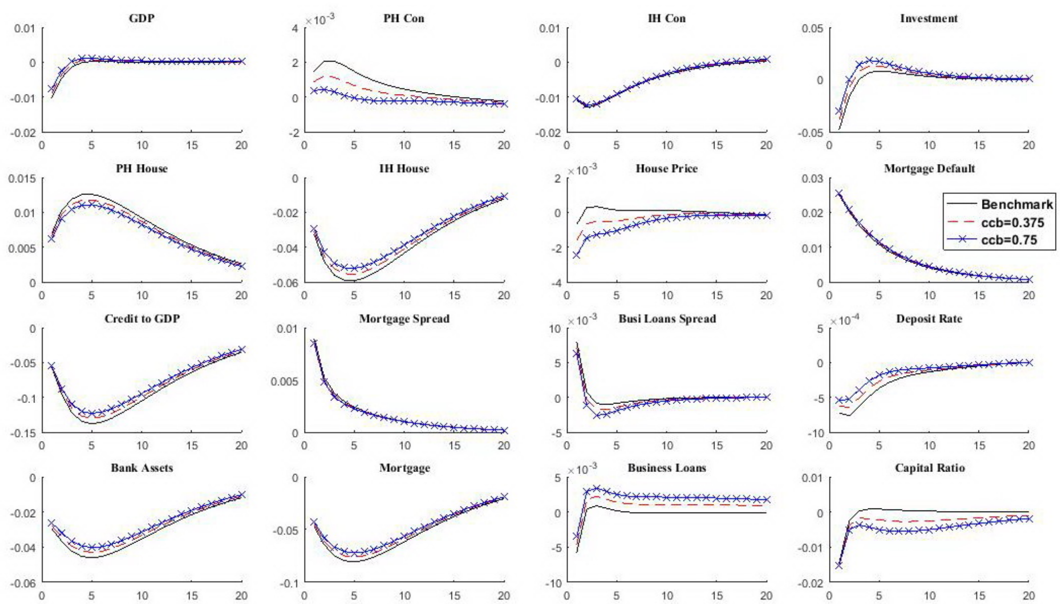
Note: the black solid line shows the response of the benchmark economy. The red dashed line and blue crossed line show the response of the economy with LTV caps $\widetilde{m}^I = 0.675$ and $\widetilde{m}^I = 0.65$, respectively.

Figure 14: Response of the Economy to Risk Premium Shocks (Benchmark VS LTV)



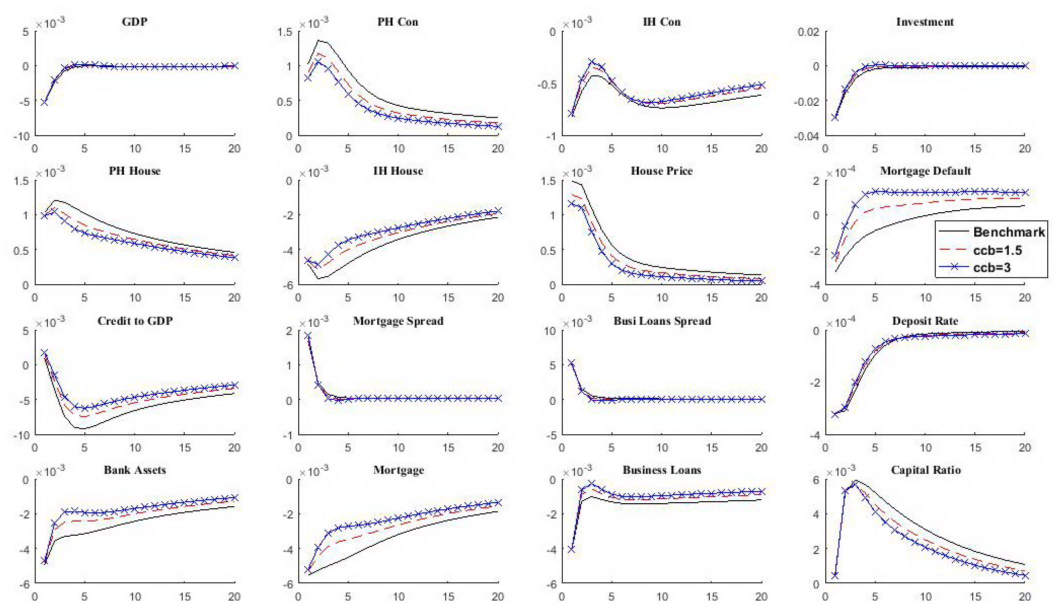
Note: the black solid line shows the response of the benchmark economy. The red dashed line and blue crossed line show the response of the economy with LTV caps $\widetilde{m}^I = 0.675$ and $\widetilde{m}^I = 0.65$, respectively.

Figure 15: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Housing Risk Shocks (Benchmark Model)



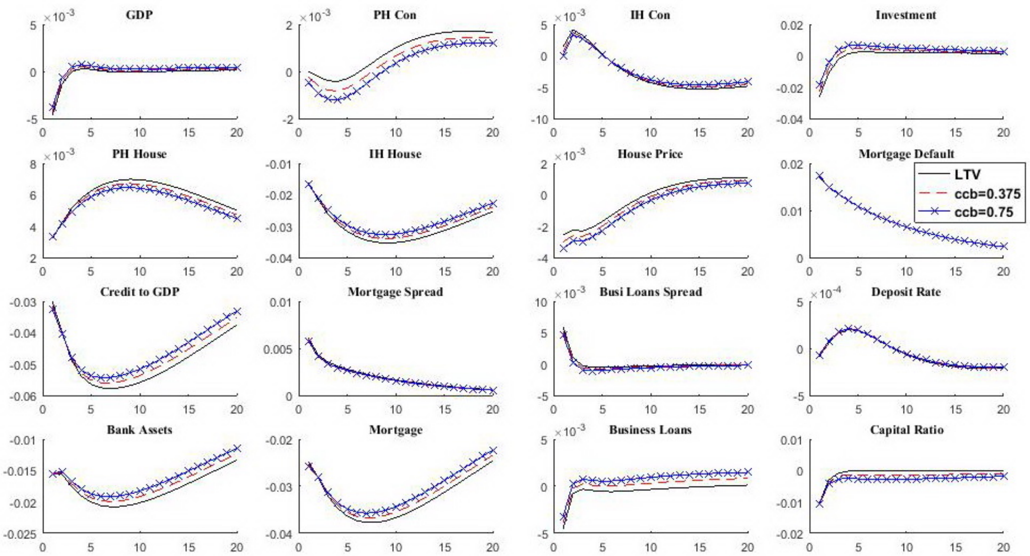
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 0.375$ and $\Phi_k = 0.75$, respectively.

Figure 16: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Risk Premium Shocks (Benchmark Model)



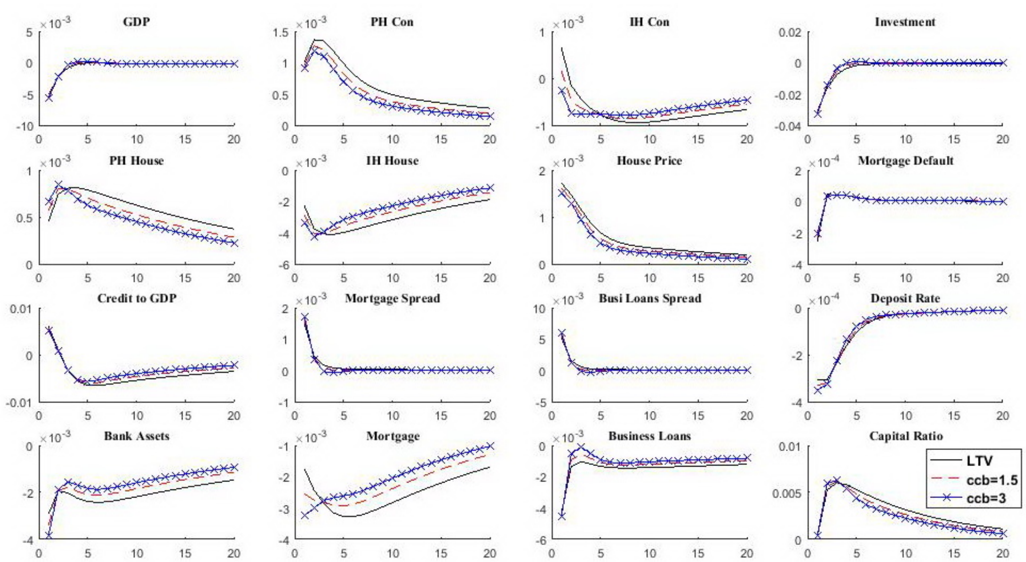
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 1.5$ and $\Phi_k = 3.0$, respectively.

Figure 17: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Housing Risk Shocks (LTV Model)



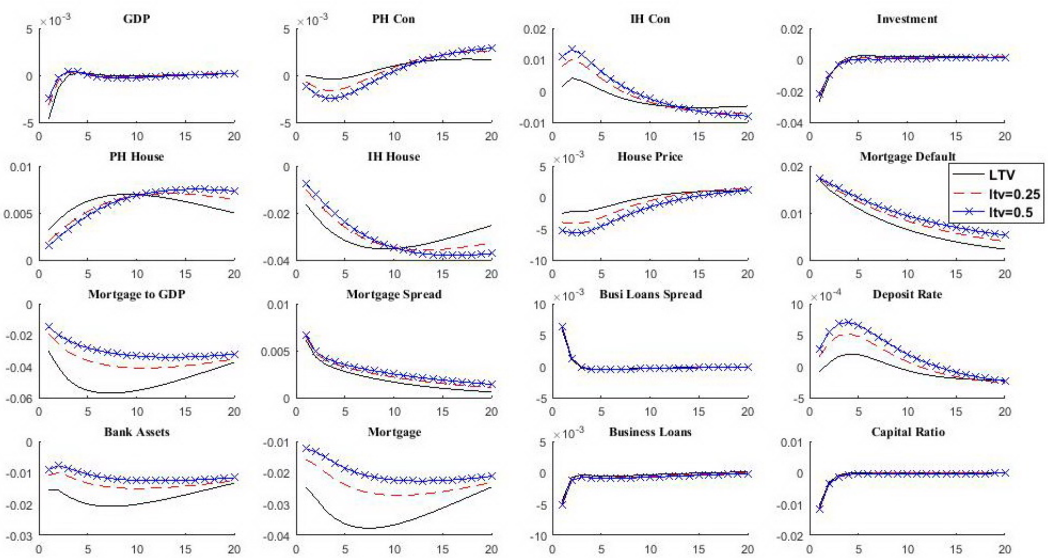
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 0.375$ and $\Phi_k = 0.75$, respectively.

Figure 18: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Risk Premium Shocks (LTV Model)



Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 1.5$ and $\Phi_k = 3.0$, respectively.

Figure 19: Assessing the Effectiveness of State-contingent LTV Ratio in the Event of Housing Risk Shocks (LTV Model)



Note: The red dashed and the crossed blue lines show the response of the economy with state-contingent LTV ratio with $\Phi_m = 0.25$ and $\Phi_m = 0.5$, respectively.