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Securitization of subprime credit and the propagation of housing shocks

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ABSTRACT

The 2007–2009 global financial crisis which originated in the U.S. subprime mortgage market and then spread to the whole financial system, drew attention to the impact that subprime lending and subprime mortgage securitization can have on the real economy. This paper explores the dynamics of the economy with a subprime mortgage market and the financial innovation in that sector when housing shocks arise. I develop a DSGE model with different types of borrowers and a shadow banking sector that is involved in subprime lending and securitization activities. The model shows that the process of securitizing risky credit amplifies the propagation of housing shocks in the economy through creating a link between the financial sector and the real sector.

1. Introduction

The 2007–2009 global financial crisis, which originated in the U.S. financial system and quickly spread into the global financial markets, provoked a sharp economic downturn in the world economy that came to be labelled as the "Great Recession". In August 2007, financial markets and institutions all over the world were hit by the negative developments that started earlier in the U.S. subprime mortgage market. Consequently, financial institutions wrote-off billions of dollars' worth of losses, consumer spending plunged, investor confidence was shaken, and stock markets plummeted. At the roots of this financial crisis were the subprime mortgage market and the processes of securitization and re-securitization of subprime mortgage contracts. In fact, subprime mortgage securitization that had been a relatively small niche market in the early 1990′s was soon transformed into a core activity of the U.S. financial sector during the decade that followed.

The sensitivity of the U.S. subprime mortgage market to the developments in the housing market became evident in the second half of 2006 and early 2007. With falling house prices and decreasing housing demand, the performance of subprime mortgage loans suddenly and substantially deteriorated (Federal Reserve Bank of San Francisco, 2008). In fact, as house prices growth turned negative, the burden on subprime mortgage debt became too heavy for borrowers who had no choice but to default on their loan obligations. Trouble in the subprime mortgage market started with early payment defaults, which were soon followed by rising subprime delinquency and foreclosure rates. By the years 2007 and 2008, the U.S. subprime mortgage industry started collapsing with a growing number of home owners falling behind their mortgage payments and an unprecedented rise in foreclosure rates. As such, the subprime mortgage crisis revealed that house prices matter to the performance of subprime mortgages (See Fig. 1) and several studies since then

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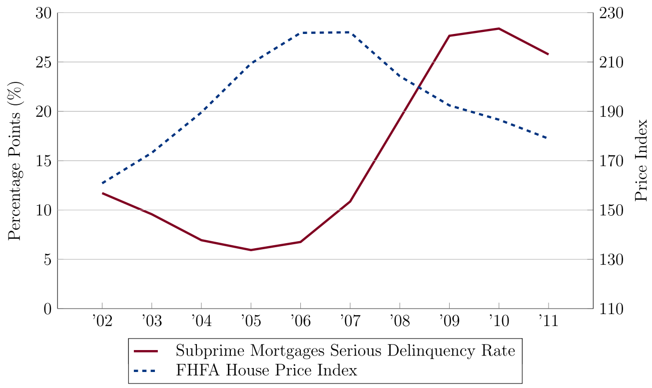

Fig. 1. Evolution of U.S. Subprime Mortgage Default and House Prices. Sources: Author's calculations; Mortgage Bankers Association; The Federal Housing Finance Agency.

have shown that house prices constitute a major determinant of subprime mortgage default.[1]

Against this background, this paper examines the role of the subprime mortgage market and the financial innovation in that sector in the transmission of business cycles. Since the negative developments in the subprime mortgage market were the initiating factors of the Great Recession, I examine how the issuance and securitization of risky credit affect the propagation of negative housing shocks to the economy. I build on Gerali et al. (2010) Dynamic Stochastic General Equilibrium (DSGE) model and add a shadow banking sector to the financial market that is involved in subprime lending and securitization activities. Subprime mortgages are assumed to be risky as subprime borrowers exhibit an inherent risk of default on loan obligations that is sensitive to the developments in the housing market. The issuance of subprime loans is financed through the securitization of this risky credit. The subprime mortgage-backed securities are assumed to be pass-through securities and are structured into two tranches – senior and equity – that differ in their priority claims. I then examine how shocks to the housing market influence the developments in the rest of the economy in the model with subprime lending and securitization compared to a benchmark model in which these features are absent. As such, the main goal of the paper is to explore the dynamic behavior of the economy with subprime mortgage-backed securities when housing shocks arise. Yet, the paper does not take a definitive stance on whether the net contribution of the subprime lending market was a net positive or a negative. Instead, we examine how shocks to the housing market are transmitted through the economy when such securities are present.

The results reveal that the responses of key macroeconomic and financial variables to negative housing shocks hitting the economy are amplified in the presence of subprime mortgage lending and securitization. Through the process of securitizing risky credit, losses incurred on the risky mortgages portfolio following negative shocks to the housing market are transferred to the investors in the mortgage-backed securities. Particularly, investors in the equity tranche of these securities face the biggest losses on their investment portfolio and this translates into lower investment and consumption in the economy. Furthermore, as commercial banks also hold a position in the risky securities, the decline in value of mortgage-backed securities following a negative housing shock results in lower value of commercial bank assets. As these banks face a target capital requirement, the fall in the value of assets implies that these banks should undergo a necessary period of deleverage and balance sheet adjustment in order to restore their capital-adequacy ratio. Deleveraging thus involves the crowding-out of business loans, which puts further constraint on investment in the economy.

This work is connected to two strands of the literature. One strand incorporates a role for financial intermediaries in general equilibrium macroeconomics. Prominent examples in the literature include Kiyotaki & Moore (1997), Iacoviello (2005), Goodfriend & McCallum (2007), Cùrdia and Woodford (2009), Gerali et al. (2010) and Gertler & Karadi (2011). The second strand focuses on heterogeneity in the financial system and incorporates shadow banking and securitization within a general equilibrium framework. Verona et al. (2011) introduce heterogeneity into the financial system by incorporating a distinct class of financial intermediaries, labelled shadow banks, into a standard New Keynesian DSGE model and find that a monetary policy shock has a persistent pro-cyclical effect on the growth of commercial bank assets, whereas it has a counter-cyclical effect of shadow banks' securitization activity. Meeks et al. (2013) develop a DSGE model in which commercial banks can offload risky loans to shadow banks and show that high leverage in the shadow banking sector results in excess vulnerability of the economy to aggregate disturbances. Hobijn & Ravenna (2010) augment a standard New Keynesian model with an imperfect credit market and endogenous loan securitization to show that endogenous loan securitization amplifies the transmission of monetary policy shock in the economy when compared to a standard New Keynesian model. Grodecka-Messi (2019) investigates the impact of securitization of subprime loans on the economy and shows that the securitization of subprime loans can be stabilizing or destabilizing to the economy depending on the buyers of the securities.

The paper proceeds as follows. Section 2 describes the structure and derives the model. In Section 3, the calibration of the model to U.S. data is described. Section 4 reports the dynamics of the model in response to housing shocks while Section 5 demonstrates the

[1] In a study by Gerardi et al. (2007), the authors conclude that house prices have been the main driver of the rising foreclosure rates during the U. S. subprime mortgage crisis.

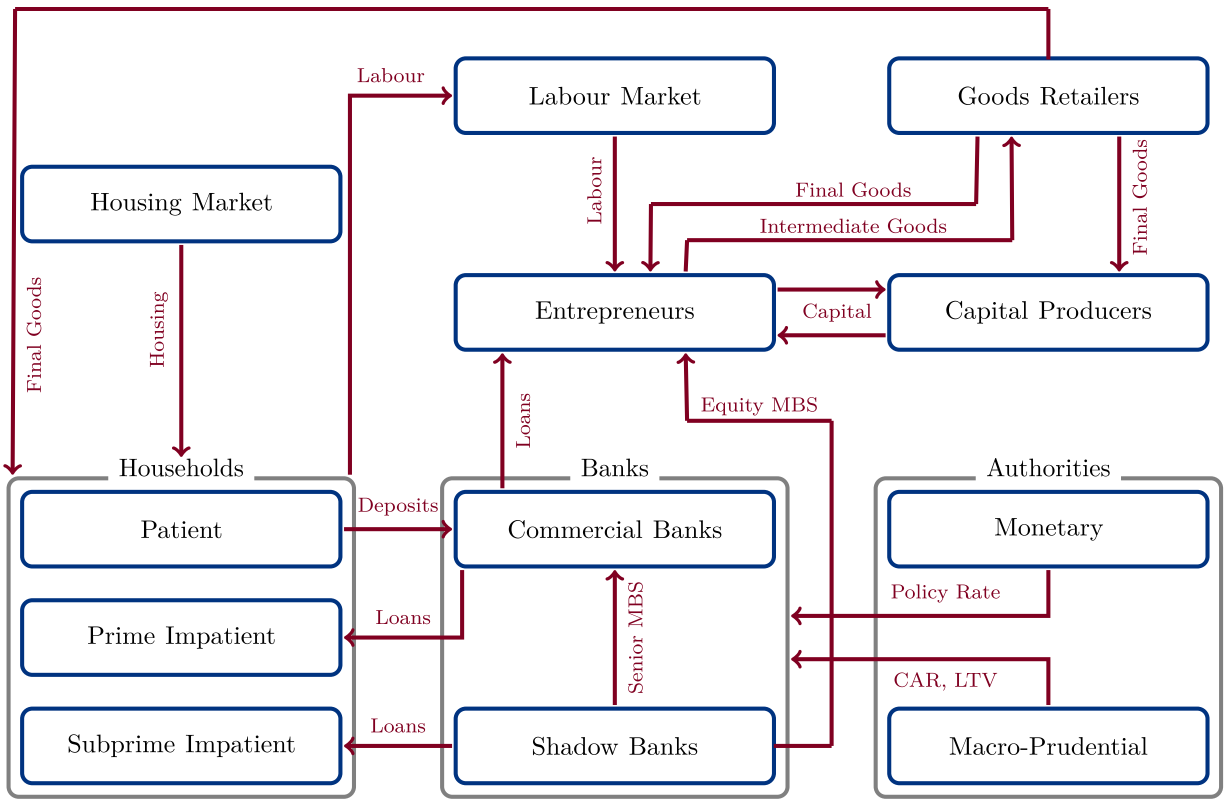

Fig. 2. Structure of the DSGE Model.

sensitivity of housing shocks' propagation to some model parameters. Section 6 highlights some future extensions to the modeling framework and Section 7 summarizes the results and concludes.

2. The model

I augment the Dynamic Stochastic General Equilibrium model developed by Gerali et al. (2010) with a shadow banking sector that has some elements of its structure similar to Grodecka-Messi (2019). There are three types of households (patient, prime impatient, and subprime impatient) and entrepreneurs in the economy. Households purchase consumption goods, supply labour and accumulate housing, while entrepreneurs purchase physical capital from capital goods producers in order to produce homogeneous intermediate goods. The heterogeneity in the degree of impatience among these households and entrepreneurs (reflected in the difference in discount factors) results in patient households saving through providing deposits, while impatient households and entrepreneurs borrowing through taking loans. When taking out loans, impatient households and entrepreneurs face a borrowing constraint à la Iacoviello (2005), linked to the value of their housing and physical capital, respectively. While prime impatient households and entrepreneurs repay their loans in full, subprime impatient households exhibit an inherent risk of default on loan obligations.

The banking industry is composed of a continuum of commercial banks and shadow banks. Commercial banks supply two financial instruments: saving contracts (deposits) to patient households and borrowing contracts (loans) to prime impatient households and entrepreneurs. Additionally, commercial banks invest in the senior tranche of the mortgage-backed securities issued by shadow banks. Meanwhile, shadow banks provide loans to subprime impatient households, and finance the loans issuance through securitization. The mortgage-backed securities are pass-through securities, in the sense that the proceeds from the securitized loans are passed to the investors in these securities. The structure of these securities consists of two tranches: a senior tranche sold to commercial banks and an equity tranche sold to entrepreneurs. Unlike Grodecka-Messi (2019) in which subprime lenders are assumed to securitize a fixed fraction of the issued loans each period and sell them to investors, the decisions of shadow banks to securitize loans and investors to invest in mortgage-backed securities are determined endogenously in this model. Both commercial banks and shadow banks enjoy some market power in setting interest rates on deposits and loans, and the prices of mortgage-backed securities. Further, the capitals of commercial and shadow banks accumulate out of profits.

Fig. 2 illustrates the interactions among the agents in the economy. In what follows, I describe the main features of the model and consign the common features with Gerali et al. (2010) to the Online Appendix.

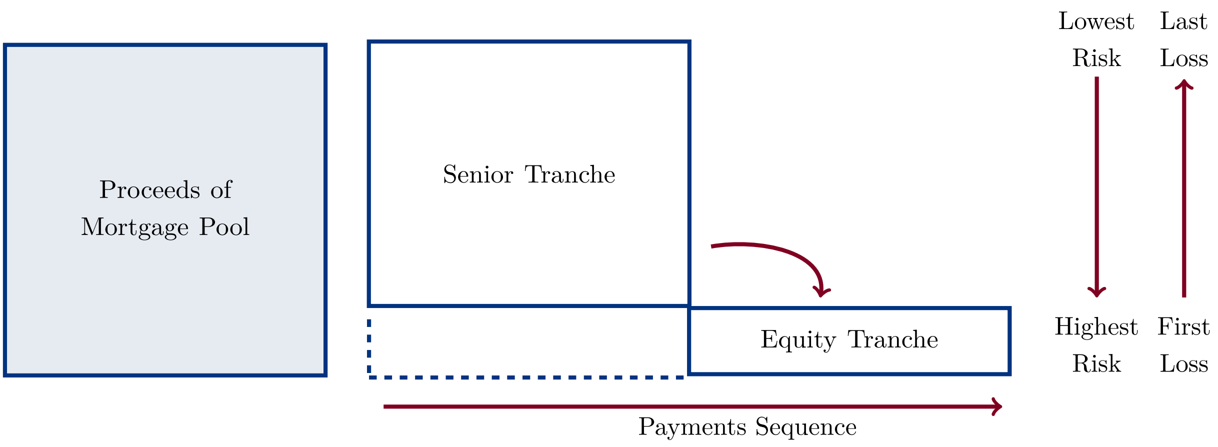

Fig. 3. Tranching of Mortgage-Backed Securities.

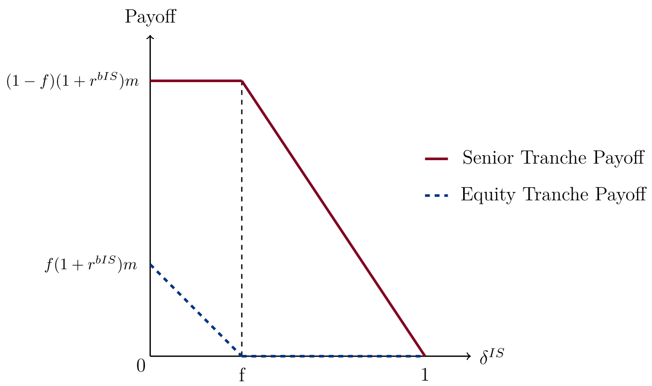

Fig. 4. Payoff of Mortgage-Backed Securities Tranches.

2.1. Mortgage-backed securities

Mortgage-backed securities are "debt obligations that represent claims to the cash flows from pools of mortgage loans, most commonly on residential property" (Hayre, chap. 1, 2001). Mortgage-backed securities exhibit a variety of structures. The basic structure is the pass-through in which principal and interest payments (net of servicing fees) from the pool of mortgage loans are passed on to the holders of the securities (Hayre & Young, 2004). More complicated structures include collateralized mortgage obligations, principal-only STRIPs and interest-only STRIPs that modify the cash flow structure to create securities with different prepayment and maturity profiles (Kane, chap. 2, 2001). In the model, mortgage-backed securities are pass-through. Hence, investors in these securities, in effect, buy claims on the cash flows of the underlying loans.

One characteristic of securitization is that it allows credit risk sharing among different markets. In the model, shadow banks engage in credit risk transfer where the risk of default is shared among shadow banks and the investors in the mortgage-backed securities. The involvement of shadow banks in securitization leads to an increase in subprime lending, making it possible for individuals with low credit ratings to obtain housing loans, thus expanding the subprime mortgage market. However, in case of subprime mortgage defaults, the losses from the subprime mortgage portfolio has a negative impact on the real economy as investors in mortgage-backed securities incur losses.

An appeal of securitization is the diversification of risk due to the exposure to a broad pool of obligations with different default probabilities (Luttrell et al., 2012). In the model, subprime impatient households in the model have the same default rate. As such, while subprime borrowers may have differing probability of default at the individual level, the model's default rate represents the mean of the aggregate distribution of the subprime default rate.

Another characteristic of mortgage-backed securities is that they enable risk distribution through dividing the mortgage pool into tranches (Luttrell et al., 2012). These tranches are ranked hierarchically: the highest tranches have seniority of claim over subordinated securities. Following Grodecka-Messi (2019), the mortgage-backed securities in the model consist only of two tranches: a senior tranche and an equity tranche. The size of the equity tranche determines its degree of subordination and the maximum risk exposure of investors in this tranche. Furthermore, these securities exhibit a waterfall payment structure where the proceeds from the mortgage pool are paid first to the senior tranche then to the equity tranche. Fig. 3 illustrates the waterfall structure of the securities in the model.

Under the waterfall structure, the payoff of the senior tranche is given by:

$$\Pi_t^s = \min\left(1-f, 1-\delta_{t+1}^{IS}\right) \times \left(1+r_t^{bIS}\right)m_t \tag{1}$$

where f is the size of the equity tranche, δ_t^{IS} is the default rate, r_t^{bIS} is the subprime loans' net interest rate, and m_t is the total value of mortgage-backed securities. Accordingly, if the total loss on the loan portfolio due to default is less than the equity tranche's size, then the senior tranche is paid in full. Meanwhile, if the default rate exceeds equity tranche's size, the payoff of investors in the senior tranche of the mortgage-backed securities is reduced.

The payoff of the equity tranche is given by:

$$\Pi_t^e = \max\left(f-\delta_{t+1}^{IS}, 0\right) \times \left(1+r_t^{bIS}\right)m_t \tag{2}$$

If the rate of default on subprime loans is lower than the equity tranche's size, the payoff of investors in this tranche is a portion, equal to the size of the tranche less the default rate, of the total proceeds on the securitized mortgage pool. Otherwise, if the default rate exceeds the equity tranche's size, investors in this tranche would not earn a payoff. Fig. 4 illustrates the payoff structure of the tranches of the mortgage-backed securities.

2.2. Patient households

The representative patient household i maximizes the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1-a^P)\varepsilon_t^c \log\left(c_t^P(i) - a^P c_{t-1}^P\right) + \varepsilon_t^h \gamma_h \log h_t^P(i) - \frac{l_t^P(i)^{1+\phi}}{1+\phi} \right] \tag{3}$$

which is a function of current individual consumption of final goods $c_t^P(i)$, lagged aggregate consumption c_{t-1}^P, housing $h_t^P(i)$ (where γ_h represents the weight of housing services in the household's utility), and hours worked $l_t^P(i)$. Following Gerali et al. (2010), consumption exhibits external and group-specific habits, where a^P is the habit formation coefficient. Individuals experience disutility from supplying labor, where the parameter ϕ represents the reciprocal of the Frisch elasticity of labor supply. Two disturbances affect preferences: one affecting consumption (ε_t^c) and the other affecting housing demand (ε_t^h).[2] The representative patient household's decisions should match the following budget constraint (in real terms):

$$c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i) \le w_t^P l_t^P(i) + \frac{(1+r_{t-1}^d)d_{t-1}^P(i)}{\pi_t} + t_t^P(i) \tag{4}$$

The patient household spends on current consumption, accumulates housing services (with q_t^h the real house price), and saves through real deposits $d_t^P(i)$. Meanwhile, the household receives wage earnings $w_t^P l_t^P(i)$ (where w_t^P is the real wage rate for the patient household's labour input), gross interest income on the deposits made in the last period $(1+r_{t-1}^d)d_{t-1}^P(i)/\pi_t$ (where $\pi_t \equiv P_t/P_{t-1}$ denotes gross inflation), and lump-sum transfers t_t^P that are comprised of net labour union membership fees, as well as dividends from banks and firms, both of which are solely owned by patient households.

2.3. Prime impatient households

The representative prime impatient household i maximizes the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_{IP}^t \left[(1-a^{IP})\varepsilon_t^c \log(c_t^{IP}(i) - a^{IP} c_{t-1}^{IP}) + \varepsilon_t^h \gamma_h \log h_t^{IP}(i) - \frac{l_t^{IP}(i)^{1+\phi}}{1+\phi} \right] \tag{5}$$

which is a function of current individual consumption of final goods $c_t^{IP}(i)$, lagged aggregate consumption c_{t-1}^{IP}, housing $h_t^{IP}(i)$, and hours worked $l_t^{IP}(i)$. Consumption of prime impatient households also exhibits external and group-specific habits, where a^{IP} is the habit formation coefficient. Similar to patient households, labour disutility is also parametrized by ϕ. The consumption disturbance ε_t^c and the housing demand disturbance ε_t^h affecting preferences of prime impatient households are the same as those affecting the utility of patient households. The representative prime impatient household's decisions should match the budget constraint (in real terms):

$$c_t^{IP}(i) + q_t^h \Delta h_t^{IP}(i) + \frac{(1+r_{t-1}^{bIP})b_{t-1}^{IP}(i)}{\pi_t} \le w_t^{IP} l_t^{IP}(i) + b_t^{IP}(i) + t_t^{IP}(i) \tag{6}$$

where resources spent on current consumption, accumulation of housing, and gross reimbursement of borrowing from last period $b_{t-1}^{IP}(i)$ (where r_{t-1}^{bIP} is the net interest rate on loans to prime borrowers) must be financed with wage earnings $w_t^{IP} l_t^{IP}(i)$ (where w_t^{IP} is the

[2] In this model, any shock εt is assumed to follow a stochastic autoregressive process of order one given as , where ρε is the AR(1) coefficient, ε is the steady-state value, and follows a normal i.i.d. process with and .

real wage rate for the prime impatient household's labour input), new borrowing $b_t^{IP}(i)$, and lump-sum transfers $t_t^{IP}(i)$ that include only net labour union membership fees.

Furthermore, the amount of funds that prime impatient households can borrow is tied to the value of their housing stock according to the borrowing constraint:

$$\left(1+r_t^{bIP}\right)b_t^{IP}(i) \leq f_t^{IP}E_t\left[q_{t+1}^h h_t^{IP}(i)\pi_{t+1}\right] \tag{7}$$

where f_t^{IP} is the loan-to-value (LTV) ratio for prime mortgages which determines the amount of credit commercial banks can provide to prime impatient households. The LTV ratio f_t^{IP} is assumed to follow an exogenous stochastic process:

$$\ln f_t^{IP} = \left(1-\rho_{f^{IP}}\right)\ln f^{IP} + \rho_{f^{IP}}\ln f_{t-1}^{IP} + \varepsilon_{f^{IP},t}$$

where $\varepsilon_{f^{IP},t} \sim N\left(0,\sigma_{f^{IP}}^2\right)$ is a white noise shock.

2.4. Subprime impatient households

Subprime impatient households are distinguished from prime impatient households in that they exhibit a risk of default and may not commit to paying back their loan obligations. The representative subprime impatient household i maximizes the expected utility,

$$E_0\sum_{t=0}^{\infty}\beta_{IS}^t\left[\left(1-a^{IS}\right)\varepsilon_t^c\log\left(c_t^{IS}(i)-a^{IS}c_{t-1}^{IS}\right)+\varepsilon_t^h\gamma_h\log h_t^{IS}(i)-\frac{l_t^{IS}(i)^{1+\phi}}{1+\phi}\right] \tag{8}$$

which is a function of current individual consumption of final goods $c_t^{IS}(i)$, lagged aggregate consumption c_{t-1}^{IS}, housing $h_t^{IS}(i)$, and hours worked $l_t^{IS}(i)$. Consumption habits are measured by the parameter a^{IS}; the consumption disturbance ε_t^c and the housing demand disturbance ε_t^h are the same as those affecting the preferences of patient and prime impatient households. The representative subprime impatient household faces the budget constraint (in real terms):

$$c_t^{IS}(i) + q_t^h\Delta h_t^{IS}(i) + \left(1-\delta_t^{IS}\right)\frac{\left(1+r_{t-1}^{bIS}\right)b_{t-1}^{IS}(i)}{\pi_t} \leq w_t^{IS}l_t^{IS}(i) + b_t^{IS}(i) + t_t^{IS}(i) \tag{9}$$

where wage earnings $w_t^{IS}l_t^{IS}(i)$ (w_t^{IS} is the real wage rate for the subprime impatient household's labour input), new borrowing $b_t^{IS}(i)$, and lump-sum transfers $t_t^{IS}(i)$ that only consist of net labour union fees must finance spending on current consumption, purchase of housing services, and gross repayment of undefaulted borrowing from last period $\left(1-\delta_t^{IS}\right)b_{t-1}^{IS}(i)$ (where r_{t-1}^{bIS} is the net interest rate on loans to subprime borrowers).

I assume that the decision of subprime impatient households to honour their mortgage commitments is sensitive to house price changes, such that falling house prices increase the mortgage default rate. This formulation of default probability is motivated by the significant literature which shows that house prices are a main factor explaining default behaviour. Quercia & Stegman (1992) document 29 empirical studies on the determinants of residential mortgage default. They conclude that home equity has been consistently found to influence the default decision. Kau et al. (1994) also find that the probability of mortgage default rises ever increasingly as house prices are lowered, until reaching a certain level when house prices are sufficiently low. In a more recent study, Bajari et al. (2008) empirically examine the relative importance of the various drivers of subprime borrowers' default decision. They particularly emphasize the role of a nationwide decrease in house prices as the main driver of subprime default. Also, Amromin & Paulson (2009) study how borrowers and loans' characteristics impact the default decision of both prime and subprime borrowers. They find that house prices are a major determinant of the desire and ability of households to commit to subprime mortgage obligations. Further, Hatchondo et al. (2015) show how house prices and mortgage defaults are related: A rapid drop in house prices causes a sharp rise in mortgage defaults since households find themselves with negative home equity. The default rate δ_t^{IS} is modelled using a reduced form specification and is assumed to be sensitive to house prices. This reflects strategic default in which the drop in house prices triggers higher default since the debt owed becomes greater relative to the value of housing. Specifically, the default rate is determined by:

$$\delta_t^{IS} = \delta^{IS} - \varphi^{sh}\left(\frac{q_t^h}{q^h}-1\right) \tag{10}$$

where δ^{IS} is the steady-state default rate, φ^{sh} is the sensitivity of subprime impatient household's default to house price changes, and q^h is the steady-state real house price.

Subprime impatient households face a constraint on the amount of funds they can borrow tied to the value of their housing collateral:

$$\left(1+r_t^{bIS}\right)b_t^{IS}(i) \leq f_t^{IS}E_t\left[q_{t+1}^h h_t^{IS}(i)\left(1-\delta_t^{IS}\right)\pi_{t+1}\right] \tag{11}$$

where f_t^{IS} is the loan-to-value ratio for subprime mortgages which determines the subprime households' access to credit from shadow banks. To reflect a penalty for default, only the undefaulting portion of subprime households can borrow against the discounted value of their housing stock. As such, defaulting subprime households are excluded from the credit market during the period they default in. Such a formulation provides a further amplification mechanism of housing shocks (Marshall & Shea, 2015). The LTV ratio f_t^{IS} is assumed to follow an exogenous stochastic process:

$$\ln f_t^{IS} = (1-\rho_{f^{IS}})\ln f^{IS} + \rho_{f^{IS}}\ln f_{t-1}^{IS} + \varepsilon_{f^{IS},t}$$

where $\varepsilon_{f^{IS},t} \sim N(0, \sigma_{f^{IS}}^2)$ is a white noise shock.

2.5. Entrepreneurs

Entrepreneurs in the current model face a problem similar to the one described in Gerali et al. (2010). However, there are two key differences. Firstly, in Gerali et al. (2010) entrepreneurs utilize two types of labor input: patient and impatient, whereas in the current model, they employ three types of labor input: patient, prime impatient, and subprime impatient. Secondly, while Gerali et al. (2010) abstract from subprime lending and subprime mortgage securitization, the entrepreneurs in the current model invest in the equity tranche of mortgage-backed securities. The representative entrepreneur i maximizes the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \left[(1-a^E)\log\left(c_t^E(i) - a^E c_{t-1}^E\right) \right] \tag{12}$$

which depends only on the deviation of current individual consumption of final goods $c_t^E(i)$ from lagged aggregate consumption c_{t-1}^E, with a^E being the habit formation coefficient. The representative entrepreneur's decisions should match the budget constraint (in real terms):

$$\begin{aligned} c_t^E(i) \quad & + w_t^P l_t^{E,P}(i) + w_t^{IP} l_t^{E,IP}(i) + w_t^{IS} l_t^{E,IS}(i) + \frac{(1+r_{t-1}^{bE})b_{t-1}^E(i)}{\pi_t} + p_t^e m_t^e(i) + q_t^k k_t^E(i) \\ & + \psi(u_t(i))k_{t-1}^E(i) \le \frac{y_t^E(i)}{x_t} + b_t^E(i) + \frac{F_{t-1}^e(1+r_{t-1}^{bIS})m_{t-1}^e(i)}{f\pi_t} + q_t^k(1-\delta)k_{t-1}^E(i) \end{aligned} \tag{13}$$

where resources from the production of intermediate output $y_t^E(i)/x_t$, (where $x_t = P_t/P_t^W$ is the final goods price P_t markup over the wholesale goods price P_t^W), new borrowing $b_t^E(i)$, the payoff from last period's investment in the equity tranche of mortgage-backed securities $m_{t-1}^e(i)$ (where $F_t^e = \max(f - \delta_{t+1}^{IS}, 0)$), and the value of undepreciated capital from the previous period $q_t^k(1-\delta)k_{t-1}^E(i)$ (q_t^k is the real price of capital and δ is the depreciation rate of capital) must finance spending on current consumption, cost of labour, gross reimbursement of borrowing from last period $b_{t-1}^E(i)$ (where r_{t-1}^{bE} is the net interest rate on loans to entrepreneurs), purchase of capital $q_t^k k_t^E(i)$, investment in the equity tranche of mortgage-backed securities $m_t^e(i)$ (with real price p_t^e), and the real cost of using capital with intensity of utilization u_t given by $\psi(u_t(i))k_{t-1}^E(i)$. Following Schmitt-Grohè and Uribe (2006), the real cost of capacity utilization is assumed to be of the form:

$$\psi(u_t) = \xi_1(u_t - 1) + \frac{\xi_2}{2}(u_t-1)^2. \tag{14}$$

Each entrepreneur faces a standard Cobb-Douglas production technology given by:

$$y_t^E(i) = a_t^E \left[k_{t-1}^E(i)u_t(i)\right]^{\alpha} l_t^E(i)^{1-\alpha} \tag{15}$$

where a_t^E denotes total factor productivity. Labour inputs from patient, prime impatient, and subprime impatient households are combined into aggregate labour l_t^E according to:

$$l_t^E = (l_t^{E,P})^{\mu_1}(l_t^{E,IP})^{\mu_2}(l_t^{E,IS})^{1-\mu_1-\mu_2} \tag{16}$$

where μ_1, μ_2, and $1-\mu_1-\mu_2$ measure the labour income shares of patient, prime impatient, and subprime impatient households, respectively.

Furthermore, entrepreneurs face a borrowing constraint,

$$(1+r_t^{bE})b_t^E(i) \le f_t^E E_t\left[q_{t+1}^k(1-\delta)k_t^E(i)\pi_{t+1}\right] \tag{17}$$

where the amount of resources available for entrepreneurs to borrow is limited by the value of their capital holding. As such, the representative entrepreneur's balance-sheet condition (given by their capital holding) reflects their creditworthiness and determines their access to funding from commercial banks. The LTV ratio f_t^E is assumed to follow an exogenous stochastic process:

$$\ln f_t^E = (1-\rho_{f^E})\ln f^E + \rho_{f^E}\ln f_{t-1}^E + \varepsilon_{f^E,t}$$

where $\varepsilon_{f^E,t} \sim N(0, \sigma^2_{f^E})$ is a white noise shock.

2.6. Commercial banks

When conducting intermediation activity, commercial banks enjoy market power allowing them to set interest rates on deposits and loans. Commercial banks fund the issuance of loans to prime impatient households and entrepreneurs through deposits collected from patient households. Commercial banks also invest in the senior tranche of the mortgage-backed securities issued by shadow banks. While performing the intermediation activity, these banks have to abide by a balance-sheet identity of the form *loans + securities = deposits + capital*. Additionally, commercial banks have a target capital constraint set by the macroprudential authority, deviation from which implies a quadratic cost. Hence, commercial banks' capital position affects their lending and investment behaviour resulting in a feedback loop between the financial sector and the real economy.

In order to facilitate exposition, I follow Gerali et al. (2010) by modelling each commercial bank $j \in [0,1]$ as encompassing one wholesale branch and two retail branches. The wholesale branch is responsible for managing the capital position of the group. Meanwhile, one retail branch grants differentiated loans to prime impatient households and to entrepreneurs, and the other retail bank raises differentiated deposits. Interest rates on deposits and loans are set by the retail branches in a monopolistic fashion.

2.6.1. Wholesale branch

Each wholesale branch conducts its activity in a perfectly competitive environment. The branch has real bank capital (K^b_t) and real wholesale deposits (D_t) as liabilities, while it issues real wholesale loans (B_t) and invests in the senior tranche of mortgage-backed securities (m^s_t) purchased at the real price p^s_t. Furthermore, the wholesale branch faces a constraint regarding its capital position. In particular, it faces a target risk-weighted capital adequacy ratio that results in a cost when deviating from it. This optimal ratio thus captures the trade-off arising in the decision of how much resources to invest in different assets with different risk weights. It also provides a short-cut for understanding the implications of regulatory requirements on capital.

Bank capital is assumed to be almost fixed in the short run and is adjusted only through accumulation of retained earnings:

$$\pi_t K^b_t = (1-\delta^b)K^b_{t-1} + (1-\omega_b)\Omega^b_{t-1} \tag{18}$$

where δ^b denotes the fraction of capital holdings used to manage bank capital, ω_b is the dividend pay-off ratio,[3] and Ω^b_t are the real profits of each commercial bank's three branches combined. The wholesale branch maximizes the discounted sum of real cash flows:

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \Lambda^P_{0,t} \Bigg[& (1+R^b_t)B_t - B_{t+1}\pi_{t+1} + \frac{F^s_t(1+r^{bIS}_t)}{1-f} m^s_t - p^s_{t+1} m^s_{t+1}\pi_{t+1} - (1+R^d_t)D_t + D_{t+1}\pi_{t+1} \\ & - \frac{\kappa_{Kb}}{2}\left(\frac{K^b_t}{\chi_B B_t + \chi_m p^s_t m^s_t} - \nu^b\right)^2 K^b_t + (K^b_{t+1}\pi_{t+1} - K^b_t) \Bigg] \end{aligned} \tag{19}$$

where R^b_t is the net wholesale loans rate, R^d_t is the net wholesale deposits rate, κ_{Kb} determines the cost for adjusting the capital adequacy ratio and $F^s_t = \min(1-f, 1-\delta^{IS}_{t+1})$. χ_B and χ_m are risk weights of wholesale loans and senior mortgage-backed securities, respectively. Also, ν^b is a constant target risk-weighted capital adequacy ratio set by the macroprudential authority. The maximization of discounted real cash flows is subject to the balance-sheet constraint given by:

$$B_t + p^s_t m^s_t = D_t + K^b_t \tag{20}$$

The representative wholesale branch chooses B_t, m^s_t, and D_t in order to maximize the discounted sum of real cash flows subject to the balance-sheet constraint. The first order conditions are:

$$R^b_t = R^d_t - \kappa_{Kb}\chi_B\left(\frac{K^b_t}{\chi_B B_t + \chi_m p^s_t m^s_t} - \nu^b\right)\left(\frac{K^b_t}{\chi_B B_t + \chi_m p^s_t m^s_t}\right)^2 \tag{21}$$

$$\frac{\frac{F^s_t(1+r^{bIS}_t)}{1-f} - p^s_t}{p^s_t} = R^d_t - \kappa_{Kb}\chi_m\left(\frac{K^b_t}{\chi_B B_t + \chi_m p^s_t m^s_t} - \nu^b\right)\left(\frac{K^b_t}{\chi_B B_t + \chi_m p^s_t m^s_t}\right)^2 \tag{22}$$

The first-order conditions indicate that complying with regulatory capital requirements creates a gap between the deposit rate and the return on lending and investing. In equation 21, the marginal benefit of lending given by the loan rate R^b_t must be equal to the marginal cost given by the sum of the deposit rate and the cost of deviating from the regulatory capital adequacy ratio. In equation 22, the marginal benefit of investing in senior mortgage-backed securities must equate to the marginal cost given by the sum of the deposit rate and the cost of deviating from the regulatory capital adequacy ratio due to this investment.

[3] Consequently, $(1-\omega_b)$ is the share of commercial bank profits that accumulate to new bank capital. Assuming $\omega_b = 0$ implies that commercial banks follow a zero-dividends policy and hence all bank profits are employed to build up their capital.

To close the model, commercial banks are assumed to enjoy unlimited financing at the policy rate r_t from the central bank's lending facility. Thus, assuming no arbitrage opportunities entails that the wholesale deposit rate must be equal to the policy rate:

$$R_t^d = r_t \tag{23}$$

2.6.2. Retail loan branch

The retail loan branch of the commercial bank j obtains the real wholesale loans $B_t(j) = b_t^{IP}(j) + b_t^E(j)$ from the wholesale branch at the wholesale loan rate R_t^b, differentiates them costlessly and sells them to prime impatient households and entrepreneurs after applying two different markups. The retail loan branch faces a quadratic adjustment cost proportional to the total returns on loans if it changes the interest rates charged on these loans. This quadratic adjustment cost as originally proposed by Rotemberg (1982), allows the introduction of sticky interest rates into the model.

The retail loan branch of commercial bank j chooses the interest rates $r_t^{bIP}(j)$ and $r_t^{bE}(j)$ in order to maximize its expected real return given by:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Bigg[r_t^{bIP}(j) b_t^{IP}(j) + r_t^{bE}(j) b_t^E(j) - R_t^b B_t(j) - \frac{\kappa_{bIP}}{2} \left(\frac{r_t^{bIP}(j)}{r_{t-1}^{bIP}(j)} - 1 \right)^2 r_t^{bIP} b_t^{IP} - \frac{\kappa_{bE}}{2} \left(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1 \right)^2 r_t^{bE} b_t^E \Bigg] \tag{24}$$

where κ_{bIP} and κ_{bE} determine the costs for adjusting the interest rates on prime impatient household loans and entrepreneur loans, respectively.

2.6.3. Retail deposit branch

The retail deposit branch of the commercial bank j collects the differentiated deposits $d_t^P(j) = D_t(j)$ from patient households, passes them on to the wholesale branch and receives back return at the wholesale deposit rate R_t^d. The retail deposit branch faces a quadratic adjustment cost proportional to aggregate interest paid on deposits if it changes over time the interest rate paid on these deposits.

The retail deposit branch of commercial bank j chooses the interest rate $r_t^d(j)$ in order to maximize its expected real return given by:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[R_t^d(j) D_t(j) - r_t^d(j) d_t^P(j) - \frac{\kappa_d}{2} \left(\frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 r_t^d d_t^P \right] \tag{25}$$

where κ_d determines the cost for adjusting the interest rates paid on patient household deposits.

2.6.4. Commercial bank profit

The commercial bank's profit is the sum of net earnings from the three branches. This profit, after deleting intragroup transactions, is given by:

$$\Omega_t^b = r_t^{bIP} b_t^{IP} + r_t^{bE} b_t^E - r_t^d d_t^P + \frac{F_t^s (1 + r_t^{bIS})}{1 - f} m_t^s - p_t^s m_t^s - \frac{\kappa_{Kb}}{2} \left(\frac{K_t^b}{\chi_B B_t + \chi_m p_t^s m_t^s} - \nu^b \right)^2 K_t^b - \frac{\kappa_{bIP}}{2} \left(\frac{r_t^{bIP}}{r_{t-1}^{bIP}} - 1 \right)^2 r_t^{bIP} b_t^{IP} - \frac{\kappa_{bE}}{2} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right)^2 r_t^{bE} b_t^E - \frac{\kappa_d}{2} \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right)^2 r_t^d d_t^P \tag{26}$$

2.7. Shadow banks

Similar to commercial banks, shadow banks enjoy market power in setting interest rates on loans and the prices of mortgage-backed securities tranches. Shadow banks issue loans to subprime impatient households and finance the issuance through their capital as well as by securitizing a portion of these loans in the form of mortgage-backed securities. While performing these activities, shadow banks have to abide by a balance sheet identity of the form *loans* = *issued securities* + *capital*. Unlike commercial banks, shadow banks do not face a constraint regarding their capital position and thus do not have to abide by a target risk-weighted capital adequacy ratio. This reflects the unregulated environment that shadow banks operate in.

To facilitate exposition, each shadow bank $k \in [0,1]$ can also be thought of as being composed of one wholesale branch and two retail branches. The wholesale branch is responsible for managing the capital position of the group. As for the retail branches, they provide differentiated loans to subprime impatient households and mortgage-backed securities to investors by setting interest rates and prices in a monopolistic way.

2.7.1. Wholesale branch

Each wholesale branch operates in a perfectly competitive environment. On the assets side, it issues real wholesale loans (B_t^{IS}), while on the liabilities side, it combines real bank capital (K_t^s) and wholesale mortgage-backed securities (M_t) that are divided into two tranches: a senior tranche ($M_t^s = (1 - f) M_t$) and an equity tranche ($M_t^e = f M_t$). The wholesale mortgage-backed securities are also pass-through securities, in the sense that the underlying wholesale loans' earnings are passed on to the retail securities branch investing in them.

Shadow bank capital is assumed to be almost fixed in the short run and is adjusted only through accumulation of retained earnings:

$$\pi_t K_t^s = (1-\delta^s)K_{t-1}^s + (1-\omega_s)\Omega_{t-1}^s \tag{27}$$

where δ^s denotes the fraction of capital holdings used to manage bank capital, ω_s is the dividend pay-off ratio,[4] and Ω_t^s are the real profits of each shadow bank's three branches combined. The wholesale branch maximizes the discounted sum of real cash flows:

$$\begin{aligned} &E_0\sum_{t=0}^{\infty}\Lambda_{0,t}^P\big[\big(1+R_t^{bIS}\big)B_t^{IS} - B_{t+1}^{IS}\pi_{t+1} - \big(1+R_t^{bIS}\big)M_t^s + P_{t+1}^s M_{t+1}^s\pi_{t+1} \\ &-\big(1+R_t^{bIS}\big)M_t^e + P_{t+1}^e M_{t+1}^e\pi_{t+1} + \big(K_{t+1}^s\pi_{t+1} - K_t^s\big)\big] \end{aligned} \tag{28}$$

where R_t^{bIS} is the net wholesale subprime loan rate, P_t^s is the wholesale price of the senior tranche of the mortgage-backed securities, and P_t^e is the wholesale price of the equity tranche of the mortgage-backed securities.

The maximization of discounted real cash flows is subject to the balance-sheet constraint given by:

$$B_t^{IS} = P_t^s M_t^s + P_t^e M_t^e + K_t^s \tag{29}$$

The representative wholesale branch chooses B_t^{IS} and M_t in order to maximize the discounted sum of real cash flows subject to the balance-sheet constraint. The first order condition is:

$$R_t^{BIS} = \frac{1+R_t^{BIS}}{(1-f)P_t^s + fP_t^e} - 1 \tag{30}$$

This equation reveals that the marginal benefit of lending given by the return on wholesale subprime loans R_t^{BIS} must be equal to the net payment to investors in the issued wholesale mortgage-backed securities $(1+R_t^{BIS})/((1-f)P_t^s + fP_t^e) - 1$.

2.7.2. Retail loan branch

The retail loan branch of the shadow bank k obtains the real wholesale loans $B_t^{IS}(k) = b_t^{IS}(k)$ from the wholesale branch at the wholesale subprime loan rate R_t^{bIS}, differentiates them costlessly and sells them at a markup to subprime impatient households. The retail loan branch faces a quadratic adjustment cost proportional to the total returns on loans if it changes the interest rate charged on these loans.

The retail loan branch of shadow bank k chooses the interest rate $r_t^{bIS}(k)$ in order to maximize its expected real return given by:

$$E_0\sum_{t=0}^{\infty}\Lambda_{0,t}^P \quad \left[\left(r_t^{bIS}(k)(1-\delta_{t+1}^{IS}) - \delta_{t+1}^{IS}\right)b_t^{IS}(k) - R_t^{bIS}B_t^{IS}(k) - \frac{\kappa_{bIS}}{2}\left(\frac{r_t^{bIS}(k)}{r_{t-1}^{bIS}(k)} - 1\right)^2 r_t^{bIS}b_t^{IS}\right] \tag{31}$$

where κ_{bIS} determines the cost for adjusting the interest rates on subprime impatient household loans.

2.7.3. Retail securities branch

The retail securities branch of the shadow bank k obtains the real wholesale senior ($M_t^s = m_t^s$) and equity ($M_t^e = m_t^e$) tranches of the mortgage-backed securities from the wholesale branch, differentiates them costlessly and sells them at a markup to investors.

The retail securities branch of shadow bank k chooses the prices of the mortgage-backed securities tranches $p_t^s(k)$ and $p_t^e(k)$ in order to maximize its expected real return given by:

$$\begin{aligned} &E_0\sum_{t=0}^{\infty}\Lambda_{0,t}^P\Big[p_t^s(k)m_t^s(k) + p_t^e(k)m_t^e(k) - \frac{F_t^s}{1-f}\big(1+r_t^{bIS}(k)\big)m_t^s(k) - \frac{F_t^e}{f}\big(1+r_t^{bIS}(k)\big)m_t^e(k) \\ &- P_t^s M_t^s(k) - P_t^e M_t^e(k) + \big(1+R_t^{BIS}\big)M_t^s(k) + \big(1+R_t^{BIS}\big)M_t^e(k)\Big] \end{aligned} \tag{32}$$

2.7.4. Shadow bank profit

The shadow bank's profit is the sum of net earnings from the three branches. This profit, after deleting intragroup transactions, is given by:

[4] Consequently, $(1-\omega_s)$ is the share of shadow bank profits that accumulate to new bank capital. Assuming $\omega_s = 0$ implies that shadow banks follow a zero-dividends policy and hence all bank profits are employed to build up their capital.

Table 1
Calibrated Parameters.

Parameter	Description	Value
β_P	Patient households' discount factor	0.994
β_{IP}	Prime impatient households' discount factor	0.975
β_{IS}	Subprime impatient households' discount factor	0.975
β_E	Entrepreneur's discount factor	0.975
a^P	Patient households' habit coefficient	0.33
a^{IP}	Prime impatient households' habit coefficient	0.58
a^{IS}	Subprime impatient households' habit coefficient	0.58
a^E	Entrepreneurs' habit coefficient	0.58
α	Capital share in the production function	0.33
μ_1	Patient households' wage share	0.81
μ_2	Prime impatient households' wage share	0.15
ϕ	Inverse Frisch elasticity	1.0
ε^y	$\frac{\varepsilon^y}{\varepsilon^y-1}$ is the markup in the final goods market	6.0
ε^l	$\frac{\varepsilon^l}{\varepsilon^l-1}$ is the markup in the labour market	5.0
δ	Depreciation rate of physical capital	0.025
γ_h	Weight of housing in households' utility function	0.18
f^{IP}	Prime impatient households' LTV ratio	0.72
f^{IS}	Subprime impatient households' LTV ratio	0.80
f^E	Entrepreneurs' LTV ratio	0.16
δ^{IS}	Subprime default rate	0.0253
φ^{sh}	Sensitivity of subprime default to house prices	0.87
f	Size of the mortgage-backed securities' equity tranche	0.088
ω_b	Commercial banks' dividend pay-off ratio	0.68
ω_s	Shadow banks' dividend pay-off ratio	0.68
δ^b	Cost for managing commercial banks' capital position	0.0180
δ^s	Cost for managing shadow banks' capital position	0.0125
χ_B	Risk weight of commercial bank loans	1.0
χ_m	Risk weight of senior mortgage-backed securities	1.5
ν^b	Target risk-weighted capital adequacy ratio	0.13
ε^d	$\frac{\varepsilon^d}{\varepsilon^d-1}$ is the markdown on the deposit rate	-4.712
ε^{bIP}	$\frac{\varepsilon^{bIP}}{\varepsilon^{bIP}-1}$ is the markup on the prime mortgage rate	2.894
ε^{bIS}	$\frac{\varepsilon^{bIS}}{\varepsilon^{bIS}-1}$ is the markup on the subprime mortgage rate	6.924
ε^{bE}	$\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$ is the markup on the entrepreneurs' loans rate	3.323
ε^{ms}	$\frac{\varepsilon^{ms}}{\varepsilon^{ms}-1}$ is the markdown on the senior securities return	-4.924
ε^{me}	$\frac{\varepsilon^{me}}{\varepsilon^{me}-1}$ is the markdown on the equity securities return	-4.924
ϕ_R	Policy rate inertia in Taylor rule	0.843
ϕ_π	Weight assigned to inflation in Taylor rule	1.674
ϕ_y	Weight assigned to output in Taylor rule	0.569
ξ_1	Capacity utilization adjustment cost	0.0489
ξ_2	Capacity utilization adjustment cost	0.00489

$$\Omega_t^s = \left(r_t^{bIS}(1-\delta_{t+1}^{IS}) - \delta_{t+1}^{IS}\right)b_t^{IS} + p_t^s m_t^s + p_t^e m_t^e - \frac{F_t^s}{1-f}(1+r_t^{bIS})m_t^s$$
$$-\frac{F_t^e}{f}(1+r_t^{bIS})m_t^e - \frac{\kappa_{bIS}}{2}\left(\frac{r_t^{bIS}}{r_{t-1}^{bIS}}-1\right)^2 r_t^{bIS} b_t^{IS} \tag{33}$$

2.8. Monetary policy

Following Gerali et al. (2010), the central bank follows a Taylor type rule for setting the policy rate r_t:

$$(1+r_t) = (1+r)^{(1-\phi_R)}(1+r_{t-1})^{\phi_R}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)}\left(\frac{y_t}{y_{t-1}}\right)^{\phi_y(1-\phi_R)}\varepsilon_t^r \tag{34}$$

where r is the steady-state policy rate, ϕ_π is the weight assigned to inflation and ϕ_y is the weight assigned to output growth. Further, ε_t^r is a white noise monetary policy shock.

2.9. Market clearing

The market clearing condition in the goods market is:

$$y_t = c_t + q_t^k[k_t - (1-\delta)k_{t-1}] + k_{t-1}\psi(u_t) + \delta^b\frac{K_{t-1}^b}{\pi_t} + \delta^s\frac{K_{t-1}^s}{\pi_t} + Adj_t \tag{35}$$

where $c_t \equiv c_t^P + c_t^{IP} + c_t^{IS} + c_t^E$ is aggregate consumption, k_t is aggregate physical capital, K_t^b is aggregate commercial bank capital, K_t^s is aggregate shadow bank capital, and Adj_t includes all adjustment costs.

Market clearing also requires that supply is equal to demand in the physical capital market ($k_t = k_t^E$), final goods market ($y_t = y_t^E$), labour market ($l_t^P = l_t^{E,P}$; $l_t^{IP} = l_t^{E,IP}$; $l_t^{IS} = l_t^{E,IS}$), and housing market where the supply of housing is assumed to be fixed ($\bar{h} = h_t^P + h_t^{IP} + h_t^{IS}$).

3. Calibration and steady state analysis

I calibrate the parameters that pin down the steady state of the model to match the key features of the U.S. economy. Meanwhile, I set the parameters guiding the dynamics of the model to the values estimated in Gerali et al. (2010). Table 1 reports the values of the calibrated parameters while the parameters guiding the dynamics are reported in Table A3 in Appendix B.

3.1. Subprime mortgage market parameters

Using pre-crisis data on the U.S. subprime mortgages serious delinquency rate (percentage of subprime mortgages which are more than 90 days past due and in foreclosure), I calibrate the steady state quarterly subprime default rate, δ^{IS}, to 2.53% to obtain an annual subprime mortgage default rate of 10.12%. This calibration is consistent with the data presented in Demyanyk & Hemert (2011), where subprime delinquency rate on outstanding mortgages is shown to have varied in the range 9%−11% during the period 2000–2007. To calibrate the parameter φ^{sh} which measures the sensitivity of subprime mortgage default to changes in house prices, I estimate an Ordinary Least Squares (OLS) regression of subprime mortgages serious delinquency rate on quarterly annualized percentage change in real U.S. house prices for the period 2002:Q1 to 2011:Q4.[5] The estimated OLS regression yields a statistically significant value $\varphi^{sh} = 0.87$, indicating that a 1% decrease in real house prices raise the subprime mortgage default rate by 0.87% points.

To reflect the subordination structure of U.S. subprime mortgage-backed securities, the size of the equity tranche f is set to 0.088. The calibrated value is based on the aggregation of the sizes of the BBB tranche (4.3%), the BB tranche (2.6%) and the over collateralization (1.9%) of a typical subprime mortgage-backed security (Ashcraft & Schuermann, 2008). This calibration of the subordination structure ensures that the senior tranche of the mortgage-backed securities is deemed to be very safe and is fully paid back in the steady state while the equity tranche incurs losses due to subprime default.

3.2. Commercial banking parameters

The commercial banking parameters are calibrated to match the interest rates and spreads for the U.S. economy over the sample period 1970:Q1 to 2016:Q2. In the model, the key parameters which determine interest rate spreads are the steady-state markups/markdowns on the policy rate which are specified as a function of the interest elasticities of demand for deposits and loans. For the interest rate on deposits, the steady-state markdown on the policy rate is determined by $\frac{\varepsilon^d}{\varepsilon^d - 1}$, where ε^d is the interest elasticity of deposits demand. Given that sample average annual deposit rate is 4.48% and the average annual spread between this rate and the federal funds rate is 95 basis points, I calibrate ε^d at −4.712. For the interest rates on prime mortgage loans and commercial loans, the steady-state markups on the policy rate are given by $\frac{\varepsilon^{bIP}}{\varepsilon^{bIP} - 1}$ and $\frac{\varepsilon^{bE}}{\varepsilon^{bE} - 1}$, where ε^{bIP} and ε^{bE} are the interest elasticities of prime mortgage loans demand and commercial loans demand, respectively. With an average annual spread between the prime mortgage rate and the federal funds rate of 286 basis points, ε^{bIP} is calibrated at 2.894. Similarly, I calibrate ε^{bE} at 3.323 to reflect a spread of 233 basis points between the commercial lending rate and the federal funds rate.

To calibrate the LTV ratio for prime mortgages, I compute a sample average loan-to-value ratio for all mortgages reported in the Fannie Mae and Freddie Mac single-family data set over the period 2008–2014.[6] Based on this computation, the steady-state LTV ratio for prime mortgages, f^{IP}, is set to 0.72. The calibration lies in the range of the 76% LTV ratio reported in Iacoviello & Neri (2010) and the average LTV ratio of 70% estimated by the Federal Housing Finance Board. The calibration of entrepreneurs' LTV ratio is somewhat problematic since commercial loans are typically collateral-free debt. I compute, for the U.S. economy, the average proportion of non-financial corporate loans to the value of shares and other equities of the non-financial corporations, and accordingly set f^E at 0.16.

[5] The results of the OLS regression are reported in Table A1 of Appendix A.

[6] Fannie Mae and Freddie Mac single-family data set reports loan-to-value ratio at origination for each mortgage in the sample. Given that the survey results are reported using five different ranges, I assume that the data distribution is symmetric and hence consider the mean of each range in computing the LTV ratio.

This calibration is in line with entrepreneur LTV ratios found in the literature – Christensen et al. (2007) for Canada, Gerali et al. (2010) for the Euro Area, Brzoza-Brzezina & Makarski (2011) for Poland – that are typically much smaller than the LTV ratios for mortgages.

The target risk-weighted capital adequacy ratio for commercial banks, ν^b, is set at 13%, equal to the sample bank regulatory capital to risk-weighted assets for U.S. commercial banks during the period 1998:Q1 to 2013:Q4. The risk weight of loans provided by commercial banks, χ_B, is set to 1.0 based on the regulations set by the Federal Deposit Insurance Corporation.[7] Further, I calibrate the risk weight of the senior tranche of subprime mortgage-backed securities, χ_m, to 1.5 (three times the risk weight of prime mortgage-backed securities). This is consistent with the guidelines stipulated in the Expanded Guidance for Subprime Lending Programs which state that the capital held against subprime assets should be equivalent to one and a half to three times the amount held against non-subprime assets of a similar type.

Using quarterly data on U.S. commercial banks' aggregate balance sheet and income statement, I calibrate the retained earnings-to-net income ratio at 0.32, hence implying a dividend pay-off ratio, ω_b, of 0.68. This value exactly coincides with the calibration in Hollander & Liu (2014) for the U.S. economy. The parameter δ^b which measures the depreciation rate of commercial bank capital is set at 0.0180 so as ensures that the risk-weighted capital adequacy ratio is equal to 0.13 in the steady state.

3.3. Shadow banking parameters

I calibrate the annual interest rate on subprime mortgages to 18.8% so as the net return on subprime mortgages is the same as the return to prime mortgages. As such, the spread between the prime mortgage lending rate and the subprime mortgage interest rate exactly reflects the default rate on subprime mortgages. It is noteworthy that the data reveals a lower prime-subprime interest rates spread. However, usually when a household fails to honour the mortgage contract, the bank claims ownership of the collateralized property and sells it to receive some return from foreclosure. Because in the model I assume that the debt obligation is written-off in case of default, then the subprime lending rate in the model also incorporates an additional required return to recover the lost principal on the loan, which makes it higher than the subprime interest rate in the data. In order to calibrate the interest elasticity of subprime mortgage loans demand and the price elasticities of senior and equity mortgage-backed securities demand, I assume that the retail loan branch and the retail securities branch of shadow banks have the same market power and contribute equally to the profits of the banks. Hence, solving the steady state equations of the model for the elasticities, I set the interest elasticity of subprime mortgage loans demand, ε^{bIS}, to 6.924 and the price elasticities of mortgage-backed securities demand, ε^{ms} and ε^{me}, to $-$ 4.924.

I calibrate the steady-state LTV ratio for subprime mortgages, f^{IS}, to 0.80. This calibration is based on computing the sample average loan-to-value ratio for subprime loans during 2004–2007 as reported in Amromin & Paulson (2009). To facilitate comparison, I calibrate shadow banks' dividend pay-off ratio, ω_s, to be equal to that of commercial banks at 0.68. I set the steady-state securitized share of subprime mortgages (i.e., those passed to investors via mortgage-backed securities) to 0.85 which matches the data during the pre-crisis period (Gorton, 2008). Accordingly, the parameter δ^s which measures the depreciation rate of shadow bank capital is calibrated at the value 0.0125 in order to ensure that 85% of subprime mortgages are securitized in the steady state.

3.4. Investment parameters

I calibrate the quarterly physical capital depreciation rate δ at 0.025, using data on current-cost depreciation and current-cost net stock of private non-residential fixed assets reported by the Bureau of Economic Analysis (BEA). National accounts data on the ratio of compensation of employees to net income reveals that almost 67% of U.S. income is paid to labour. Hence, the capital share in the production function α is set at 0.33, which is consistent with the value used in the literature for the U.S. economy (Iacoviello & Neri, 2010; Gertler & Karadi, 2011). The weight of housing services in the utility function is calibrated using data on housing expenditure and personal consumption expenditure during the period 1990:Q1 to 2015:Q4. Accordingly, the weight of housing in the utility function γ_h is set to 0.18, similar to that in Gerali et al. (2010) and Iacoviello & Neri (2010).

3.5. Household dynamics parameters

The patient households' discount factor β_P is calibrated by imposing on the data the steady state equation of the nominal interest rate given by

$$r = \left(\frac{\pi}{\beta_P} - 1\right)\left(\frac{\varepsilon^d}{\varepsilon^d - 1}\right)$$

Steady-state gross inflation π is set to 1.005 to match the U.S. annual target inflation rate of 2%. The steady-state markdown on the policy rate is calibrated to the sample data as discussed above, and the annual policy rate is calibrated to 5.42% based on the average federal funds rate during the period 1970:Q1 to 2016:Q2. Accordingly, patient household's discount factor β_P is set to 0.994. The discount factors of prime impatient households β_{IP}, subprime impatient households β_{IS}, and entrepreneurs β_E are set to 0.975 as in

[7] These regulations are detailed in the Code of Federal Regulations - Title 12: Banks and Banking, 12 CFR Appendix A to Part 325 - Statement of Policy on Risk-Based Capital.

Table 2
The Model's Steady State Properties.

Target	Interpretation	Model	U.S.
c/y	Household consumption to GDP ratio	0.733	0.683
i/y	Non-residential investment to GDP ratio	0.141	0.126
$k/(4 \times y)$	Business capital to GDP ratio	1.406	1.258
$(b^{IP} + b^{IS})/y$	Mortgage debt outstanding to GDP ratio	0.691	0.727
b^E/y	Nonfinancial corporate debt to GDP ratio	0.865	0.720
$K^b/(4 \times y)$	Commercial bank capital to GDP ratio	0.052	0.061
$b^{IS}/(b^{IP} + b^{IS})$	Subprime mortgages to total mortgages ratio	0.221	0.224
m/b^{IS}	Securitized share of subprime mortgages	0.850	0.850
$4 \times r$	Annual nominal policy rate	0.0542	0.0543
$4 \times r^d$	Annual nominal deposit rate	0.0447	0.0448
$4 \times r^{bIP}$	Annual nominal prime mortgage rate	0.0827	0.0830
$4 \times r^{bIS}$	Annual nominal subprime mortgage rate	0.1887	0.1201
$4 \times r^{bE}$	Annual nominal entrepreneur loan rate	0.0775	0.0778

Iacoviello (2005) and Gerali et al. (2010).

Following Iacoviello & Neri (2010), I set patient households' degree of habits in consumption a^P at 0.33, as opposed to habit formation coefficients of 0.58 for impatient households and entrepreneurs. The higher degree of consumption habits for credit-constrained households and entrepreneurs is attributed to the fact that they cannot smooth consumption through savings as patient households. Accordingly, a larger habit formation coefficient is required to match the persistence of aggregate consumption.

The patient households' wage share μ_1 is calibrated to 0.87 based on the estimates of Jappelli (1990) who identifies that credit-constrained families constitute 19% of U.S. families. Prime impatient households' wage share μ_2 is set at 0.15 so that the steady-state share of subprime mortgages out of total mortgage loans is almost 22% as revealed in pre-crisis data.

3.6. *Elasticities and markups*

The steady-state markups in the labour market and the final goods market are reflected through the elasticity of substitution parameters ε^l and ε^y, respectively. Following Gerali et al. (2010), I assume a steady-state markup of 25% in the labour market and accordingly set ε^l at 5. For the final goods market, I set ε^y at 6 to reflect a 20% steady-state markup that is commonly assumed in the literature. The labour disutility parameter ϕ is set at 1 as in Gerali et al. (2010), which implies a unitary Frisch elasticity of labour supply.

3.7. *Monetary policy rule*

I follow Iacoviello (2005) in recovering the parameters determining monetary policy from the estimate of the Taylor rule. For the period 1978:Q1 to 2015:Q4, I estimate an OLS regression of the quarterly annualized Federal funds rate on its own lag, quarterly annualized inflation, and quarterly annualized output growth.[8] The parameter values for the weights assigned to each of inflation and output resulting from the estimation are similar to those estimated in Iacoviello (2005). Meanwhile, the data sample I consider infers a higher degree of policy rate inertia than the one considered by Iacoviello (2005).

It is noteworthy that the estimated coefficients do not directly translate to the calibrated parameters as a result of the specification of the policy rule in the model that is given by

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

Due to the fact that the calibrated parameters interact with the policy rate inertia, the estimated coefficients on inflation and output growth are therefore scaled upwards by a factor $(1 - \phi_R)$. Consequently, the policy rate inertia ϕ_R is calibrated at 0.843, the weight assigned to inflation ϕ_π is set to 1.674, and the weight assigned to output ϕ_y is set to 0.569.

3.8. *Evaluation of calibrated parameters*

In order to evaluate the calibrated parameters, I compare the model-implied to the data-implied values for key macroeconomic targets. Table 2 reports the steady-state values obtained from model as well as the averages in the U.S. data over the period 1990:Q1 to 2015:Q4. As most target values predicted by the model are broadly in line with the characteristics of the data, the model does capture the main aspects of the U.S. economy.

[8] The results of the OLS regression are reported in Table A2 of Appendix A.

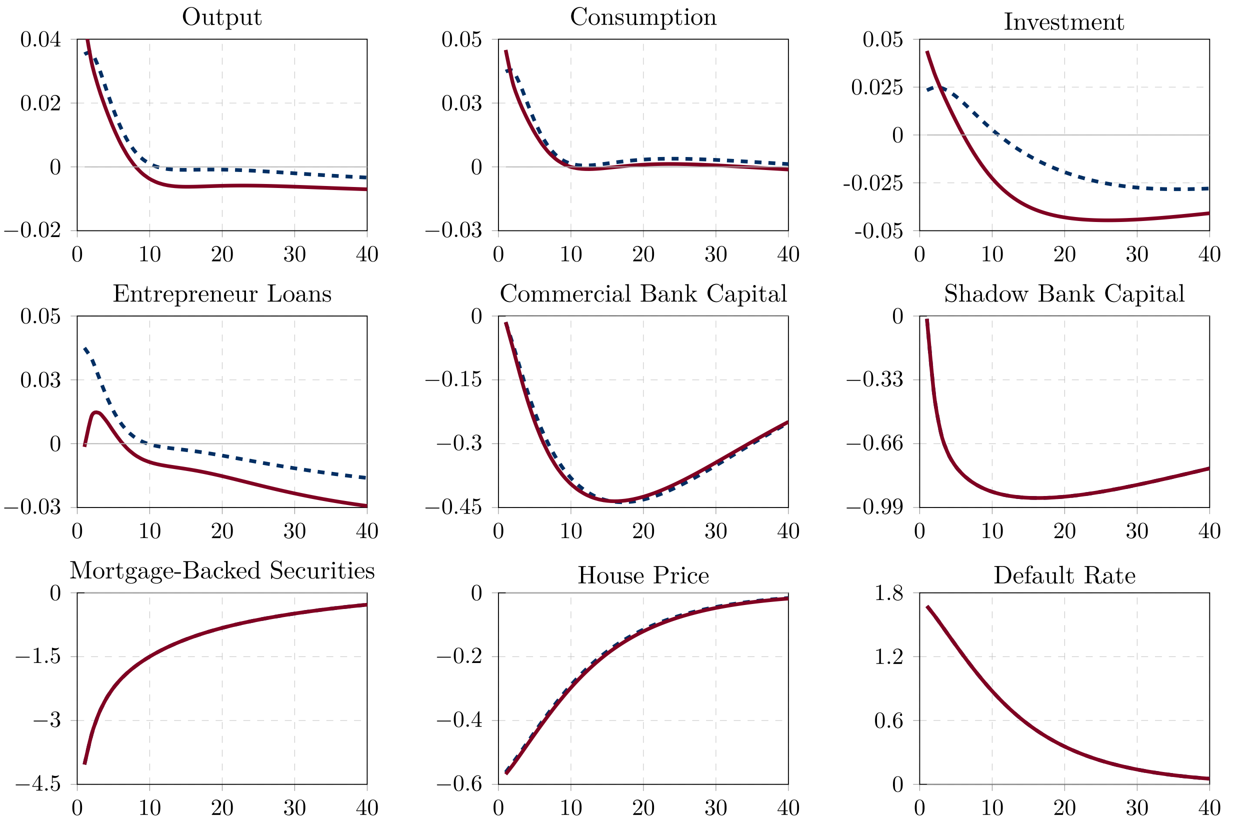

Fig. 5. Impulse Response Functions to a Negative Housing Preference Shock. Notes: Default rate is expressed in percentage points and is displayed as annualized absolute deviations from steady state. All other variables are percentage deviations from steady state. The dashed line is from the benchmark model (BM). The solid line is from the model with subprime default and securitization of subprime mortgage loans (SM).

4. The propagation of housing shocks

In this section, I examine how housing shocks are transmitted to the economy and how this transmission is affected by the presence of subprime default and subprime mortgage securitization. The inclusion of a shadow bank which is involved in subprime lending and securitization implies that a new layer of complexity is introduced to the model that provides further insight into the behaviour of the subprime mortgage market.[9] In order to highlight the role of the subprime mortgage market in the propagation of business cycles in response to housing shocks, I compare this model (SM for subprime market) to a benchmark model (BM for benchmark) that excludes all elements of subprime lending and securitization.

4.1. Housing preference shock

In the model, a housing preference shock is assumed to be a stochastic disturbance to housing in households' utility functions. The housing preference shock is not as straightforward to analyze as a shock to technology or monetary policy. Iacoviello & Neri (2010) suggest that a housing preference shock can be representative of cyclical variations in the demand for housing which arise due to social and institutional changes that shift preference for housing or due to other influences on housing demand that are not captured by the model. Using data on the U.S. economy, Iacoviello & Neri (2010) find that variables omitted from the model account only for part of the preference shock, hence suggesting a role for housing taste in the interpretation of a housing preference shock. Fig. 5 plots the impulse response functions of the key macroeconomic and financial variables to a negative housing preference shock.

In response to a negative housing preference shock that shifts the demand away from housing, real house prices fall. As households have a stronger preference for consumption than housing, the demand for final consumption goods expands and so consumption increases. The falling demand for housing investment coupled with the rising demand for consumption crowds-in business investment. Particularly, investment in physical capital by entrepreneurs expands in order to produce the final consumption good. Consequently, total output increases following the negative housing preference shock, driven by rising investment and consumption. The higher

[9] Given the non-linearity of the payoff functions for the mortgage backed securities' tranches, I use the piecewise linear algorithm developed by Guerrieri & Iacoviello (2015) for solving models with occasionally binding constraints.

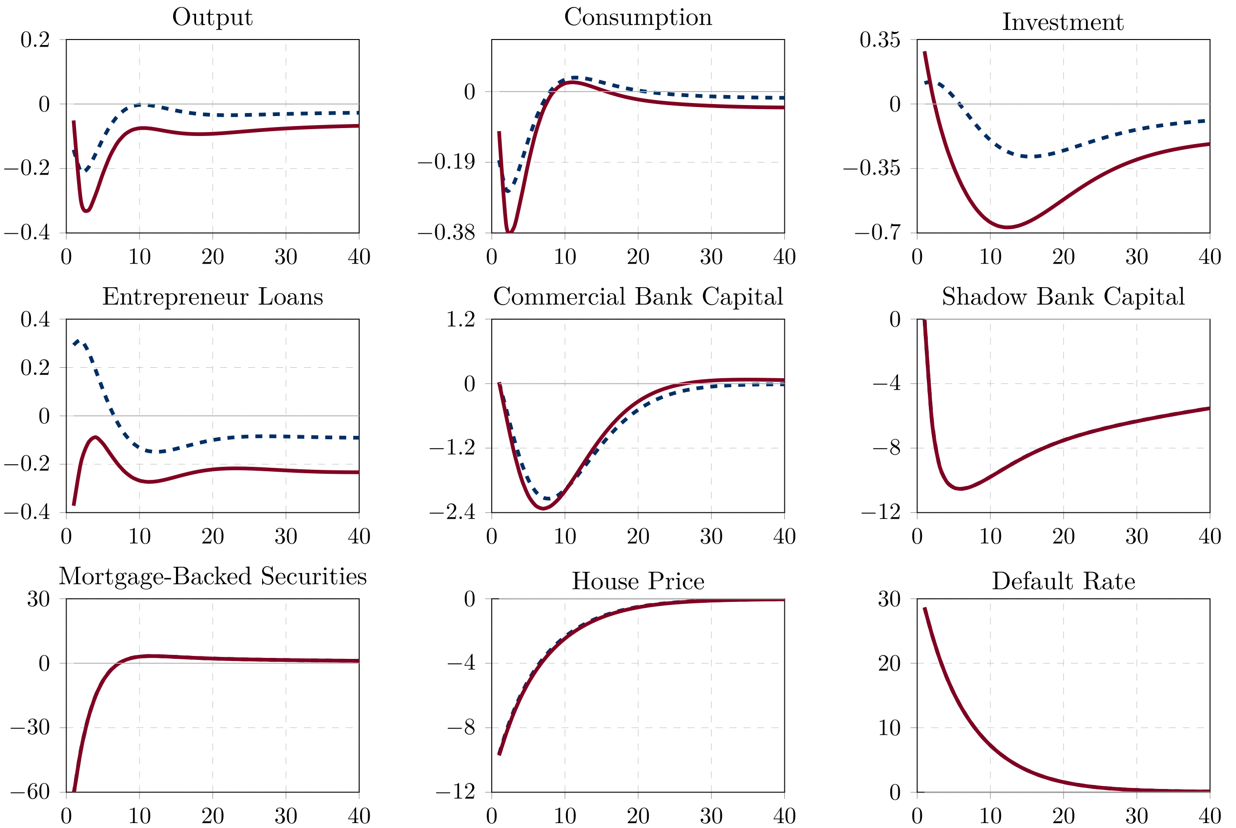

Fig. 6. Impulse Response Functions to a Negative Expected Future House Price Shock. Notes: Default rate is expressed in percentage points and is displayed as annualized absolute deviations from steady state. All other variables are percentage deviations from steady state. The dashed line is from the benchmark model (BM). The solid line is from the model with subprime default and securitization of subprime mortgage loans (SM).

consumption demand exerts an upward pressure on prices that translates into an increase in the inflation rate. Accordingly, the central bank, which follows a Taylor rule for setting monetary policy, responds by increasing the policy rate.

The increase in investment and physical capital expands the entrepreneurs' access to loans through the collateral channel. Meanwhile, as the demand for housing falls, prime impatient households' demand for loans also decreases. Consequently, the prime mortgage rate declines and the amount of prime mortgage loans falls. The increase in business lending fails to offset the drop in mortgage lending and so commercial banks' profits and capital deteriorate.

When it comes to the subprime mortgage market, the shift in taste away from housing and the resulting decrease in the value of housing property result in increasing default on subprime mortgages. Through securitization, the losses on the subprime mortgage loans portfolio are transferred to the economy through two effects: direct and indirect. The direct effect occurs due to the fact that entrepreneurs invest in the equity tranche of the mortgage-backed securities. As the equity tranche is characterized by the highest risk exposure, entrepreneurs incur losses on their investment portfolio. This explains why the impulse response of investment to the housing preference shock changes sign and becomes negative after almost 6 quarters in the model with a subprime mortgage market and stays below its steady-state level. The indirect effect happens through the balance sheet of commercial banks. As commercial banks are the investors in the senior tranche of the mortgage-backed securities, they face a tighter capital constraint in this model than in the benchmark model. In response to the negative housing preference shock that negatively impacts commercial banks' assets and profits, these banks react to the tighter capital constraint by reducing their investment in mortgage-backed securities and would increase their supply of business loans at a slower pace than in the benchmark model. Consequently, these effects result in output falling below its steady state in this model as opposed to going back to its equilibrium path in the benchmark model.

4.2. *Expected future house price shock*

Following Bernanke & Gertler (1999) who model a bubble as an exogenous shock to asset prices, I model the housing bubble by introducing a shock to the expected future house prices. The stochastic shock to the expected future house prices is included in the patient households, prime impatient households, and subprime impatient households' housing demand equations – i.e. the arbitrage equations derived from the first order conditions of the households' utility maximization problems with respect to housing. The housing bubble shock is aimed to capture changes in households' expectations about future housing prices that may be due to herd

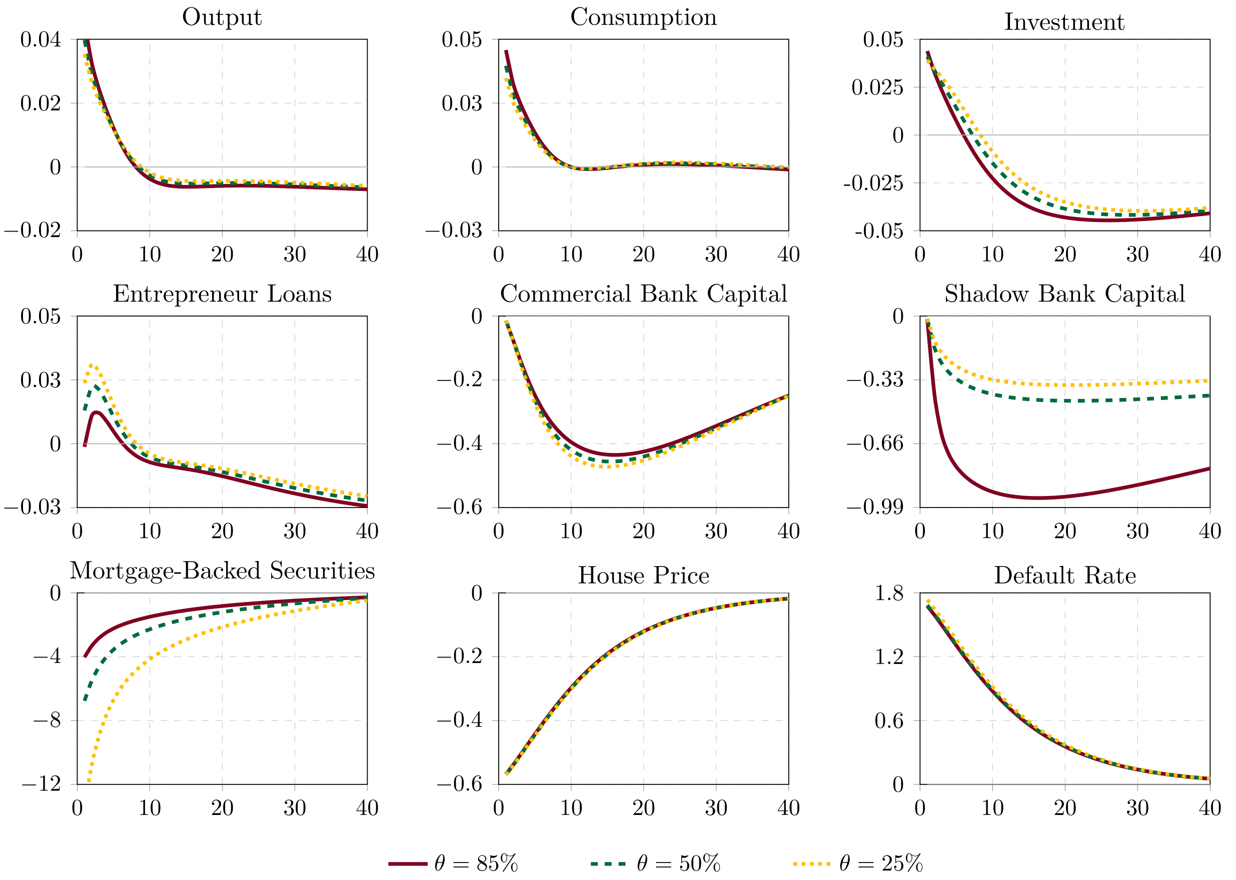

Fig. 7. Degree of Securitization and Negative Housing Preference Shock. Notes: All rates are expressed in percentage points and are displayed as annualized absolute deviations from steady state. All other variables are percentage deviations from steady state.

behaviour, momentum investors, or waves of optimism or pessimism. Such changes in expectations about future house prices result in the temporary deviation of house prices from their long-run value – leading to the rise and bust of housing bubbles – and consequently distort housing investment decisions. Fig. 6 shows the impulse response functions of the key macroeconomic and financial variables to a negative expected future house price shock that decreases current house prices by 10%.

The negative shock to expected future house prices directly influences current real house prices. The negative housing bubble shock tightens the binding borrowing constraint of credit-constrained households. As house prices are expected to fall, the value of available housing collateral of impatient households decreases. As a result, impatient households' access to mortgage loans is restricted and their demand for housing falls, which translates into lower current house prices. The fall in impatient households' collateral value and the decline in their accessible funds also negatively impact their investment in housing as well as their consumption. The negative shock to expected future house prices also affect patient households through its impact on savers' wealth. The falling house price leads to a contraction in the value of housing stock owned by patient households, an asset which constitutes a major component of these households' wealth. As their wealth is expected to be lower in the future, patient households reduce their spending on consumption. As such, total consumption and consequently total output drop below their steady states in response to the negative housing bubble shock. Unlike other macroeconomic variables in the economy that experience immediate declines following the negative shock to expected future house prices, investment in physical capital and loans to entrepreneurs initially rise. However, as commercial banks experience falling profits, the amount of entrepreneur loans is reduced. The restricted access to lending coupled with falling demand for final goods also leads investment to fall soon after.

The fall in expected future house prices and the resulting direct decline in current house prices imply that the value of loan repayment due becomes higher relative to the value of housing stock owned. This triggers subprime impatient households to reduce their housing stock and to default on their mortgage obligations. The losses on the subprime loan portfolio are transferred to entrepreneurs who hold the equity tranche of the mortgage-backed securities. As entrepreneurs' wealth is further reduced, investment in physical capital further declines and this explains the amplified response of investment to the negative housing bubble shock when compared with the benchmark model. Additionally, loans granted to entrepreneurs exhibit an amplified reaction in the model with subprime default and securitization of subprime mortgages. The contraction in lending to entrepreneurs is a result of two channels. First, commercial banks incur some losses on their holdings of mortgage-backed securities. Second, the investment in the senior tranche of mortgage-backed securities implies a tighter capital constraint faced by commercial banks when compared to the

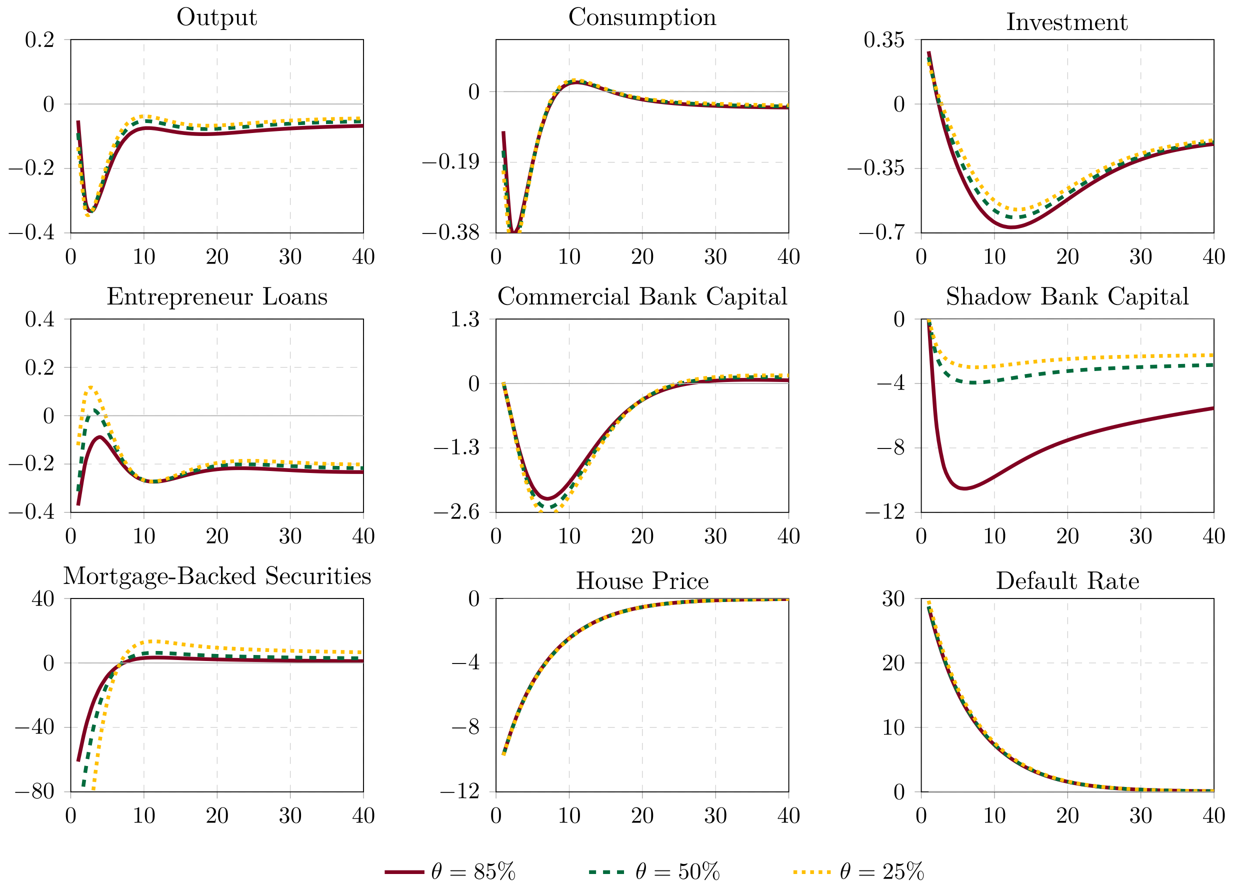

Fig. 8. Degree of Securitization and Negative Expected Future House Price Shock. Notes: All rates are expressed in percentage points and are displayed as annualized absolute deviations from steady state. All other variables are percentage deviations from steady state.

benchmark model. When commercial banks reduce their investment in the mortgage-backed securities which become riskier following the negative shock to expected future house prices, they react to the decrease in the value of their assets relative to liabilities (i.e. lower capital adequacy ratio) by deleveraging through further reducing their investment in securities as well as their lending to the business sector more so than they do in the benchmark model. Additionally, the drop in the expected future value of capital stock also contributes to the reduced lending to entrepreneurs through the collateral constraint. Hence, through the securitization of subprime loans, an amplification link is introduced between the financial sector and the production sector in the economy. This is translated into magnified response of real macroeconomic variables like output, consumption, and investment to the negative future house price shock. As such, subprime lending and subprime mortgage securitization allow further transmission of the negative housing bubble shock to the economy.

5. Sensitivity analysis

5.1. The degree of subprime mortgage securitization

I examine how the propagation of housing shocks is affected by the degree in which the economy is involved in subprime mortgage securitization. In the model's initial calibration, the steady-state securitized share of subprime mortgages (i.e., those passed to investors via mortgage-backed securities) is set to 85% in order to match the data during the pre-crisis period. Hence, to examine the effect of subprime mortgage securitization, I compare this benchmark calibration to models in which 50% and 25% of the subprime mortgages are securitized in the steady state, respectively. Fig. 7 and 8 show the impulse response functions of the key macroeconomic and financial variables in the different models in response to a negative housing preference shock and a negative expected future house price shock, respectively. The results reveal that the specific nature of subprime mortgage loans, which are prone to default and are highly sensitive to house prices, is not the only contributor to the amplified transmission of housing shocks. In fact, the securitization of subprime mortgages plays an important role in the amplification of the response of aggregate macroeconomic variables to the housing shocks.

When the degree of securitization of subprime mortgages is low, housing shocks result in a redistribution effect between subprime

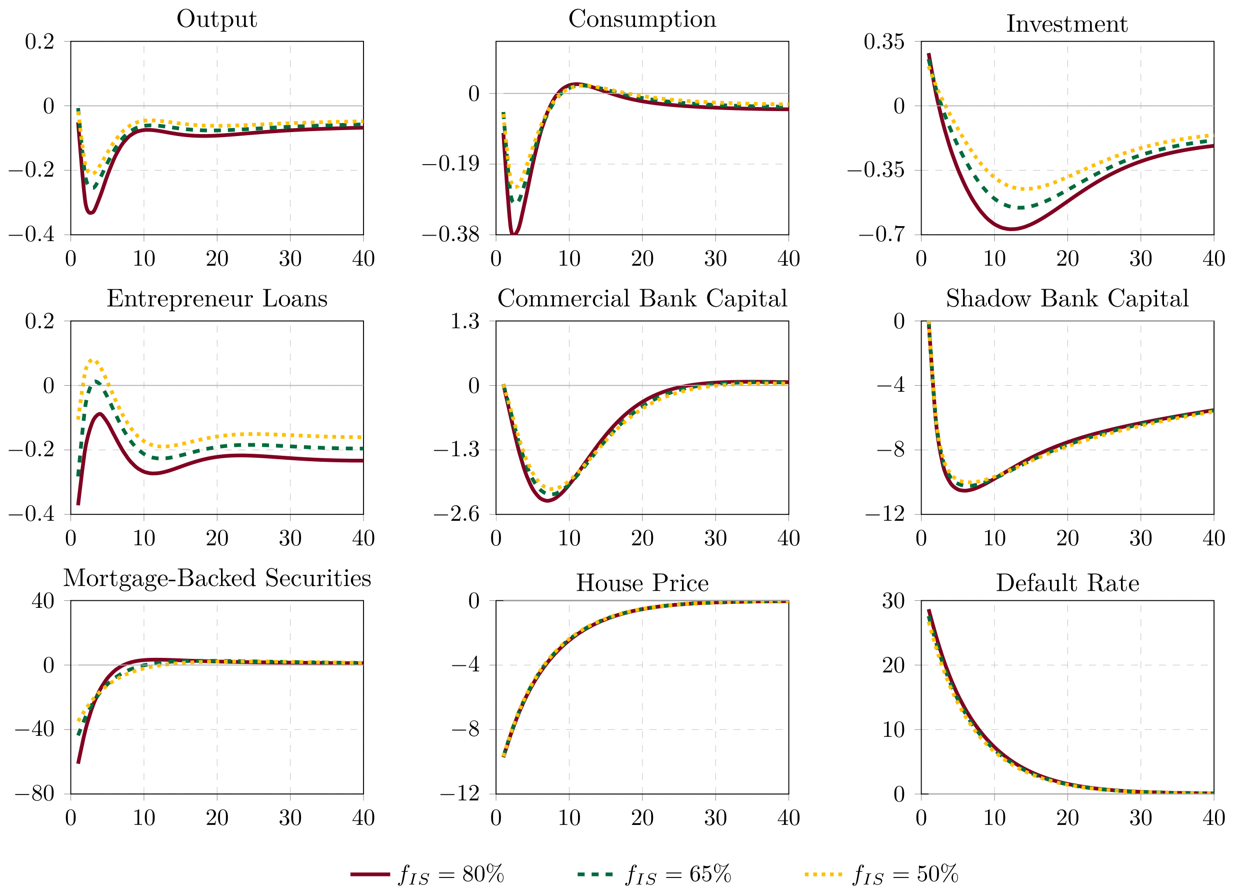

Fig. 9. Subprime Loan-to-Value Requirement and Negative Expected Future House Price Shock Notes: All rates are expressed in percentage points and are displayed as annualized absolute deviations from steady state. All other variables are percentage deviations from steady state.

impatient households and shadow banks. On one hand, as the subprime default rate rises due to falling housing prices, subprime impatient households experience a positive wealth effect since they do not honour their mortgage obligations and pay less than contracted. On the other hand, shadow banks face a negative wealth effect since they incur losses, as the contracted subprime mortgage instalments are not paid back. As shadow banks' profits and bank capital decrease, they restrict their lending to subprime households and increase the required return on subprime mortgage loans. While the described redistribution effect does have a negative impact on the overall economy, the lower degree of securitization coupled with the subdivision of the banking sector into commercial and shadow banking result in lower transmission of the negative developments in the subprime mortgage market to other productive sectors of the economy.

When shadow banks are heavily involved in the process of securitizing subprime mortgage loans, the losses on the subprime mortgage portfolio are transmitted to the real economy as the investors in mortgage-backed securities incur losses. The transmission happens through the direct and indirect effects mentioned earlier. A high degree of securitization implies that entrepreneurs are more heavily investing in the equity tranche of mortgage-backed securities and thus these risky securities constitute a bigger portion of their investment portfolio. When negative housing shocks hit the economy, entrepreneurs incur higher losses in the environment that is characterized by high subprime mortgage securitization, and hence are forced to decrease their investment in physical capital as they face a tighter budget constraint. Furthermore, a higher degree of securitization also implies that senior subprime mortgage-backed securities constitute a bigger portion of commercial banks' balance sheet and so they face tighter capital constraint. Hence, when negative housing shocks hit the economy and commercial banks' holding of mortgage-backed securities is reduced relative to their liabilities, their capital-to-asset ratio falls if they make no adjustments to liabilities, resulting in an adjustment cost due to deviation from the target capital requirement. Thus, commercial banks react to the tighter capital constraint by taking less deposits and reducing their lending to businesses more so than they do when subprime securitization is low. As for shadow banks, they also face amplified decreases in profits and bank capital when they are highly leveraged (i.e. when they finance their issuance of subprime mortgages with securitization rather than own capital). In fact, shadow banks face falling demand for mortgage-backed securities following negative housing shock. As such, these banks find themselves burdened with subprime loans they had previously planned to distribute to investors through securitization.

Table A1
Estimate of Subprime Default Sensitivity to House Prices.

Dependent Variable	Subprime Mortgages Serious Delinquency Rate
Change in Real House Prices	-0.8712 * **
	(0.145)
Constant	0.1581 * **
	(0.010)
Observations	30
Adjusted R^2	0.4807

Notes: Standard errors are shown in parentheses, (). * ** , * * and * indicate significance at 1%, 5% and 10% levels, respectively.

Table A2
Estimate of Taylor Rule for Monetary Policy.

Dependent Variable	Federal Funds Rate
Lagged Federal Funds Rate	0.8425 * **
	(0.031)
Inflation	0.2638 * **
	(0.071)
Output Growth	0.0897 * **
	(0.021)
Constant	0.0054 * **
	(0.001)
Observations	152
Adjusted R^2	0.959

Notes: Standard errors are shown in parentheses, (). * ** , * * and * indicate significance at 1%, 5% and 10% levels, respectively.

5.2. Subprime loan-to-value requirement

Listokin et al. (2000) note that low-income households are often unable to make required down payment for buying houses, especially in rapidly appreciating markets. Low-pay employment and intermittent employment make it hard for these households to save for a down payment. As such, as the down payment is usually low in the case of subprime mortgages, these loans are characterised by a high loan-to-value ratio (81% in 2005). One may therefore wonder to what extend the loan-to-value requirement for subprime loans could influence the transmission of shocks to the housing market. Fig. 9 plots the impulse response functions to a negative future house price shock for different calibrations of the subprime loan-to-value ratios.

When the loan-to-value ratio on subprime mortgages is reduced, subprime borrowers experience a tightening in credit conditions that reduces their capacity to borrow out of their housing stock. This in turn implies a smaller subprime mortgage market and consequently lowers the issuance of subprime mortgage-backed securities. With these risky securities constituting a smaller portion of entrepreneurs' investment portfolio when the subprime LTV ratio is low, a negative housing shock will have an attenuated effect compared to an economy where subprime households can borrow more against their housing stock. As such, following a negative shock to expected future house prices, entrepreneurs incur lower losses in the environment that is characterized by low subprime loan-to-value ratio, and hence would not reduce their investment as they would if the subprime LTV ratio was higher. Consequently, aggregate output and aggregate consumption exhibit attenuated responses to negative housing shocks with a tighter subprime borrowing requirement.

6. Future extensions

The current formulation of the model does not explicitly include housing production, but rather treats the housing stock as fixed. This means that the model assumes the availability of housing remains constant, regardless of changes in market conditions. However, in reality, housing supply is not fixed. An extension to the model could be to introduce a separate production function for housing, which could be modeled as a form of physical capital that is produced by entrepreneurs. This would allow for a more accurate representation of how changes in housing supply can impact the transition of housing shocks. If housing production were explicitly included, the model could capture the decline in housing construction that occurred during the 2007–2009 recession, further amplifying the impact on house prices, subprime default and the broader economy.

The model also abstracts from foreclosure and bankruptcy costs which if incorporated could potentially affect the distribution of gains and losses in the housing market as well as the propagation of housing shock. First, when bankruptcy costs are incorporated, it could impair subprime borrowers' ability to access loans following a default episode. Therefore, homeowners may be less likely to default on their mortgages which could dampen the propagation of housing shocks. Moreover, higher foreclosure costs incurred by lenders may make subprime banks more cautious when extending subprime mortgage loans which translates into fewer origination of subprime mortgages.

Table A3
Borrowed Parameters.

Parameter	Description	Value
Indexation and Adjustment Costs		
ι_p	Price indexation	0.16
ι_w	Wage indexation	0.28
κ_p	Price stickiness	28.65
κ_w	Wage stickiness	99.90
κ_i	Investment adjustment cost	10.18
κ_{Kb}	Leverage deviation cost	11.07
κ_d	Deposit rate adjustment cost	3.50
κ_{bIP}	Prime mortgage rate adjustment cost	10.09
κ_{bE}	Entrepreneurs' loans rate adjustment cost	9.36
κ_{bIS}	Subprime mortgage rate adjustment cost	10.09
AR(1) Coefficients		
ρ_{ε^c}	Disturbance to consumption preference	0.394
ρ_{ε^h}	Disturbance to housing preference	0.921
ρ_{a^E}	Total factor productivity	0.939
ρ_{ε^y}	Price markup	0.305
ρ_{ε^l}	Wage markup	0.640
$\rho_{\varepsilon^{qk}}$	Disturbance to investment efficiency	0.548
$\rho_{\varepsilon^{qh}}$	Disturbance to future house prices	0.850
$\rho_{f^{IP}}$	Prime impatient households' LTV ratio	0.929
ρ_{f^E}	Entrepreneurs' LTV ratio	0.894
$\rho_{f^{IS}}$	Subprime impatient households' LTV ratio	0.929
ρ_d	Markdown on the deposit rate	0.838
ρ_{bIP}	Markup on the prime mortgage rate	0.820
ρ_{bE}	Markup on the entrepreneurs' loans rate	0.834
ρ_{bIS}	Markup on the subprime mortgage rate	0.820
ρ_{ms}	Markdown on the senior securities return	0.838
ρ_{me}	Markdown on the equity securities return	0.838
Standard Deviations		
σ_r	Disturbance to the policy rate	0.002
σ_{ε^c}	Disturbance to consumption preference	0.027
σ_{ε^h}	Disturbance to housing preference	0.071
σ_{a^E}	Total factor productivity	0.006
σ_{ε^y}	Price markup	0.598
σ_{ε^l}	Wage markup	0.561
$\sigma_{\varepsilon^{qk}}$	Disturbance to investment efficiency	0.019
$\sigma_{\varepsilon^{qh}}$	Disturbance to future house prices	0.01
$\sigma_{f^{IP}}$	Prime impatient households' LTV ratio	0.003
σ_{f^E}	Entrepreneurs' LTV ratio	0.007
$\sigma_{f^{IS}}$	Subprime impatient households' LTV ratio	0.003
σ_d	Markdown on the deposit rate	0.032
σ_{bIP}	Markup on the prime mortgage rate	0.066
σ_{bE}	Markup on the entrepreneurs' loans rate	0.063
σ_{bIS}	Markup on the subprime mortgage rate	0.066
σ_{ms}	Markdown on the senior securities return	0.032
σ_{me}	Markdown on the equity securities return	0.032

The model considered assumes that capital requirements are predetermined. Yet, it is crucial to acknowledge that in real-world scenarios, capital requirements are frequently shaped by a multitude of factors. To account for this, one possible approach would be to incorporate the effects of changing capital requirements into the model, either as a policy variable or as an endogenous variable that responds to changes in economic conditions. This would allow for exploring how different policy settings could affect the behavior of the economy in response to housing shocks. An environment in which capital requirements respond to the state of the economy or to the level of default risk would then discourage commercial banks from holding mortgage-backed securities during adverse times as the risk-weight on these securities is high. This translates into a smaller subprime mortgage market as shadow banks face falling demand for mortgage-backed securities.

7. Conclusion

This paper develops a DSGE model with the banking industry being composed of commercial banks and shadow banks to examine how the propagation of housing shocks is affected by the presence of subprime mortgage lending and the securitization of risky credit. While commercial banks issue prime mortgage loans and business loans, shadow banks issue subprime mortgages and finance the loans issuance through securitization. As subprime borrowers exhibit a risk of default on subprime mortgages that is sensitive to housing market developments, the securities backed by these loans also involve credit risk. The model is calibrated to match the main aspects of the U.S. economy. The inclusion of a shadow bank that is involved in subprime lending and securitization provides insight into the behaviour of the subprime mortgage market and its interaction with other markets in the economy.

The model demonstrates that the presence of risky credit that is financed through securitization amplifies the response of macroeconomic and financial variables to negative housing shocks. The amplification mechanism happens through the portfolio losses incurred by the investors in the equity tranche of the mortgage-backed securities and this translates into lower investment in the economy. Further, as the commercial banking sector is involved in the subprime securities market, the decrease in value on these securities following a negative shock forces commercial banks to undergo a necessary period of deleverage and to reduce their lending to firms, which further limits investment in the real economy. Moreover, the results show that when the issuance of subprime mortgages is not heavily financed through securitization, the size of the subprime mortgage market is smaller as shadow banks would issue less subprime loans than they would do when the degree of securitization is high. This implies lower spillover effect of negative developments in the subprime market to the real economy. As such, banking sector segmentation into prime lenders and subprime lenders as well as a low degree of involvement in subprime mortgage securitization can attenuate the extent to which negative developments in the subprime market spread to the rest of the economy.

There are questions I leave for future research. The model presented assumes that the decision of subprime borrowers to honour their mortgage commitments is sensitive to changes in house prices. Hence, the model can be extended to incorporate endogenous default on loans along the lines of Forlati & Lambertini (2011). This formulation can provide a better understanding of subprime borrowers' default behaviour and its impact on the rest of the economy. Further, the parameters guiding the dynamics of the model are not estimated based on data for the U.S. economy. Estimating the model to U.S. date would provide important quantitative results. Also, a more in-depth analysis of the net desirability of subprime mortgage-backed securities is an essential area for future research. This is because taking a stance on the overall impact of the subprime lending market would require adjusting the model specification to incorporate further elements like housing production and bankruptcy costs.

Acknowledgements

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Appendix A. Data and Estimates

A.1. Data Sources

This section describes the data used to calibrate the model.

Inflation: Percentage change in the Consumer Price Index (FRED Database series CPIAUCSL). Arithmetic averaging is used to convert the monthly series into quarterly frequency.

Consumption to GDP Ratio: Personal consumption expenditures share of gross domestic product (U.S. Bureau of Economic Analysis, FRED Database series DPCERE1Q156NBEA).

Investment to GDP Ratio: Gross private domestic non-residential fixed investment share of gross domestic product (U.S. Bureau of Economic Analysis, FRED Database series A008RE1Q156NBEA).

Subprime Mortgages Default Rate: Subprime loans seriously delinquency rate which is defined as the percent of subprime loans with instalments 90 days or more past due and in foreclosure (Mortgage Bankers Association, National Delinquency Survey).

Real House Prices: The FHFA House Price Index which is a broad measure of the movement of single-family house prices in the U. S. (Federal Housing Finance Agency). For inflation adjustments, the Consumer Price Index "All Items Less Shelter" series is used (FRED Database series CUSR0000SA0L2).

Nominal Policy Rate: Effective Federal Funds Rate (FRED Database series FEDFUNDS). Arithmetic averaging is used to convert the monthly series into quarterly frequency.

Interest Rate on Deposits: Ratio of U.S. commercial banks' total annualized interest expense paid on deposits to total deposits (Federal Deposit Insurance Corporation Quarterly Banking Profile).

Interest Rate on Prime Mortgages: 30-year fixed rate mortgages interest rate (FRED Database series MORTGAGE30US). Arithmetic averaging is used to convert the weekly series into quarterly frequency.

Interest Rate on Entrepreneur Loans: Bank Prime Loan Rate (FRED Database series MPRIME). Arithmetic averaging is used to convert the monthly series into quarterly frequency.

Loan-to-Value Ratio for Prime Mortgages: Average loan-to-value ratio at origination for all mortgages in the sample (Fannie Mae and Freddie Mac Single-Family Data Set). Given that the survey results are reported using five different ranges, the average is computed by considering the mean of each range reported in the survey.

Loan-to-Value Ratio for Entrepreneur Loans: Ratio of non-financial corporate loan (FRED Database series BUSLOANS) to non-financial corporate equities (FRED Database series MVEONWMVBSNNCB).

Risk-Weighted Capital Adequacy Ratio: Bank regulatory capital to risk-weighted assets (FRED Database series DDSI05USA156NWDB).

Commercial Banks' Capital: Total equity capital for commercial banks (FRED Database series USTEQC).

Dividend Pay-Off Ratio: The share of net income which is not retained as part of a bank's net worth. The retained earnings-to-net income is the ratio of commercial banks' quarterly retained earnings to their quarterly net income after taxes (Federal Deposit

Insurance Corporation Quarterly Banking Profile).

Mortgage Debt to GDP Ratio: The ratio of mortgage debt outstanding (FRED Database series MDOAH) to gross domestic product (FRED Database series GDP).

Fixed Capital Depreciation Rate: The ratio of current-cost depreciation of private non-residential fixed assets (U.S. Bureau of Economic Analysis, FRED Database series M1TTOTL1ES000) to current-cost net stock of private non-residential fixed assets (U.S. Bureau of Economic Analysis, FRED Database series K1NTOTL1ES000).

Capital Share of Production Function: The share of net output which is not paid to labour. Net output is computed as gross domestic product (FRED Database series GDP) less net operating surplus (FRED Database series GDINOS) less taxes on production and imports less subsidies (FRED Database series ASTPISQ027S). Payment to labour is computed as compensation of employees (U.S. Bureau of Economic Analysis, FRED Database series W209RC1Q027SBEA) less government employees wages and salaries (U.S. Bureau of Economic Analysis, FRED Database series B202RC1Q027SBEA).

Weight of Housing in Utility Function: Ratio of consumption expenditure on housing and utilities (U.S. Bureau of Economic Analysis, FRED Database series DHUTRC1Q027SBEA) to total personal consumption expenditure (U.S. Bureau of Economic Analysis, FRED Database series PCE).

A.2. Default Sensitivity Estimate

Table Table A1.

A.3. Monetary Policy Rule Estimate

Table Table A2.

B. Parameters Guiding the Dynamics

Table Table A3.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at 10.1016/j.jeconbus.2023.106127.

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