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# Subprime borrowers, securitization and the transmission of business cycles <sup>\*</sup>

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February 14, 2014

## Abstract

One of the roots of the recent global financial crisis has been seen in the design of subprime mortgage contract leading to high sensitivity of such type of loans to house price changes. The market of subprime loans, especially in the last years preceding the crisis, has been highly financed by securitization. The paper investigates how borrowers with subprime characteristics influence the transmission mechanism of business cycles in the economy and whether the securitization of subprime loans has a positive effect on the economy. The formal setup is a DSGE model with different types of borrowers and banks acting as financial intermediaries, in which households and entrepreneurs borrow against housing collateral. The economy is subject to four shocks: monetary, inflationary, preference and technology. It is shown that alone the existence of subprime borrowers does not make the economy more responsive to different shocks at the aggregate level (it has only redistributive effects) and that under certain circumstances the securitization of subprime loans (in form of residential mortgage backed securities) may lead to amplification of the business cycles.

**Keywords:** Subprime Borrowers, Securitization, Financial Intermediation, Great Recession

**JEL-Classification:** E32, E44, G01, G13, G21, R21

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# 1 Introduction

The 2007-2009 crisis, labeled as the Great Recession, has been the longest and the most severe post-war recession in the US. The crisis drew the attention of economists towards such subjects as bubbles, the role of financial intermediaries in the economy, as well as various aspects of mortgage markets. A common point of departure for researchers analyzing the Great Recession is the relatively small subprime mortgage market in the US that might have been one of the roots of the prolonged downturn. Globalized financial markets and mortgage derivatives enabled the spread of the domestic housing market crisis to other countries and continents. This paper investigates potential causes of the crisis in the US market. We focus on the design of subprime mortgages, their importance for business cycles, as well as the role of securitization in financing these products.

The paper presents a model in a linear Dynamic Stochastic General Equilibrium (DSGE) framework that builds on models with credit frictions, especially collateral constraints, which are discussed in the Section 1.2 Literature review. The focus is on the role of subprime mortgages and the securitization in the recent crisis. The model, which relies on empirical observations, incorporates some aspects of financial modeling into a standard macroeconomic framework, which is the main contribution of the paper. The economy is subject to four shocks: monetary, inflationary, preference, and technology. The results show that alone the specific design of subprime mortgage contracts, which were highly sensitive to changes in house prices, did not amplify the US business cycle - it merely led to a redistribution effect between subprime borrowers and lenders. However, the securitization of subprime mortgages might have caused an amplification through the balance sheet effects of the banks that were holding the securitized products. If the mortgage backed securities (MBS) were held by non-banks, securitization would have a positive effect of risk-spreading, leading to a smoother response of output to different shocks. Securitization itself thus cannot be blamed for the severity of the crisis. This is consistent with Jaffee et al. (2009, p.71) who conclude: *The financial crisis occurred because financial institutions did not follow the business model of securitization. Rather than acting as intermediaries by transferring the risk from mortgage lenders to capital market investors, they became the investors. They put "skin in the game"*.

The results of the paper support the thesis that in principle securitization, even of the 'dangerous' subprime risk, makes sense, because different market participants have different investment horizons and may be better able to bear the credit risk than the originator. Ideally, securitized products would end up in the portfolios of such institutions as pension funds that can cushion short-term losses better than financial intermediaries. The problem occurs if financial institutions themselves engage in such transactions, because they mostly rely on short-term funding. The present model shows that if banks facing capital constraints buy MBS tranches, which lose their value in the downturn, the capital constraint gets tighter, so the whole intermediation process is disrupted and lending to other agents in economy declines, causing a credit crunch, partial termination of production and output falls.

Although the design of subprime contract and the subprime securitization in the present model is largely based on description of Gorton (2008), his answer to the question *How could a bursting of the house price bubble result in a systemic crisis?* is slightly different from the one just provided. He argues that subprime market is a unique example in which the long chain of securities (MBS were turned into collateralized debt obligations (CDO), CDO into squared CDO etc.) and the loss of information on the investors' side led to observed big output declines. The present paper does not discuss the mechanism of the information loss, focusing on the role of financial intermediaries and balance sheet effects in the crisis.

The presented model is complex, as it involves different types of households, two types of bankers, collateral constraints faced by different agents. With the introduction of the securiti-

zation process, its complexity even increases. However, this degree of complexity is necessary to obtain the final result. The existence of subprime borrowers in our model is essential, because their default rate on loans is the basis for modeling the securitization process, presented in section 3 of the paper. Without the division of the banking sector into two different segments, we could not model the securitization process in which different financial intermediaries are connected through purchase of assets. Lastly, the assumption that prime borrowers have access to long-term contracts is chosen to mimic the reality and is necessary to obtain the result that output response in the model with securitization when commercial bankers buy securitized products is amplified compared to the benchmark case without securitization (in case of monetary, preference and technology shock). Given the existence of these new elements in the model, we deliberately choose to base a large part of the modeling framework<sup>1</sup>, the choice of the shocks, and much of the calibration of the model on the Iacoviello (2005) paper to make the model's results comparable to the existing literature.

## 1.1 Subprime mortgage market

In order to understand the modeling devices used in the paper, it is important to review some facts about the recent financial crisis. Figure 1 shows real US GDP growth and US house price index in years 1975-2010, with gray bars indicating NBER recessions. We see that in the case of the recent recession, the fall in house prices led the fall in GDP growth. According to the NBER, the last recession started in December 2007 (IV quarter) and ended in June 2009 (II quarter). The developments on the housing market played an important role in this crisis, similar to other recent crisis episodes in industrialized economies (Reinhart, Rogoff, 2009).

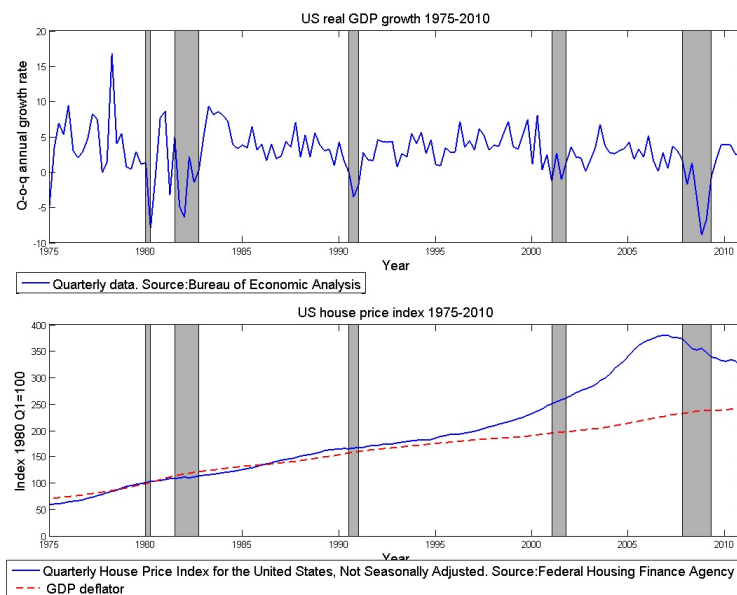


Figure 1: The evolution of GDP growth rates and house price index in the United States, 1975-2010

Source: NIPA tables 1.1.1 and 1.1.4 (GDP and GDP deflator data), Federal Housing Finance Agency USSTHPI series for the house price index.

<sup>1</sup>One could e.g. assume that entrepreneurs use also capital, not only housing stock, as collateral, or that the economy is subject to other additional shocks, but this assumptions are not necessary to obtain the main result and they would make the model even more complex and different from the existing literature and the main reference model for this paper, which is Iacoviello (2005). Also, the model could be estimated to match the data, instead of calibrated with calibration following the literature. An estimation exercise has been performed and does not change qualitative results of the paper, so it is left out, again to increase transparency.

Unlike in other countries, the fall in house prices in the US resulted in a systemic global crisis and it is important to understand how it was possible. Popular wisdom and press comments suggest that the subprime mortgage market played a substantial role in amplifying the effects of the fall in house prices, which is remarkable because it accounts for only a small percentage of the whole mortgage market. There is no exact definition of the subprime borrower or market, however, there are certain features common to all subprime loan contracts. A prime mortgage in the US is usually collateralized and has a fixed interest rate for 30 years. Subprime borrowers often can provide neither collateral, nor income (that is why they are called NINJAs - No Income, No Job or Assets). The down-payment rate in the case of prime borrowers is usually higher than in the subprime case. However, the difference is not as overwhelming as one may expect. Amromin and Paulson (2010) provide detailed data on loan to value (LTV) ratios for both groups of borrowers in years 2004-2007. In the case of prime mortgages, the average LTV ratio ranged from 74.89% to 77.75%, in the case of subprime mortgages - from 79.63% to 80.69%. The biggest difference between these two groups has been noted in the FICO score, measuring the creditworthiness of borrowers and used by lenders to determine the credit risk - in case of prime borrowers it ranged from 706 to 715, subprime - from 597 to 617 (FICO score ranges from 300 to 850, the higher, the better). Subprime borrowing was thriving thanks to a common belief that house prices will on average rise. And indeed, until the recent crisis the US market has not experienced a countrywide decrease in house prices since the 1930s.

Since subprime borrowers often do not have any assets or income, a challenge is to create a loan contract that will still enable them to pay the installments. That was made possible by creating hybrid adjustable rate mortgages of type 2/28 or 3/27, in which the first period's (2 or 3 years) interest rate was fixed and the rest (28 or 27 years respectively) varying. The shift from the fixed interest rate to the adjustable one occurred at a previously specified reset date. As Kliff and Mills (2007) note, before the outbreak of the crisis, these hybrid mortgages made up about two thirds of all ARM (adjustable rate mortgage) originations and were basically short-term fixed rate mortgages that converted into an adjustable rate mortgage after the initial period. Gorton (2008) explains how this kind of contract can be interpreted as a short-term contract. The initial interest rate depended on the loan to value ratio, which in turn depended on changes in house prices. When house prices were rising, the households were able to refinance and repay the debt and even in some cases extract equity from the homes. When house prices were falling, the LTV ratio was rising, followed by an increase in the interest rate, so that many households were not able to repay the contracted installment, or even defaulted.

Figure 2 shows the evolution of the LTV in case of a subprime contract.  $\gamma$  describes the probability of house price increase,  $1 - \gamma$  probability that the house prices fall.

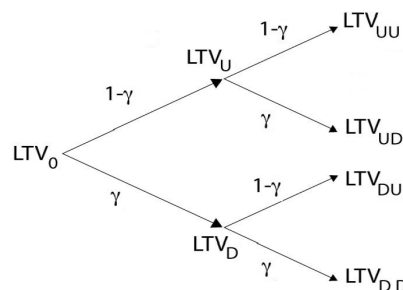


Figure 2: The evolution of house prices and the loan to value ratio

Source: Gorton (2008), p.16

The loan to value ratio moves in the opposite direction to changes in house prices. If house prices rise, the LTV ratio goes down to  $LTV_d$ , which corresponds to the borrower having positive

equity in home.  $LTV_u$  corresponds to the borrower having a negative equity position in home. When house prices fall, the LTV ratio can reach very high levels, which in case of subprime mortgages meant that lenders did not refinance the loan after the initial period of fixed interest rate. Facing increasing loan payments, the subprime borrower defaulted and the bank took over the house. In fact some people live with negative home equity. However, the data shows that with falling house prices, the motivation to repay a mortgage (especially of hybrid type) falls substantially. Amromin and Paulson (2010) provide evidence of a high sensitivity of defaults to changes in home prices among subprime borrowers already in years before the crisis, compared with a very low sensitivity among prime borrowers (for 2004: -0.183 for subprime borrowers and -0.00166 for prime borrowers).

As securitization was the main financing method for subprime originations, the majority of subprime mortgages were pooled together and sold in the financial market as MBS, which were often a base for a further securitization instrument - a CDO.<sup>2</sup> The bonds or pass-through securities (they are called so because the monthly loan payments are passed through to the holders of security) were then sold to pension funds, investment funds and personal investors. The securitization of subprime loans might have made the whole financial system vulnerable to house prices, which is much less the case when financial intermediaries only securitize prime loans, whose value does not depend so much on the condition of the housing market. Moreover, it is important to stress that securitization is not equal to loan sales. A sold loan is no more marketable than the loan itself, whereas securitization creates a new quality through various credit enhancements.<sup>3</sup> Loans are being sold in a secondary market, whereas securitization creates a new primary market. That is why Gorton (2008) calls the chain of securitized subprime securities a chain of many primary markets. At the first stage, securitization is often conducted via a special purpose vehicle (SPV) that acts only for the purpose of securitization, is set up by the originator, and even does not have any employees. The securitization process includes repackaging many assets, also car or student loans into derivative securities consisting usually of three tranches: senior, mezzanine and equity, with the latter being the most risky one. The residential mortgage backed securities (RMBS) played the biggest role in the securitization market just before and after the recent financial crisis. Along with the development of the securitization markets, the number of subprime mortgages that were taken out in the decade preceding the recent crisis rose from 7 to around 20 percent of all new originations ("2007 Annual Report"). Consequently, in our model, we concentrate on the RMBS and calibrate the share of subprime borrowers to match the data. The specific design of SPVs enables me to model the securitization process without introducing a new agent into the model economy.

## 1.2 Literature review

There is a vast macro literature concerning financial constraints and their effects on the economy. The model presented below is based on Iacoviello (2005), which in turn relies heavily on the seminal paper by Kiyotaki and Moore (1997). Kiyotaki and Moore develop a model in which capital serves both as a production factor and as collateral for loans. Due to imperfect enforcement of lenders' rights, who have a higher discount factor than borrowers and thus provide loans to other agents in the economy, the value of loans is restricted to a certain percentage of collateral. This collateral constraint leads to the amplification and a higher persistence of shocks.

Iacoviello (2005) presents a New-Keynesian DSGE model incorporating borrowing con-

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<sup>2</sup>The ratio of securitized subprime/Alt-A mortgages rose from 46% in 2001 to 93% in 2007 (Geithner, 2011, p.11).

<sup>3</sup>Credit enhancement includes: tranching of the risk of loss, over-collateralization, guarantee by an insurance company. Discussed further in Gorton, Souleles (2007).

straints and borrowers and lenders differing in their value of impatience. The housing stock may be used as collateral by both households and entrepreneurs, for whom housing is also a production factor. If borrowers repudiate their debt obligations, lenders can repossess the borrowers' assets by paying a proportional transaction cost, equal to  $(1 - m)$  times the present value of the asset. Thus, lenders will make the amount of loans depend on the parameter  $m$ , which is the LTV ratio. Households have different LTV ratios than entrepreneurs, which reflects the different riskiness of loans to the two types of agents. Collateral effects are shown to amplify the responses of output to different shocks, nominal debt feature improves the fit of the model to the data and introduces interesting inflationary effects.

Iacoviello (2013) has a similar setup to the benchmark 2005 model. However, in this model inflation and central bank are absent. Iacoviello introduces financial intermediaries, which can be interpreted as banks. They face capital constraints which lead to the amplification of financial shocks in the economy. The exogenous shock is triggered by a small sector of the economy (in this case impatient households, which are labeled subprimers) that defaults on its loans, which forces banks to recapitalize or deleverage and leads to a credit crunch. The credit constraint of the banks gives rise to a spread between the deposit and the loan rate. The paper allows for the existence of financial intermediaries absent in his 2005 model. Compared to the model without banks, the existence of banks in the economy amplifies the financial shock considerably. The crucial difference between the two models is the capital requirement faced by banks.

With respect to the securitization, there are only few papers in the area of theoretical macroeconomics that try to incorporate a secondary market into the analysis. One example is Faia (2011) in which a standard New-Keynesian DSGE model is combined with secondary market based on Parlour and Plantin (2008), who in turn base their model on the work of Holmstrom and Tirole (1997). Faia concludes that the existence of secondary markets amplifies the dynamics of macro variables. Compared to the presented model, Faia's model operates in a corporate market world without the housing market. Moreover, she models the secondary market for loans, not the securitization process. Another attempt to model securitization in the macro literature has been made by Hobijn and Ravenna (2010) who model securitization in a setup with banks that have access to the information about the credit score of the lenders. In the steady state, securitization leads to a decline in interest rates that especially benefits subprime borrowers. In the case of a shock, the reaction of financial variables such as interest rate spreads is amplified in comparison to a standard New Keynesian model.

While theoretical research on the effects of securitization in a macro framework is scarce, the empirical evidence on the recent crisis delivers many insights. The present paper mainly relies on a comprehensive study of Gorton (2008) describing in detail the subprime mortgage market in the US and the securitization of subprime mortgages. Another important reference is Gorton and Souleles (2007) who describe the basics of securitization process. Hellwig (2008) also delivers an extensive descriptive analysis of the events leading to the Great Recession. For the empirical facts, Kiff and Mills (2007), Amromin and Paulson (2010) as well as Demyanyk and Van Hemert (2011) are reliable sources. Temkin et al. (2002) provide a good summary of the regulatory changes that enabled the development of the subprime mortgage market in the US.

## 2 The benchmark model

The model economy is inhabited by a continuum of households that differ in the degree of their impatience. All households offer labor services to entrepreneurs producing intermediate output. Households consume final goods and derive utility from housing services. Patient households save in the form of deposits kept at commercial banks that grant loans to entrepreneurs and

impatient prime borrowers against housing collateral. Impatient subprime borrowers borrow from a subprime lender whose liabilities are loans from the commercial bank. Banks differentiate between borrowers. Loans granted to prime borrowers have longer maturity, whereas subprime borrowers have only access to short-term contracts, which makes their repayments sensitive to changes in house prices. The collateral constraints faced by borrowers determine the amount they can borrow from the bank, while bankers set the interest rates on loans accordingly, taking into account the length of the contract, default probabilities etc. The financial connections of the agents are shown in Figure 3. There is a central bank in the economy implementing a Taylor rule and choosing the interest rate on deposits. Retailers, who produce a final good out of the intermediary good, are the source of nominal stickiness in the economy.

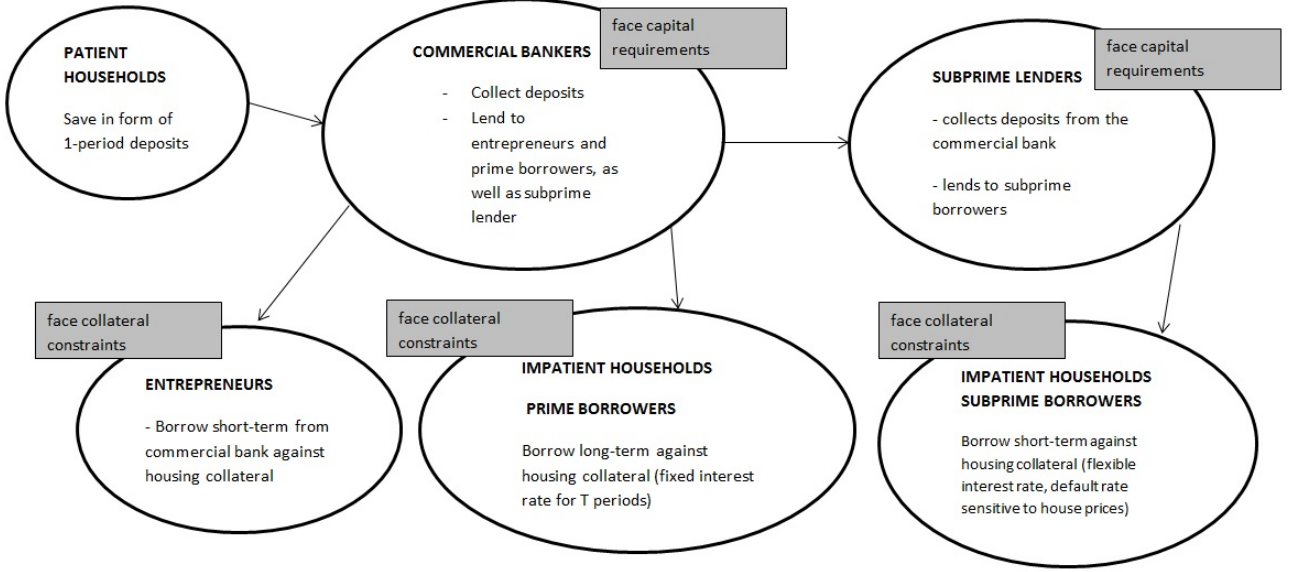


Figure 3: Financial contracts in the benchmark model

## 2.1 Patient households - savers

The problem of patient households ('patients') is identical to the one in Iacoviello (2005) with one difference. Instead of providing loans to prime households and entrepreneurs, patients save in the form of deposits held at banks. Patient households consume, work and accumulate housing. They maximize the utility function given by (small letters denote real variables):

$$\max_{b'_t, h'_t, L'_t} E_0 \sum_{t=0}^{\infty} \beta^t (\log c'_t + j_t \log h'_t - \frac{L'_t \eta'}{\eta'}), \quad (1)$$

where  $c'_t$  - consumption of the final good,  $j_t$  - marginal utility of housing subject to random disturbances (following Iacoviello, the disturbance is common to patient and impatient households and is a proxy for a housing demand or housing preference shock),  $h'_t$  - housing stock held by patients,  $L'_t$  - labor supply of patient households.

The budget constraint of the patient household in real terms is:

$$c'_t + q_t(h'_t - h'_{t-1}) + d_t = R_{d,t-1}d_{t-1}/\pi_t + w'_t L'_t + F_t, \quad (2)$$

where  $d_t$  - deposits,  $R_{d,t}$  - interest rate paid on deposits,  $F_t$  - profits from retailers (redistributed only to patient households),  $w'_t L'_t$  - labor income,  $q_t = Q_t/P_t$  - real housing price,  $\pi_t = P_t/P_{t-1}$  - inflation.



The First Order Conditions (FOCs) are:

w.r.t.  $d_t$

$$\frac{1}{c'_t} = \beta E_t \left( \frac{1}{c'_{t+1} \pi_{t+1}} \right) R_{d,t}, \quad (3)$$

w.r.t.  $h'_t$

$$\frac{q_t}{c'_t} = \beta E_t \left( \frac{q_{t+1}}{c'_{t+1}} \right) + \frac{j_t}{h'_t}, \quad (4)$$

w.r.t.  $L'_t$

$$w'_t = L_t'^{\eta'-1} c'_t. \quad (5)$$

## 2.2 Impatient households - primes

Impatient prime households ('primes') buy consumption goods and housing stock and borrow against housing collateral. They have the following utility function:

$$\max_{b''_t, h''_t, L''_t} E_0 \sum_{t=0}^{\infty} \beta^{t''} (\log c''_t + j_t \log h''_t - \frac{L_t''^{\eta''}}{\eta''}) \quad (6)$$

The setup differs from Iacoviello's version, because it is assumed that impatient prime households have access to more than one-period loans.<sup>4</sup> Their borrowing in period  $t$  depends on the expected value of housing in period  $t+T$  and the amount of outstanding debt. Figure 4 shows an example of loan installments in this setup for  $T=2$ , two-period contracts (in nominal terms). Total interest cost is due in equal fractions in every period (as in Monacelli et al. (2011)). This assumption aims to capture the characteristics of a prime mortgage contract in the US, which is characterized by a fixed interest rate over a longer time period. It also distinguishes prime borrowers from subprime who have only access to short-term, one-period loans.

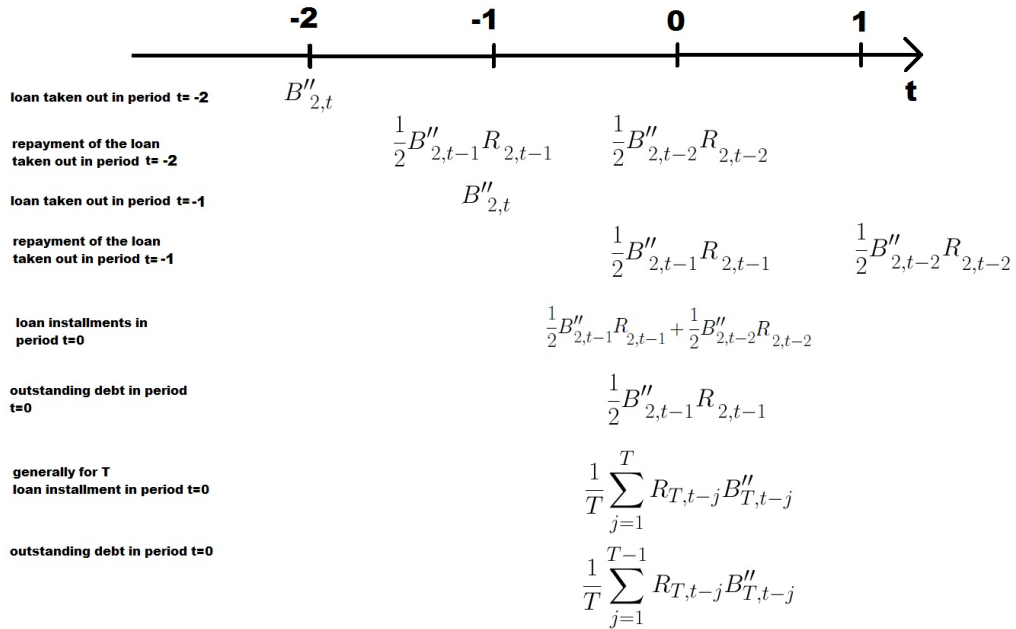


Figure 4: Installment payments of prime borrower in case of two-period contracts (in nominal terms)

<sup>4</sup>This issue has been addressed by Monacelli et al. (2011) who show that the variable-rate mortgage structure magnifies the responses of consumption and residential investment to monetary policy shock, whereas a contract in which the rate is fixed for  $T=2$  periods dampens the impulse response of considered variables. Unlike in Monacelli et al., in the present model borrowing in each period depends not only on the future value of house prices, but also on the outstanding debt from previous periods.

The budget constraint of the impatient prime household is (in real terms):

$$c_t'' + q_t(h_t'' - h_{t-1}'') + 1/T \sum_{j=1}^T \frac{R_{T,t-j} b_{T,t-j}''}{\prod_{i=0}^{j-1} \pi_{t-i}} = b_{T,t}'' + w_t'' L_t'', \quad (7)$$

where  $b_{T,t}''$  (further replaced by  $b_t''$ ) is a loan contract with maturity  $T$  purchased at time  $t$ ,  $R_{T,t}$  - prime interest rate for a loan contract with maturity  $T$  purchased at time  $t$  (further replaced by  $R_t$ ).

Notice that primes have a different discount factor than patients, while it is assumed that  $\beta'' < \beta$ . Impatients face a collateral constraint:

$$R_{T,t} b_{T,t}'' \leq m'' E_t(q_{t+T}) h_{t+T-1}'' \prod_{j=1}^T \pi_{t+j} - 1/T \sum_{j=1}^{T-1} \frac{R_{T,t-j} b_{T,t-j}''}{\prod_{i=0}^{j-1} \pi_{t-i}}, \quad (8)$$

where  $m''$  is the LTV ratio. Their new debt and outstanding debt may not exceed the future value of their housing stock.

The constraint is assumed to be always binding (as in Iacoviello (2005)). Note that borrowers in the model repay the nominal amount of debt - a feature that resembles the loan contract structure in many low-inflation countries. The consequences of the nominal debt assumption have been discussed in length in Iacoviello. In short, nominal debt assumption adds debt deflation effect to the model. As borrowers have higher propensity to consume, high inflation is beneficial for output because wealth is transferred from lenders to borrowers. In case of deflation, nominal debt has a negative effect on output.

The FOCs are ( $\lambda_t''$  is the Lagrangian multiplier on the borrowing constraint):  
w.r.t.  $b_t''$

$$\frac{1}{c_t''} = E_t(1/T \sum_{j=1}^T \beta''^j \frac{R_{T,t}}{c_{t+j}'' \prod_{i=0}^{j-1} \pi_{t+1-i}}) + \lambda_t'' R_{T,t} + E_t(1/T \sum_{j=1}^{T-1} \lambda_{t+j}'' \beta''^j \frac{R_{T,t}}{\prod_{i=0}^{j-1} \pi_{t+1-i}}), \quad (9)$$

w.r.t.  $h_t''$

$$\frac{q_t}{c_t''} = E_t(\beta'' \frac{q_{t+1}}{c_{t+1}''} + \beta''^{1-T} \lambda_{t+1-T}'' m'' q_{t+1} \prod_{i=0}^{T-1} \pi_{t+1-i}) + \frac{j_t}{h_t''}, \quad (10)$$

w.r.t.  $L_t''$

$$w_t'' = L_t'' \eta''^{-1} c_t'', \quad (11)$$

w.r.t.  $\lambda_t''$

$$R_t b_t'' = m'' E_t(q_{t+1} \prod_{j=1}^T \pi_{t+j}) h_t'' - 1/T \sum_{j=1}^{T-1} \frac{R_{T,t-j} b_{T,t-j}''}{\prod_{i=0}^{j-1} \pi_{t-i}}. \quad (12)$$

### 2.3 Impatient households - subprimers

A novelty in the model is the introduction of subprime households ('subprimers') who differ from impatient prime households in three aspects. Their loan to value ratio is slightly higher than that of prime borrowers (as in the data), they may default on their loan obligation, with the default rate sensitive to house prices, and they have only access to short-term, one-period loans, which accentuates the difference between fixed-rate prime contracts (granted mainly to prime borrowers) and variable-rate subprime contracts observed in the data. The default feature resembles a repayment shock modeled by Iacoviello (2013). However, while in Iacoviello (2013) the repayment shock is an exogenous event, in the presented model it is explicitly defined

as a default rate depending on house prices. When there is no change in the house prices, the default rate remains at its steady state level, otherwise it varies along with varying house prices.

Impatient subprime households have the following utility function:

$$\max_{b_t''', h_t''', L_t'''} E_0 \sum_{t=0}^{\infty} \beta^{mt} (\log c_t''' + j_t \log h_t''' - \frac{L_t''' \eta'''}{\eta'''}). \quad (13)$$

The budget constraint of the impatient subprime household is:

$$c_t''' + q_t(h_t''' - h_{t-1}''') + (1 - \delta_{s,t})R_{s,t-1}b_{t-1}'''/\pi_t = b_t''' + w_t'''L_t''', \quad (14)$$

where  $R_{s,t}$  is the nominal interest rate on subprime loans,  $\delta_{s,t} = \delta_s - \phi_{s,h}(q_t - Q)$  ( $\delta_s$  denotes the steady state value of default rate,  $Q$  - steady state value of house price,  $\phi_{s,h}$  - subprimers' default sensitivity to house price changes) is the default rate on loans. The dependence on house prices is chosen to capture the high sensitivity of the subprime mortgage contract to house price changes and its gamble characteristics. Subprimers enter a gamble with the bank. If house prices fall, their default rate (which is positive in steady state) will increase and they will repay less than contracted (because of the negative home equity and falling motivation to repay the loan). If house prices rise substantially, they agree to pay back the loan faster than agreed, because it is theoretically possible that the increase in house prices is so big that the subprimers' default rate turns negative. However, in the chosen calibration and in the neighborhood of the steady state, the default rate always remains positive. One would need a very large house price increase to make the default rate negative. Since the model is solved using log-linearization around the steady state, only small deviations from the steady state are considered and the default rate remains positive. The default rate is not modeled as an exogenous process, because in the version of the model with securitization we want the default risk to be incorporated in the pricing of MBS structures. If default were exogenous, the mean of the shock would be zero and the risk would not be correctly priced under the chosen solution method.

Subprime borrowers are assumed to have the same discount factor as prime borrowers:  $\beta''' = \beta'' < \beta$ . They also face a collateral constraint:

$$R_{s,t}b_t''' \leq m''' E_t(q_{t+1}\pi_{t+1})h_t'''. \quad (15)$$

The FOCs are ( $\lambda_t'''$  is the Lagrangian multiplier on the borrowing constraint):  
w.r.t.  $b_t'''$

$$\frac{1}{c_t'''} = \beta''' E_t\left(\frac{(1 - \delta_{s,t})R_{s,t}}{c_{t+1}''' \pi_{t+1}}\right) + \lambda_t''' R_{s,t}, \quad (16)$$

w.r.t.  $h_t'''$

$$\frac{q_t}{c_t'''} = \beta''' E_t\left(\frac{q_{t+1}}{c_{t+1}'''} + \lambda_t''' m''' q_{t+1} \pi_{t+1}\right) + \frac{j_t}{h_t'''}, \quad (17)$$

w.r.t.  $L_t'''$

$$w_t''' = L_t''' \eta'''^{-1} c_t''', \quad (18)$$

w.r.t.  $\lambda_t'''$

$$R_{s,t}b_t''' = m''' E_t(q_{t+1}\pi_{t+1})h_t'''. \quad (19)$$

Facing the default risk, subprime borrowers have to take into account the fact that the interest rate paid on their subprime loans includes the default premium. They pay a higher interest rate reflecting their ex ante probability of default. The subprime interest rate is determined by the subprime lenders optimization problem, and especially equation 48.

## 2.4 Entrepreneurs

The problem of entrepreneurs is identical to that in Iacoviello (2005). They produce intermediate output priced at  $P_t^w$ , using housing stock, capital and labor provided by households. They borrow short-term to cover their expenditures, facing a collateral constraint analogous to the one faced by households.

Their utility function is:

$$\max_{b_{e,t}, I_t, K_t, h_{e,t}, L'_t, L''_t, L'''_t} E_0 \sum_{t=0}^{\infty} \gamma^t \ln(c_{e,t}), \quad (20)$$

where  $b_{e,t}$  - borrowings,  $I_t$  - investment,  $K_t$  - capital,  $h_{e,t}$  - housing stock,  $L_t$  - labor of households,  $c_{e,t}$  - consumption.

The production function is:

$$Y_t = A_t K_t^\mu h_{e,t}^\nu L_t'^{\alpha(1-\mu-\nu)} L_t''^{(1-\alpha)(1-\mu-\nu)(1-s)} L_t'''^{(1-\alpha)s(1-\mu-\nu)}, \quad (21)$$

where  $A_t$  is a random variable capturing technology shock process,  $\mu$  and  $\nu$  denote respectively capital and housing share in the production function, parameter  $\alpha$  controls for patient households' labor share in the production function, and  $s$  controls for subprimers' share in the labor supply of households-borrowers.

Entrepreneurs' budget constraint is:

$$\frac{Y_t}{X_t} + b_{e,t} = c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t} b_{e,t-1} + w'_t L'_t + w''_t L''_t + w'''_t L'''_t + I_t + \xi_{K,t}, \quad (22)$$

where  $R_{e,t-1}$  is the nominal interest rate on loans between period t-1 and t,  $X_t$  is the markup of final over intermediate goods, and the last term - capital adjustment costs.

Investment is defined by:

$$I_t = K_t - (1 - \delta)K_{t-1}, \quad (23)$$

where  $\delta$  denotes the depreciation rate of capital.

The adjustment cost function is given by:

$$\xi_{K,t} = \frac{\psi_K}{2\delta} \left( \frac{I_t}{K_{t-1}} - \delta \right)^2 K_{t-1}. \quad (24)$$

Entrepreneurs face a borrowing constraint:

$$R_{e,t} b_{e,t} \leq m E_t(q_{t+1} h_{e,t} \pi_{t+1}). \quad (25)$$

The FOCs of the entrepreneur are (denote by  $u_t$  the Lagrangian multiplier on the investment constraint and by  $\lambda_{e,t}$  - on the borrowing constraint):

w.r.t  $b_{e,t}$

$$\frac{1}{c_{e,t}} = \gamma E_t \left( \frac{R_{e,t}}{c_{e,t+1} \pi_{t+1}} \right) + \lambda_{e,t} R_{e,t}, \quad (26)$$

w.r.t.  $h_{e,t}$

$$\frac{q_t}{c_{e,t}} = E_t \left[ \frac{\gamma}{c_{e,t+1}} \left( \nu \frac{Y_{t+1}}{X_{t+1} h_{e,t}} + q_{t+1} \right) + \lambda_t'' m q_{t+1} \pi_{t+1} \right], \quad (27)$$

w.r.t  $I_t$

$$u_t = \frac{1}{c_{e,t}} \left( 1 + \frac{\psi_K}{\delta} \left( \frac{I_t}{K_{t-1}} - \delta \right) \right), \quad (28)$$

w.r.t  $K_t$

$$u_t = \gamma E_t \left[ \left( \frac{Y_{t+1} \mu}{X_{t+1} K_t c_{e,t+1}} + u_{t+1} (1 - \delta) \right) + \gamma E_t \left[ \frac{1}{c_{e,t+1}} \frac{\psi_k}{\delta} \left( \frac{I_{t+1}}{K_t} - \delta \right) \frac{I_{t+1}}{K_t} - \frac{\psi_k}{2\delta} \left( \frac{I_{t+1}}{K_t} - \delta \right)^2 \right) \right], \quad (29)$$

w.r.t. labor:

$$w'_t = \frac{\alpha(1 - \mu - \nu)Y_t}{X_t L'_t}, \quad (30)$$

$$w''_t = \frac{(1 - \alpha)(1 - \mu - \nu)(1 - s)Y_t}{X_t L''_t}, \quad (31)$$

$$w'''_t = \frac{(1 - \alpha)(1 - \mu - \nu)sY_t}{X_t L'''_t}. \quad (32)$$

## 2.5 Retailers

The problem of retailers is identical to that in Iacoviello (2005). They are the source of price stickiness in the economy. Retailers acquire intermediate goods produced by the entrepreneurs at price  $P_t^w$ , then differentiate them into  $Y_t(z)$  (retailers of mass 1 are indexed by  $z$ ) and sell at price  $P_t(z)$ . The aggregate output index is given by:

$$Y_t^f = \left( \int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right)^{\frac{\varepsilon}{\varepsilon-1}}, \quad (33)$$

where  $\varepsilon > 1$ . The price index is given by:

$$P_t = \left( \int_0^1 P_t(z)^{1-\varepsilon} dz \right)^{\frac{1}{1-\varepsilon}}. \quad (34)$$

Retailers can change their sale price every period with probability  $1 - \theta$ . Fraction  $\theta$  stays unchanged every period. Denote by  $P_t^*(z)$  the reset price of the retailer and with  $Y_{t+k}^*(z) = \left( \frac{P_t^*(z)}{P_{t+k}} \right)^{-\varepsilon} Y_{t+k}$  the corresponding demand.

The retailer maximizes following equation:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,k} \left( \frac{P_t^*(z)}{P_{t+k}} - \frac{X}{X_{t+k}} \right) Y_{t+k}^*(z) \right\}, \quad (35)$$

where  $\Lambda_{t,k} = \beta^k \left( \frac{c'_t}{c'_{t+k}} \right)$  is the patient household relevant discount factor,  $X_t = \frac{P_t}{P_t^w}$  is the markup of final over intermediate goods.

The aggregate price level evolution is given by:

$$P_t = (\theta P_{t-1}^{1-\varepsilon} + (1 - \theta)(P_t^*)^{1-\varepsilon})^{\frac{1}{1-\varepsilon}}. \quad (36)$$

Combining the last two equations and log-linearizing gives us a forward-looking Phillips curve

$$\hat{\pi}_t = \beta E_t \pi_{t+1} - \kappa \hat{X}_t, \quad (37)$$

where  $\kappa \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}$  and hatted variables denote percent changes from the steady state.

## 2.6 Bankers

### 2.6.1 Commercial bankers

Commercial bankers collect deposits from patient households and issue loans to prime borrowers and entrepreneurs. They also provide interbank loans for subprime lenders that also operate

as a bank.<sup>5</sup> Commercial bankers maximize utility from their consumption (as in Iacoviello (2013)):

$$\max_{c_{b,t}} E_0 \sum_{t=0}^{\infty} \beta_b^t (\log c_{b,t}), \quad (38)$$

where  $\beta_b$  is assumed to be lower than the discount factor of patient households (necessary condition for the capital constraint to be binding - see Iacoviello (2013)).

The budget constraint of bankers is:

$$c_{b,t} + \frac{R_{d,t-1}d_{t-1}}{\pi_t} + b_t'' + bb_t + b_{e,t} = d_t + \frac{R_{b,t-1}bb_{t-1}}{\pi_t} + \frac{1}{T} \sum_{j=1}^T \frac{R_{T,t-j}b_{T,t-j}''}{\prod_{i=0}^{j-1} \pi_{t-i}} + \frac{R_{e,t-1}b_{e,t-1}}{\pi_t}, \quad (39)$$

where  $bb_t$  denotes interbank lending and  $R_{b,t}$  - interbank interest rate.

Banker's balance sheet looks as follows:

Assets	Liabilities
Loans to prime borrowers: $b_t''$	Deposits $d_t$
Interbank loans: $bb_t$	Equity $eq_t$
Loans to entrepreneurs: $b_{e,t}$	

Thus a Basel-type capital constraint, given exogenously, has the form:

$$\tau \leq \frac{b_t'' + bb_t + b_{e,t} - d_t}{\chi_3 bb_t + \chi_1 b_t'' + \chi_2 b_{e,t}}, \quad (40)$$

where  $\chi_3 < \chi_1 < \chi_2$  are risk weights of assets and  $\tau$  denotes an equity ratio set by a regulator.<sup>6</sup> The condition states that the ratio of equity (defined as asset minus deposits) to risk weighted assets has to exceed some exogenously chosen number.

The FOCs of the bankers' problem determine the interest rates paid on deposits and different types of loans ( $G_t$  denotes Lagrangian multiplier on the capital constraint):

w.r.t.  $b_t''$

$$\frac{1}{c_{b,t}} = E_t(1/T \sum_{j=1}^T \beta_b^j \frac{R_{T,t}}{c_{b,t+j} \prod_{i=0}^{j-1} \pi_{t+1-i}}) + (1 - \tau \chi_1) G_t, \quad (41)$$

w.r.t.  $bb_t$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{b,t}}{c_{b,t+1} \pi_{t+1}}) + (1 - \tau \chi_3) G_t, \quad (42)$$

w.r.t.  $b_{e,t}$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{e,t}}{c_{b,t+1} \pi_{t+1}}) + (1 - \tau \chi_2) G_t, \quad (43)$$

w.r.t.  $d_t$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{d,t}}{c_{b,t+1} \pi_{t+1}}) + G_t. \quad (44)$$

<sup>5</sup>The distinction between commercial and subprime bankers is not necessary for the benchmark version of the model, but becomes important when we introduce securitization into the model economy. The evidence from the US suggests that there were several banks and financial intermediaries that specialized specifically on the subprime market.

<sup>6</sup>The risk weight for commercial loans secured by real estate is usually higher than for private mortgages. The risk weight on loans issued to OECD banks is usually lower than for mortgage loans.

The interpretation of equations (41) to (43) is crucial for understanding the main result of the paper. The equations without considering the Lagrangian multiplier on the capital constraint represent typical Euler equations, saying that the banker must be indifferent between consuming one unit of consumption today and lending one unit today and consuming it tomorrow. The capital constraint of bankers introduces a wedge between the cost and marginal gain from lending. If it is binding, bankers will be willing to sacrifice consumption today in order to relax the constraint. By consuming less today the bankers raise their equity and may increase profitable lending which makes the capital constraint looser.

### 2.6.2 Subprime lenders

Subprime lenders operate as financial intermediaries that collect the deposits from the interbank market and issue subprime loans.

Their optimization problem is:

$$\max_{c_{bb,t}} E_0 \sum_{t=0}^{\infty} \beta_b^t (\log c_{bb,t}), \quad (45)$$

s.t.

$$c_{bb,t} + b_t''' + R_{b,t-1} b_{t-1} / \pi_t = b b_t + R_{s,t-1} (1 - \delta_{s,t}) b_{t-1}''' / \pi_t \quad (46)$$

Subprime bankers' balance sheet is (we assume that banks hold a reserve for future losses, taking into account ex ante (steady state) default rate):

Assets	Liabilities
Loans to subprime borrowers: $b_t'''$	Interbank deposits $b b_t$
Loss reserve $-\delta_s b_t'''$	

Thus a Basel-type capital constraint, given exogenously, has the form:

$$\tau \leq \frac{(1 - \delta_s) b_t''' - b b_t}{\chi_2 (1 - \delta_s) b_t'''} \quad (47)$$

where the risk weight on subprime loans equals the risk weight on entrepreneurial loans secured by real estate.<sup>7</sup>

The FOCs of the bankers' problem ( $GG_t$  denotes Lagrangian multiplier on the capital constraint of subprime lenders) are:

$$\text{w.r.t. } b_t''' \quad \frac{1}{c_{bb,t}} = \beta_b E_t \left( \frac{R_{s,t}(1 - \delta_{s,t+1})}{c_{bb,t+1} \pi_{t+1}} \right) + (1 - \tau \chi_2) (1 - \delta_s) GG_t, \quad (48)$$

$$\text{w.r.t. } b b_t \quad \frac{1}{c_{bb,t}} = \beta_b E_t \left( \frac{R_{b,t}}{c_{bb,t+1} \pi_{t+1}} \right) + GG_t. \quad (49)$$

Equation 48 determines the interest rate paid on subprime loans. The steady state value of the subprime interest rate is given by:  $RS = (1 - GG * CBB(1 - \tau \chi_2)(1 - \delta_s)) / (\beta_b(1 - \delta_s))$ , while without the ex-ante known probability of default it would look as follows:  $RS = (1 - GG * CBB(1 - \tau \chi_2)(1 - \delta_s)) / (\beta_b)$ . Thus, while pricing the subprime loan, subprime lender takes into account the default probability of the borrowers and sets a higher steady state interest rate.

<sup>7</sup>Depending on the country, subprime loans may have the same risk weight than prime loans, however, in the US they have been given a higher risk weight if LTV ratio surpasses 0.8 (which is the case for an average subprime borrower).

## 2.7 Central bank

The central bank implements a Taylor type interest rate rule (identical to Iacoviello, 2005). It is assumed that interest rate set by the central bank equals the interest rate paid on deposits (disregarding reserve requirement):

$$R_{d,t} = (R_{d,t-1})^{r_R} E_t(\pi_{t-1}^{1+r_\pi} (\frac{Y_{t-1}}{Y})^{r_y r_{\bar{r}}})^{1-r_R} e_{R,t}. \quad (50)$$

## 2.8 Market clearing conditions

The market clearing condition for the housing market is:

$$1 = h'_t + h''_t + h'''_t + h_{e,t}. \quad (51)$$

As Iacoviello (2005) we assume that real estate is fixed in the aggregate, which guarantees a variable price of housing. The goods market clearing condition is given by:

$$Y_t = c'_t + c''_t + c'''_t + c_{e,t} + c_{b,t} + c_{bb,t} + I_t. \quad (52)$$

The market clearing conditions for labor are defined by equations 5 and 30 for patient households' labor supply and demand, equations 11 and 31 for impatient prime households' labor market, and by equations 18 and 32 for impatient subprime labor market. The lending to different agents is determined through their collateral constraints and the market clearing conditions for the loan and deposits markets are given by the capital constraints of the bankers (equation 40 and 47).

## 2.9 Solution method and calibration

The model is log-linearized around the steady state. The log-linearized equations present variables in the form of percent deviations from the steady state, which makes the interpretation of model variables easier. The steady state values and log-linearized equations describing the benchmark model (also shock processes) are given in Appendix A. We calibrate the model parameters using values from the literature, as well as empirical papers (for details see Table 1).

Following Iacoviello (2005 and 2011) we assume that patient households have the highest discount factor, followed by entrepreneurs and both types of bankers. The most impatient agents in the economy are prime and subprime borrowers. The choice of discount factors assures that the collateral constraints in the model are always binding. The parameter  $J$  controls the stock of residential housing over annual output in the steady state,  $J = 0.09$  fixes this ratio around 150%, which is in line with the data from the Flow of Funds accounts (table B.100, row 4). The LTV ratios for different types of borrowers are chosen to match the data in the years preceding the crisis (values for households represent an average for years 2004-2007, based on Paulson and Amromin (2010) and are in line with other studies on the LTV ratios (Demyanyk and Van Hemert (2011)). The data for the LTV ratio on commercial real estate is not as detailed as in households' mortgage case, but  $m = 0.75$  is a commonly used value. We assume that residential real estate is easier collateralizable than the commercial real estate. Subprime households' labor share of 0.15 fixes the steady state consumption of subprime borrowers and the share of subprime borrowing in all households' borrowing at around 16.5%, which means that subprimers account only for around 2.4% of all borrowing (including entrepreneurs). Parameter  $\eta$  is chosen to fix the Frisch labor supply elasticity at 1. It is an important parameter governing the behavior of labor supply in response to shocks. The chosen value lies between the estimates provided by microeconomic studies (0-0.54) and by macroeconomic studies (2-4) (see Peterman,



Description	Parameter	Value	Source
discount factor of patient households	$\beta$	0.99	Iacoviello (2005)
discount factor of impatient households	$\beta''' = \beta''$	0.96	Iacoviello (2011)
discount factor of entrepreneurs and bankers	$\gamma = \beta_b$	0.98	Iacoviello (2005)
weight on housing services	J	0.09	Flow of Funds table B.100
loan to value prime households	m''	0.761375	data: Paulson, Amromin (2010)
loan to value entrepreneurs	m	0.75	data: Gyourko (2010)
loan to value subprime households	m'''	0.8032	data: Paulson, Amromin (2010)
subprime households wage share	s	0.15	around 18% subprime borrowers
labor supply aversion	$\eta' = \eta'' = \eta'''$	2	labor Frisch elasticity 1
capital share in production function	$\mu$	0.33	data: Jones (2003)
labor share in production function	$\nu$	0.031	Iacoviello (2005)
capital depreciation rate	$\delta$	0.025	10% per year
steady state gross markup	X	1.05	Iacoviello (2005)
patient households wage share	$\alpha$	0.87	Japelli(1990)
probability fixed price	$\theta$	0.55	Dhyne et al. (2006)
capital adjustment costs	$\phi$	2	Iacoviello (2005)
risk weight of interbank loans	$\chi_3$	3* 0.2	3*US regulation (FDIC)
risk weight of commercial and subprime loans	$\chi_2$	3*1	3* US regulation (FDIC)
risk weight of prime mortgage loans	$\chi_1$	3*0.5	3* US regulation (FDIC)
capital requirement	$\tau$	3*0.08	3*Basel regulation
subprimers' default sensitivity to house price changes	$\phi_{sh}$	0.183	data: Paulson, Amromin (2010)
steady state subprime default rate	$\delta_s$	0.05	data (Demyanyk, van Hemmert (2011))
weight of policy response to int.rate	$r_R$	0.77	Orphanides (2005)
weight of policy response to inflation	$r_\pi$	0.89	Orphanides (2005)
weight of policy response to output	$r_y$	0.18	Orphanides (2005)
autocorrelation of preference shock	$\rho_j$	0.85	Iacoviello(2005)
autocorrelation of inflationary shock	$\rho_u$	0.59	Iacoviello(2005)
autocorrelation of technology shock	$\rho_a$	0.03	Iacoviello(2005)
standard deviation of preference shock	$\sigma_{\varepsilon_j}$	24.89	Iacoviello(2005)
standard deviation of inflationary shock	$\sigma_{\varepsilon_u}$	0.17	Iacoviello(2005)
standard deviation of technology shock	$\sigma_{\varepsilon_a}$	2.24	Iacoviello(2005)
standard deviation of monetary shock	$\sigma_{\varepsilon_R}$	0.29	Iacoviello(2005)

Table 1: Calibrated parameters

2012). Iacoviello (2005) chooses a value of  $\eta$  at 1.01, which implies a very high labor Frisch elasticity: 100, and the utility function almost linear in leisure. The discussion of how different values of  $\eta$  impact the results of the paper are shown in Appendix B. The patient households' wage share of 0.87 corresponds to the conclusions of Japelli (1990) who finds out that 19% of US families are rationed in credit markets and they account for 12.7% of total income. The value of 0.55 for the parameter  $\theta$  describing the price rigidity is consistent with the evidence of Dhyne et. al (2006) who show that the average price duration in the United States equals 6.7 months. The value for the capital adjustment costs follows Iacoviello (2005). Parameters describing the risk weights of different types of loans are based on the US regulation of Federal Deposit Insurance Corporation (Code of Federal Regulations - Title 12: Banks and Banking, 12 CFR Appendix A to Part 325 - Statement of Policy on Risk-Based Capital). However, the original parameters have been multiplied with 3 to ensure the compliance with Blanchard-Kahn criteria for the solution of rational expectation models.<sup>8</sup>

<sup>8</sup>The model suffers from instability. For the original value of parameters (thus the values set by the regulator), the Blanchard-Kahn conditions are not satisfied. Blanchard-Kahn (1980) method is used to find unique and stable solutions of rational expectations models. In short, the matrix containing model parameters has to be subject to Jordan decomposition, which involves computing eigenvalues. In order for the solution of a given model to be stable and unique, the number of eigenvalues outside the unit circle (larger than 1 in modulus) has to equal the number of forward-looking variables. If the number of eigenvalues outside the unit circle is smaller than the number of forward-looking variables in the model, multiple equilibria occur. If instead the number of eigenvalues outside the unit circle is larger than the number of forward looking variables, no stable solution exists, which is the case of this model. Changing the matrix of parameters often helps to resolve the problem of not satisfied Blanchard-Kahn conditions, thus the calibration of the model has to be changed accordingly. The model of Iacoviello (2005) does not have the instability problem. Since the benchmark model presented in this paper differs from Iacoviello's (2005) model mainly through the introduction of bankers and their capital constraints, the values changing the new elements of model have to be responsible for the instability. Indeed, it turns out that with risk weights and capital requirement parameters set at the values proposed by US

The sensitivity of subprime households to house price changes has been chosen according to the pre-crisis data. Over time, the sensitivity changed, however, on average one can assume that it did not exceed 20% (Paulson and Amromin (2010)). Subprime default rate is chosen to be 5% in the steady state. According to the data presented in Demyanyk and van Hemmert (2011), in the decade preceding the crisis, the default rate on subprime hybrid loans was oscillating around 10%. However, usually when a household defaults on its mortgage, the bank seizes and sells the property, receiving some foreclosure value. The present model does not have this feature, thus the steady state default rate is half of that in the data. Also, a higher steady state default rate would result in an unreasonably high steady state value for interest rate on subprime loans. The Taylor rule coefficients are taken from the study of Orphanides (2005). Parameters describing the autocorrelation and the standard deviation of shocks in the economy have the same values as in Iacoviello (2005) to make the model comparable to the existing literature on the role of housing markets in the economy.

## 2.10 Model dynamics

Similarly to Iacoviello (2005) the present model is subject to four different shocks. The monetary shock is defined as an exogenous increase in the interest rate set by central bank and can be interpreted as the move of the central bank which is inconsistent with the usually applied Taylor rule. The inflation shock is defined as an exogenous increase in the inflation rate in the economy and shows up in the Phillips curve. The negative preference shock captures change in preference for housing among households. This may capture - in reduced form - a regulatory or taxation reform which makes the investment in housing less attractive to households (regulatory reforms allowing for a large range of mortgage products could have led to a positive preference shock in the US (see Temkin et al. (2002))). A technology shock is defined as an increase in productivity that is one of the variables in the production function. It may capture some major technological invention that increases the efficiency of the production process.

The present model has two important features distinct from the model of Iacoviello (2005). First of all, it is assumed that prime households have access to long-term loans and that for  $T$  periods (here  $T = 4$ ) the interest rate on the given loan contract remains fixed. Moreover, unlike in Monacelli et al. (2011), it is assumed that prime households may borrow up to the future value of their collateral minus their outstanding debt. The difference between the length of the prime and subprime contract should capture the difference between fixed interest rate and variable interest rate loan contracts. One could assume longer maturity of multi-period loans, as well as longer maturity of short-term subprime loans. To check whether the results and conclusions are robust to the changes in the maturity of loans, we also run the model for six-period prime loans and two-period subprime loans (instead of four-period prime loans and one-period subprime loans). The qualitative results of the model do not change in this case, and the quantitative impact is limited. The second distinct feature of the presented model is the existence of subprime borrowers and lenders, and, importantly, the sensitivity of subprime default rate to change prices. The importance of the two model devices is described in the following passages.

Figure 5 shows impulse responses of variables related to the prime borrowers in the economy in the case of one-period loans for all borrowers (solid line) and for the benchmark model (dotted line).

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regulation, the consumption of both types of bankers is very small, in case of subprime lenders practically zero, because they only consume the profit on spread. A way to increase the spread-markup is to increase the risk weights and capital requirement capital - then the steady state consumption of both types of bankers increases and the equilibrium is determinate. The value 3 for the multiplier is chosen to ensure a stable equilibrium in different versions of the model presented in the paper.

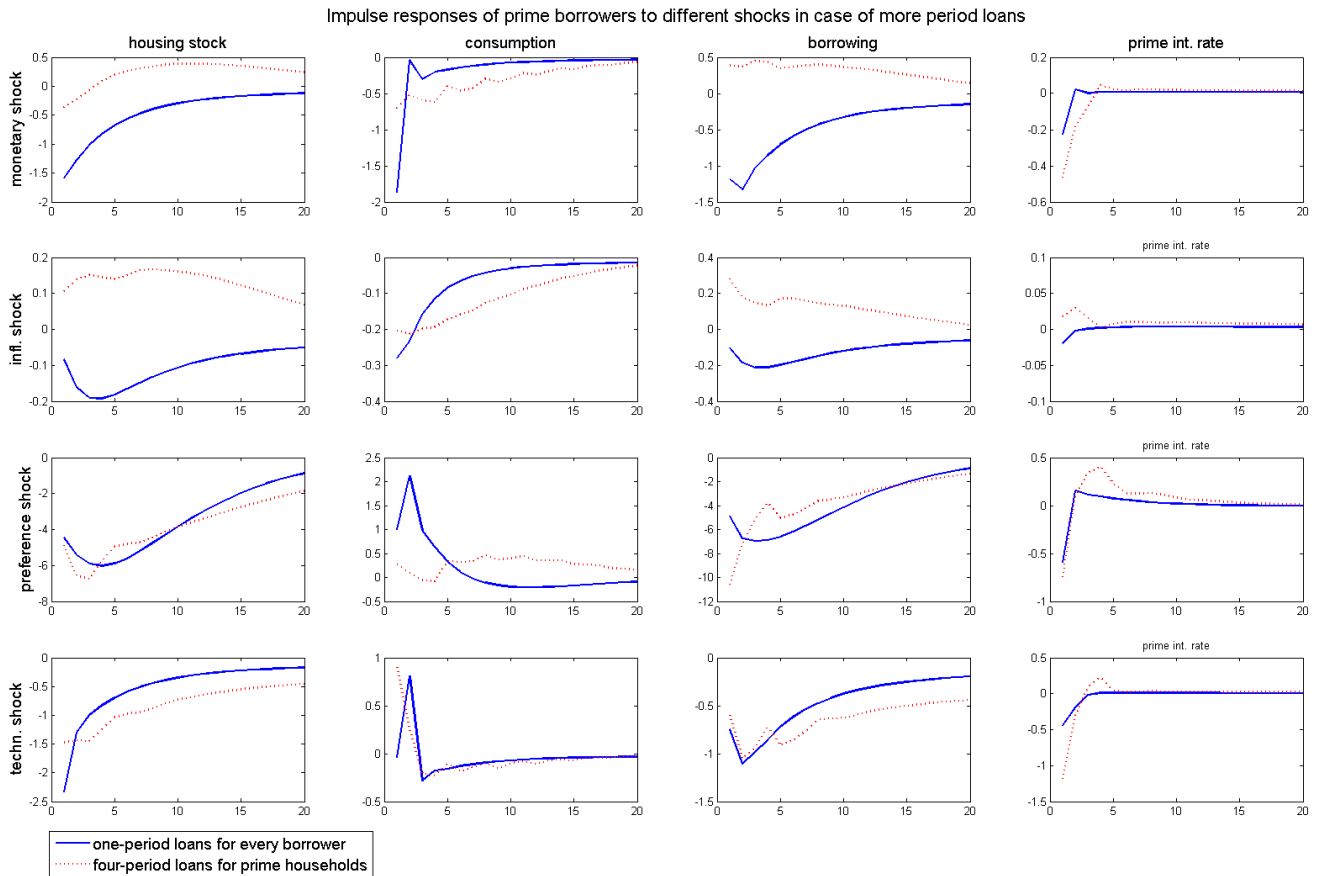


Figure 5: Impulse responses of models without subprimers with one- and four-period loans for primes (in percentage deviations from steady state)

We see that in case of all four shocks the introduction of long-term loans for prime borrowers results in a subdued response of primes' housing stock and consumption as compared to the version of the model in which all borrowers take out loans for one period. The standard deviation of prime borrowers' consumption is 39.55% higher in the case when they can only borrow short-term, when compared to the benchmark case, while the standard deviation of their borrowing is 3.55% higher. To sum up, the introduction of long-term loans adds realistic features to the model, making the borrowing and consumption of prime borrowers less responsive to different shocks and distinguishing this type of borrowers from subprime and corporate debtors. Substantially lower volatility of final goods consumption increases the welfare of prime borrowers. In a slightly different multi-period setup Monacelli et al. (2011) (who do not make the collateral constraint depending on the amount of outstanding debt) show (for  $T = 2$ ) that variable interest rates amplify the response of economy after a monetary shock when compared to a fixed rate setup. The present paper confirms this result and extends it to other shocks.

The second important modeling device is the assumption of the existence of subprime borrowers in the economy and the dependence of their default rate on the house prices. Alone the introduction of subprime borrowers and lenders to the model economy does not change the behavior of aggregate model variables. Also the assumption of default sensitivity to house prices alone does not lead to any amplification effects in the economy. The only effect that we may note while examining impulse response functions of the benchmark model and the model in which default rate of subprime borrowers is not dependent on the evolution of house prices is the redistribution effect between subprime borrowers and lenders, presented in figure 6.

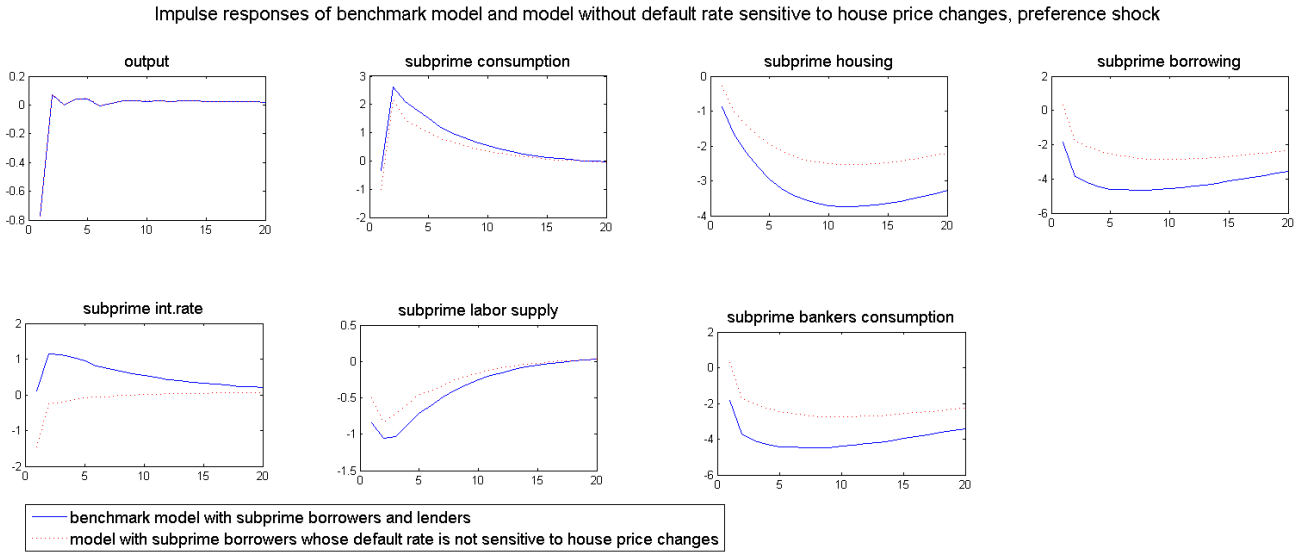


Figure 6: Impulse responses of benchmark model and model without default rate sensitive to house price changes, preference shock

That redistribution effect resembles the dynamics observed in Iacoviello (2013) after an exogenous financial shock. The varying default rate, precisely, the rising default rate after a negative shock leading to a house price fall, is from the subprimers' perspective a positive wealth effect - they may repay less than contracted. Feeling wealthier, subprime borrowers will reduce their labor supply when compared to the case when the default rate does not vary, which drives the output down. For the subprime lenders, the rising default rate represents a negative wealth effect, because they do not get back all the contracted loan installments. Suffering losses on their loan portfolio, subprime lenders face a tighter capital constraint. They will reduce their lending to subprime borrowers and raise the interest rate on subprime loans, however, also their consumption will go down. Although the described redistribution effect and balance sheet effect have a negative effect on the overall consumption and more responsive house prices affect other borrowers in the economy that use housing stock as collateral for their loans, the subdivision of the banking sector into the subprime and the commercial segments prevents the negative developments in the subprime market to spread to other sectors of the economy, especially the production sector which is unaffected by subprimers' defaults and we do not observe an effect on aggregate output. The impulse response functions of both models are practically identical if we consider such variables as nominal interest rate, inflation, house prices and output, so the figure 7 presents the results of the benchmark model and the results of the Iacoviello model, for comparison.

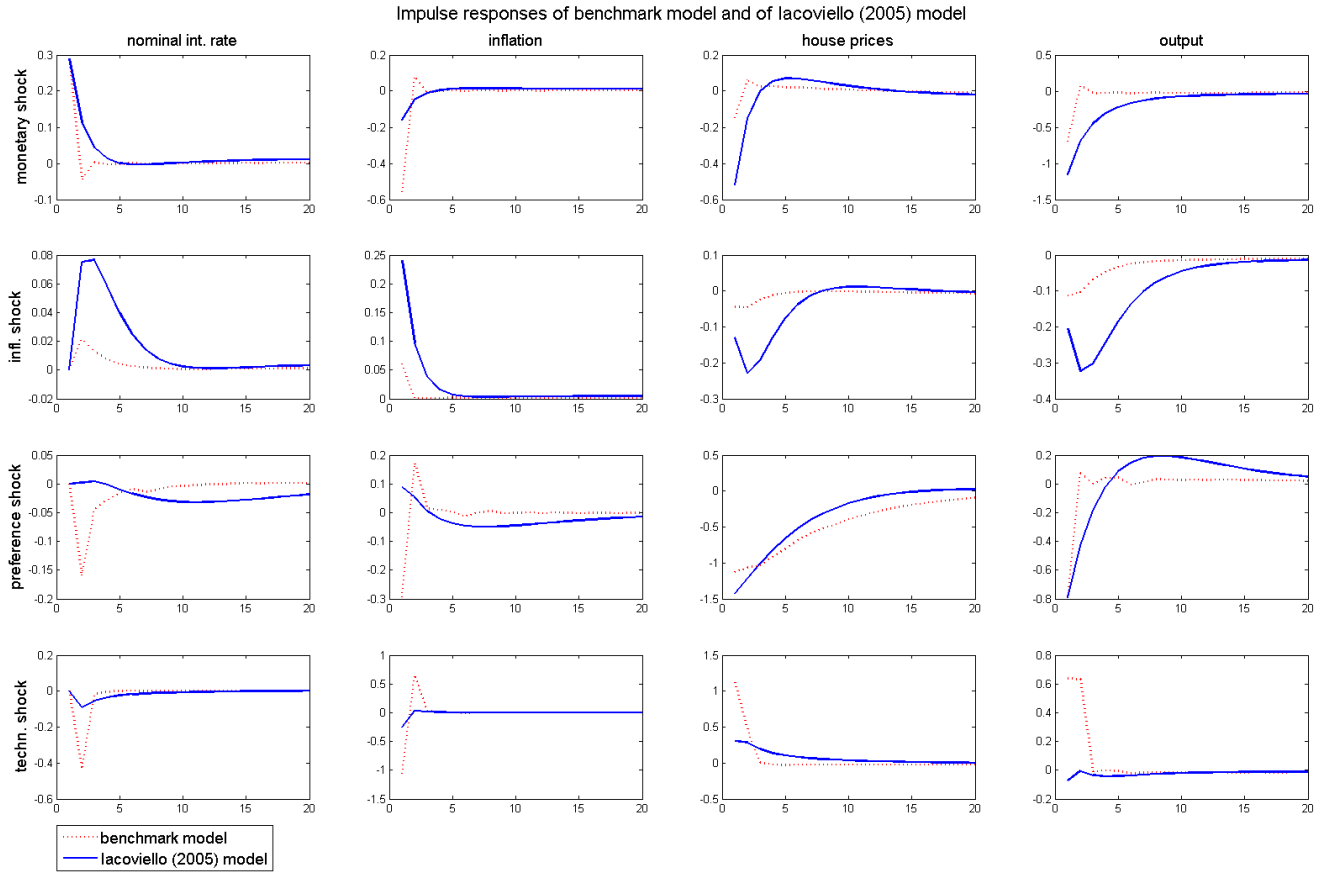


Figure 7: Impulse responses of the benchmark model and the model of Iacoviello (2005)

The impulse responses to the four shocks in Figure 7 resemble the impulse responses of Iacoviello (2005). After an exogenous increase in the nominal interest rate set by central bank, we observe a fall in inflation and a comovement of house prices and output. The impulse responses are in line with the conventional view of the effects of a monetary shock. An inflation shock, which is calibrated to be both not very persistent and of a rather small amplitude, leads to a very small fall in house prices and output. The nominal interest rate rises. The negative preference shock for housing stock results in a fall of house prices and output. Also inflation and nominal interest rate show downward dynamics. The model, similarly to Iacoviello (2005), exhibits a comovement of house prices and output responses to different shocks, also after the technology shock, which is not the case in the model of Iacoviello<sup>9</sup>.

### 3 Model with securitization of subprime loans

The data provides evidence for the importance of securitization in subprime lending. The majority of subprime loans have been securitized, first in form of a RMBS that often was a building block of CDO structures. Usually, different subprime borrowers have different default probabilities, so securitization may be a way to average the risk on subprime exposure. In the present model, all subprime borrowers have the same default rate. However, we can think

<sup>9</sup>The seemingly contra-intuitive result obtained by Iacoviello is driven mainly by two forces in the model - the nominal rigidity and debt deflation effects. In the existence of a nominal rigidity in the model a positive technology shock may lead to a negative short-run effect on the employment (see Galí (1999)). Moreover, a positive technology shock leads to a fall in inflation. Deflation redistributes wealth from borrowers to lenders in the economy and since in the presented setup borrowers are more prone to consume due to their impatience, deflation has a negative impact on the output. In our benchmark setup and given a different calibration, a positive TFP shock leads to an increase in output, which is in line with conventional wisdom.

about that default rate as the default rate representing the aggregate distribution over all subprime borrowers, who differ in their default sensitivity at an individual level. Typically, an MBS structure consists of three tranches: senior, mezzanine and equity. To simplify the computation, we assume that the model's RMBS consists only of two tranches: senior and equity.<sup>10</sup> Figure 8 illustrates the payoff functions of investors in the RMBS.

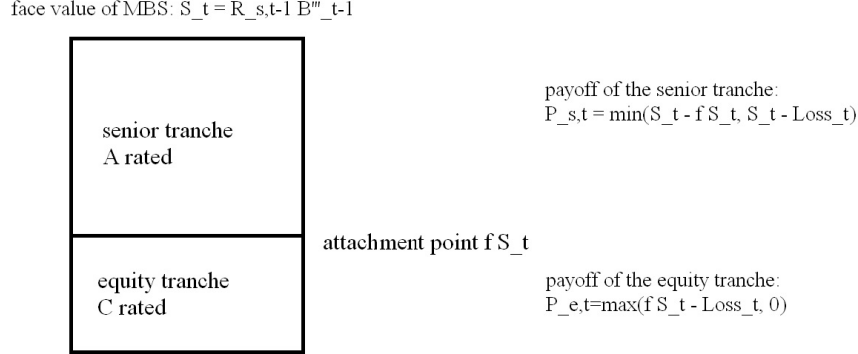


Figure 8: A two tranche MBS

The security is a pass-through security, which means that the nominal loan proceedings are redistributed to the MBS investors. The payoff of equity tranche investors is the larger, the smaller the loss on the underlying loan portfolio (determined by the default rate). The size of the equity tranche defines the maximal risk exposure of equity tranche investors. If there is a loss on the underlying loan portfolio, the equity tranche investors get the difference between the size of the equity tranche and the loss. However, if the loss exceeds the size of the tranche, the equity tranche investors simply get nothing from their investment, and the senior tranche investors begin to suffer. Their payoff function is a minimum function. They either get back the tranche size, or the difference between the face value of the MBS and the loss (in case when losses are bigger than the size of the equity tranche).  $P_{s,t} = \min(S_t - f S_t, S_t - \text{Loss}_t)$  denotes the payoff of senior tranche buyers and  $P_{e,t} = \max(f S_t - \text{Loss}_t, 0)$  denotes the payoff of equity tranche buyers, where the principal of the MBS is (in real terms)  $S_t = R_{s,t-1} b'''_{t-1} / \pi_t$ , loss equals  $\delta_{s,t} S_t$ . Cash flows obtained from subprime loans (in real terms) are equal to  $S_t(1 - \delta_{s,t}) = R_{s,t-1} b'''_{t-1}(1 - \delta_{s,t}) / \pi_t$ .

How is the face value of the security divided into the two tranches? The equity tranche will absorb the losses up to a certain point, called in the CDO jargon the attachment point (defined in the model by a parameter  $f$ ). The parameter  $f$  describes the amount of subordination the senior tranche enjoys. If losses on the portfolio are bigger than the thickness of the equity tranche (determined by the parameter  $f$ ), the senior tranche holders start to suffer. The equity tranche suffers losses from 0% to  $f$  (attaches at 0% and detaches at  $f$ ), whereas the senior tranche suffers all losses that are bigger than percentage  $f$  of the face value of the security (the tranche attaches at  $f$  and detaches at 100%). Independently on the outcome, the cash flows distributed to investors always equal cash flows from subprime loans (including losses), which is illustrated in Table 2:

<sup>10</sup>Gorton (2008) argues that subprime securitization differs from the securitization of other assets because the tranche sizes are not fixed. There is dynamic tranching as a function of excess spread and prepayments, so the whole structure is sensitive to house prices. At the beginning of the existence of a subprime MBS, the equity tranches are usually very thin and along with repayments of the subprime loans they reach their target level. However, if house prices decline from the very beginning, the equity tranche remains very thin and thus senior tranche holders are subject to a very large subprime risk (that was the case for MBS issued in 2006 and later). This works as another amplification mechanism in the design of subprime security. In the presented model it is assumed that tranche sizes are fixed from the beginning. Including varying tranche sizes in the model would amplify the effects of shocks in the economy.

	Scenario	
	Loss is bigger than the equity tranche $\delta_{s,t}S_t > fS_t$	Loss is smaller than the equity tranche $\delta_{s,t}S_t < fS_t$
payoff of equity tranche holder	0	$fS - \delta_{s,t}S_t$
payoff of senior tranche holder	$S_t - \delta_{s,t}S_t$	$S_t - fS_t$
sum of payoffs	$S_t - \delta_{s,t}S_t$	$S_t - \delta_{s,t}S_t$

Table 2: MBS payoffs - two scenarios

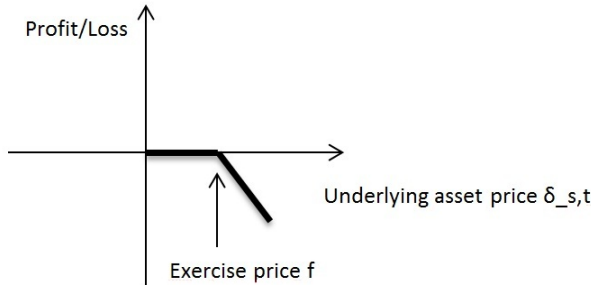
Note that while evaluating the expected payoff of tranches,  $E_t(Loss_t) = E_t(\delta_{s,t+1}S_{t+1})$  is unknown, because the default rate is a jump variable. The payoffs of equity and senior tranche holders resemble payoffs from investment in European options. A European option is a financial instrument that gives the holder the right (but not obligation) to buy (in case of a call option) or to sell (in case of a put option) the underlying asset at a certain price (reference price, called also strike) at a certain period in time (expiration date of the option). Buying a call option or writing (selling) a put option, we bet on the increase of the underlying asset price. Selling a call option (having a short call position) or buying a put option (having a long put position), we bet on the fall in the underlying asset price. The holder of an equity tranche of the MBS gets payoffs equal to the ones from a long put position - he invests in the hope that the default rate (underlying asset) will decrease. Also investing in a senior tranche of an MBS is profitable when the default rate decreases. Note that

$$P_{s,t} = \min(S_t - fS_t, S_t - \delta_{s,t}S_t) = S_t(1-f) - \max(S_t\delta_{s,t} - fS_t, 0) = S_t(1-\delta_{s,t}) - \max(fS_t - \delta_{s,t}S_t, 0). \quad (53)$$

Thus the payoff of the senior tranche can be rewritten as having a long position in the face value of the tranche and a short call position, or a long position in the cash flows from subprime loans and a short put. Notice that both in the case of the equity tranche and the senior tranche payoff we can factor out the face value of the MBS,  $S_t$ . The underlying asset for the investors of MBS tranches is the default on subprime loans  $\delta_{s,t}$ , whereas the exercise price of the options they trade equals  $f$  (our attachment point of senior tranche). Figure 9 visualizes the profit (on the vertical axis) of investing in a short call and long put position depending on the default on subprime loans (horizontal axis). The lower the default, the higher the profit of investors (or the lower the loss).

Senior tranche investor payoff:  $S_t(1-f) + \text{short call}$

short call:  $-\max(\delta_{s,t}S_t - fS_t, 0) = \min(fS_t - \delta_{s,t}S_t, 0) = S_t \min(f - \delta_{s,t}, 0)$



Equity tranche investor payoff: long put

long put:  $\max(fS_t - \delta_{s,t}S_t, 0) = S_t \max(f - \delta_{s,t}, 0)$

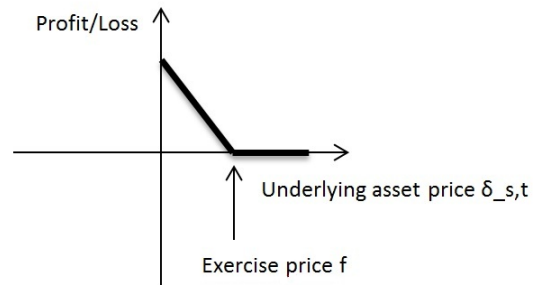


Figure 9: Option position of MBS investors

After a shock, payoffs are realized and it is known whether the loss was bigger than the size of equity tranche. Thus the investors get a well-known proportion of subprime cashflow. However, while deciding about the investment in the next period, they take into account the expected future value of payoffs to evaluate the amount of money they want to pay for the given tranche. Thus an appropriate expression for  $E_t[\min(S_{t+1} - fS_{t+1}, S_t - \delta_{s,t+1}S_{t+1})]$  and

$E_t[\max(fS_{t+1} - \delta_{s,t+1}S_{t+1}, 0)]$  is needed. As noted before, in both cases the  $E_t[S_{t+1}]$  can be factored out. However the uncertainty remains with respect to the development of  $E_t[\delta_{s,t+1}]$ . One can use the Black-Scholes formula to evaluate payoffs, but this requires certain assumptions that cannot be made here (stable volatility of default rate, risk-free interest rate). However, there is a simple method allowing to smoothly approximate a function with a kink, like the ones drawn above. The logistic function provides a very good approximation of maximum and minimum functions, which makes the solution tractable.<sup>11</sup> The maximum and minimum payoffs can be thus approximated with a logistic function:  $E_t[\max(f - \delta_{s,t+1}, 0)] \approx E_t[f - \frac{\delta_{s,t+1} - f}{1 + e^{(\delta_{s,t+1} - f)}}]$ , whereas  $E_t[\max(\delta_{s,t+1} - f, 0)] \approx E_t[-f - \frac{\delta_{s,t+1} + f}{1 + e^{(-\delta_{s,t+1} + f)}}]$ . Equation (53) shows three analogous representations of payoff that goes to senior tranche holders. From this representation one can see that the minimum function can be rewritten in such a way that only one approximation with the logistic function has to be made to find expected payoffs of both tranche holders (for long put). Having rewritten expected payoffs using the approximating function, one can log-linearize the conditions determining the behavior of price of MBS tranches and consumption of agents engaged in the transaction.

To investigate whether the engagement of commercial banks in the securitization process could be one of the factors amplifying the negative results of different shocks in the economy, we consider two cases. In the first case, we assume that the generated MBS tranches are bought by patient households (because they are more patient, they acquire claims on the senior tranche) and entrepreneurs (because of their degree of impatience, they are more prone to acquire claims on the equity tranche). In the second case, we assume that the commercial bankers buy senior tranche of the MBS and the entrepreneurs invest in the equity tranche (one could also assume that the commercial bankers buy both the equity and the senior tranche, which would be a more extreme case and would lead to qualitatively stronger results). In both cases subprime lenders retain a vertical fraction  $t$  of the issued security (equivalent to retaining percentage  $t$  of cash flows).<sup>12</sup> Why may commercial bankers buy claims on MBS? For example to diversify their credit risk and get exposure to a different credit market. Also, they may be as optimistic as subprime borrowers are, and believe that the house prices will continue to rise. Moreover, senior tranches usually have the highest possible rating, so the risk weight on them is very low and the purchase has a positive impact on the balance sheet of the banks. Why may patient households and entrepreneurs buy MBS tranches? For them this investment is just another possibility to smooth their consumption.

We assume that certain agents in the economy invest in the MBS securities and we do not model their decision as a portfolio choice decision. The reason for it is that under the first order approximation the portfolio decisions are not well-defined. Moreover, the investment decisions of the MBS investors were not made optimally anyway due to a range of reasons, among them the lack of information. Also, many institutional investors invested in the MBS because the securitized products offered a higher return than safe assets but were seemingly of the same risk as the diversification and repackaging were believed to reduce the risk and secured a high rating even for the subprime MBS. Short-term oriented compensation schemes in the financial industry were also a part of the problem. Since this paper focuses more on the possible transmission channels of the recent crisis than its microfoundations, we take the shortcut and assume two cases of securitization to compare their different effects on the economy.

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<sup>11</sup>Actually, logistic function is used in one of the financial methods of estimating the value of securitized products. In finance, apart from Black-Scholes formula and copula methods for option pricing, neural networks have been used to price options (that have a logistic function in the solution) at least since the publication of Hutchinson et al. (1994).

<sup>12</sup>In general, literature discusses three main types of retention: vertical slice retention, horizontal slice retention, and an equivalent exposure of the securitized pool, discussed further in Geithner (2011). In the presented model's case, vertical slice retention generates the same payoff for the bank as equivalent exposure.



### 3.1 Version in which patient households and entrepreneurs invest in MBS tranches

In the first version of the model with securitization of subprime loans patient household invest in the senior tranche, and entrepreneurs in the equity tranche.<sup>13</sup>

The budget constraints of investors change and a new term describing the investment in derivative security appears. First denote the payoff of senior tranche  $\min(S_t - fS_t, S_t - \delta_{s,t}S_t)$  as  $MBS_{s,t-1}$  and  $E_t[\min(S_{t+1} - fS_{t+1}, S_{t+1} - \delta_{s,t+1}S_{t+1})]$  as  $MBS_{s,t}$  and the price of the senior tranche by  $p_{s,t}$ . Then the budget constraint of the patient household is (remember that subprime lenders retain portion  $t$  of every tranche):

$$c'_t + q_t(h'_t - h'_{t-1}) + d_t + (1-t)p_{s,t}MBS_{s,t} = R_{d,t-1}d_{t-1}/\pi_t + w'_tL'_t + F_t + (1-t)MBS_{s,t-1}. \quad (54)$$

Each period patient household gets revenue from investing in the senior tranche and buys a claim on future proceedings from investment in the MBS. The FOCs of prime households do not change but there is a new equation determining the price of the new claim.

$$\beta \frac{1}{c'_{t+1}} = p_{s,t} \frac{1}{c'_t}. \quad (55)$$

Analogously, denote the terms describing the investment in the equity tranche  $E_t[\max(fS_{t+1} - \delta_{s,t+1}S_{t+1}, 0)]$  as  $MBS_{e,t}$  and  $\max(fS_t - \delta_{s,t}S_t, 0)$  as  $MBS_{e,t-1}$  and the price of the equity tranche by  $p_{e,t}$ . Then the budget constraint of the entrepreneur is:

$$\begin{aligned} \frac{Y_t}{X_t} + b_{e,t} + (1-t)MBS_{e,t-1} = \\ c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t}b_{e,t-1} + w'_tL'_t + w''_tL''_t + w'''_tL'''_t + I_t + \xi_{K,t} + (1-t)p_{e,t}MBS_{e,t}. \end{aligned} \quad (56)$$

The FOC w.r.t to the new claim is:

$$\gamma \frac{1}{c_{e,t+1}} = p_{e,t} \frac{1}{c_{e,t}}. \quad (57)$$

Apart from the optimization problems of agents investing in the security, also the problem of subprime lenders changes in the wake of securitization of subprime loans. They have only to include the retained proportion of subprime loans in their balance sheet:

Assets	Liabilities
Loans to subprime borrowers: $tb'''_t$	Interbank deposits $bb_t$
Loss reserve $-t\delta_s b'''_t$	

Thus a Basel-type capital constraint, given exogenously is:

$$\tau \leq \frac{t(1-\delta_s)b'''_t - bb_t}{\chi_2 t(1-\delta_s)b'''_t}. \quad (58)$$

The budget constraint of subprime lenders changes. Note that when it comes to the transfer of already realized cashflows, we have:

$$(1-t)[\min(S_t - fS_t, S_t - \delta_{s,t}S_t) + \max(fS_t - \delta_{s,t}S_t, 0)] = (1-t)[S_t(1-\delta_{s,t})] = (1-t)[R_{s,t-1}b'''_{t-1}(1-\delta_{s,t})/\pi_t],$$

<sup>13</sup>Corresponding changes steady state values, as well as loglinearized equations may be found in Appendix X.

whereas in case of the purchase of claims on future proceedings this shortcut cannot be made because the prices of both tranches differ, since the agents that buy them have different discount factors. Thus the budget constraint of subprime lender is:

$$c_{bb,t} + b_t''' + R_{b,t-1}bb_{t-1}/\pi_t - (1-t)[p_{s,t}MBS_{s,t} + p_{e,t}MBS_{e,t}] = bb_t + tR_{s,t-1}(1-\delta_{s,t})b_{t-1}'''/\pi_t. \quad (59)$$

The prices of tranches are determined by equations (55) and (57).

### 3.2 Version in which commercial bankers and entrepreneurs invest in MBS tranches

In the second version of the model with securitization commercial bankers invest in the senior tranche, whereas entrepreneurs, as in the first case, buy claims on the equity tranche. The problem of entrepreneurs does not change with respect to the version of model when patient households and entrepreneurs buy MBS tranches. The budget constraint of commercial bankers changes then, as well as their balance sheet and capital constraint. We assume here that the risk weight on senior tranche is as high as in case of interbank deposits (since it is highly rated), whereas the risk weight on equity tranche equals the risk weight of subprime loans.

Commercial bankers' balance sheet is:

Assets	Liabilities
Loans to prime borrowers: $b_t''$	Deposits $d_t$
Interbank loans : $bb_t$	Equity $eq_t$
Loans to entrepreneurs: $b_{e,t}$	
MBS security - senior tranche: $(1-t)MBS_{s,t}$	

Thus a Basel-type capital constraint, given exogenously, has the form:

$$\tau \leq \frac{b_t'' + bb_t + b_{e,t} + (1-t)MBS_{s,t} - d_t}{\chi_3 bb_t + \chi_1 b_t'' + \chi_2 b_{e,t} + \chi_3 (1-t)MBS_{s,t}}. \quad (60)$$

The budget constraint of commercial bankers is now:

$$c_{b,t} + R_{d,t-1}d_{t-1}/\pi_t + b_t'' + bb_t + b_{e,t} + (1-t)p_{s,t}MBS_{s,t} = d_t + R_{b,t-1}bb_{t-1}/\pi_t + 1/T \sum_{j=1}^T \frac{R_{T,t-j}b_{T,t-j}''}{\prod_{i=0}^{j-1} \pi_{t-i}} + R_{e,t-1}b_{e,t-1}/\pi_t + (1-t)MBS_{s,t-1}. \quad (61)$$

New FOC:

w.r.t.  $MBS_{s,t-1}$

$$\beta_b \frac{1}{c_{b,t+1}} = p_{s,t} \frac{1}{c_{b,t}}. \quad (62)$$

The problem of subprime lender is the same as in the case when patient households and entrepreneurs buy MBS tranches.

### 3.3 Calibration

Parameters chosen for calculation are presented in Table 3<sup>14</sup>:

Description	Parameter	Value	Source
tranche retention by banks	$t$	0.01	Global Financial Stability Report (2009)
attachment point of senior tranche	$f$	0.2	Hull, White (2010, p.3)

Table 3: Calibrated parameters in the model with securitization

### 3.4 Results

Figure 10 presents the impulse responses of the benchmark model (solid line) and two versions of model with securitization. The dashed line shows the responses of the model in which patient households and entrepreneurs buy MBS tranches, whereas the dotted line shows the responses of model in which commercial bankers and entrepreneurs buy MBS tranches. In case of all four shocks we see that the model in which patient households acquire claims on senior tranche and entrepreneurs on equity tranche, the output response is smaller than in the benchmark case. Due to the securitization, the capital constraint of subprime lenders becomes looser and their consumption is less responsive to shocks than in the benchmark model. Of course, buying claims on MBS tranches changes the budget constraints of the investors and has impact on their consumption, however they can absorb losses on MBS through working and saving (patient households) or borrowing (entrepreneurs). The overall effect of securitization is positive, because the risk is spread among different agents in the economy. This is the way how the securitization was expected and supposed to work.

However, also another possibility was considered - that commercial bankers (instead of patients) buy senior MBS tranches. Looking at Figure 10 we see that if securitized assets are bought by commercial bankers and entrepreneurs, there is an amplification of output response after three shocks - monetary, preference and technology. The amplification occurs not only in comparison to the version of model in which securitized products are bought by patients and entrepreneurs, but also with respect to the benchmark model without securitization. What is the reason for this amplified contraction? The contraction is not driven by the losses of commercial banks due to the investment in the senior tranche of MBS, because in case of all shocks the equity tranche investors (entrepreneurs) cover the majority of losses on the subprime portfolio. The net payoff from the investment in the senior tranche of the MBS is almost negligible for the commercial bankers (and it is slightly negative only in case of the monetary shock), since they price the MBS tranche taking into account possible subprime defaults. All the effects occur through balance sheet of both types of bankers. Issuing MBS makes the capital constraint of subprime lenders looser (in case of a negative shock), whereas it tightens the capital constraint of commercial bankers because they hold the senior tranche of the MBS (that is declining in value after a negative shock increasing the default rate) on their balance sheets. To reduce the tightness of the constraint, commercial bankers may either reduce their consumption or lending (similar mechanism occurs in Iacoviello (2013)). In the present model, they do both.

<sup>14</sup>Evidence suggests that on average retention of securitized assets is higher in Europe than in the US. Whereas in Europe originators usually held around 5% of issued securities, in the US the retention rate was often at 0% and rarely exceeded 1% for MBS. Retention percentages for CDOs and ABS were usually higher, but in years 2002-2009 on average did not exceed 7% (Global Financial Stability Report, October 2009, p. 100-107).

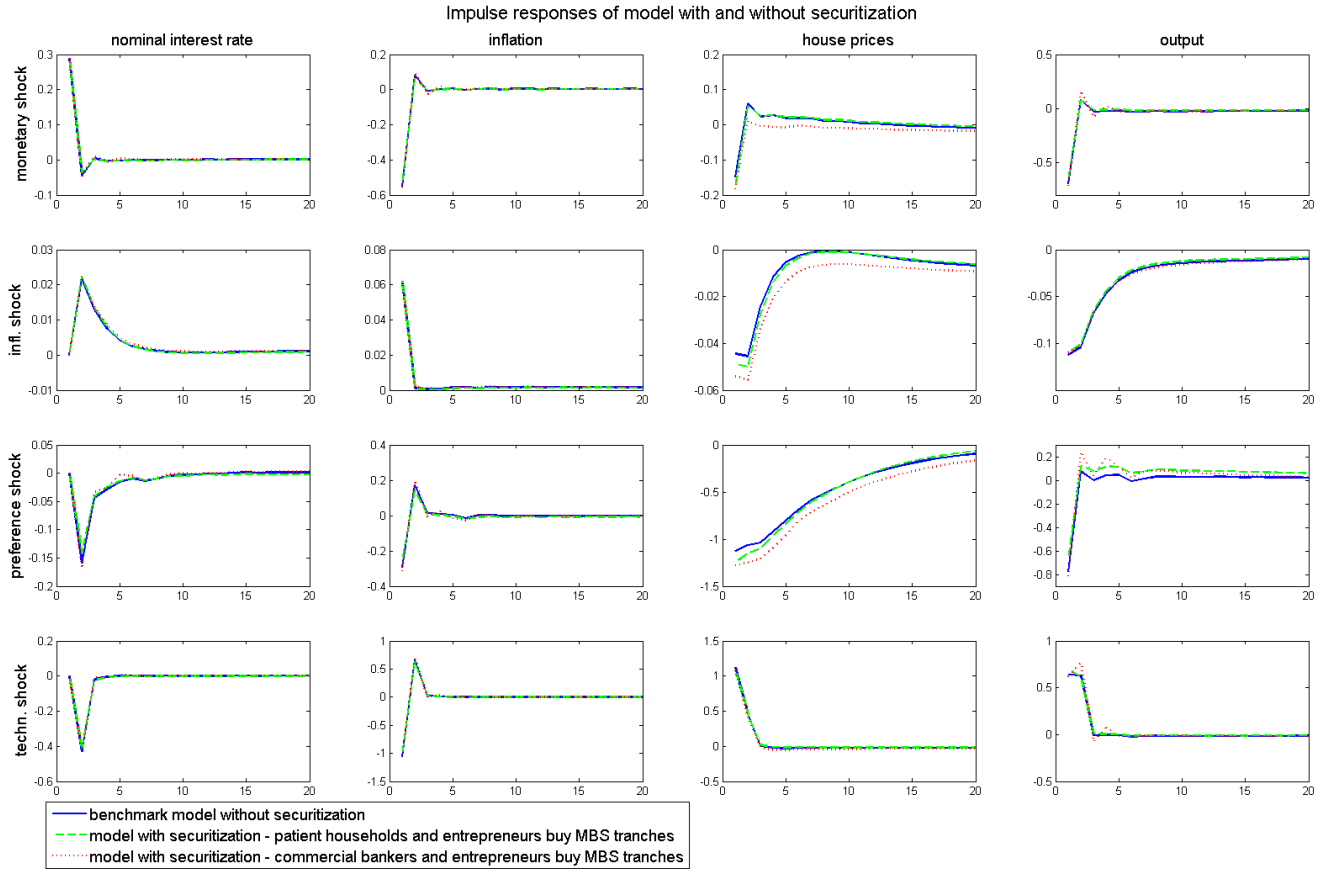


Figure 10: Impulse responses of models with and without subprime securitization

When a negative shock hits the economy and commercial bankers buy senior MBS tranches, their capital constraint gets tighter and they reduce the lending to prime borrowers and entrepreneurs who finance housing stock purchases with the money from bank. As housing stock is a production factor, the output in economy goes down more than without the securitization. When non-banks buy MBS tranches, there is a direct effect of this investment on the consumption of the investors, but there is no loss on the balance sheet of the commercial bankers and thus the intermediation process is unaffected and the securitization has an overall positive effect. In the benchmark case the entrepreneurs are unaffected by the defaults in the subprime sector, through the securitization, when the commercial bankers engage in the transaction, a link is created between the production sector and the subprime mortgage market, so that indirectly the entrepreneurs suffer from losses in the subprime portfolio. This dynamics is visible in the Figure 11 that presents chosen model variables after a monetary shock. We may see that if commercial bankers become buyers of MBS, the entrepreneurial borrowing, housing stock, as well as borrowing and housing stock of prime households are considerably lower than in the benchmark case or in the case when only patient households and entrepreneurs buy MBS.

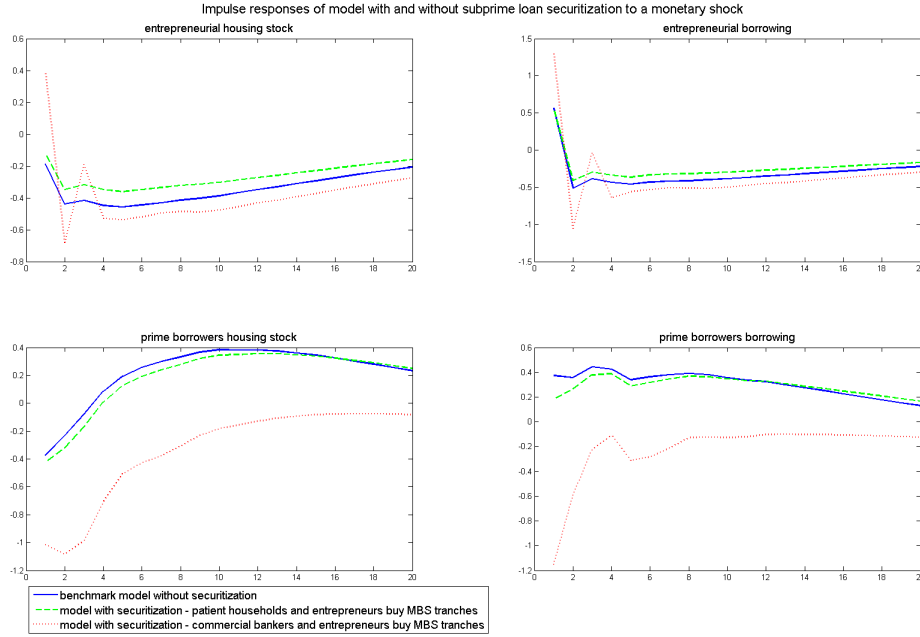


Figure 11: Impulse responses of models with and without subprime securitization after a monetary shock

The fact that bankers face a capital constraint is crucial for obtaining the above result. Because the binding capital constraint leads to a disruption of the credit process when bankers engage in the securitization process, it is better for the model economy when the regulatory constraint is set at a lower level. Thus, the higher the initial leverage of the banks, the less pronounced negative results of the securitization in our model. This seemingly paradoxical result stems from the fact that it is indeed the constraint that the bankers face that turns out to be the main friction in this case.

Apart from considering the impulse response functions, one can also have a look at the model's theoretical moments. Table 4 presented below shows standard deviation of main variables of interest for the benchmark model and 2 versions of model with securitization. For the purpose of the table, we denote the model with securitization in which entrepreneurs and patient households buy MBS as Sec1, and the model in which entrepreneurs and commercial bankers buy MBS as Sec2.

Variable	Standard deviation		
	Benchmark	Sec1	Sec2
output	1.4082	1.3999	1.5500
aggregate consumption	1.3056	1.3117	1.3830
aggregate lending	3.1871	4.0179	5.8080
inflation	1.4081	1.3612	1.4300
nominal interest rate	0.5509	0.5357	0.5545
house prices	2.9046	3.0222	3.3807
entrepreneurial consumption	5.4085	5.1268	6.2243
entrepreneurial borrowing	5.0638	6.4078	6.8642
entrepreneurial housing stock	6.5205	8.0582	7.4751

Table 4: Simulated moments of chosen variables

We may note that in case of each variable, the standard deviation of the model in which entrepreneurs and commercial bankers buy MBS is considerably larger than in the benchmark case without securitization. In case of model in which entrepreneurs and patient households buy MBS, such clear conclusion cannot be made, as for different variables the standard deviation is larger or smaller compared to the benchmark case.

Model results suggest that the presence of the securitized products on the balance sheet of the banks might be negatively correlated with the value of commercial loans given out to entrepreneurs or, specifically, with the value of commercial real estate loans. This conjuncture is easy to check in the data for the assets and liabilities of commercial banks in the United States. Figure 12 shows total MBS (both agency and non-agency MBS) as the percentage of total bank assets (solid line), commercial real estate loans as the percentage of total bank assets (dotted line), as well as commercial loans (broader category, includes also industrial loans, not necessarily collateralized by real estate) as the percentage of total bank assets (dashed line). We see that indeed the percentage of MBS on the balance sheets of banks is negatively correlated with both other series. Whereas for the considered time period the correlation coefficient between total MBS and commercial real estate loans as percentage of total assets is -0.39, the correlation between total MBS and commercial loans as percentage of total assets is already -0.76. Thus, the data seems to support model's result that securitized assets might have partially crowded out lending to entrepreneurs in the US.

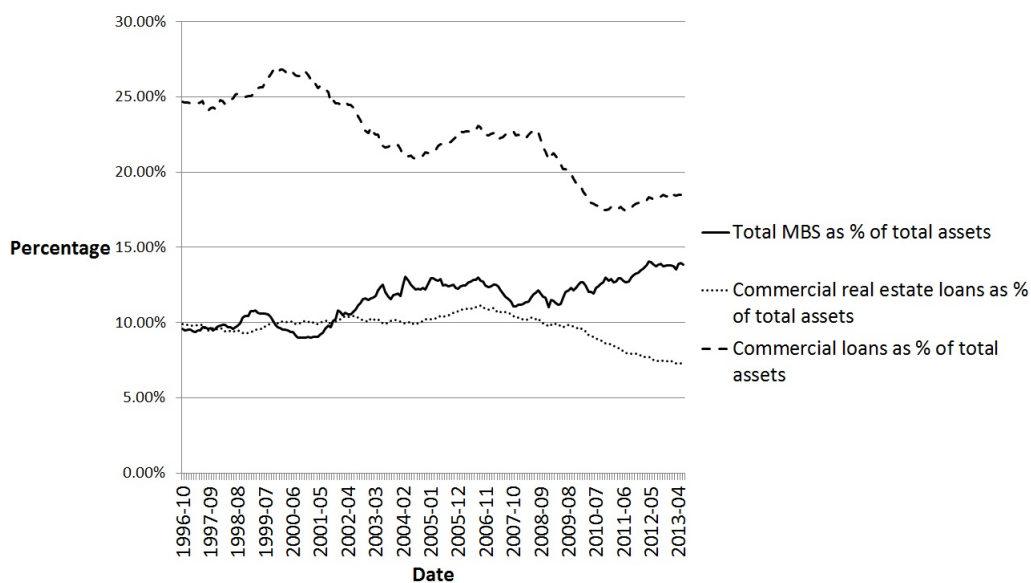


Figure 12: Different asset categories as percentage of total assets 10.1996-06.2013 (monthly data)

Source: Federal Reserve, Table H.8 Assets and Liabilities of Commercial Banks in the United States, Series: B1301NLGAM, B1303NLGAM, B1151NLGAM, B1023NLGAM, B1219NLGAM.

## 4 Conclusion

In this paper, we analyzed the importance of the specific design of subprime contract and securitization of subprime loans in generating cyclical fluctuations in the US in a New-Keynesian model based on Iacoviello (2005). The model incorporates four shocks: monetary, inflationary, preference and technology. The evidence suggests that alone the existence of subprime borrowers cannot account for the amplification of the response of output and house prices to different shocks in the economy. The paper also gives an answer to the question whether the securitization of subprime loans could be a factor amplifying the response of the economy to negative shocks, as the one we observed during the Great Recession. It turns out that the effects of securitization of subprime loans depend on who is the buyer of securitized assets. If households and entrepreneurs purchase the MBS tranches, securitization has a positive effect on the economy, spreading the subprime risk among different agents. Facing a negative shock and losses on securitized portfolio, these agents adjust their labor supply and saving decisions

(patient households) or borrowing (entrepreneur) so as to cushion the effects of the exogenous disturbances. However, if financial intermediaries (that are source of credit to households and firms in the economy) purchase the MBS tranches, the securitization has negative effects. It results in a bigger contraction of output after a negative shock when compared with the case in which non-banks buy the MBS tranches or without securitization. The risk-sharing aspect is absent in this situation, because the capital constraint on the side of the banks is a source of additional financial frictions. The assumptions that the default rate moves endogenously with changes in house prices and that part of the borrowers have access to long-term loans are crucial for obtaining the final result.

The results of the paper are in line with narrative explanations of the crisis provided by Hellwig (2008) and Jaffee et al. (2009). It is shown that securitization per se cannot be blamed for the crisis, because it may have a positive impact on the economy, as hoped for, if the securitized products are bought by agents that do not play the role of a financial intermediary in the economy. Obviously, it may be that unless there was the possibility of securitization, the bankers would not issue as many subprime loans as they did in the first place. The present paper deals however with the possible transmission mechanism in an economy with subprime borrowers and securitization and not the reasons for the existence of the subprime market and the subprime securitization with their incentive problems.

Moreover, paper's results suggest that the segmentation of the banking sector and avoiding interbanking linkages between banks operating in different segments may be a good way of preventing the negative spillovers of credit defaults in the economy. This may not only reflect the separation of the subprime and prime loans segments, but also separation of commercial and investment banking, which was the case in the United States for several decades due to the Glass-Steagall Act of 1933. The separation between commercial and investment banks was abolished with the begin of the new century and it might have been one of the causes of the widespread crisis, as current paper shows. Thus, from the point of view of the policymaker it is crucial to make sure that banks disclose all the information about their assets, even these hidden from the balance sheet that may give a hint about potential linkages between different banking sectors and branches.

The model operates in a closed-economy setup, however it is easy to imagine that the two banking sectors presented in the model represent financial intermediaries of two different countries. If toxic assets generated in country A are sold to the commercial banks in country B, country A is basically able to transfer all the default risk and losses to country B, which will suffer from recession due to the engagement in the international financial market (country A will remain practically intact). The same happens if private agents of country B buy the toxic assets, although in this case the recession is not as pronounced as when financial intermediaries engage in the process. This narrative can be easily adopted to partially explain what happened during the recent financial crisis. The US was the country issuing toxic assets and it was selling them to foreign investors, transferring the subprime risk from the country to the international market. This is why e.g. many European banks, municipalities etc. had problems when the defaults in the US subprime market started, and crisis spread around the world. In reality, not only the international buyers of the RMBS suffered from losses, the US economy experienced a recession as well (thus the country A from our example did not remain intact). This is partially due to the fact that the US banks also engaged in the acquisition of the toxic assets. Also other factors, such as labor market developments in the US, played a role, which are, however, not considered in this model.

To sum up, the paper combines the macroeconomic framework with financial economics, presenting one important channel that might have played a role in the amplification of the recent crisis in the US economy. It provides evidence that financial intermediaries and the constraints they are facing are an important feature of macroeconomic models.

# A Appendix A

## A.1 Steady state values

$$RD = 1/(beta)$$

$$gac = 1 - \beta_b RD$$

$$RB = (1 - gac(1 - \tau\chi_3))/\beta_b$$

$$gacb = 1 - \beta_b RB$$

$$R = (1 - gac(1 - \tau\chi_1))/(0.25\beta_b + \beta_b^2 0.25 + \beta_b^3 0.25 + \beta_b^4 0.25)$$

$$R_e = (1 - gac(1 - \tau\chi_2))/\beta_b$$

$$RS = (1 - gac(1 - \tau\chi_2)(1 - \delta_s))/(\beta_b(1 - \delta_s))$$

$$Y = 1$$

$$PI = 1$$

$$F = (1 - 1/X)Y$$

$$\zeta_1 = (\gamma\mu)/(1 - \gamma(1 - \delta))X$$

$$K = \zeta_1 Y$$

$$I = \delta K$$

$$si = (\alpha(1 - \mu - \nu) + X - 1)/X$$

$$sii = (1 - \alpha)(1 - s)(1 - \mu - \nu)/X$$

$$w''L'' = siiY$$

$$w'''L''' = (1 - \alpha)s(1 - \mu - \nu)Y/X$$

$$w'L' = siY - F$$

$$\zeta_2 = (\gamma\nu)/(1 - \gamma - ((1 - \gamma R_e)m/R_e))X$$

$$\zeta_3 = J'/(1 - \beta)$$

$$\zeta_4 = J''/(1 - beta'' - (1 - \beta'''m''(4 - \beta''R - \beta''^2R - \beta'''^3R - \beta''^4R)/(4R + \beta''R + \beta''^2R + \beta'''^3R))$$

$$\zeta_7 = J'''RS/(RS - RS\beta''' - (1 - \beta'''RS(1 - \delta_s))m''')$$

$$C_e = Y/X - \delta K + (m_e\zeta_2 Y/R_e)(1 - R_e) - w'L' - w''L'' - w'''L'''$$

$$C''' = RS w'''L'''/(RS - m''' \zeta_5(1 - RS(1 - \delta_s)))$$

$$C'' = ((7/4)R w''L'')/((7/4)R - m''\zeta_4(1 - R))$$

$$CB = (mii * z4 * CII / ((3/4) * R + R)) * (R - 1 + (1 - RD) * (1 - \tau * \chi_1)) + (1 - \delta_s) * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII / (RS)) * (RB - 1 + (1 - RD) * (1 - \tau * \chi_3)) + (m * \zeta_2 * Y / R_e) * (R_e - 1 + (1 - RD) * (1 - \tau * \chi_2))$$

$$CBB = (miii * \zeta_7 * CIII / (RS)) * (RS * (1 - \delta_s) - 1 + (1 - \delta_s) * (1 - \tau * \chi_2) * (1 - RB))$$

$$C' = Y - CB - CBB - C'' - I - C_e - C'''$$

$$Q = \zeta_3 C' + \zeta_4 C'' + \zeta_5 C''' + \zeta_2 Y$$

$$H' = \zeta_3 C' / Q$$

$$H''' = \zeta_7 C''' / Q$$

$$H'' = \zeta_4 C'' / Q$$

$$H_e = \zeta_2 Y / Q$$

$$B'' = m'' Q H'' / ((3/4)R + R)$$

$$B''' = m''' Q H''' / RS$$

$$B_e = m Q H_e / R_e$$

$$BB = (1 - \delta_s)(1 - \tau\chi_2)B'''$$

$$D = (1 - \tau\chi_1)B'' + (1 - \tau\chi_2)B_e + (1 - \tau\chi_3)BB$$

$$\lambda'' = (4 - \beta''R - \beta''^2R - \beta'''^3R - \beta''^4R)/(4RC''' + \beta''RC''' + \beta''^2RC''' + \beta'''^3RC''')$$

$$\lambda''' = (1 - \beta'''RS(1 - \delta_s))/C'''RS$$

$$\lambda_e = (1 - \gamma R_e)/(C_e R_e)$$

$$\text{Auxiliary: } z = 1 - \gamma(1 - \delta)$$

$$\kappa = (1 - \theta)(1 - \beta\theta)/\theta$$



## A.2 Loglinearized model (abandoned $E_t$ , hatted variables denote percentage deviations from ss)

### 1. Aggregate demand block

$$C' \hat{c}_t' = \hat{Y}_t - C'' \hat{c}_t'' - C''' \hat{c}_t''' - I \hat{I}_t - C_e c_{e,t} - CB c_{b,t} - CBB c_{bb,t} \quad (63)$$

$$\hat{c}_t' = c_{t+1}' + \pi_{t+1} - \hat{R}_{d,t} \quad (64)$$

$$\hat{c}_t''' = -\beta''' RS(\hat{R}_{s,t} - c_{t+1}''' - \pi_{t+1}) + \beta''' RS \delta_s(\hat{R}_{s,t} - c_{t+1}''' - \pi_{t+1} + \delta_{s,t+1}) - \lambda''' RSC'''(\hat{\lambda}_t''' + \hat{R}_{s,t}) \quad (65)$$

$$\begin{aligned} \hat{c}_t'' &= -\beta''(1/4)R(\hat{R}_t - c_{t+1}'' - \pi_{t+1}) - \beta''^2(1/4)R(\hat{R}_t - c_{t+2}'' - \pi_{t+1} - \hat{\pi}_t) \\ &- \beta''^3(1/4)R(\hat{R}_t - c_{t+3}'' - \pi_{t+1} - \hat{\pi}_t - \pi_{t-1}) - \beta''^4(1/4)R(\hat{R}_t - c_{t+3}'' - \pi_{t+1} - \hat{\pi}_t - \pi_{t-1} - \pi_{t-2}) - \lambda'' RC'''(\hat{\lambda}_t'' + \hat{R}_t) \\ &- (1/4)\beta''\lambda'' RC'''(\hat{\lambda}_{t+1}'' + \hat{R}_t - \pi_{t+1}) - (1/4)\beta''^2\lambda'' RC'''(\hat{\lambda}_{t+2}'' + \hat{R}_t - \pi_{t+1} - \hat{\pi}_t) \\ &- (1/4)\beta''^3\lambda'' RC'''(\hat{\lambda}_{t+3}'' + \hat{R}_t - \pi_{t+1} - \hat{\pi}_t - \pi_{t-1}) \end{aligned} \quad (66)$$

$$\begin{aligned} \hat{c}_{b,t} &= -\beta_b(1/4)R(\hat{R}_t - c_{b,t+1} - \pi_{t+1}) - \beta_b^2(1/4)R(\hat{R}_t - c_{b,t+2} - \pi_{t+1} - \hat{\pi}_t) \\ &- \beta_b^3(1/4)R(\hat{R}_t - c_{b,t+3} - \pi_{t+1} - \hat{\pi}_t - \pi_{t-1}) - \beta_b^4(1/4)R(\hat{R}_t - c_{b,t+4} - \pi_{t+1} - \hat{\pi}_t - \pi_{t-1} - \pi_{t-2}) \\ &- gac(1 - \tau\chi_1)\hat{G}_t \end{aligned} \quad (67)$$

$$\hat{c}_{b,t} = -\beta_b RD(\hat{R}_{d,t} - c_{b,t+1} - \pi_{t+1}) - gac\hat{G}_t \quad (68)$$

$$\hat{c}_{b,t} = -\beta_b R_e(\hat{R}_{e,t} - c_{b,t+1} - \pi_{t+1}) - gac(1 - \tau\chi_2)\hat{G}_t \quad (69)$$

$$\hat{c}_{b,t} = -\beta_b RB(\hat{R}_{b,t} - c_{b,t+1} - \pi_{t+1}) - gac(1 - \tau\chi_3)\hat{G}_t \quad (70)$$

$$\hat{c}_{e,t} = -\gamma R_e(\hat{R}_{e,t} - c_{e,t+1} - \pi_{t+1}) - \lambda_e R_e C_e(\hat{\lambda}_{e,t} + \hat{R}_{e,t}) \quad (71)$$

$$\hat{c}_{e,t} = c_{e,t+1} - z(y_{t+1} - X_{t+1} - \hat{K}_t) + \psi(\hat{I}_t - K_{t-1} - \gamma(I_{t+1} - \hat{K}_t)); \quad (72)$$

$$\hat{c}_{bb,t} = -\beta_b RS(\hat{R}_{s,t} - c_{bb,t+1} - \pi_{t+1}) + \beta_b RS \delta_s(\hat{R}_{s,t} + \delta_{s,t+1} - c_{bb,t+1} - \pi_{t+1}) - gac(1 - \delta_s)(1 - \tau\chi_2)\hat{G}_t \quad (73)$$

$$\hat{c}_{bb,t} = -\beta_b RB(\hat{R}_{b,t} - c_{bb,t+1} - \pi_{t+1}) - gacbG\hat{G}_t \quad (74)$$

### 2. Aggregate supply

$$\hat{Y}_t = \hat{A}_t + \nu h_{e,t-1} + \mu K_{t-1} + \alpha(1 - \mu - \nu)\hat{L}_t' + (1 - \alpha)(1 - s)(1 - \mu - \nu)\hat{L}_t'' + (1 - \alpha)s(1 - \mu - \nu)\hat{L}_t''' \quad (75)$$

$$\hat{Y}_t = \hat{X}_t + \eta'' \hat{L}_t'' + \hat{c}_t'' \quad (76)$$

$$\hat{Y}_t = \hat{X}_t + \eta' \hat{L}_t' + \hat{c}_t' \quad (77)$$

$$\hat{Y}_t = \hat{X}_t + \eta''' \hat{L}_t''' + \hat{c}_t''' \quad (78)$$

$$\hat{\pi}_t = \beta \pi_{t+1} - \kappa \hat{X}_t + \hat{u}_t \quad (79)$$

### 3. Housing market block

$$0 = H' \hat{h}_t' + H'' \hat{h}_t'' + H''' \hat{h}_t''' + H_e \hat{h}_{e,t} \quad (80)$$

$$\hat{q}_t = \hat{c}_t + \beta(Q_{t+1} - C_{t+1}') + (1 - \beta)(\hat{j}_t - \hat{h}_t') \quad (81)$$

$$(Q/C''')(\hat{q}_t - \hat{c}_t''') = (J'''/H''')(\hat{j}_t - \hat{h}_t''') + (\beta''' Q/C''')(q_{t+1} - c_{t+1}'') + (\lambda''' Qm''')(\hat{\lambda}_t''' + q_{t+1} + \pi_{t+1}) \quad (82)$$

$$(Q/C'')(q_t - \hat{c}_t'') = (J''/H'')(\hat{j}_t - \hat{h}_t'') + (\beta''Q/C'')(q_{t+1} - \hat{c}_{t+1}'') + (\lambda''Qm''/\beta''^3)(\lambda_{t-3}' + q_{t+1} + \pi_{t+1} + \hat{\pi}_t + \pi_{t-1} + \pi_{t-2}) \quad (83)$$

$$(Q/C_e)(\hat{q}_t - c_{e,t}) = (\gamma Q/C_e)(q_{t+1} - c_{e,t+1}) + (\lambda_e Qm)(\lambda_{e,t} + q_{t+1} + \pi_{t+1}) + (\gamma/C_e)((\nu Y)/(XH_e))(y_{t+1} - \hat{h}_{e,t} - x_{t+1} - c_{e,t+1})) \quad (84)$$

4. Borrowing constraints

$$\hat{b}_t''' = q_{t+1} + \hat{h}_t''' - \hat{R}_{s,t} + \pi_{t+1} \quad (85)$$

$$\begin{aligned} RB''(\hat{b}_t'' + \hat{R}_t) + (1/4)RB''(\hat{b}_{t-1}'' + \hat{R}_{t-1} - \hat{\pi}_t) + (1/4)RB''(\hat{b}_{t-2}'' + \hat{R}_{t-2} - \hat{\pi}_t - \pi_{t-1}) \\ + (1/4)RB''(\hat{b}_{t-3}'' + \hat{R}_{t-3} - \hat{\pi}_t - \pi_{t-1} - \pi_{t-2}) \\ = m''QH''(q_{t+4} + \hat{h}_{t+3}'' + \pi_{t+4} + \pi_{t+3} + \pi_{t+2} + \pi_{t+1}) \end{aligned} \quad (86)$$

$$\hat{b}_{e,t} = q_{t+1} + \hat{h}_{e,t} - \hat{R}_{e,t} + \pi_{t+1} \quad (87)$$

$$BBb\hat{b}_t = (1 - \delta_s)(1 - \tau\chi_2)B'''b_t''' \quad (88)$$

$$D\hat{d}_t = (1 - \tau\chi_3)BBb\hat{b}_t + (1 - \tau\chi_1)B''b_t'' + (1 - \tau\chi_2)B_e\hat{b}_{e,t} \quad (89)$$

$$\delta_s\hat{\delta}_{s,t} = -\phi_{sh}Q\hat{q}_t \quad (90)$$

5. Budget constraints/ evolution of state variables

$$\hat{K}_t = \delta\hat{I}_t + (1 - \delta)K_{t-1} \quad (91)$$

$$B'''b_t''' = C'''c_t''' + QH'''(\hat{h}_t''' - \hat{h}_{t-1}''') + RSB'''(R_{s,t-1} + \hat{b}_{t-1}'' - \hat{\pi}_t) - (\hat{Y}_t - \hat{X}_t)w'''L''' - \delta_s RSB'''(R_{s,t-1} + \hat{b}_{t-1}'' + \delta_{s,t} - \hat{\pi}_t) \quad (92)$$

$$\begin{aligned} B_e\hat{b}_{e,t} = C_e c_{e,t} + QH_e(\hat{h}_{e,t} - \hat{h}_{e,t-1}) + I\hat{I}_t + R_e B_e(R_{e,t-1} + \hat{b}_{e,t-1} - \hat{\pi}_t) \\ - (1 - s_{ii} - s_{iii})(\hat{Y}_t - \hat{X}_t) - w'''L'''(\hat{Y}_t - \hat{X}_t) \end{aligned} \quad (93)$$

$$\begin{aligned} B''b_t'' = C''c_t'' + QH''(\hat{h}_t'' - \hat{h}_{t-1}'') - s_{ii}(\hat{Y}_t - \hat{X}_t) \\ + (1/4)RB''(\hat{R}_{t-1} + \hat{b}_{t-1}'' + \hat{R}_{t-2} + \hat{b}_{t-2}'' + \hat{R}_{t-3} + \hat{b}_{t-3}'' + \hat{R}_{t-4} + \hat{b}_{t-4}'' - 4\hat{\pi}_t - 3\pi_{t-1} - 2\pi_{t-2} - \pi_{t-3}) \end{aligned} \quad (94)$$

$$\begin{aligned} CBc_{b,t} + R_d D(R_{d,t-1} + \hat{d}_{t-1} - \hat{\pi}_t) + BBb\hat{b}_t + B''b_t'' + B_e\hat{b}_{e,t} \\ = D\hat{d}_t + (1/4)RB''(\hat{R}_{t-1} + \hat{b}_{t-1}'' + \hat{R}_{t-2} + \hat{b}_{t-2}'' + \hat{R}_{t-3} + \hat{b}_{t-3}'' + \hat{R}_{t-4} + \hat{b}_{t-4}'' - 4\hat{\pi}_t - 3\pi_{t-1} - 2\pi_{t-2} - \pi_{t-3}) \\ + RBBB(R_{b,t-1} + \hat{b}_{b,t-1} - \hat{\pi}_t) + R_e B_e(R_{e,t-1} + \hat{b}_{e,t-1} - \hat{\pi}_t) \end{aligned} \quad (95)$$

$$\begin{aligned} CBBc_{bb,t} + RBBB(R_{b,t-1} + \hat{b}_{b,t-1} - \hat{\pi}_t) + B'''b_t''' \\ = BBb\hat{b}_t + R_s B'''(R_{s,t-1} + \hat{b}_{t-1}'' - \hat{\pi}_t) - \delta_s R_s B'''(R_{s,t-1} + \hat{b}_{t-1}'' + \hat{\delta}_{s,t} - \hat{\pi}_t) \end{aligned} \quad (96)$$

6. Shock processes and monetary policy rule

$$\hat{j}_t = \rho_j \hat{j}_{t-1} + \varepsilon_{j,t} \quad (97)$$

$$\hat{A}_t = \rho_a \hat{A}_{t-1} + \varepsilon_{a,t} \quad (98)$$

$$\hat{u}_t = \rho_u \hat{u}_{t-1} + \varepsilon_{u,t} \quad (99)$$

$$\hat{R}_{d,t} = (1 - r_R)(1 + r_\pi)(\pi_{t+1}) + r_y(1 - r_R)Y_{t+1} + r_R \hat{R}_{d,t-1} + \varepsilon_{\hat{R}} \quad (100)$$

## B Appendix B

### The sensivity of benchmark model results to different values of Frisch elasticity

The Frisch labor supply elasticity measures the substitution effect of a change in wage rate on labor supply. If wages rise, *ceteris paribus*, leisure becomes relatively more costly than consumption, as its opportunity cost increases, and due to this substitution effect workers will supply more labor. Frisch labor supply elasticity tells us, how strong this effect will be. With the given utility function

$$\max_{b'_t, h'_t, L'_t} E_0 \sum_{t=0}^{\infty} \beta^t (\log c'_t + j_t \log h'_t - \frac{L'_t \eta'}{\eta'}), \quad (101)$$

the Frisch elasticity of labor supply is given by  $\varsigma = 1/(\eta - 1)$ . Thus when Iacoviello (2005) sets  $\eta = 1.01$ , this implies the labor Frisch elasticity of 100. Most microeconomic studies report the labor Frisch elasticity in the range 0-0.5 (see Peterman, 2012), the US Congretional Budget Office uses 0.4 as a central estimate (see Reichling and Whalen, 2012). However, as Peterman (2012) notes, the values used by macroeconomists to calibrate general equilibrium models are often of range 2-4. The calibration used in this paper, which sets  $\eta$  at 2, implies a labor Frisch elasticity of labor of 1. This is a value lying between the micro- and macroeconomic estimates, as well as a value suported by Keane and Rogerson (2012) who write in their conclusion (p.475): *In our view, the literature we have described can credibly support a view that compensated and intertemporal elasticities at the macro level fall in the range of 1 to 2 that is typically assumed in macro general equilibrium models.*

To investigate how much the value of  $\eta$  changes the results of the benchmark model, I compare the impulse response functions for three different levels of theta: 1.01 (implying Frisch elasticity 100, used by Iacoviello, 2005), 2 (implying Frisch labor elasticity of 1), and 3.5 (implying Frisch elasticity of 0.4, value used by CBO). The Figure 13 presents the results.

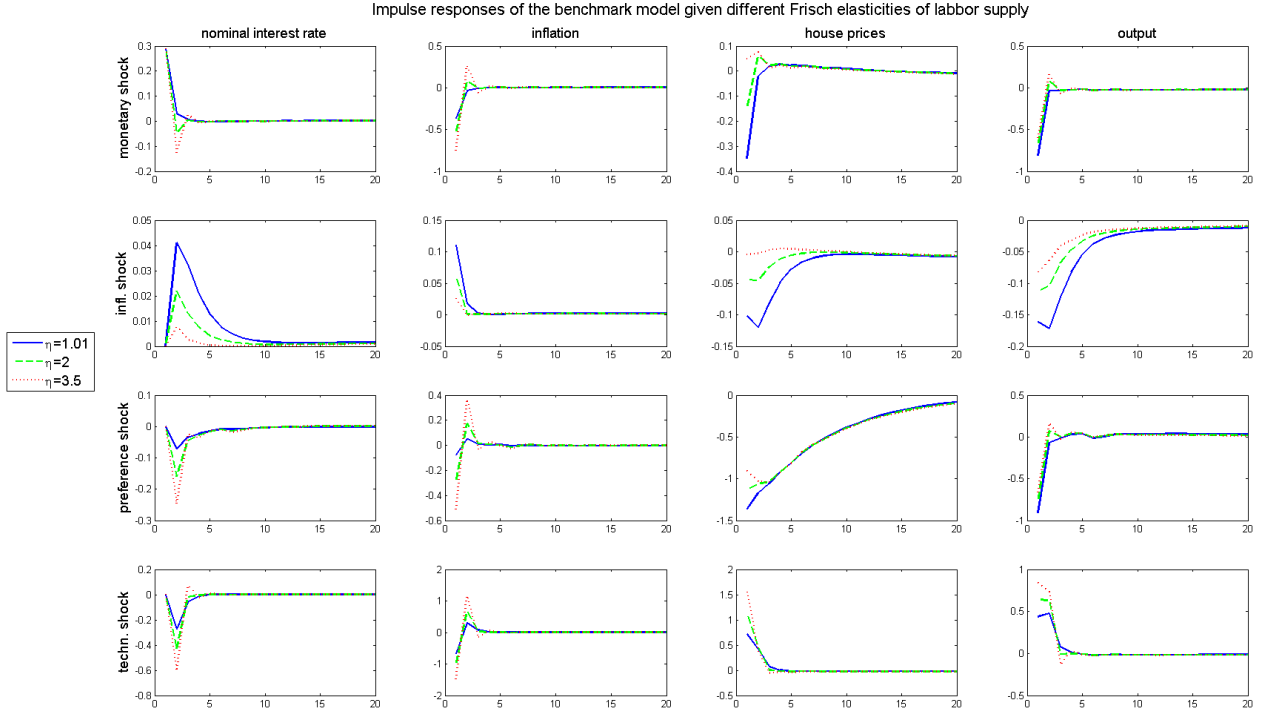


Figure 13: Impulse response functions of the benchmark model for different Frisch elasticities of labor supply

We see that different levels of Frisch elasticity of labor supply do not have a considerable impact on the model's dynamic. We may notice, however, that the lower the  $\eta$ , thus the higher the Frisch elasticity of labor supply, the more amplified responses of house prices and output to a given shock. With falling Frisch elasticity the impulse response functions are of smaller magnitude, which confirms the intuition that a smaller substitution effect of a change in wage on labor supply will have lower impact on aggregate output, since labor is one of the production factors. The chosen value of  $\eta = 2$  generates impulse response functions that lie inbetween two other considered cases, thus the assumption about Frisch elasticity of labor supply equal to 1 is relatively uncontroversial in the context of this model.

## C Appendix C

Details on model with securitization - changes with respect to the benchmark model.

### C.1 Securitization with patients and entrepreneurs as buyers of MBS tranches

SS values:

$$PE = \gamma$$

$$PS = \beta$$

$$P = f - \frac{(\delta_s - f)}{(1 + \exp(\delta_s - f))}$$

$$C_e = Y/X - \delta K + (m_e \zeta_2 Y/R_e)(1 - R_e) - w' L' - w'' L'' - w''' L''' + (1 - PE)(1 - t)(P m''' z 7 C''')$$

$$BB = t(1 - \delta_s)(1 - \tau \chi_2) B'''$$

$$CBB = t * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII/RS) * (1 - \delta_s) + (miii * \zeta_7 * CIII/RS) * (t * RS * (1 - \delta_s) - 1) + (1 - t) * (PS * (miii * \zeta_7 * CIII * (1 - \delta_s) - miii * \zeta_7 * CIII * P) + PE * miii * \zeta_7 * CIII * P)$$

$$CB = (mii * z_4 * CII / ((3/4) * R + R)) * (R - 1 + (1 - RD) * (1 - \tau * \chi_1)) + t * (1 - \delta_s) * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII / (RS)) * (RB - 1 + (1 - RD) * (1 - \tau * \chi_3)) + (m * \zeta_2 * Y/R_e) * (R_e - 1 + (1 - RD) * (1 - \tau * \chi_2))$$

The equation determining the price of the MBS:

$$\hat{c}_{e,t} = c_{e,t+1} + \hat{p}_{e,t} \quad (102)$$

$$\hat{c}_{s,t} = c_{s,t+1} + \hat{p}_{s,t} \quad (103)$$

The loglinearized equation describing the evolution of long put:

$$P \hat{p}_t = - \frac{1 + (1 - \delta_s + f) e^{\delta_s - f}}{(1 + e^{\delta_s - f})^2} \delta_s \delta_{s,t+1}^{\hat{}} \quad (104)$$

The budget constraint of the entrepreneur:

$$B_e \hat{b}_{e,t} - (1 - t) R_s B''' PEP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{e,t} - \pi_{t+1}) = \\ C_e \hat{c}_{e,t} + QH_e(\hat{h}_{e,t} - \hat{h}_{e,t-1}) + R_e B_e(\hat{R}_{e,t-1} + \hat{b}_{e,t-1} - \hat{\pi}_t) - (1 - sii - siii)(\hat{Y}_t - \hat{X}_t) - w''' L'''(\hat{Y}_t - \hat{X}_t) \quad (105)$$

(in case of monetary, inflation and preference shock when default surpasses the size of the equity tranche)

$$B_e \hat{b}_{e,t} - (1 - t) R_s B''' PEP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{e,t} - \pi_{t+1}) \\ + (1 - t)(f R_s B'''(R_{s,t-1} + \hat{b}_{t-1}''' - \hat{\pi}_t) - \delta_s R_s B'''(R_{s,t-1} + \hat{b}_{t-1}''' + \delta_{s,t}^{\hat{}} - \hat{\pi}_t)) = \\ C_e \hat{c}_{e,t} + QH_e(\hat{h}_{e,t} - \hat{h}_{e,t-1}) + R_e B_e(\hat{R}_{e,t-1} + \hat{b}_{e,t-1} - \hat{\pi}_t) - (1 - sii - siii)(\hat{Y}_t - \hat{X}_t) - w''' L'''(\hat{Y}_t - \hat{X}_t) \quad (106)$$

(in case of positive technology shock, when default does not surpass the size of the equity tranche)

Changed equations concerning the subprime lender:

$$BB \hat{b} \hat{b}_t = t(1 - \delta_s)(1 - \tau \chi_2) B''' \hat{b}_t''' \quad (107)$$

$$\begin{aligned}
& CBBc_{bb,t} + RBBB(R_{b,t-1} + bb_{t-1} - \hat{\pi}_t) + B'''b_t'' \\
& - (1-t)[(R_s B''' PEP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{e,t} - \pi_{t+1}) + R_s B''' PS(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_{s,t} - \pi_{t+1}) \\
& - \delta_s R_s PSB'''(\hat{R}_{s,t} + \hat{b}_t''' + \delta_{s,t+1} + \hat{p}_{s,t} - \pi_{t+1}) - R_s B''' PSP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{s,t})] \\
& = BBb_t + t[R_s B'''(R_{s,t-1} + b_{t-1}'' - \hat{\pi}_t) - \delta_s R_s B'''(R_{s,t-1} + b_{t-1}'' + \delta_{s,t} - \hat{\pi}_t)] \quad (108)
\end{aligned}$$

$$D\hat{d}_t = t * (1 - \tau\chi_3)BBb_t + (1 - \tau\chi_1)B''b_t'' + (1 - \tau\chi_2)B_e b_{e,t} \quad (109)$$

## C.2 Securitization with commercial banker as buyer of the MBS tranches

$$\begin{aligned}
PE &= PS = \beta_b \\
P &= f - \frac{(\delta_s - f)}{(1 + \exp(\delta_s - f))} \\
BB &= t(1 - \delta_s)(1 - \tau\chi_2)B''' \\
D &= (1 - \tau\chi_1)B'' + (1 - \tau\chi_2)B_e + (1 - \tau\chi_3)BB + (1 - \tau\chi_3)(1 - t)(R_s B'''(1 - \delta_s) - R_s B'''P) \\
CB &= ((1 - \tau * \chi_1) * (mii * \zeta_4 * CII / ((3/4) * R + R)) + (1 - tau * \chi_2) * (m * \zeta_2 * Y / R_e) + (1 - \tau * \chi_3) * t * (1 - \delta_s) * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII / (RS)) + (1 - tau * \chi_3) * (1 - t) * (miii * \zeta_7 * CIII * (1 - \delta_s) - miii * z7 * CIII * P)) * (1 - RD) + t * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII / RS) * (1 - \delta_s) * (RB - 1) + (mii * \zeta_4 * CII / ((3/4) * R + R)) * (R - 1) + (m * \zeta_2 * Y / R_e) * (R_e - 1) + (1 - t) * (1 - PS) * (miii * \zeta_7 * CIII * (1 - \delta_s) - miii * \zeta_7 * CIII * P) \\
CBB &= t * (1 - \tau * \chi_2) * (miii * \zeta_7 * CIII / RS) * (1 - \delta_s) + (miii * \zeta_7 * CIII / RS) * (t * RS * (1 - \delta_s) - 1) + (1 - t) * (PS * (miii * \zeta_7 * CIII * (1 - \delta_s) - miii * \zeta_7 * CIII * P) + PE * miii * \zeta_7 * CIII * P)
\end{aligned}$$

Log-linearized equations concering commercial banker (subprime lenders problem as above):

$$\hat{c}_{b,t} = c_{b,t+1} + \hat{p}_{e,t} \quad (110)$$

$$\begin{aligned}
& D\hat{d}_t = (1 - \tau\chi_3)BBb_t + (1 - \tau\chi_1)B''b_t'' + (1 - \tau\chi_2)B_e b_{e,t} \\
& + (1 - \tau\chi_3)(1 - t)(R_s B'''(\hat{R}_{s,t} + \hat{b}_t''' - \pi_{t+1}) - \delta_s R_s B'''(\hat{R}_{s,t} + \hat{b}_t''' + \delta_{s,t+1} - \pi_{t+1}) - R_s B'''P(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t - \pi_{t+1})) \quad (111)
\end{aligned}$$

$$\begin{aligned}
& CBBc_{b,t} + R_d D(R_{d,t-1} + d_{t-1} - \hat{\pi}_t) + BBb_t + B''b_t'' + B_e b_{e,t} \\
& + (1 - t)[R_s B''' PS(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_{s,t} - \pi_{t+1}) \\
& - \delta_s R_s PSB'''(\hat{R}_{s,t} + \hat{b}_t''' + \delta_{s,t+1} + \hat{p}_{s,t} - \pi_{t+1}) - R_s B''' PSP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{s,t} - \pi_{t+1})] \\
& = D\hat{d}_t + (1/4)RB''(R_{t-1} + b_{t-1}'' + R_{t-2} + b_{t-2}'' + R_{t-3} + b_{t-3}'' + R_{t-4} + b_{t-4}'' - 4\hat{\pi}_t - 3\pi_{t-1} - 2\pi_{t-2} - \pi_{t-3}) \\
& + RBBB(R_{b,t-1} + bb_{t-1} - \hat{\pi}_t) + R_e B_e(R_{e,t-1} + b_{e,t-1} - \hat{\pi}_t) \\
& + (1 - t)[R_s B'''(R_{s,t-1} + b_{t-1}'' - \hat{\pi}_t) - \delta_s R_s B'''(R_{s,t-1} + b_{t-1}'' + \delta_{s,t} - \hat{\pi}_t)] \quad (112)
\end{aligned}$$

(in case of monetary, inflation and preference shock when default surpasses the size of the equity tranche).

$$\begin{aligned}
& CBc_{b,t} + R_d D(R_{d,t-1} + d_{t-1} - \hat{\pi}_t) + BBb\hat{b}_t + B''\hat{b}_t'' + B_e b_{e,t} \\
& + (1-t)[R_s B''' PS(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_{s,t} - \pi_{t+1}) \\
& - \delta_s R_s PSB'''(\hat{R}_{s,t} + \hat{b}_t''' + \delta_{s,t+1} + \hat{p}_{s,t} - \pi_{t+1}) - R_s B''' PSP(\hat{R}_{s,t} + \hat{b}_t''' + \hat{p}_t + \hat{p}_{s,t} - \pi_{t+1})] \\
= & D\hat{d}_t + (1/4)RB''(R_{t-1} + \hat{b}_{t-1}' + R_{t-2} + \hat{b}_{t-2}' + R_{t-3} + \hat{b}_{t-3}' + R_{t-4} + \hat{b}_{t-4}' - 4\hat{\pi}_t - 3\pi_{t-1} - 2\pi_{t-2} - \pi_{t-3}) \\
& + RBBB(R_{b,t-1} + \hat{b}_{b,t-1} - \hat{\pi}_t) + R_e B_e(R_{e,t-1} + \hat{b}_{e,t-1} - \hat{\pi}_t) \\
& + (1-t)(1-f)[R_s B'''(R_{s,t-1} + \hat{b}_{t-1}'' - \hat{\pi}_t) - \delta_s R_s B'''(R_{s,t-1} + \hat{b}_{t-1}'' + \delta_{s,t} - \hat{\pi}_t)] \quad (113)
\end{aligned}$$

(in case of technology shock when default surpasses the size of the equity tranche).

The problem of subprime lender is identical as in the version, where patient households and entrepreneurs invest in MBS securities.

The loglinearized equation describing the evolution of long put is given by equation 105.

$$D\hat{d}_t = t * (1 - \tau\chi_3)BBb\hat{b}_t + (1 - \tau\chi_1)B''\hat{b}_t'' + (1 - \tau\chi_2)B_e b_{e,t} \quad (114)$$

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