Essays on Business Cycles

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Introduction

The recent Great Recession has renewed interest in the role of financial markets and credit in the economy, as well as in the boundaries of monetary, macroprudential and fiscal policies that impact macroeconomic developments and may influence business cycles. In the first two chapters of this thesis, I devote my attention to the role of credit backed by real estate in the economy. In the first chapter of the dissertation,[1] I investigate the role of subprime securitization on U.S. business cycles in order to provide a better understanding of secondary financial markets and their impact on macroeconomic variables. In the second chapter, based on joint work with Florian Kirsch, I study the effects of monetary and macroprudential policies on the economy with a special focus on housing prices. The third chapter of this dissertation, based on joint work with Karlygash Kuralbayeva,[2] features a real business cycle model with a climate change externality and addresses the design of optimal environmental instruments. The analysis of the optimal policy instrument to control CO2 emissions under uncertainty arising from business cycles has also gained relevance in the aftermath of the financial and economic crisis of 2008, particularly in the context of reforming the European Union Emissions Trading System (EU ETS). In what follows, I present more details about the three chapters of this dissertation.

CHAPTER 1. The first chapter examines the role of subprime securitization in the transmission of business cycles, with a special focus on the role of the interbank market in the Great Recession and the characteristics of subprime loans. The design of hybrid subprime mortgage contracts arguably lies at the roots of the recent global

[1] Based on earlier work in Grodecka (2013).

[2] Grodecka and Kuralbayeva (2014).

financial crisis, as it made the payoffs from these types of loans sensitive to changes in housing prices. The market of subprime mortgages, in turn, was highly financed by securitization. Therefore, subprime securitization appears to be at the heart of understanding the Great Recession. The formal setup used in the first chapter is a quantitative macroeconomic model with different types of borrowers and banks acting as financial intermediaries, in which households and entrepreneurs borrow against housing collateral. It is shown that due to interbank linkages and banks facing binding capital requirements, the existence of subprime securitization has ambiguous effects on business cycle fluctuations, depending on who is the final buyer of securitized assets.

The results suggest that if commercial banks buy mortgage backed securities issued by other financial intermediaries, business cycle fluctuations are amplified as a result of the larger systemic risk. The existence of the secondary market exposes the commercial banks, which are otherwise considered "safe", to a risky segment of the loan market, namely subprime mortgages, and through the existence of low risk-weights imposed by regulators on securitized assets, this leads to a higher leverage in the economy. As a consequence, when a negative exogenous shock hits the economy, it affects lending to productive firms in the economy relatively strongly, as the deleveraging process is more accentuated. The opposite is true when the securitized assets are sold to non-financial intermediaries. In that case, the subprime risk is transferred from the intermediation sector to a group of agents that are better able to digest the losses on the underlying loan portfolio, and the contraction in banks' balance sheets is less pronounced than without securitization.

The main contribution of this chapter is the incorporation of some aspects of financial modelling (mortgage backed securities) into an otherwise standard macroeconomic model. Moreover, the results of this chapter make clear that what should be accounted for in the analysis of the effects of securitization on the economy are not only the different abilities of financial versus non-financial agents to bear certain losses, but also the fact that financial intermediaries among themselves differ in their loss-bearing capacity. This is due to diverse regulations imposed on financial intermediaries acting in different loan segments, as well as distinct asset portfolios that are unique for each intermediary and affect their individual leverage. As a result, for the transmission of business cycles in the economy, it is crucial not only whether certain assets are retained in the banking sector or not, but also in which part of the banking sector they are retained. Without accounting for heterogeneity in the financial intermediaries' sector and the existence of the interbank market, it is impossible to correctly assess the role of securitization in the Great Recession.

CHAPTER 2. The second chapter builds on joint work with Florian Kirsch. Using vector autoregressions for U.S. and U.K. time series, we investigate the effects of credit and monetary shocks in the housing market to compare their effectiveness as policy measures in affecting house prices. To identify the model, we use sign restrictions derived from impulse responses generated by a DSGE model including credit and housing. We find that a negative monetary shock leads to a decline in house prices in both countries. The impact of a negative credit shock on house prices remains unclear for U.S. data but is negative for the U.K. Both shocks generally tend to be more powerful in the U.K. than in the U.S., which might be due to the different structure of mortgage contracts in both countries. Using a historical decomposition, we also investigate the role of credit and monetary shocks for house price developments during the Great Recession.

The main contribution of this chapter is the analysis of the effectiveness of different policy measures aimed at influencing the house price dynamics in an economy in which housing purchases are mainly financed through credit. As Jordà, Schularick, and Taylor (2014) note, p. 1: "*to say that the recent crisis and its aftermath has led to a reassessment of the importance of the housing finance for the macroeconomy would be a distinct understatement*." We are the first to conduct the analysis using sign restrictions derived directly from a structural DSGE model, in the context of credit and house prices. From the perspective of a policy-maker, it is especially important to know the effectiveness of different measures to intervene in the market for housing credit and their consequences for the broader economy.

CHAPTER 3. The third chapter builds on joint work with Karlygash Kuralbayeva. In this chapter, we study the design of optimal environmental policies in a business cycle framework. Two classical alternatives for regulating pollutants are a cap-and-trade or a tax; the former is a quantity control and the latter is a price control. In applying Weitzman's result (Weitzman, 1974) to the problem of greenhouse gas emissions, the price-quantity literature has shown that, under uncertainty about abatement costs, price instruments (carbon taxes) are preferred to quantity restrictions (caps on emission), since the damages from climate change are relatively flat. In contrast, another recent piece of academic literature (Heutel, 2012) has highlighted the importance of adjusting carbon taxes to business cycle fluctuations in a procyclical manner. In this chapter, we bridge these two bodies of research, by analyzing the relative performance and revisiting the optimal design of two instruments (prices and quantities) in the face of shocks driving business cycles.

Our theoretical framework is a general equilibrium real business cycle model with a climate change externality and distortionary fiscal policy. First, we find that state-contingent policies imply that the carbon tax is approximately constant, while emissions fluctuate more in response to a productivity shock. Second, we find that a *fixed* price instrument is superior to a *fixed* quantity instrument due to the cyclical behavior of abatement costs, which tend to increase during expansions and decline during economic downturns. Our results suggest that the carbon tax is approximately constant over business cycles due to "flat" damages in the short-run and thus, procyclical behavior as suggested by other studies cannot be justified merely on the grounds of targeting the climate externality.

The main contribution of this chapter is extending Weitzman's results to a general equilibrium framework under uncertainty and showing that the main intuition behind the price-quantity argument holds in the "idealized" world in which the regulator has access to state-contingent environmental instruments. We stress that in order to study the optimal design of carbon taxes, one has to assure the completeness of the tax system; otherwise the carbon tax may end up accommodating the business cycles.

Chapter 1

Subprime Borrowers, Securitization and the Transmission of Business Cycles

1.1 Introduction

The 2007-2009 crisis, labeled as the Great Recession, has been the longest and the most severe post-war recession in the U.S. 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 often the relatively small subprime mortgage market in the U.S. that may have been one of the roots of the prolonged downturn. Globalized financial markets and mortgage derivatives enabled the domestic housing market crisis to spread to other countries and continents. This chapter investigates potential sources of the amplification mechanism during the recent crisis in the U.S. market. I focus on the design of hybrid subprime mortgages that were a combination of fixed-rate and adjustable-rate contracts which allowed hybrid mortgages to have a short-term character, and their importance for business cycles. Moreover, I discuss the role of securitization, a process that transfers the underlying risk from loan originators to investors through the creation of securities backed by pooled mortgages, in financing subprime loans. Since the subprime mortgage crisis in the U.S. closely preceded the Great Recession, I want to investigate how these two events are linked. Specifically, I analyze different securitization scenarios to see under which conditions the securitization of subprime loans would have a dampening impact on the responses of the economy to negative shocks.

This chapter presents a calibrated model in a linear New-Keynesian Dynamic Stochastic General Equilibrium (DSGE) framework that builds on models with credit frictions, particularly collateral constraints. The focus is on the role of subprime mortgages and securitization in the recent crisis, and the importance of the bank lending channel in the presence of binding capital requirements. The model incorporates some aspects of financial modeling (mortgage-backed securities, MBS) into a standard macroeconomic framework, which is the main contribution of this chapter. Four different versions of the model are compared: a baseline model without securitization, two models with securitization in which only non-financial agents buy securitized assets, and a model with securitization in which financial intermediaries acquire asset-backed securities. I leave aside the modeling of the portfolio decisions of agents. The aim of the exercise is much more modest; assuming that securitization took place and securitized products were bought by different agents in the economy, I want to investigate whether there is any difference in the reaction of the economy to different shocks, depending on who is the ultimate bearer of the subprime risk.

In my analysis, I focus on two shocks: monetary and preference. The monetary shock is modeled as an exogenous increase in the nominal interest rate set by the central bank, that in the current setup equals to the interest rate on deposits. It is important to understand the response of the model economy to such a change in monetary policy, as the period of rising interest rates (starting from July 2004 and ending in August 2007) immediately preceded the outbreak of the Great Recession in the U.S. Moreover, it is a shock that is usually discussed in the macroeconomic literature, which makes the predictions generated by the present model comparable with other papers in that field. Secondly, I discuss the impact of a negative preference shock in the economy, designed as an exogenous change in the demand for housing stock experienced by households. A negative housing preference shock leads to a fall in housing prices, which is the event that I am most concerned with in this chapter for two main reasons: first, because the developments on the housing market played a crucial role in the Great Recession, and second, because they are related to the default behavior of adjustable-rate mortgages that I model in this chapter.

The results show that the specific design of subprime mortgage contracts alone, which were highly sensitive to changes in housing prices, did not amplify the U.S. business cycle - it merely led to a redistribution effect between subprime borrowers and lenders. However, the securitization of subprime mortgages may have caused an amplification through the balance sheet effects of banks that were holding the securitized products. If MBS were held by non-banks, securitization would have had 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 this chapter support the proposition 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 institutions such 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 mainly rely on short-term funding. The present model shows that, if banks facing capital requirements buy MBS tranches, which lose value in the downturn, the capital requirement gets tighter, so the whole intermediation process is disrupted. Through the deleveraging process, lending to other agents in the economy declines, causing a credit crunch, partial termination of production and a fall in output. The model demonstrates the relevance of this process in a general equilibrium framework and offers a theoretical explanation for the negative correlation between subprime defaults and commercial lending observed for U.S. banks during the crisis. It is important to note that, although this chapter is motivated by the events in the subprime securitization market and hence, I model specifically the securitization of adjustable-rate mortgages, the main mechanism through which securitization impacts the economy in the model is the balance sheet dynamics of financial intermediaries. Therefore, the model is also applicable to the securitization of different types of assets, not only mortgages.

The present chapter relates to three main strands of the literature. It is an extension of Iacoviello (2005) that relies on the seminal paper by Kiyotaki and Moore (1997). In both models, the importance of collateral constraints and the imperfect enforcement of lenders' rights that lead to the establishment of a certain loan to value ratio are emphasized. Iacoviello (2005) focuses on loans backed by real estate, which makes his model a natural starting point for my exercise investigating the role of subprime securitization. I extend the model by adding the banking sector and considering the securitization of subprime loans. The balance sheet effects discussed in the chapter resemble dynamics occurring in Iacoviello (2014) that models the consequences of an exogenous fall in banks' equity. The second strand of literature important for this chapter is mainly represented by Adrian and Shin (2010) and Adrian and Shin (2011) that focus on the balance sheets of financial intermediaries and the empirical properties of the behavior of banks. Lastly, the empirical evidence on the recent crisis delivers many insights. The present chapter mainly relies on a comprehensive study of Gorton (2008), who describes in detail the subprime mortgage market in the U.S. and the securitization of subprime mortgages. Another important reference is Gorton and Souleles (2007) who describe the basics of the securitization process. Hellwig (2009) also delivers an extensive descriptive analysis of the events leading to the Great Recession.

When it comes to the modeling of securitization in a general equilibrium macroeconomic model, to my knowledge only three attempts have been made, and all of them focus on the problem of asymmetric information. Faia (2011) models the secondary market for bank loans in a model with solid micro-foundations in which several economic agents face a moral hazard problem. On the one hand, capital producers that obtain funds from banks may choose to exert low effort, which undermines the success probability of their project, but provides them with a private benefit. On the other hand, the incentive to monitor the projects decreases for bankers, once a secondary market for loans exists. Faia (2011) concludes that the existence of secondary markets amplifies the dynamics of macro variables. Hobijn and Ravenna (2010) model securitization in a setup with banks that have access to costly screening which provides them with information about the credit score of borrowers. Borrowing households are either honest or dishonest, which leads to default events. Hobijn and Ravenna (2010) demonstrate that securitization reduces the equilibrium interest rates, and the decline is most pronounced for riskier, subprime borrowers who gain the most from the securitization process. The authors examine the response of financial variables, such as interest rate spreads, to a monetary and financial shock and conclude that with securitization the reaction of financial variables is amplified in comparison to a standard New-Keynesian model. Lastly, Kuncl (2014) analyzes the role of asymmetric information in the secondary loan market, in a setup in which firms with profitable investment opportunities sell the cash-flows from their projects to firms with low or no investment opportunities. Although all three papers deal with securitization, the focus and modeling devices applied in these papers differ considerably from the setup in this chapter. Firstly, I focus on the real estate market, which is not described in any of the discussed papers. Secondly, in this chapter, the intermediation role of banks (absent in Kuncl, 2014) plays an important part, as well as the interbank market. Finally, while information asymmetry is at the heart of analysis of the other three papers, in this work it appears only indirectly through the existence of borrowing and capital constraints.

Why is it important to consider recent developments in a general equilibrium macro framework when the finance and microeconomics literature deliver a fairly good description of economic agents' incentives and amplification processes caused by financial frictions? The general equilibrium macroeconomic setup is especially useful for examining the positive aspects of securitization through inter-market linkages. To show why securitization may smooth out the business cycle, I explicitly model the interbank sector. When distinct financial intermediaries are connected through loan and deposit contracts (i.e. assets of one banking institution correspond to liabilities of another banking institution), changes in the balance sheet of one of them will automatically lead to changes in the balance sheet of the second intermediary. Securitization of subprime loans releases the pressure on the subprime loan originators' balance sheets, which, through the interbank market, has a positive effect on the balance sheets of other financial intermediaries in the economy, since they finance subprime lenders with deposits. This positive aspect of securitization is present in all versions of the model with securitization that I consider. However, the overall impact of securitization on the economy depends on other endogenously arising processes. It turns out that the effect on business cycle fluctuations may be amplifying, if the deleveraging effect, present in the model with banks investing in MBS, is stronger than the positive effect of securitization. Moreover, deleveraging may lead to a vicious circle of falls in asset prices and further deleveraging (Adrian and Shin, 2010), leading even to instability of the system, if capital requirements imposed on banks are very low. Low capital requirements lead to higher leverage and subsequently, more pronounced deleveraging, when a negative shock hits the economy. It is important to note that, even if in the present model some decisions and constraints are exogenously imposed on agents in the economy, their responses to shocks are endogenous, and by calibrating the model to U.S. data, one can measure and assess the strength of these reactions. Comparing different versions of the model with securitization enables me to further conduct counterfactual analysis and determine how the U.S. economy could have evolved after the initial shocks, had people followed the intended business model of securitization. The results suggest that in this case the maximum quarterly output loss in the U.S. economy during the Great Recession would have amounted to 13% of that observed in the data.

The model presented in this chapter is complex, as it incorporates agents differing in their impatience level, two types of bankers, as well as diverse collateral constraints. Yet, the main message of the chapter is simple - binding collateral constraints faced by financial intermediaries may lead to disruptions in the lending market and may amplify losses from an exogenous negative shock, leading to a decline in output. The understanding of the deleveraging of banks' balance sheets is crucial for the analysis of the presented general equilibrium model. Readers who are not familiar with the importance of binding capital requirements for the balance sheet dynamics of banks may find the plain numerical example presented in Appendix 1.A helpful. In what follows, I describe the peculiarities of the subprime market (Section 1.2.1) and some empirical relations between the MBS and commercial loans observed in the data during the crisis (Section 1.2.2), which will make the interpretation of chosen assumptions and modeling devices easier. Section 1.3 presents the baseline model and Section 1.4 is its extension with securitization. The main results are presented in Section 1.5. Section 1.6 presents sensitivity analysis and discusses an extension to the model in which I introduce impatient prime borrowers into the model economy who may borrow long-term, which reflects the existence of fixed-interest rate mortgages in real life. The main conclusions of the chapter are summarized in Section 1.7.

1.2 Stylized Facts

1.2.1 Subprime Mortgage Market

The subprime mortgage market became one of the scapegoats of the Great Recession in the United States. However, some commentators (see Liebowitz, 2009) point to the fact that subprime borrowers themselves are not to blame, but rather adjustable rate mortgages (particularly hybrid mortgages) that led to disruptions in both the subprime and prime mortgage markets. This section provides evidence on the foreclosures and delinquencies[1] in the U.S. mortgage market, as well as a short review of empirical facts that help to address this comment.

It is remarkable that the events in the subprime mortgage market are important for the understanding of the roots of the crisis, because subprime borrowing accounts for only a small percentage of the whole mortgage market (the share of subprime originations is depicted in Figure 1.1). Although there is no exact definition of a subprime borrower or market, there are certain features common to all subprime loan contracts. A prime mortgage in the U.S. is usually collateralized and has a fixed interest rate for 30 years. Subprime borrowers often can provide neither collateral, nor income (so called "NINJAs" - No Income, No Job or Assets, see Jovanoviċ, 2013). 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 the years 2004-2007. In the case of prime mortgages, the average LTV ratio ranged from 74.89% to 77.75%, while in the case of subprime mortgages, it ranged from 79.63% to 80.69%. The biggest difference between these two groups has been noted in the FICO score, which measures the creditworthiness of borrowers and is used by lenders to determine the credit risk. In the case of prime borrowers it ranged from 706 to 715, while in the case of subprime borrowers, it ranged from 597 to 617 (the FICO score ranges from 300 to 850, with the higher, the better). Subprime borrowing was thriving thanks to a common belief that housing prices will rise on average. Indeed, until the recent crisis the U.S. market did not

[1] A delinquent loan is a loan with a delay of payment of at least 30 days. The total delinquency rate takes into account all past-due categories (30, 60, 90 days and over), but excludes loans in the foreclosure process.

experience a countrywide decrease in housing prices since the 1930s.

Since subprime borrowers often do not have well-documented assets or income, it poses a challenge to create a loan contract that will enable them to pay the installments. The solutions to this problem were 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) was 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, households were able to refinance and repay the debt at the reset date, and in even some cases, extract equity from homes. When house prices were falling, the LTV ratio was rising, followed by an increase in the interest rate at the reset date, so that many households were not able to repay the contracted installment, or even defaulted. Amromin and Paulson (2010) provide evidence of a high sensitivity of defaults to changes in home prices among subprime borrowers already in the years before the crisis, compared to a very low sensitivity among prime borrowers (for 2004: -0.183 for subprime borrowers and -0.00166 for prime borrowers). The short-term characteristics of subprime loans as well as their high sensitivity to housing prices observed in the data enable me to model the subprime loan contract as a one-period contract with the possibility of default linked to changes in house prices.

How do developments in the subprime mortgage market relate to the economic performance of the U.S.? Figure 1.1 presents subprime loans originations as a share of the total market, non-agency[2] securitization activity (RMBS - residential mortgage backed securities - and securities based on home equity loans), as well as the real GDP growth rate.

[2] Agency securities are securities that are either issued or guaranteed by federal agencies and government sponsored enterprises, such as Ginnie Mae, Fannie Mae or Freddie Mac. Non-agency securities are securities issued by private companies and lack the explicit or implicit guarantee of the U.S. government.

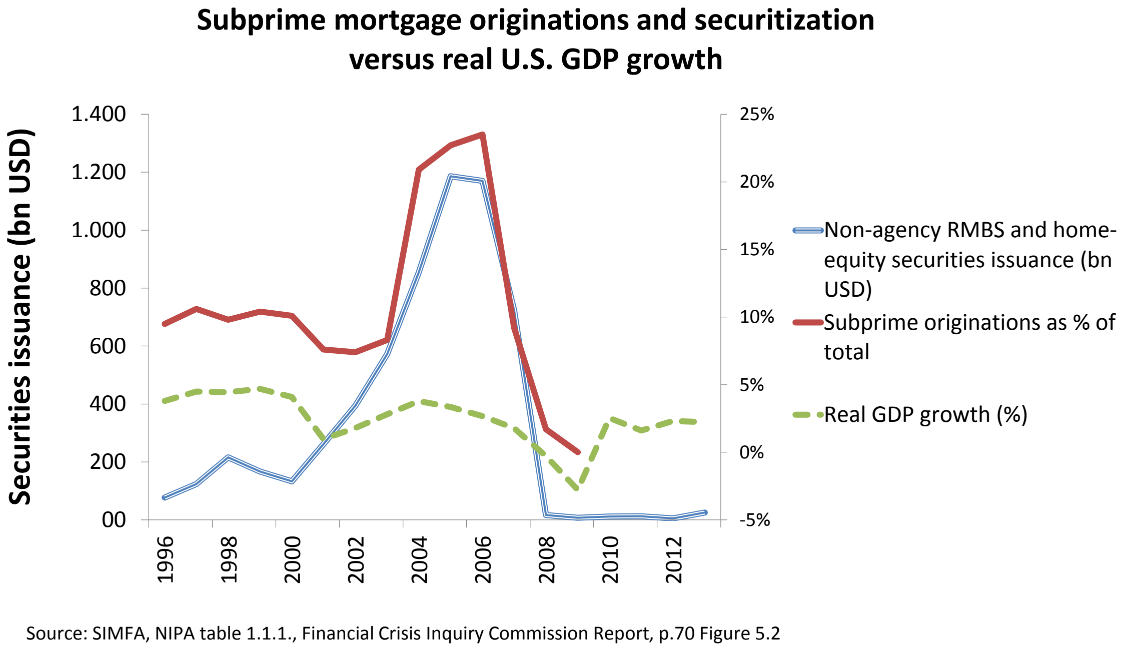


Figure 1.1: Subprime market and real GDP (annual data)

The peak of subprime originations coincided with the peak in non-agency securitization activities and both of them almost dried out in 2008 (further data for subprime originations not available). This reflects the fact that 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 collateralized debt obligation (CDO).[3] Subprime originations peaked in 2006, while the 4th quarter of 2006 denotes the peak in the U.S. house price index (USSTHPI). The developments in the housing and mortgage market led the changes in U.S. GDP growth. According to the NBER, the last recession started in December 2007 (4th quarter) and ended in June 2009 (2nd quarter). Thus, the data supports the proposition that the recession was linked to the housing market, similar to other recent crisis episodes in industrialized economies (Reinhart and Rogoff, 2009). In this chapter, I investigate a potential transmission mechanism through which changes in the housing market affect U.S. GDP growth.

As noted before, the distinguishing feature of subprime mortgages was their hybrid

[3]The ratio of securitized subprime/Alt-A mortgages rose from 46% in 2001 to 93% in 2007 (Geithner, 2011, p.11). Alt-A mortgages are mortgages with characteristics that places them between prime and subprime mortgages.

character. However, prime borrowers also take out ARM loans. Examining foreclosures and delinquencies data (exclusive of loans in the foreclosure process) enables me to address the question of whether the subprime market or the ARM market was decisive for the GDP developments. Figure 1.2 depicts the share of mortgages entering the foreclosure process in the U.S., both for subprime and prime borrowers, taking into account ARM and FRM (fixed rate mortgages).

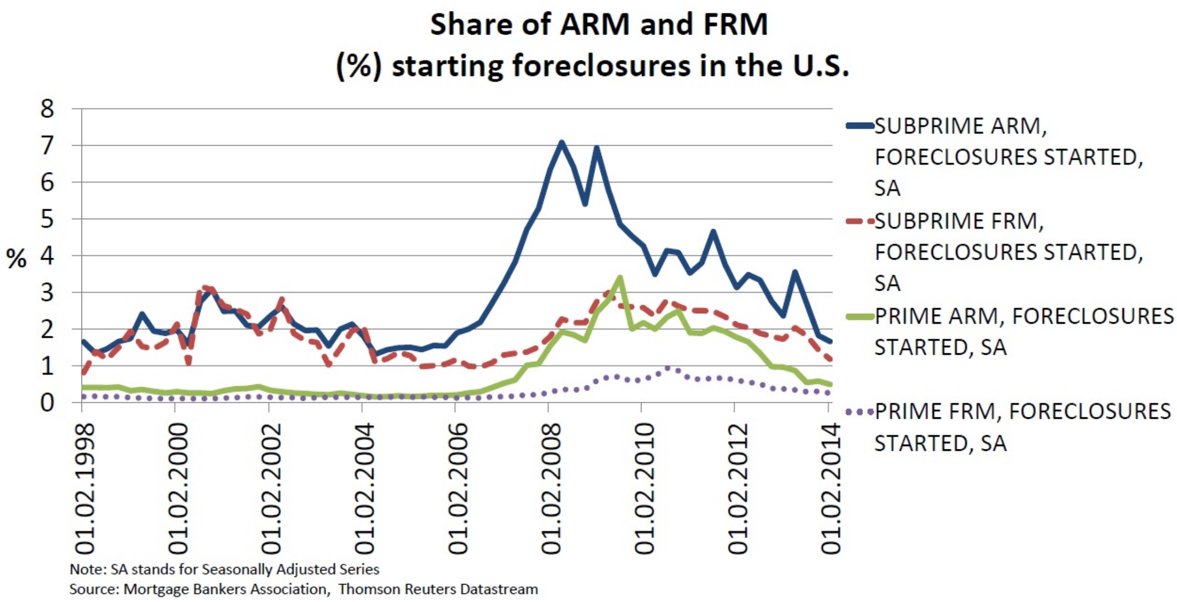


Figure 1.2: Foreclosures

Figure 1.2 reveals that the fraction of foreclosures is the highest among ARMs, but it is clear that the fraction of subprime foreclosures was higher and prime foreclosures only followed the developments in the subprime market. An interesting observation can be drawn from comparing Figure 1.2 with Figure 1.3, which presents delinquencies for the same type of loans. The peak in loan delinquencies occurs visibly later than the peak in foreclosures, which partially results from governmental actions in the U.S. aimed at reducing the share of foreclosures in order to stop declines in house prices. In 2009, the Home Affordable Modification Program was launched, which *"is designed to help financially struggling homeowners avoid foreclosure by modifying loans to a level that is affordable for borrowers now and sustainable over the long term"*.[4] The increasing rate of delinquencies, even when foreclosures already started to

[4] https://www.hmpadmin.com/portal/programs/hamp.jsp

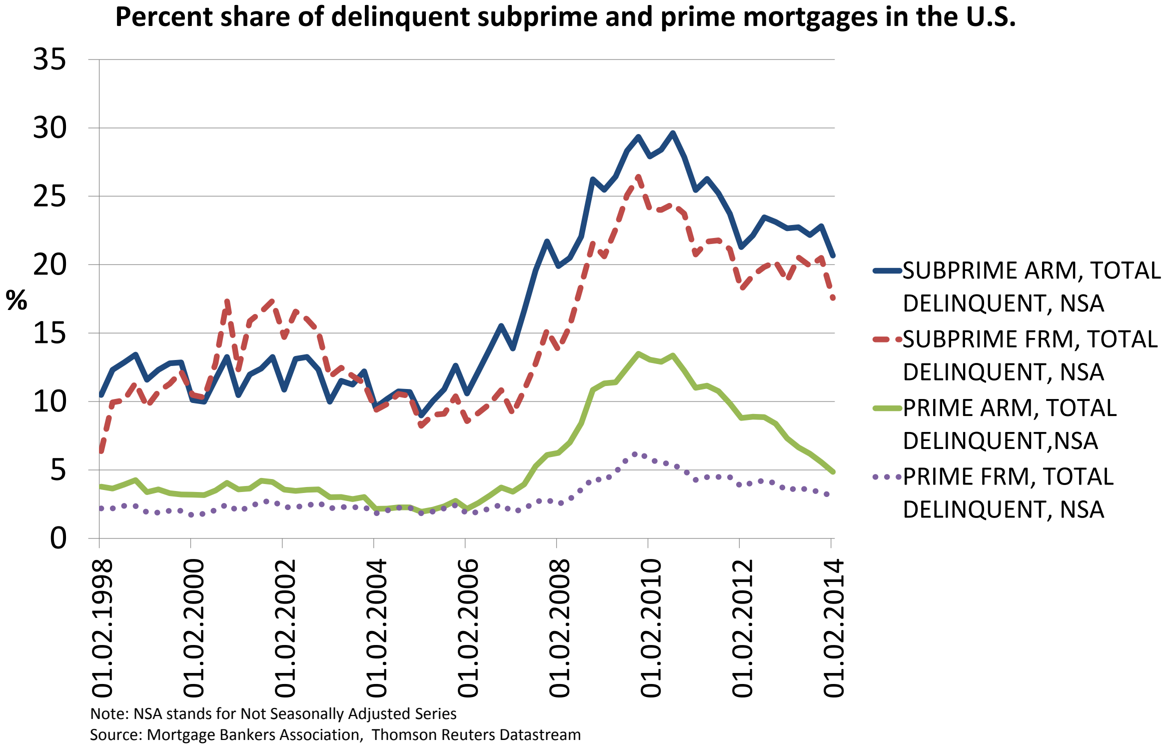


Figure 1.3: Delinquencies

fall, suggests that banks and financial institutions that were exposed to subprime risk, were holding the assets on their balance sheets. Notably, although ARM delinquencies are much higher than FRM delinquencies for both types of borrowers, in the case of subprime borrowers, the FRM delinquencies are almost as high as delinquencies on the hybrid loans, and much higher than any delinquencies observed for prime borrowers. Thus, Liebowitz (2009)'s conclusion that the mortgage crisis was caused by ARMs, and not subprime loans, is not entirely correct. It was rather a combination of subprime borrowing and adjustable rate mortgages that turned out to be problematic. In what follows, the focus of this chapter is put on hybrid subprime mortgages, the subcategory of ARMs. Their market almost vanished after the crisis. However, ARMs still exist within and outside the U.S. despite the drop in the share of the market (see Moench et al., 2010).

1.2.2 MBS and Commercial Loan Holdings by Banks

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. The bonds or pass-through securities (called so because the monthly loan payments are passed through to the holders of security) were then sold to pension funds, banks, investment funds and personal investors. The securitization of subprime loans might have made the whole financial system vulnerable to housing 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.[5] Loans are 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 exists only for the purpose of securitization, is set up by the originator, and does not even have any employees. The securitization process includes repackaging many assets, including 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 process of tranching is the most important credit enhancement of securitized products, without which it would be difficult to explain the demand of investors for the product. Individual pricing and payoff structures of distinct tranches provide incentives for the acquisition - e.g. senior tranches were usually given an A rating by rating agencies, which made them a perfect asset for banks wanting to loosen their capital requirement. The residential mortgage backed securities (RMBS) played the biggest role in the securitization market just before and after the recent financial crisis. Consequently, in my model, I concentrate on RMBS. The specific design of SPVs enables me to model the securitization process without introducing a new agent into the model economy.

The present model is calibrated to the U.S. economy, as it has been the root of the financial crisis. The chapter emphasizes the importance of financial intermediation

[5]Credit enhancement includes: tranching of the risk of loss, over-collateralization, guarantee by an insurance company. Discussed further in Gorton and Souleles (2007).

for the production process that is financed by bank loans. It is a well-known fact that opposite to European markets where banks are an important source of credit to firms (bank-based system), the U.S. is characterized by a market-based system, i.e. firms resort more to corporate bonds and stock financing rather than bank loans. Although banks played a less and less important role over time in the financing of non-financial businesses in the U.S.,[6] bank loans still provide around 12% of funds to non-financial corporations. This is a considerable share, and the bank lending channel presented in this chapter may be one of the explanations for the size and length of the Great Recession.

In order to understand the crisis, it is informative to look not only at the balance sheets of non-financial businesses and their funding sources, but also at the balance sheets of U.S. banks. In the following, I will focus on the asset side of banks, with a special emphasis on commercial real estate loans (modeled in this chapter) and MBS holdings. Figure 1.4 presents the fraction of MBS holdings, commercial real estate loans and commercial loans (all loans to firms, including real estate) in all bank assets over time. The graph is generated using data for large domestically-chartered commercial banks that are a good proxy for all U.S. banks and are chosen due to the better availability of data. A detailed data description is available in Appendix 1.B. It is visible that the fractions of MBS and commercial real estate loans went into opposite directions from ca. 2007. The negative correlation between the fractions can be also observed while taking into account total commercial loans, not only the real estate ones. An analogous graph for lending levels that exhibits the same pattern can be found in Appendix 1.C (Figure 1.17).

Recalling Figure 1.3, one can see that the divergence in the fractions of MBS and commercial real estate loans is preceded by a large surge in subprime default rates that started in 2006 and coincided with the beginning of the fall in housing prices. The fraction of MBS and commercial real estate loans were approximately equal when expressed as a percentage of U.S. bank assets until the subprime default rates began to increase. Only with an increase in subprime delinquencies did the fraction of total MBS rise and the fraction of commercial real estate loans fall, suggesting that securitized assets experiencing a fall in value may have crowded out lending to

[6]Detailed data on the balance sheets of non-financial businesses are available in the Flow of Funds Tables of the Federal Reserve Board, Financial Accounts - Z.1, for flows see F.101, for levels: L.101, `http://www.federalreserve.gov/apps/fof/FOFTables.aspx`.

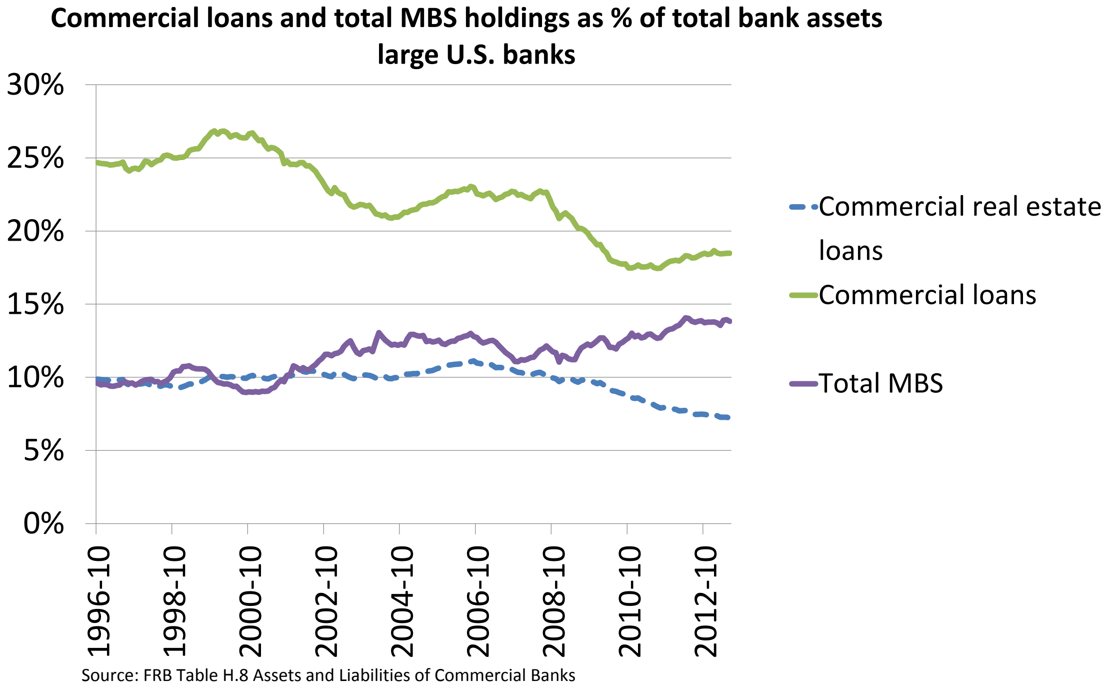


Figure 1.4: Composition of large banks' balance sheets

entrepreneurs.

We should thus observe a negative correlation between the fraction of commercial real estate loans on the asset side of the bank and the subprime default rates. The correlation is clearly negative for the period 2006-2010, as can be inferred from Figure 1.5. The graph presenting the correlation for the whole sample period 1998-2013 is given in Appendix 1.C (Figure 1.18). No visible correlation can be observed in the pre-and post-crisis data. The negative correlation does not imply any causal effects, but this chapter offers an explanation for the empirical facts. Rising subprime default rates lead to a fall in the value of subprime loans or securitized products backed by these loans. This puts a strain on banks' balance sheets and forces them to deleverage, which reduces lending to firms. Why does the fraction of held MBS increase during the crisis despite the rising default rates on these securities? The banks, even if they wanted, could not sell the toxic assets as the market for them dried out when the scale of the crisis was made public: subprime MBS suddenly became illiquid. The omnipresent illiquidity prompted the Federal Reserve to introduce some

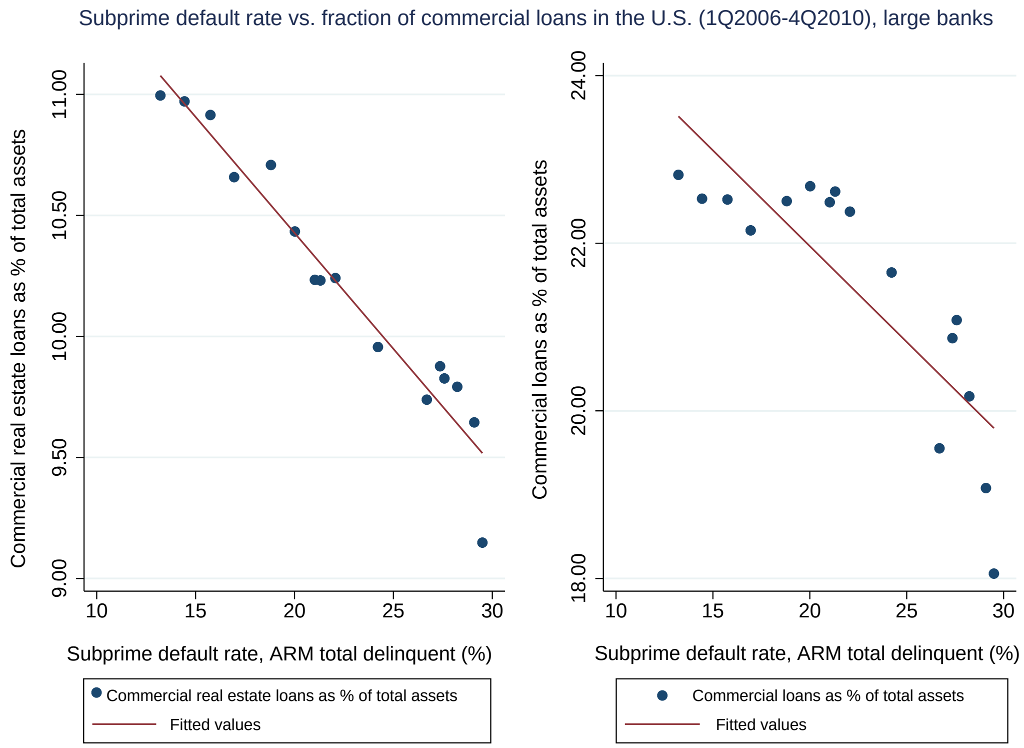


Figure 1.5: Subprime default rates and commercial loans in the U.S., large banks

Source: Thomson Reuters Datastream and FRB data

of its programs aimed at increasing liquidity,[7] but the first acquisitions of toxic assets in 2009 were focused on guaranteed agency mortgages whose boom and bust was less pronounced than developments in the non-agency mortgage market. In fact, it turns out that the role of government is decisive for the shape of the graph shown in Figure 1.4. If one takes the agency and non-agency MBS held by banks separately into account, it turns out that the agency MBS holdings were going up, while the non-agency MBS holdings stabilized at the peak of the crisis (which confirms the illiquidity hypothesis) and started to experience a persistent decline at the end of 2009, which is depicted in Figure 1.19 presented in Appendix 1.C. The Figure 1.20, also presented in Appendix 1.C, shows the agency and non-agency MBS holdings as a fraction of total assets.

I do not model the portfolio decision of banks - I assume that in a world with

[7]http://www.marketwatch.com/story/fed-starts-program-to-buy-illiquid-mortgage-assets

securitization they hold MBS on their balance sheet. It is a strong assumption, but not so unrealistic given the empirical observations just discussed. In some states of the world, like a financial crisis leading to the disruption of market liquidity, banks may indeed have no choice but to keep some assets on their balance sheets.

1.3 The Benchmark Model

The model economy is inhabited by a continuum of households that differ in their degree of 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 offer loans on the interbank market. In the baseline version of the model, it is assumed that all impatient borrowers have subprime characteristics: they borrow from a subprime lender against housing collateral (an extension involving the existence of prime borrowers who may borrow for long-term and do not default on their loan obligations is presented in section 1.6.2 and Appendix 1.G). The collateral constraints faced by borrowers determine the amount they can borrow from the bank, while bankers set the interest rates on loans, taking into account different borrowing constraints and default probabilities. The debt contracts in the economy are written in nominal terms, as in Iacoviello (2005). The financial connections of the agents are shown in Figure 1.6. 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.

1.3.1 Patient Households: Savers

The problem of patient households ('savers') is identical to the one in Iacoviello (2005) with one difference: instead of providing loans to households and entrepreneurs, they save in the form of one-period deposits held at banks. Patient households consume, work and accumulate housing. Their optimization problem and the First Order Conditions (FOCs) are presented in Appendix 3.C.1.

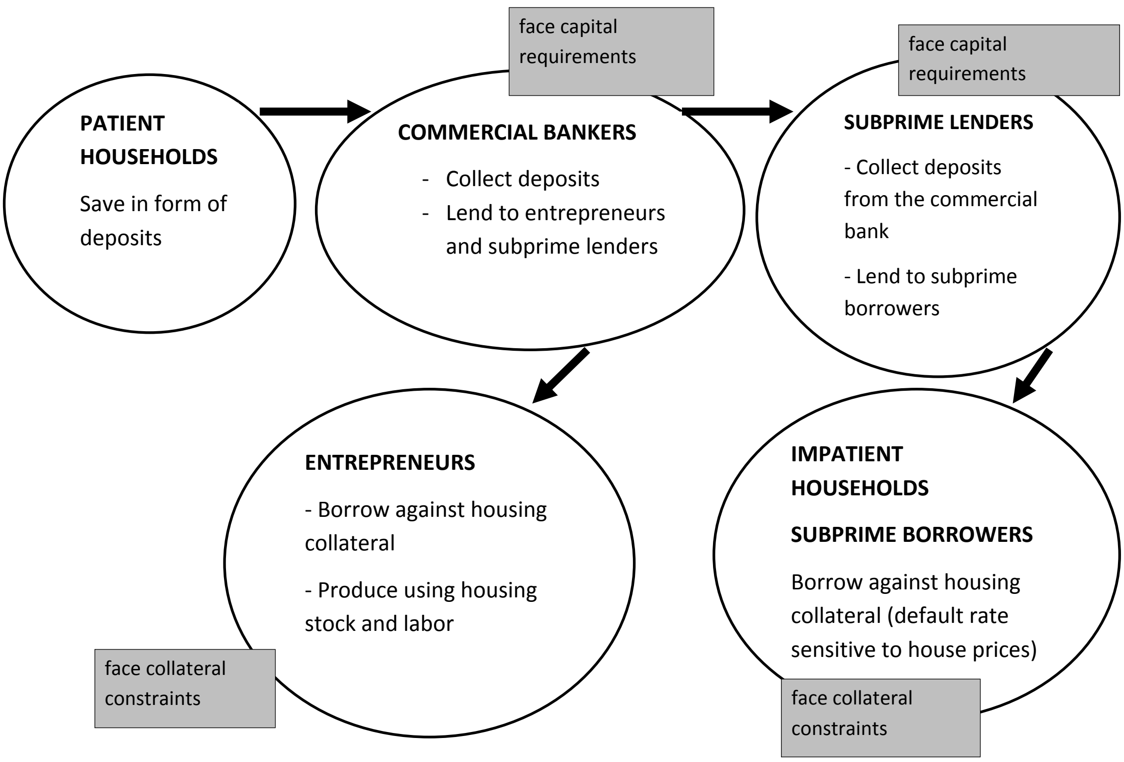


Figure 1.6: Financial connections in the benchmark model

1.3.2 Impatient Households: Subprimers

Impatient households are borrowers in the model economy. The feature that distinguishes them from impatient households modeled in Iacoviello (2005) is that they may default on their loan obligation, with the default rate sensitive to house prices, which reflects the adjustable-rate feature observed in the data.

Impatient subprime households have the following utility function:

$$\max_{b_t^{Sub}, h_t^{Sub}, L_t^{Sub}} E_0 \sum_{t=0}^{\infty} \beta^{Sub,t} \left(\log c_t^{Sub} + j_t \log h_t^{Sub} - \frac{{L_t^{Sub}}^{\eta^{Sub}}}{\eta^{Sub}} \right), \tag{1.3.1}$$

where c_t^{Sub} denotes the subprimers' consumption of the final good, j_t is the 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^{Sub} is the housing stock held by subprime households, L_t^{Sub} denotes labor supply of impatient subprime households. The budget constraint of the impatient subprime household in real terms is:

$$c_t^{Sub} + q_t(h_t^{Sub} - h_{t-1}^{Sub}) + (1 - \delta_{s,t})R_{s,t-1}b_{t-1}^{Sub}/\pi_t = b_t^{Sub} + w_t^{Sub}L_t^{Sub}, \tag{1.3.2}$$

where $R_{s,t}$ is the nominal interest rate on subprime loans b_t^{Sub}, $q_t = Q_t/P_t$ denotes the real housing price, $\pi_t = P_t/P_{t-1}$ is inflation and

$$\delta_{s,t} = \delta_s - \phi_{s,h}(q_t - Q) \tag{1.3.3}$$

is the default rate on loans (δ_s denotes the positive steady state value of default rate, Q is the steady state value of housing prices,[8] $\phi_{s,h}$ denotes subprimers' default sensitivity to house price changes). The dependence on house prices is chosen to capture the high sensitivity of the hybrid subprime mortgage contract to changes in housing prices and its gamble characteristics.[9] Subprime lenders bet on an increase

[8]The price level in the steady state (P) equals 1.

[9]Forlati and Lambertini (2011) consider a model with risky mortgages and endogenous default rate arising from idiosyncratic shocks to households' housing investment, which is also a proxy for modeling negative home equity and its consequences. However, in their model firms do not borrow capital from financial intermediaries, so one important transmission channel of the crisis is excluded.

in house prices because they may then expect a lower than predicted default rate and thus, faster repayment of the loan.[10] Note that the debt contracts in this model are written in nominal terms (following Iacoviello, 2005), which reflects the majority of loan contracts in low-inflation countries.

Impatient households may borrow against the future value of their housing collateral:

$$R_{s,t} b_t^{Sub} \leq m^{Sub} E_t(q_{t+1}\pi_{t+1}) h_t^{Sub}, \tag{1.3.4}$$

where m^{Sub} determines the LTV ratio for subprime borrowers.

The FOCs of subprime borrowers are presented in Appendix 1.D.2.

It is important to note that, although the collateral constraint of subprime borrowers does not refer to their possible default, 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, see equation 1.3.14.

1.3.3 Entrepreneurs

The problem of entrepreneurs is similar to that in Iacoviello (2005) with the exclusion of capital accumulation and investment conducted by firms.[11] They produce intermediate output priced at P_t^w, using housing stock and labor provided by households, and sell it to retailers. They borrow short-term to cover their expenditures, facing a collateral constraint analogous to the one faced by households. Their optimization problem and the FOCs are presented in Appendix 1.D.3.

1.3.4 Retailers

The problem of retailers is identical to that in Iacoviello (2005). They are the source of price stickiness in the economy. I present the equations concerning the retailer sector in Appendix 1.D.4.

[10] Given the formulation in equation 1.3.3, theoretically, when a large shock occurs, the default rate can turn negative. However, the positive steady state rate of default, as well as the fact that in a log-linearized model only shocks of a small amplitude can be considered, prevent this from happening in the current setup.

[11] Capital and investment were part of the model in the earlier version of this chapter, Grodecka (2013), and their inclusion does not change the results qualitatively, so for simplicity reason they were left out from this analysis.

1.3.5 Bankers

Commercial Bankers

Commercial bankers collect deposits from patient households and issue loans to entrepreneurs. They also provide interbank loans for subprime lenders that operate as a bank.[12] Commercial bankers maximize utility from their consumption c_b (as in Iacoviello, 2014):[13]

$$\max_{c_{b,t}} E_0 \sum_{t=0}^{\infty} \beta_b^t (\log c_{b,t}), \tag{1.3.5}$$

where β_b is assumed to be lower than the discount factor of patient households (necessary condition for the capital requirement to be binding - see Iacoviello, 2014).

The budget constraint of bankers is:

$$c_{b,t} + \frac{R_{d,t-1} d_{t-1}}{\pi_t} + bb_t + b_{e,t} = d_t + \frac{R_{b,t-1} bb_{t-1}}{\pi_t} + \frac{R_{e,t-1} b_{e,t-1}}{\pi_t}, \tag{1.3.6}$$

where $R_{d,t}$ is the interest rate on deposits d_t, bb_t denotes interbank lending and $R_{b,t}$ is the interbank interest rate, $b_{e,t}$ are the loans to entrepreneurs and $R_{e,t-1}$ is the interest rate on corporate loans.

The commercial banker's balance sheet looks as follows:

Assets	Liabilities
Interbank loans: bb_t	Deposits d_t
Loans to entrepreneurs: $b_{e,t}$	Equity eq_t

[12] The distinction between commercial and subprime bankers is not necessary for the benchmark version of the model, but becomes important once securitization is introduced into the model economy. The evidence from the U.S. suggests that there were several banks and financial intermediaries that specialized specifically in the subprime market.

[13] Note that this formulation considers a risk-averse banker. Although financial intermediaries are often considered to be risk-neutral, there is some evidence of their risk-aversion (see Ratti, 1980 and Angelini, 2000). More recently, examining interest rates for different deposit maturities for a set of U.S. banks, Nishiyama (2007) concludes that individual banks' relative risk aversion coefficients fall between 0 and 1 (most likely around 0.2), which means that they are slightly risk averse. The log-utility function is characterized by the decreasing absolute risk aversion and constant relative risk aversion of order 1, it is thus higher than the estimates of Nishiyama (2007). However, in the current setup the degree of risk-aversion does not matter. As the model is solved using the log-linearization technique, it has the feature of certainty equivalence: what matters for the solution are the first order-moments of variables, but not higher-order moments, such as variance. Since uncertainty does not play a role under the first-order-approximation, the solution of the model would not change if I assumed the risk-neutrality of bankers.

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

$$\tau \leq \frac{bb_t + b_{e,t} - d_t}{\chi^{Intb} bb_t + \chi^{Firm} b_{e,t}}, \tag{1.3.7}$$

where $\chi^{Intb} < \chi^{Firm}$ are risk weights of assets and τ denotes an equity ratio set by a regulator. The condition states that the ratio of equity (defined as assets 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 the Lagrangian multiplier on the capital requirement):

w.r.t. bb_t

$$\frac{1}{c_{b,t}} = \beta_b E_t \left(\frac{R_{b,t}}{c_{b,t+1} \pi_{t+1}} \right) + (1 - \tau \chi^{Intb}) G_t, \tag{1.3.8}$$

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

$$\frac{1}{c_{b,t}} = \beta_b E_t \left(\frac{R_{e,t}}{c_{b,t+1} \pi_{t+1}} \right) + (1 - \tau \chi^{Firm}) G_t, \tag{1.3.9}$$

w.r.t. d_t

$$\frac{1}{c_{b,t}} = \beta_b E_t \left(\frac{R_{d,t}}{c_{b,t+1} \pi_{t+1}} \right) + G_t. \tag{1.3.10}$$

The interpretation of equations 1.3.8 to 1.3.10 is crucial for understanding the main result of the chapter. The equations without considering the Lagrangian multiplier on the capital requirement 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 requirement of bankers introduces a wedge between the cost and marginal gain from lending. Its bindingness influences the bankers' decisions between consumption and borrowing/lending and gives rise to the process of deleveraging. This results in a shrinking balance sheet in the face of a negative shock, as bankers are impatient and prefer to consume rather than raise equity or increase their lending.

Subprime Lenders

Subprime lenders operate as financial intermediaries that collect deposits bb_t from the interbank market and issue subprime loans b_t^{Sub}.

Their optimization problem is:

$$\max_{c_{bb,t}} E_0 \sum_{t=0}^{\infty} \beta_{bb}^t (\log c_{bb,t}), \tag{1.3.11}$$

s.t.

$$c_{bb,t} + b_t^{Sub} + R_{b,t-1} bb_{t-1}/\pi_t = bb_t + R_{s,t-1}(1-\delta_{s,t}) b_{t-1}^{Sub}/\pi_t, \tag{1.3.12}$$

where $c_{bb,t}$ denotes subprime lenders' consumption. I assume that subprime lenders hold a reserve for future losses, taking into account the ex ante (steady state) default rate. The subprime banker's balance sheet is:

Assets	Liabilities
Loans to subprime borrowers: b_t^{Sub}	Interbank deposits bb_t
Loss reserve $-\delta_s b_t^{Sub}$	Equity eq_t

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

$$\tau^{Sub} \leq \frac{(1-\delta_s) b_t^{Sub} - bb_t}{\chi^{Sub}(1-\delta_s) b_t^{Sub}}, \tag{1.3.13}$$

where the risk weight on subprime loans is denoted by χ^{Sub} and τ^{Sub} is the capital ratio imposed on subprime lenders by the regulator.

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

w.r.t. b_t^{Sub}

$$\frac{1}{c_{bb,t}} = \beta_{bb} E_t \left(\frac{R_{s,t}(1-\delta_{s,t+1})}{c_{bb,t+1}\pi_{t+1}} \right) + (1-\tau^{Sub}\chi^{Sub})(1-\delta_s) GG_t, \tag{1.3.14}$$

w.r.t. bb_t

$$\frac{1}{c_{bb,t}} = \beta_{bb} E_t \left(\frac{R_{b,t}}{c_{bb,t+1}\pi_{t+1}} \right) + GG_t. \tag{1.3.15}$$

Equation 1.3.14 determines the interest rate paid on subprime loans and makes clear that when pricing the subprime loan, the subprime lender takes into account the default probability of the borrowers. As a consequence, the steady state interest rate on subprime loans is higher than that of loans with a zero default probability.

1.3.6 Central Bank

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

$$R_{d,t} = (R_{d,t-1})^{r_R} \left(\pi_{t-1}^{1+r_\pi} \left(\frac{Y_{t-1}}{Y} \right)^{r_y} \bar{rr} \right)^{1-r_R} e^{e_{R,t}}. \tag{1.3.16}$$

1.3.7 Market Clearing Conditions

I assume that real estate is fixed in the aggregate, which guarantees a variable price of housing. The market clearing condition for the housing market is:

$$1 = h_t^{Savers} + h_t^{Sub} + h_{e,t}. \tag{1.3.17}$$

The goods market clearing condition is given by:

$$Y_t = c_t^{Savers} + c_t^{Sub} + c_{e,t} + c_{b,t} + c_{bb,t}. \tag{1.3.18}$$

The market clearing conditions for labor are defined by equations 1.D.5 and 1.D.15 for the patient households' labor supply and demand, and by equations 1.D.8 and 1.D.16 for the impatient subprime households. The lending to different agents is determined through their collateral constraints, while the market clearing conditions for the loan and deposits markets are given by the capital requirements of the bankers (equation 1.3.7 and 1.3.13).

1.4 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 the form of a RMBS, which 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, which can be interpreted as a default rate representing the mean of 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, I assume that the model's RMBS consists only of two tranches: senior and equity.[14] Figure 1.7 illustrates the payoff functions of investors in the RMBS.

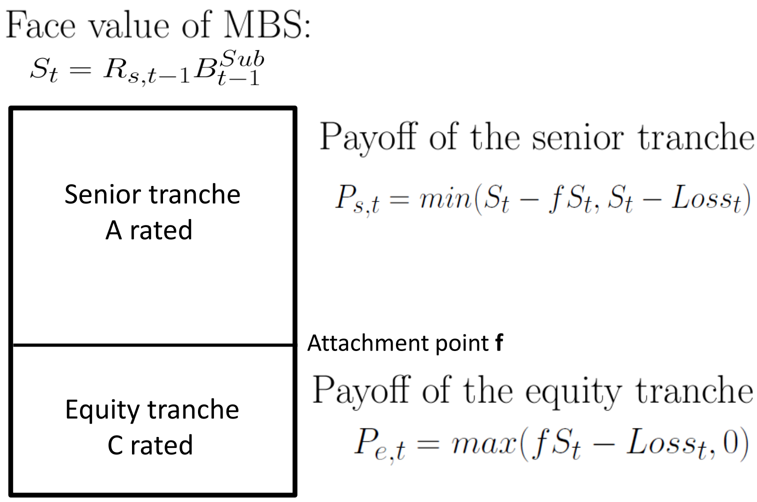


Figure 1.7: A two-tranche MBS (face value written in nominal terms)

The security is a pass-through security, which means that the nominal loan proceeds are redistributed to the MBS investors. The smaller the loss on the underlying loan portfolio (determined by the default rate), the larger is the payoff of equity tranche

[14]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 version of the present model in which different tranches are bought by different agents, presented in Appendix 1.E, 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.

investors. The size of the equity tranche, determined by the parameter f, called the attachment point in the CDO jargon, defines the maximum 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 the case where losses are bigger than the size of the equity tranche). $P_{s,t} = min(S_t - fS_t, S_t - Loss_t)$ denotes the payoff of senior tranche buyers, and $P_{e,t} = max(fS_t - Loss_t, 0)$ denotes the payoff of equity tranche buyers, where the principal of the MBS is (in real terms) $S_t = R_{s,t-1}b^{Sub}_{t-1}/\pi_t$, and loss equals $\delta_{s,t}S_t$. Independent of the outcome, the cash flows distributed to investors always equal the cash flows from subprime loans (including losses), which is illustrated in Table 1.1:

	Scenario	
	Loss >the equity tranche $\delta_{s,t}S_t > fS_t$	Loss < 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 1.1: MBS payoffs - two scenarios

The characteristics of the MBS presented in Table 1.1 make the inclusion of securitization in the benchmark model straightforward. In what follows, I assume in each version of the model with securitization that the same investor buys both the senior and the equity tranche of the MBS, in practice acquiring the whole cash-flow from loan proceeds. It is also possible to assume that different tranches are bought by different investors. I consider this case in Appendix 1.E that explains how equity and senior tranche payoffs resemble payoffs from investment in European options and presents the characteristics of the chosen approximation of the maximum and minimum functions (the logistics function), which are functions with a kink (see Figure 1.21). The qualitative results of my analysis do not change irrespective of the fact whether different agents buy different tranches (results with the use of the logistics function presented in Appendix 1.E) or one agent buys both tranches (presented in the main part of the chapter).

In what follows, I present results for three different models with securitization: in the first version, the entrepreneur invests in the loan proceeds; in the second version, it is the patient household that acquires the MBS claims; and in the third version, commercial bankers are investors in securitized assets. Why might commercial bankers buy claims on MBS? One reason may be the diversification of their credit risk and the exposure to a different credit market. Also, they may be as optimistic as subprime borrowers are, and believe that housing 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 banks. The regulatory capital arbitrage is the reason why subprime lenders may want to conduct securitization and why commercial bankers may want to buy certain tranches, as described in Jones (2000). Why might patient households and entrepreneurs buy MBS tranches? For them, this investment is just another possibility to smooth their consumption.

I assume that certain agents in the economy invest in MBS securities, and I do not model their decision as a portfolio choice decision, which allows me to use the first order approximation to solve the model.[15] For answering the research question of this chapter this approach is sufficient, as I do not aim to explain how the securitized assets were distributed among the investors.

Securitization changes the capital requirement faced by originators of the subprime loans, as they may remove part of the risk from the balance sheet due to the repackaging and sale of the assets. In the case of entrepreneurs and patient households who buy MBS tranches, their budget constraint changes to include the new asset acquired, and the FOC with respect to the new asset determines its price. When commercial bankers invest in MBS tranches, apart from a changed budget constraint, the capital requirement of the bankers also changes in order to include the new asset into the balance sheet of the investor. Since these changes are not substantial relative to the baseline model, I discuss their impact on specific model equations in Appendix 1.F.

[15] For the determination of the portfolio choice, higher-order solutions have to be used, as under the first order approximation, the equilibrium portfolio is not determined (Devereux and Sutherland, 2010).

1.5 Calibration and Results

1.5.1 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. All equations describing the model (also shock processes) are given in Appendix 1.D.5.[16] I calibrate the model using parameter values from the literature, as well as empirical papers (see Table 1.2).

Following Iacoviello (2005), I 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 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 firms and subprime borrowers are set at 0.99, which is a high value, but is consistent with the literature (Iacoviello, 2014). Parameter η is chosen to fix the Frisch labor supply elasticity at 1. The chosen value lies between the estimates provided by microeconomic studies (0-0.54) and by macroeconomic studies (2-4) (see Peterman, 2012). The steady state gross markup is a value taken from Iacoviello (2005). The patient households' wage share of 0.87 corresponds to the conclusions of Jappelli (1990a) who finds that 19% of U.S. families are rationed in credit markets and they account for 12.7% of total wage income. The value of 0.55 for the parameter θ 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.

Parameters describing the risk weights of different types of loans are based on U.S. regulations of the 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). Interbank loans have the lowest risk weight, followed by the risk weight on commercial loans (the factor for risky loans

[16] A list of the log-linearized equations for the extended version of the model (including capital and investment, as well as impatient prime borrowers), may be found in the previous working paper version of this model, Grodecka (2013).

Description	Parameter	Value
Discount factor of patient households	β	0.995
Discount factor of impatient households	β^{Sub}	0.93
Discount factor of entrepreneurs	γ	0.96
Discount factor of commercial bankers	β_b	0.97
Discount factor of subprime lenders	β_{bb}	0.95
Weight on housing services	J	0.09
Loan to value entrepreneurs	m	0.99
Loan to value subprime households	m^{Sub}	0.99
Labor supply aversion	$\eta^{Savers} = \eta^{Sub}$	2
Housing share in production function	ν	0.15
Steady state gross markup	X	1.05
Patient households wage share	α	0.87
Probability fixed price	θ	0.55
Capital adjustment costs	ϕ	2
Risk weight of interbank loans	χ^{Intb}	0.2
Risk weight on commercial loans	χ^{Firms}	1.5
Risk weight of subprime loans	χ^{Sub}	4.5
Commercial bankers capital requirement	τ	0.13
Subprime lenders capital requirement	τ^{Sub}	0.2
Subprimers' default sensitivity to house price changes	ϕ_{sh}	0.183
Steady state subprime default rate	δ_s	0.05
Weight of policy response to interest rate	r_R	0.73
Weight of policy response to inflation	r_π	0.27
Weight of policy response to output	r_y	0.13
Autocorrelation of preference shock	ρ_j	0.95
Standard deviation of preference shock	σ_{ε_j}	1
Standard deviation of monetary shock	σ_{ε_R}	1
Tranche retention by banks	t	0.01

Table 1.2: Calibrated parameters

has been applied). The risk weight on subprime loans has a very high value, which is consistent with the Expanded Guidance for Subprime Lending Programs,[17] stating *"that an institution would hold capital against subprime portfolios in an amount that is one and a half to three times greater than what is appropriate for non-subprime assets of a similar type"*. The capital ratio for commercial bankers corresponds to the average regulatory capital to risk-weighted assets for the United States before the crisis, reported in the FRED database.[18] The capital ratio for subprime lenders is higher than for commercial bankers, which again, corresponds to the Expanded Guidance for Subprime Lending Programs: *"Institutions with subprime programs affected by this guidance should have capital ratios that are well above the averages for their traditional peer groups or other similarly situated institutions that are not engaged in subprime lending. (...) institutions that underwrite higher-risk subprime pools, such as unsecured loans or high loan-to-value second mortgages, may need significantly higher levels of capital, perhaps as high as 100% of the loans outstanding depending on the level and volatility of risk"*.

The sensitivity of subprime households to housing price changes has been chosen according to the pre-crisis data. Over time, the sensitivity changed, but on average one can assume that it did not exceed 20% (Amromin and Paulson, 2010). The subprime default rate is chosen to be 5% in the steady state. According to the data presented in Demyanyk and Hemert (2011), in the decade preceding the crisis, the default rate on subprime hybrid loans oscillated 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 the interest rate on subprime loans. The Taylor rule coefficients are taken from Iacoviello (2005). The shocks are assumed to be persistent, with the autocorrelation coefficient equal to 0.95. I consider a 1 percent shock in each case. For the parameters governing the securitization process, evidence suggests that on average, retention of securitized assets is higher in Europe than in the U.S. Whereas originators usually held around 5% of issued securities in Europe, the retention rate was often at 0% and rarely

[17] `http://www.federalreserve.gov/boarddocs/srletters/2001/sr0104a1.pdf`
[18] Series DDSI05USA156NWDB

exceeded 1% for MBS in the U.S. Retention percentages for CDOs and ABS (Asset Backed Securities) were usually higher, but in the years 2002-2009, on average they did not exceed 7% (Global Financial Stability Report, October 2009, p. 100-107).

1.5.2 Model Dynamics

I consider two shocks: monetary and preference.[19] The monetary shock is defined as an exogenous increase in the interest rate set by the central bank and can be interpreted as a discretionary deviation from the Taylor rule. The negative preference shock represents a change in the preference for housing among households. This may capture - in reduced form - a regulatory or taxation reform that makes investment in the housing market less attractive to households (regulatory reforms allowing for a large range of mortgage products could have led to a positive preference shock in the U.S., see Temkin et al., 2002).

The introduction of a subprimers' default rate sensitive to housing prices has only a negligible impact on impulse response functions to shocks in the baseline model without securitization. The varying default rate, particularly, the rising default rate after a negative shock leading to a fall in housing prices, is a positive wealth effect from the subprimers' perspective - they may repay less than contracted. Feeling wealthier, subprime borrowers will reduce their labor supply when compared to the case where the default rate does not vary, which drives output down. For 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 requirement. They will reduce their lending to subprime borrowers and raise the interest rate on subprime loans, but their consumption will also go down. The described redistribution effect and balance sheet effect have a negative effect on overall consumption, and more responsive housing prices affect other borrowers in the economy who use housing stock as collateral for their loans. However, the subdivision of the banking sector into the subprime and the commercial segments prevents the negative developments in the subprime market from spreading to other sectors of the economy, especially the production

[19] An earlier working paper version presenting this model (Grodecka, 2013) includes also a technology and an inflation shock. Monetary and preference shocks are the most important in explaining the main transmission mechanism, so I only focus on them.

sector which is unaffected by subprimers' defaults and no significant effect on the aggregate output can be observed.

A more interesting comparison is given in Figure 1.8 which presents the impulse responses for output of the benchmark model (solid line) and three versions of the model with securitization. Impulse responses are presented as percent deviations from the steady state. The dashed green line shows the responses of the model in which entrepreneurs buy MBS tranches, the dotted magenta line presents the second version of the model with securitization, in which patient households buy MBS tranches, whereas the dashed-dotted red line shows the responses of the model in which commercial bankers buy MBS tranches. In the case of both shocks in the model, in which patient households or entrepreneurs acquire claims on subprime loans, the output response is smaller than in the benchmark case. While looking at Figure 1.8, it is important to note that the model with securitization in which patient households buy MBS claims leads to a relatively worse output performance compared to the version in which entrepreneurs become the investors of new assets. This is due to the special role patient households play in the model economy: they are the source of commercial bankers' deposits, and their savings behavior affects the aggregate balance sheet of the economy. In the model in which they invest in MBS, they have less resources to save in form of deposits, and so this version of the model with securitization leads to less lending than the version in which firms acquire subprime loan proceeds.

Due to securitization, the capital constraint of subprime lenders becomes relatively looser (they hold less assets decreasing in value on their balance sheets; the numerical example discussing the relation between the value of assets and the bindingness of the capital constraint is given in Appendix 1.A) and their consumption is less responsive to shocks than in the benchmark model. As subprime lenders' liabilities (interbank deposits) are assets of commercial bankers, securitization, by enabling subprime lenders to sell toxic assets, will protect their balance sheets from shrinking in the case of a negative shock. The mechanism of interbank linkages is presented in Figure 1.9, which shows balance sheets of the subprime lender and the commercial lender (balance sheets do not necessarily have to be of the same size, as depicted in Figure 1.9). Before a negative shock, the balance sheets have a size depicted by the solid black line. After a negative shock, the overall lending decreases, but the deleveraging

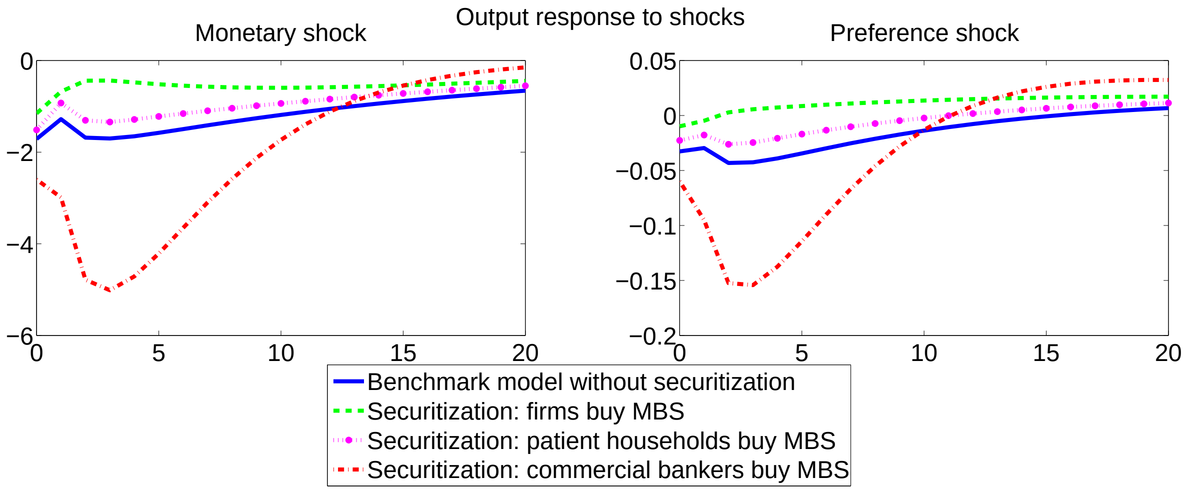


Figure 1.8: Output responses of model versions with and without subprime securitization

Note: All impulse responses are measured in percentage deviations from steady state

effect is different depending on who is the ultimate bearer of the securitized risk.

Through the interbank linkages, a larger (relative to the benchmark without securitization) subprime balance sheet leads, ceteris paribus, to a larger commercial bankers' balance sheet, and thus more potential lending to firms. Of course, buying claims on MBS tranches changes the budget constraints of the investors and has impacts on their consumption, but they can absorb losses on MBS through working and saving (patient households) or borrowing (entrepreneurs). The overall effect of securitization is to dampen the fall in lending and output, because the risk is spread among different agents in the economy. This is the way securitization was expected and is supposed to work.

However, another possibility was also considered - that commercial bankers buy MBS proceeds. If securitized assets are bought by commercial bankers, there is an amplification of the output response after shocks. The amplification occurs not only in comparison to the version of the model in which securitized products are bought by savers and entrepreneurs, but also with respect to the benchmark model without securitization. What is the reason for this amplified contraction? All the effects occur through the balance sheets of both types of bankers. Issuing MBS makes the capital constraint of subprime lenders looser (in the case of a negative shock), whereas it

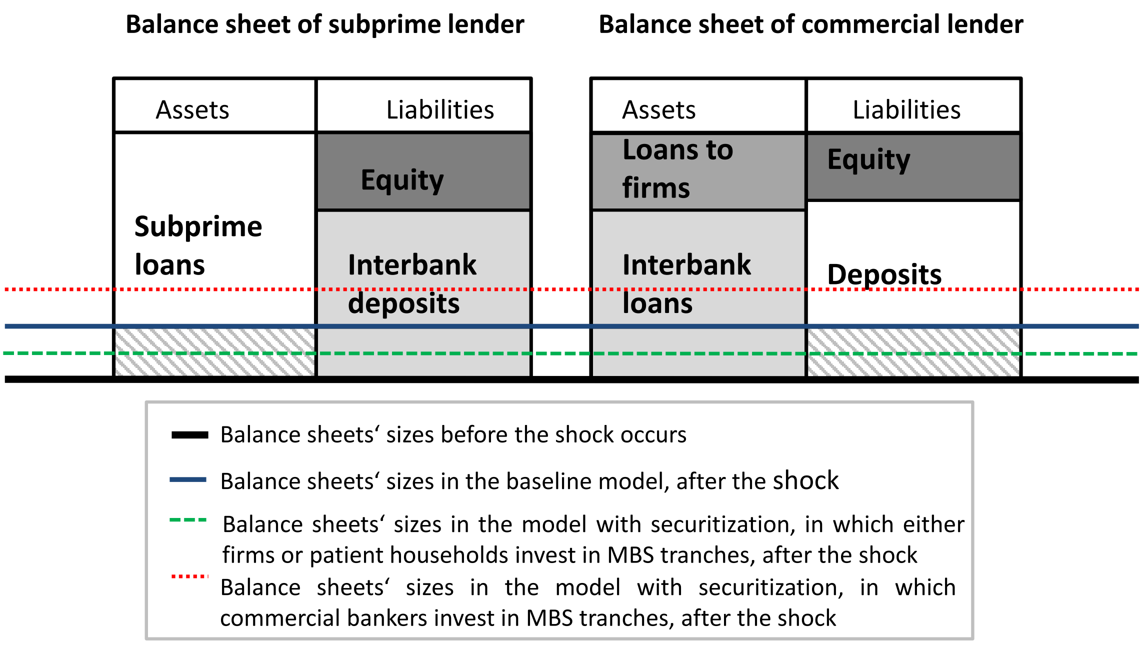


Figure 1.9: Interconnected balance sheets of financial intermediaries in the model

tightens the capital constraint of commercial bankers because they hold the MBS (that is declining in value after a negative shock because of the increasing default rate) on their balance sheets. To reduce the tightness of the constraint, commercial bankers may either reduce their consumption or lending (a similar mechanism occurs in Iacoviello, 2014). In the present model, they do both.

When a negative shock hits the economy and commercial bankers buy MBS tranches, their capital constraint gets tighter and they reduce the lending to entrepreneurs who finance housing stock purchases with loans from the bank. As the housing stock is a production factor, output in the economy goes down more than without securitization. When non-banks buy MBS tranches, there is no loss on the balance sheet of commercial bankers and securitization reduces business cycle fluctuations. In the benchmark case, entrepreneurs are relatively unaffected by the defaults in the subprime sector. When commercial bankers engage in securitization, a more direct link is created between the production sector and the subprime mortgage market, so that entrepreneurs suffer from losses in the subprime portfolio more than in the benchmark case. These dynamics are visible in Figures 1.10 and 1.11 which present

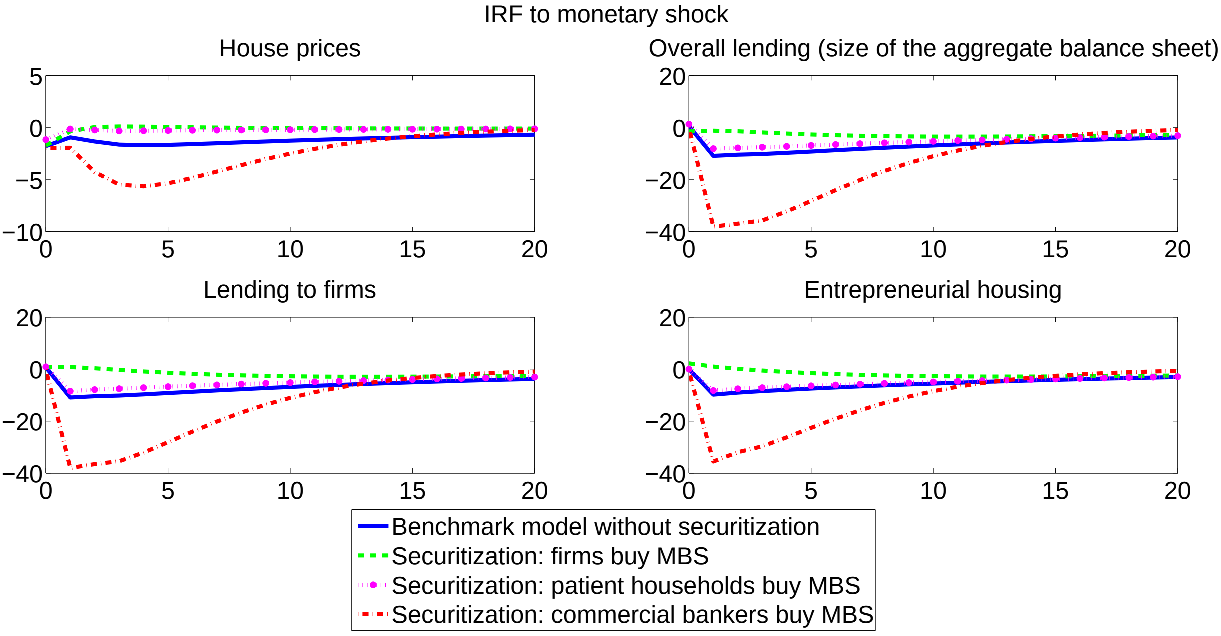


Figure 1.10: Impulse responses of models with and without subprime securitization

Note: All impulse responses are measured in percentage deviations from steady state

chosen model variables after a monetary shock and the preference shock. From Figures 1.10 and 1.11 it is visible that commercial bankers become buyers of MBS, the entrepreneurial borrowing and housing stock are considerably lower than in the benchmark case and in the case where only patient households and entrepreneurs buy MBS. Also the aggregate balance sheet represented by the overall lending sector confirms the intuition presented in Figure 1.9. Due to a negative shock, the lending goes down in all of the considered models, but the strength of this effect differs. The fact that bankers face a capital requirement is crucial for obtaining the above result.

Apart from considering the impulse response functions, one can also have a look at the model's theoretical moments. Table 1.3 presented below shows the standard deviations of the main variables of interest for the benchmark model and the three versions of the model with securitization. For the purpose of the table, I denote the model with securitization in which entrepreneurs buy MBS as Sec1, the model in which patient households buy MBS by Sec2 and the model in which commercial bankers buy MBS as Sec3. I normalize the standard deviations of the benchmark model to 1 and present the standard deviations for the other models in relation to the

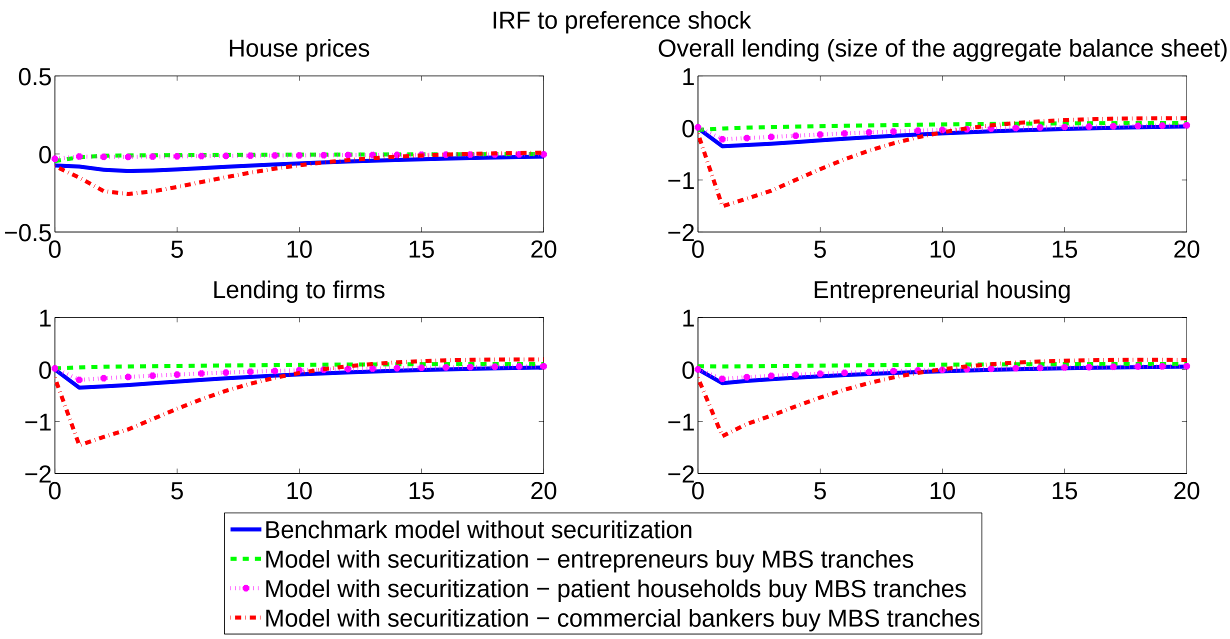


Figure 1.11: Impulse responses of model versions with and without subprime securitization

Note: All impulse responses are measured in percentage deviations from steady state

benchmark, so the numbers presented in columns 3-5 have a percentage interpretation. A number smaller than 1 means that a given variable is less volatile relative to the benchmark model without securitization, while a number larger than 1 denotes larger volatility.

	Standard deviation			
Variable	Benchmark	Sec1	Sec2	Sec3
Output	1	0.503	0.795	1.664
Aggregate lending	1	0.442	0.790	2.454
Nominal interest rate	1	0.485	0.668	1.421
House prices	1	0.252	0.212	1.75
Entrepreneurial borrowing	1	0.378	0.791	2.455
Entrepreneurial housing stock	1	0.464	0.933	2.527

Table 1.3: Simulated moments of chosen variables

In case of each variable, the standard deviation of the model in which commercial bankers buy MBS (Sec3) is considerably larger than in the benchmark case without securitization. In the case of the model where entrepreneurs (Sec1) and patient households (Sec2) buy MBS, the opposite is the case: both models exhibit a much smaller volatility of considered variations relative to the benchmark. Notably, the model with patient households as MBS investors (Sec2) demonstrates larger variable volatility than the model with entrepreneurs as investors. Thus, the simulated moments of the economy confirm the intuition provided by the analysis of impulse response functions: securitization may either dampen or amplify aggregate volatility depending on the final buyer of securitized assets, and they are most positive in the model in which entrepreneurs invest in MBS tranches.

1.5.3 Crisis Experiment

How do the model's predictions relate to the housing prices and output fall observed in the data during the Great Recession? To answer this question, I take into account the seasonally adjusted USSTHPI series[20] and real GDP (available from the Bureau of Economic Analysis). The raw data exhibits a trend in both cases. In order to make the data comparable to the model outcomes presented as percentage change from the steady state, I use the HP-filter to calculate the trend and cyclical component of both series and express the cyclical component as percentage deviations from the trend. Figure 1.12 presents the percent deviations from trend observed in the data for real GDP (upper panel) and housing prices (lower panel) in the U.S. in the years 1975-2013. The gray bars indicate NBER recessions. The last recession started in December 2007 (4th quarter) and ended in June 2009 (2nd quarter).

The analysis reveals that the cyclical component of housing prices fell below zero (steady state) between the 4th quarter of 2007 and the 1st quarter of 2008 (and crosses the zero-line from below for one period in the 2nd quarter of 2008), while the cyclical component of GDP turned negative two quarters after housing prices fell, in the 3rd quarter of 2008. Notice that the time when the cyclical component turns negative does not coincide with the peak of GDP and housing prices, as in both cases, the peaks represent positive cyclical divergence from the steady state. Using a log-linearized DSGE model as an analysis tool, I can by construction only look at the deviations from the steady state - before the exogenous shock occurs, the economy is at the steady state. After the cyclical component of house prices turns negative, it reaches a low of -3.81% in the 4th quarter of 2009. The low of the GDP cyclical

[20]The series has been adjusted using the X-12-ARIMA program.

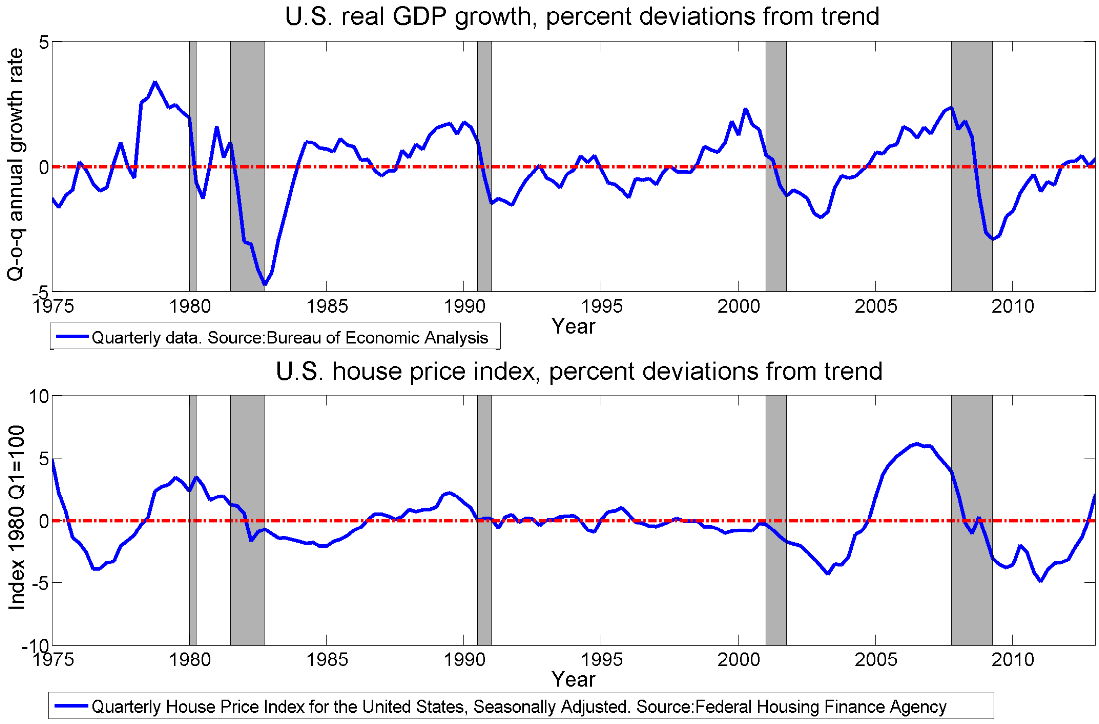


Figure 1.12: U.S. GDP and USSTHPI

component, -2.91%, occurs earlier, even if the fall itself starts later, and experiences a relatively fast recovery afterwards (while the cyclical component of housing prices shows a W-shaped pattern).

To investigate how the predictions of my stylized model correspond to the dynamics observed in the data, I calibrate the housing preference shock in three considered models to get an initial fall in housing prices of 1.2627%, as this has been the deviation from the trend in the first two quarters when the cyclical component of housing prices turned negative. Figure 1.13 shows the results of this exercise, presenting the results for three models and the data series (starting from the 3rd quarter of 2008, when the cyclical component of GDP turns negative and the cyclical component of housing prices falls below zero for the second time) for the first 10 quarters after the shock.

The model, especially its version with banks investing in MBS does a good job replicating the hump-shaped response of output after the negative preference shock. The initial fall of housing prices of 1.2627% leads to a relatively fast come-back of housing prices to the steady state in the two models with securitization in which

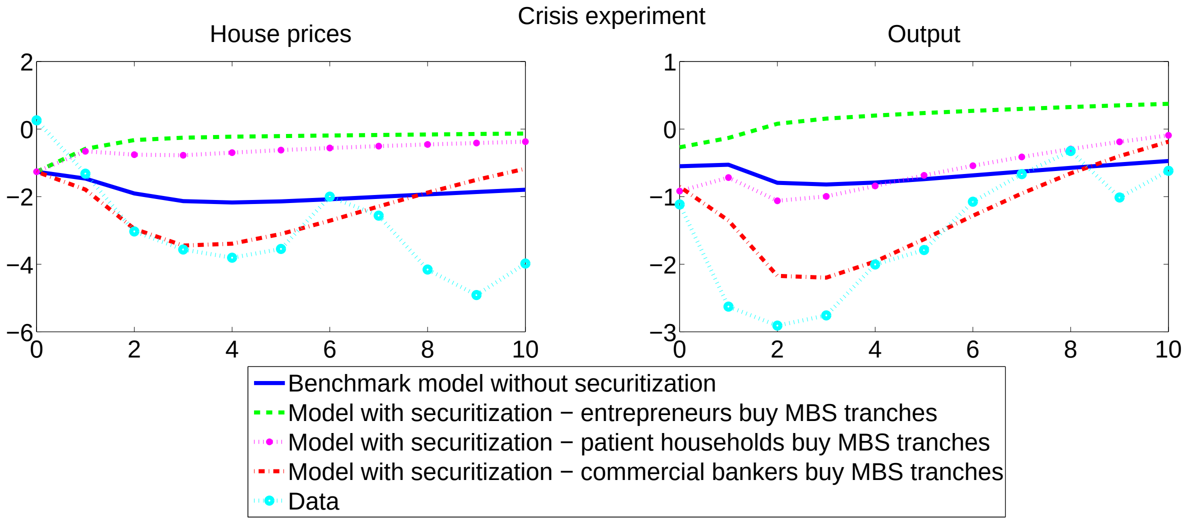


Figure 1.13: Crisis experiment

Note: All impulse responses are measured in percentage deviations from steady state

non-financial agents buy claims on MBS. The baseline model predicts a maximum drop in housing prices of 2.17% and the model with securitization in which bankers invest in MBS shows a drop of 3.45%, which is closest to the data (3.81%). When it comes to the output response, unsurprisingly the model with securitization in which commercial bankers engage in the acquisition of MBS tranches, comes closest to the data, generating an output fall of 2.2% (compared to 2.91% in the data). The deviations from trend observed in the data are larger than the ones generated by the model, but having in mind Figure 1.12, one may recall that the fall in prices and GDP started from an above-trend level, which may have given more impetus to the variables.

Given the simplicity of the model and the fact that the model is not explicitly estimated to match the data, the comparison of the model and data series is more than satisfying. The version of the model in which bankers buy MBS generates impulse response functions similar to the output behavior in the data, which suggests that the model may highlight an important amplification mechanism that played a role in the crisis. A comparison of the red dashed-dotted line in Figure 1.13 with the other lines allows for conducting a simple counterfactual exercise and shows how output could have evolved if there was no securitization or if securitized products were bought by final buyers other than commercial bankers. In both cases, the fall in output would be lower and the recovery would be faster. Specifically, the maximum output fall in the model with securitization and entrepreneurs as investors corresponds to only ca. 13% of the maximum output fall in the model with bankers as investors. Assuming that in reality the latter case occurred and applying this number to the output fall in the data, we get a maximum output fall of 0.36% instead of 2.91% observed in the data, corresponding to the case in which only non-financial investors (entrepreneurs) buy MBS tranches.

1.6 Sensitivity Analysis and Extension

1.6.1 Sensitivity Analysis

In order to test the model's robustness, I compute a sensitivity analysis with respect to the housing share in the production function, commercial bankers' capital ratio and tranche retention by subprime lenders. The results are presented as the difference between the IRFs of the benchmark model (solid blue line in all graphs) and the model with securitization in which bankers are the investors, after a monetary shock.[21] The larger the difference, the larger the negative effect compared to the economy without securitization.

Figure 1.14 presents the differences for different values of housing share in the production function. The larger the housing share, the stronger the negative effects of securitization on housing prices and output. This is an intuitive result: given that entrepreneurial housing stock falls in response to the negative shock, if it is a relatively more important factor of production (ν is larger), output will experience a larger drop.

[21]Results for the preference shock are qualitatively the same.

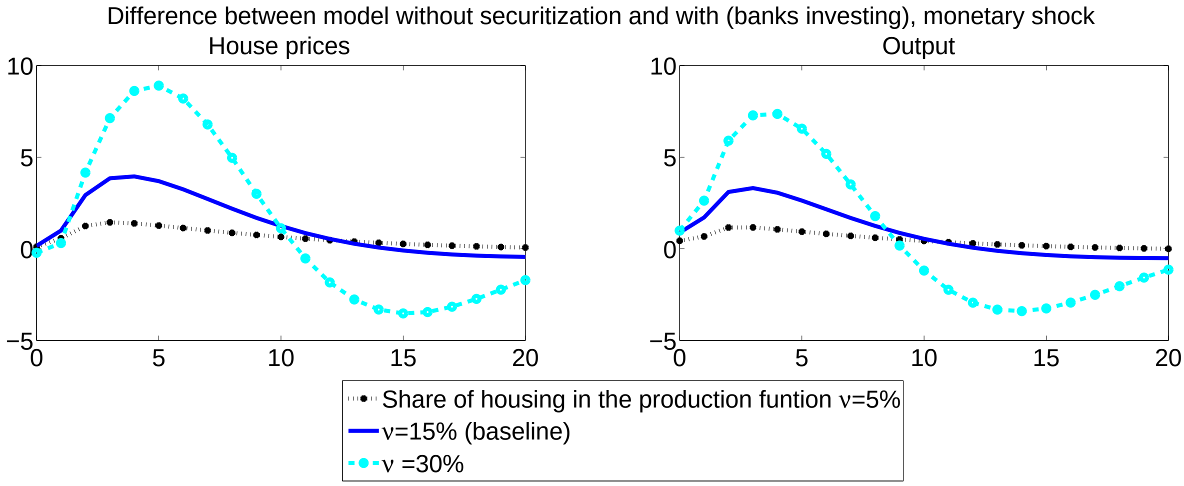


Figure 1.14: Sensitivity w.r.t. ν

From the policymaker's point of view, it is important to examine the effects of increasing regulation in the banking market. Could more strict regulations, i.e. higher capital ratios and higher tranche retention rates protect the economy from large output falls, analogous to those that occurred during the Great Recession? Figure 1.15 presents the sensitivity analysis w.r.t. different capital ratios, and Figure 1.16 presents results for different tranche retention rates.

Figure 1.15 shows that, as capital ratios for commercial bankers increase, the difference between the baseline model and the model with bankers as investors in securitized assets falls. This suggests that, given the existence of equity constraints, their higher value is better for the economy, as it reduces deleveraging effects and the fall in housing prices and output. When it comes to imposing higher retention rates on subprime lenders, Figure 1.16 suggests that such a macroprudential policy is less effective than determining the level of capital ratios. Higher retention rates lead to smaller differences between the baseline and the 'bad securitization' model, but the effects are quantitatively negligible even for tranche retention rates as high as 50%. This can hinge on the fact that the subprime lending sector is more regulated in the first place. Higher capital ratios for subprime lenders and high risk weights on subprime loans significantly reduce the leverage of the subprime sector as compared to the commercial banking sector, so introducing stricter regulations has a relatively smaller marginal impact on the behavior of the economy.

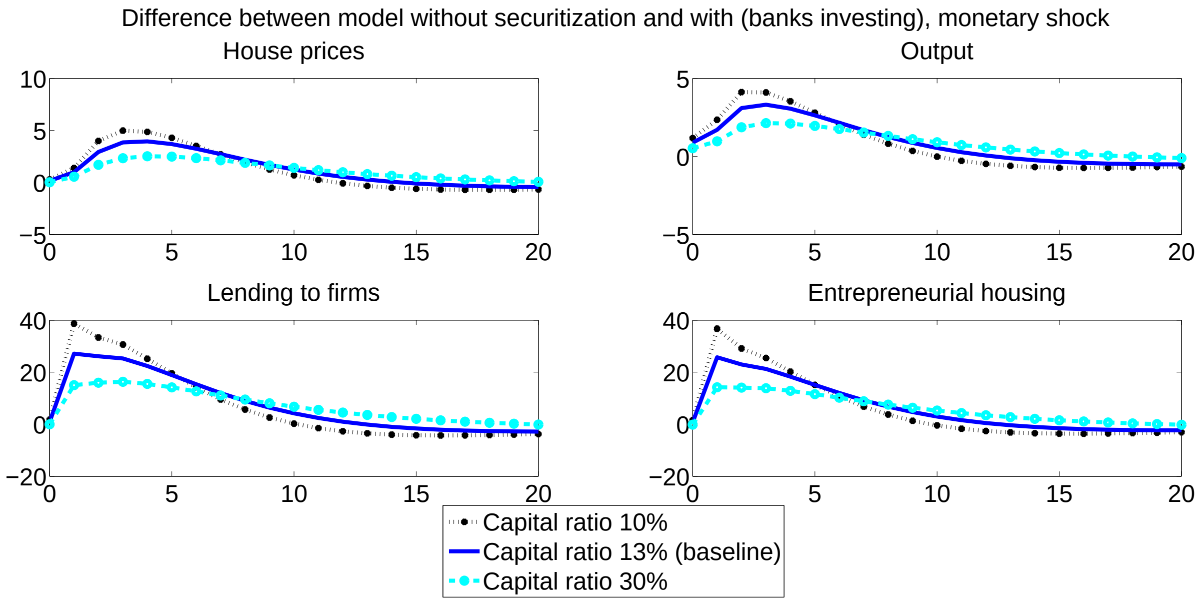


Figure 1.15: Sensitivity w.r.t. τ

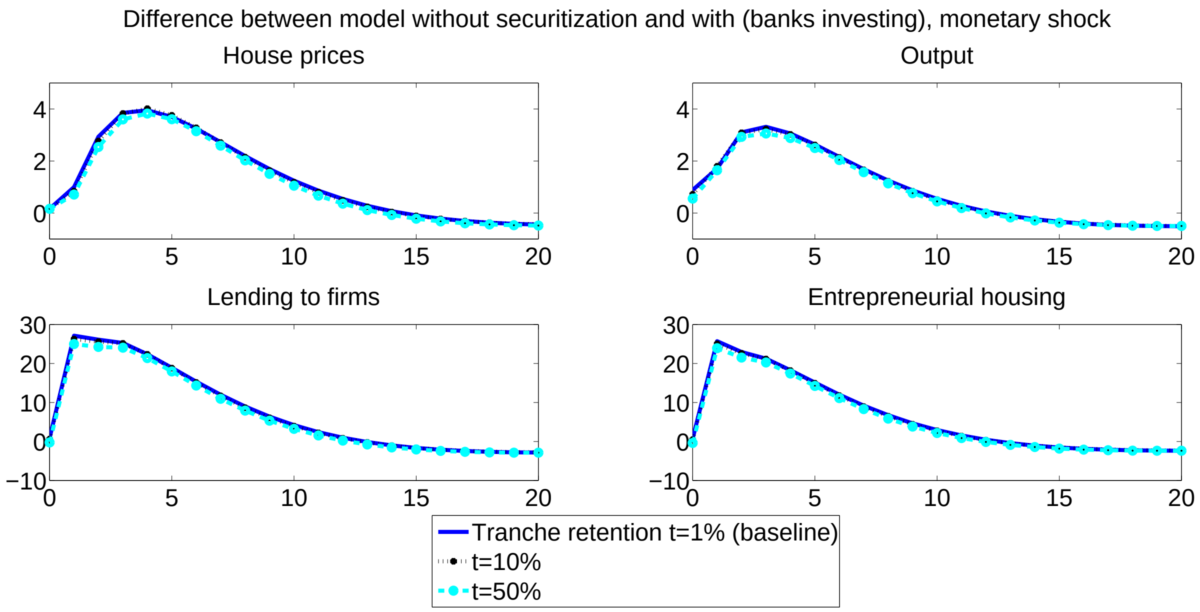


Figure 1.16: Sensitivity w.r.t. t

1.6.2 Extension

In the baseline version of the model, I consider only subprime impatient borrowers that constitute 100% of all households' borrowing. As discussed in Section 1.2.1, subprime hybrid contracts were in reality a minor part of the U.S. mortgage market, which was dominated by prime fixed-interest rate contracts. In an extension of the model, I consider the existence of impatient prime borrowers that do not default on their loans and have access to long-term contracts. Equations describing the optimization problem of the prime borrower are presented in Appendix 1.G. I assume that prime borrowers, unlike subprime borrowers, have access to loans offered by commercial bankers. In this version of the model, I calibrate the subprimers' share in the market to reflect the average share observed in the data in the pre-crisis years: 20%. I also assume that prime borrowers have access to 4-period contracts.[22]

It turns out that adding impatient prime borrowers to the model reduces the volatility of the model's variables. Prime households that take out fixed interest rate loans are not as sensitive to changes in housing prices and interest rates as the subprimers, which makes their borrowing less responsive to shocks. As subprimers are now only a subset of borrowing households, in the extended model, their default leads to less disruptions. The effects are quantitatively less strong than in the presented baseline model, but the qualitative results remain the same. In addition to the deleveraging effect w.r.t. lending to firms, the extended version of the model features also a reduction in lending to prime households in the model with bankers as investors in the securitization market. The graphs presenting the behavior of the main variables of interest for the model with prime borrowers are included in Appendix 1.G.

1.7 Conclusion

In the first chapter, I analyze the importance of the specific design of subprime contracts and the securitization of subprime loans in generating cyclical fluctuations in the U.S. in a New-Keynesian model. The evidence suggests that the existence of subprime borrowers alone cannot account for the amplification of the responses of

[22] In the earlier version of the model, two-period subprime and six-period prime loans were also considered. The results do not change qualitatively in this case, and the quantitative impact is limited.

output and housing prices to different shocks in the economy. This chapter also gives an answer to the question whether the securitization of subprime loans could be a factor that amplified the response of the economy to negative shocks, like the ones we observed during the Great Recession. It turns out that the effects of securitization of subprime loans depend on who is the final buyer of securitized assets. If households and entrepreneurs purchase MBS tranches, securitization reduces business cycle fluctuations, spreading the subprime risk among different agents. Facing a negative shock and losses on securitized portfolios, these agents adjust their labor supply and saving decisions (patient households) or borrowing (entrepreneur) so as to cushion the effects of the exogenous disturbances. The positive effects of securitization arise thanks to an interconnected banking sector in which changes in the balance sheet of one financial intermediary have an impact on the balance sheets of other financial intermediaries in the economy through interbank loan contracts. However, if financial intermediaries (that are the source of credit to firms in the economy) purchase MBS tranches, the negative effects of securitization prevail. This results in a bigger contraction of output after a negative shock when compared with the case where non-banks buy MBS tranches or without securitization. The positive risk-sharing aspect of securitization is mostly suppressed in this situation, because the capital requirement on the side of banks is a source of additional financial frictions. The counterfactual exercise conducted in this chapter suggests that if financial institutions followed the intended business model of securitization, the maximum quarterly output loss in the U.S. economy during the Great Recession would have been much smaller and shorter-lasting compared to that actually experienced.

The results of the model are in line with narrative explanations of the crisis provided by Hellwig (2009) and Jaffee et al. (2009). It is shown that securitization per se cannot be blamed for the crisis, because it may dampen business cycles arising in response to negative shocks 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 model deals, however, with the possible transmission mechanism in an economy with subprime borrowers and securitization, rather than the reasons for the existence of the subprime market and the subprime securitization with their incentive problems.

The setup addresses several important issues in policymaking, like the burden of regulation in the economy. It turns out that raising capital ratios is an effective method of reducing negative deleveraging effects, while imposing higher tranche retention rates on subprime lenders is relatively less efficient, as they are already more regulated and the marginal effect of additional regulation is comparatively small. Moreover, the chapter's results suggest that the segmentation of the banking sector and avoiding interbank 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 the 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 at the beginning of the new century, and it might have been one of the causes of the widespread crisis, as the current chapter shows. Thus, from the point of view of the policymaker, it is crucial to ensure that banks disclose all information about their assets, even those 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.[23] If toxic assets generated in country A are sold to 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 a recession due to the engagement in the international financial market (country A will remain practically intact). This narrative can be easily adopted to explain what happened during the recent financial crisis. The U.S. 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 U.S. subprime market started, and the crisis spread around the world. In reality, not only did the international buyers of RMBS suffer from losses, but the U.S. 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 U.S. banks also

[23] Kollmann et al. (2011) investigate the role of bank capital requirements in the international context, modeling a global bank subject to loan default shocks.

engaged in the acquisition of toxic assets. Also, other factors, such as labor market developments in the U.S. played a role, which are, however, not considered in this model.

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

Appendix to Chapter 1

1.A Bank Capital Requirements and Deleveraging

One of the major results of this chapter hinges on the fact that the financial intermediaries face collateral constraints, forcing them to maintain a certain equity to assets ratio. Following Adrian and Shin (2010), this section focuses on the balance sheet effects of capital requirements faced by bankers that are crucial to understand the effects of securitization in the model presented in this chapter. Consider a simplified balance sheet of a financial intermediary:

Assets	Liabilities
Loans L = 100	Deposits D=90
	Equity E= 10

The ratio of equity to assets is given by 10/100 = 10%. Assume that these 10% correspond to the capital requirement set by the regulator. The leverage ratio is given by the inverse of the capital ratio, i.e. 100/10 = 10. The capital constraint is always binding, i.e. the banker will avoid holding excess equity which would lower his leverage ratio, and I assume that equity adjusts first to changes on the asset side. Consider a scenario in which the value of assets falls by 1%. The balance sheet looks in this case as follows:

Assets	Liabilities
Loans L = 99	Deposits D=90
	Equity E= 9

At first, the capital ratio falls to 9/99 = 9.09% and leverage increases to 99/9 = 11. A banker trying to maintain a constant equity ratio will try to bring leverage down to the previous level and he can do so in two ways. He may choose to deleverage, i.e. reduce lending from depositors, which would lead to a shrinking balance sheet, since as D falls, loans L also have to fall. To reduce leverage to 10, the banker has to reduce deposits and assets by D solving the following equation: $(99 - D)/9 = 10$. Thus, borrowing from depositors has to be reduced by 9 units which results in the following balance sheet:

Assets	Liabilities
Loans L = 90	Deposits D=81
	Equity E= 9

After this operation, the capital ratio and leverage are back to the original levels. The initial fall in asset prices of 1% resulted in a fall in lending by 10%. Alternatively, the banker may choose to raise new equity, which would result in an expansion of the balance sheet. To determine how much equity needs to be raised, we solve for E in equation $(99 + E)/(9 + E) = 10$. The bank needs to raise 1 additional unit of equity to bring the leverage down to the previous level, which results in the same balance sheet as before the fall in asset prices.

Which of the two alternative ways of reducing leverage is mostly chosen by financial intermediaries that face a fall in their asset prices? Unfortunately, the first one is more common, i.e. deleveraging leading to shrinking balance sheets and sales of assets. It is unfortunate, as the initial fall in prices may lead to sales of assets, which may further drive their prices down, leading to a vicious circle. Why do banks tend to adjust their deposits rather than equity? As Adrian and Shin (2011) document, the equity of financial intermediaries behaves in many cases like a pre-determined variable and it is relatively sticky, which may be explained by possible non-pecuniary benefits to bank owners (new equity leads to dilution of the value of stakes of the insiders, loss of the control over shares). In the stock market context, raising new equity through issuing new shares may be difficult in times of falling asset prices. Thus, even if theoretically a financial intermediary facing an increased leverage has two options to cope with that situation, a fall in asset prices often leads to a contraction in the balance sheet.

This mechanism is crucial for understanding the behavior of bankers in the model. Facing losses on subprime MBS, bankers decide to reduce their lending to productive firms, worsening the effects of the initial negative shock in the economy. They could raise new equity, but this would mean that they have to reduce their current consumption. As they are modeled as impatient agents maximizing their consumption, a shortcut that enables me to capture the stickiness of the equity observed by Adrian and Shin (2011), they choose to deleverage rather than cut consumption.

Can higher capital ratios reduce the deleveraging effect? Consider an economy in which there is a capital ratio of 20%. Then, the balance sheet looks as follows:

Assets	Liabilities
Loans L = 100	Deposits D=80
	Equity E= 20

In this case, a fall of asset prices by 1% will require an adjustment by D units: $19/(99 - D) = 20\%$. D=4, i.e. the initial fall of 1% will lead to shrinking of the balance sheet by overall 5 units, which is 5% of its overall size, as opposed to 10% when the capital ratio was 10%. Thus, a higher capital requirement reduces the negative deleveraging effects.

How does the risk-weighting of assets (present in Basel regulations and in this model) change the considerations about changes in the size of the balance sheet? Until now, it was assumed that the risk-weight of the assets is 1. What if it were twice as big or two times smaller? Consider the second case and assume that L=100 and the required capital ratio is 10%. The risk weighting enables us to keep only 5 units of equity E (E/0.5*L=10%), and finance the lending mostly with deposits D=95, which means that our leverage increases to 20 (10 in the base case without risk-weighting). What happens if asset prices fall by 1%? The capital ratio becomes $4/0.5 * 99 = 8.08\%$. To bring the capital ratio up to 10%, the banker will reduce its borrowing and lending by D: $4/0.5 * (99 - D) = 10\%$. The solution is D=19. That means that the initial fall of asset prices by 1% leads to the overall decline in lending by 20%. Introducing the risk weights influences the strength of the bankers' response in the event of asset price decline. A risk weight smaller than 1 increases the leverage of the financial intermediary and exacerbates the deleveraging process, whereas a risk weight larger than 1 will have stabilizing effects.

The basic analysis of banks' balance sheets suggests that higher capital ratios and risk weights higher than 1 (100%) may help reduce the negative effects of a fall in asset prices in the economy. Will the dynamic general equilibrium model confirm these conclusions? It turns out that yes - binding capital constraints may indeed lead to large amplification effects in the face of a crisis, and higher capital requirements reduce the deleveraging effect.

1.B Data Description

To produce the Figures 1.5 and 1.18 and compare them to the data for all U.S. chartered banks, I use monthly data provided by the Federal Reseve in Table H.8 Assets and Liabilities of Commercial Banks in the United States.[24] The data on MBS holdings and data on commercial real estate loans begins in 10.1996 for large commercial banks. If I wanted to use data for all commercial banks, the data on MBS holdings starts in 07.2009 and the data on commercial real estate loans begins in 06.2004. Since I am interested in a longer perspective, I use data for large banks as a proxy for all U.S. banks. The total assets of the large domestically-chartered commercial banks constituted in years 1985-2013 around 56% to 68.5%, with a falling tendency over time. The developments in the fractions of total commercial loans and commercial real estate loans follow similar patterns. In the period 06.2004-06.2013, the correlation coefficient between the fraction of total commercial loans in large domestically-chartered banks and all banks stood at 91.14%. For the fraction of commercial real estate loans, the coefficient in the same period was even larger: 95.38%. Thus, the conclusions remain relevant for the whole banking sector in the U.S., even though some of the graphs in this chapter are only prepared using data for large domestically-chartered banks. For total consumer loans, the corresponding correlation coefficients are significantly lower: for the fraction of consumer real estate loans we obtain a correlation of 61.34%, while for the fraction of total consumer loans the correlation is 59.02%.

I use the following series:

For large domestically chartered commercial banks:

Commercial and industrial loans: B1023NLGAM

Commercial real estate loans:B1219NLGAM

Commercial loans: B1023NLGAM + B1219NLGAM

Treasury and agency securities: Mortgage-backed securities (MBS): B1301NLGAM

Other securities: Mortgage-backed securities: B1303NLGAM

Total MBS holdings: B1301NLGAM+ B1303NLGAM

Consumer real estate loans: B1027NLGAM + B1220NLGAM

Other consumer loans: B1029NLGAM

[24]Available on `http://www.federalreserve.gov/releases/h8/current/`.

Total consumer loans: B1029NLGAM+ B1027NLGAM + B1220NLGAM
Total assets:B1151NLGAM
For all commercial banks:
Commercial and industrial loans: B1023NCBAM
Commercial real estate loans: B1219NCBAM
Commercial loans: B1023NCBAM+ B1219NCBAM
Treasury and agency securities: Mortgage-backed securities (MBS): B1301NCBAM
Other securities: Mortgage-backed securities: B1303NCBAM
Total MBS holdings: B1301NCBAM+ B1303NCBAM
Consumer real estate loans: B1027NCBAM+B1220NCBAM
Other consumer loans: B1029NCBAM
Total consumer loans: B1029NCBAM+ B1027NCBAM+B1220NCBAM
Total assets: B1151NCBAM

1.C Additional Graphs

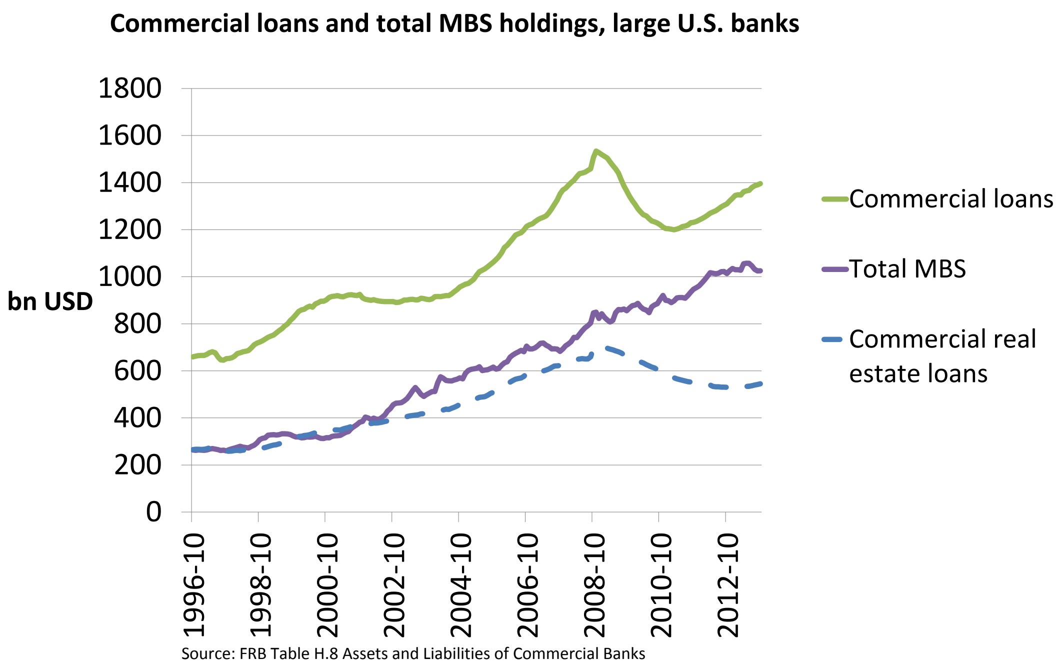


Figure 1.17: Commercial loan holdings in the U.S., large banks

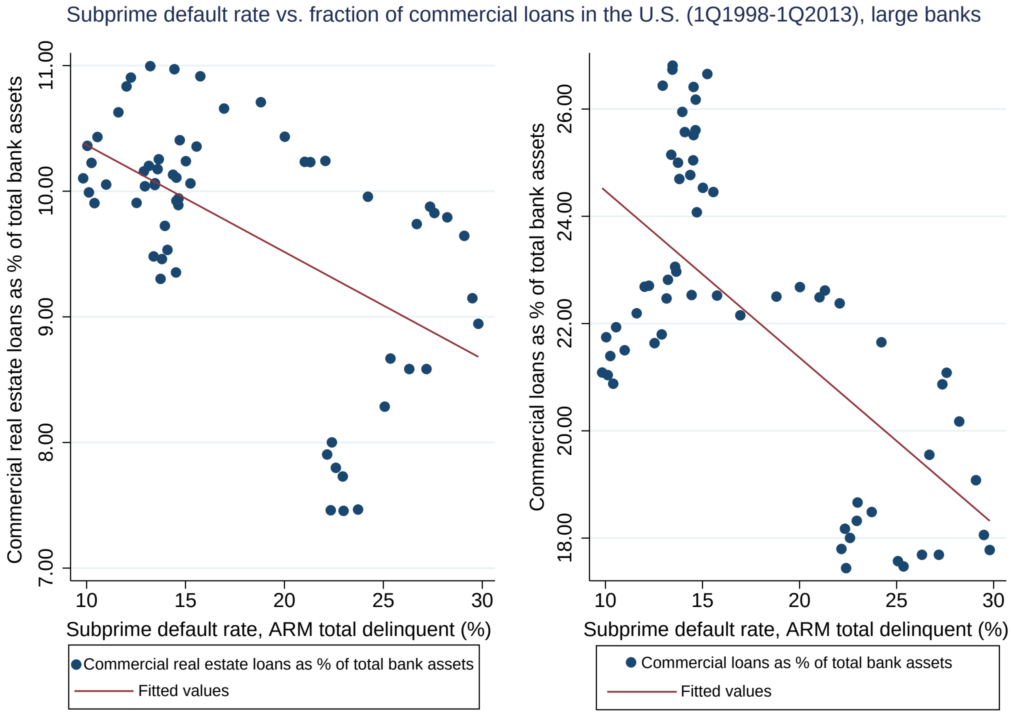


Figure 1.18: Subprime default rates and commercial loans in the U.S.

Source: Thomson Reuters Datastream and FRB data

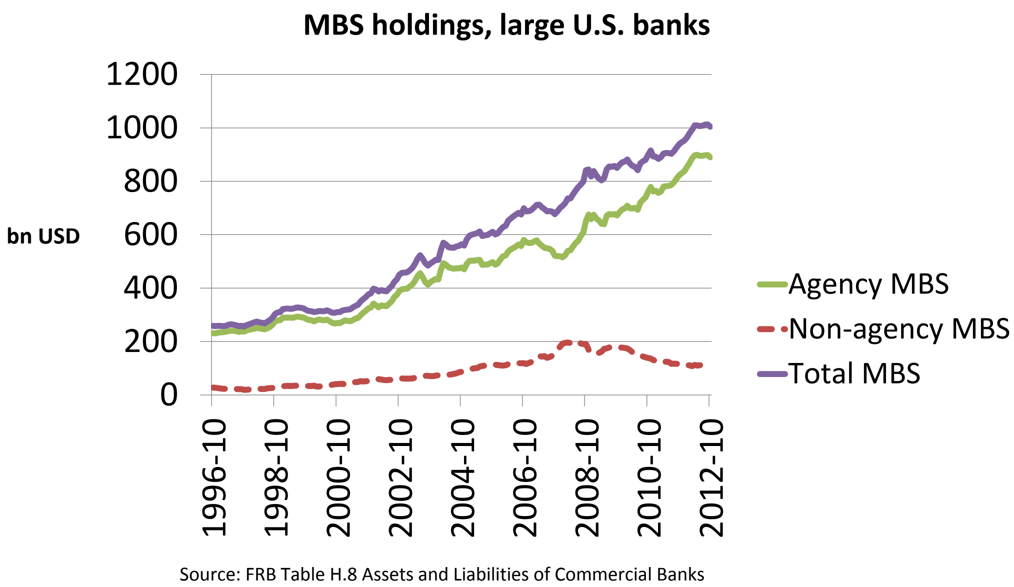


Figure 1.19: MBS holdings, large U.S. banks

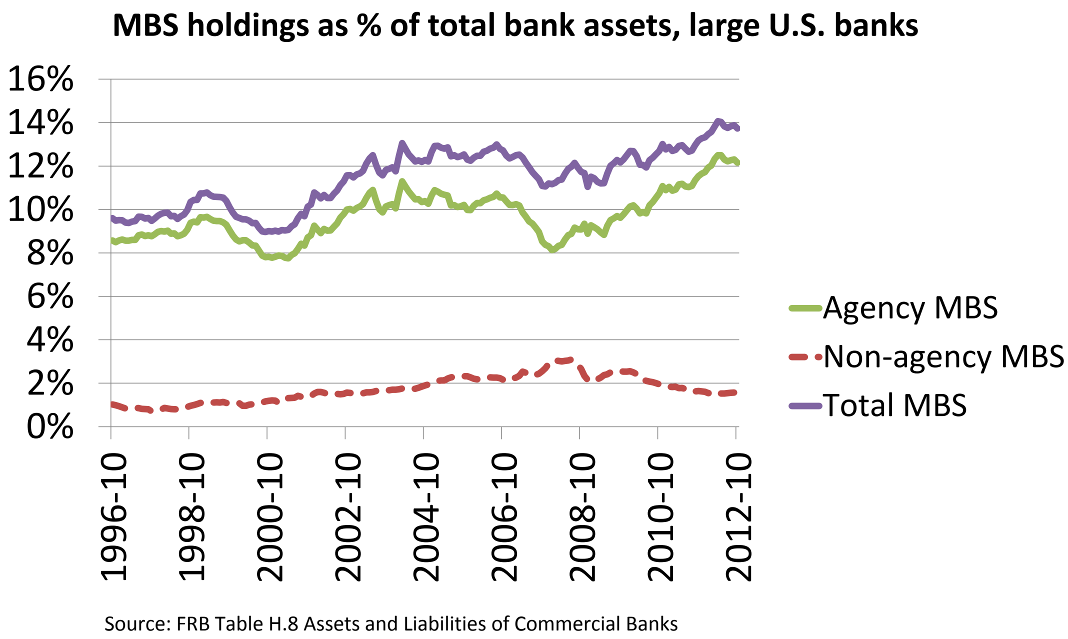


Figure 1.20: MBS holdings as fraction of total bank assets, large U.S. banks

1.D Baseline Model Equations

1.D.1 The Optimization Problem of the Patient Household

All equations and constraints are written in real terms. Patient households maximize the utility function given by:

$$\max_{b_t^{Savers}, h_t^{Savers}, L_t^{Savers}} E_0 \sum_{t=0}^{\infty} \beta^t \left(\log c_t^{Savers} + j_t \log h_t^{Savers} - \frac{L_t^{Savers \eta^{Savers}}}{\eta^{Savers}} \right), \quad (1.D.1)$$

where c_t^{Savers} denotes the consumption of the final good, j_t is the 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^{Savers} is the housing stock held by savers, L_t^{Savers} denotes labor supply of patient households.

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

$$c_t^{Savers} + q_t(h_t^{Savers} - h_{t-1}^{Savers}) + d_t = R_{d,t-1}d_{t-1}/\pi_t + w_t^{Savers}L_t^{Savers} + F_t, \quad (1.D.2)$$

where d_t denotes deposits, $R_{d,t}$ is the interest rate paid on deposits, F_t are profits from retailers (redistributed only to patient households), $w_t^{Savers}L_t^{Savers}$ is labor income, $q_t = Q_t/P_t$ denotes the real housing price, $\pi_t = P_t/P_{t-1}$ is inflation. The deposit contract is a nominal debt contract.

The First Order Conditions (FOCs) are:

w.r.t. d_t

$$\frac{1}{c_t^{Savers}} = \beta E_t\left(\frac{1}{c_{t+1}^{Savers}\pi_{t+1}}\right)R_{d,t}, \quad (1.D.3)$$

w.r.t. h_t^{Savers}

$$\frac{q_t}{c_t^{Savers}} = \beta E_t\left(\frac{q_{t+1}}{c_{t+1}^{Savers}}\right) + \frac{j_t}{h_t^{Savers}}, \quad (1.D.4)$$

w.r.t. L_t^{Savers}

$$w_t^{Savers} = L_t^{Savers\eta^{Savers}-1}c_t^{Savers}. \quad (1.D.5)$$

1.D.2 FOCs of the Impatient Subprime Household

The FOCs are (λ_t^{Sub} is the Lagrangian multiplier on the borrowing constraint):

w.r.t. b_t^{Sub}

$$\frac{1}{c_t^{Sub}} = \beta^{Sub}E_t\left(\frac{(1-\delta_{s,t})R_{s,t}}{c_{t+1}^{Sub}\pi_{t+1}}\right) + \lambda_t^{Sub}R_{s,t}, \quad (1.D.6)$$

w.r.t. h_t^{Sub}

$$\frac{q_t}{c_t^{Sub}} = \beta^{Sub}E_t\left(\frac{q_{t+1}}{c_{t+1}^{Sub}} + \lambda_t^{Sub}m^{Sub}q_{t+1}\pi_{t+1}\right) + \frac{j_t}{h_t^{Sub}}, \quad (1.D.7)$$

w.r.t. L_t^{Sub}

$$w_t^{Sub} = L_t^{Sub\eta^{Sub}-1}c_t^{Sub}, \quad (1.D.8)$$

1.D.3 The Optimization Problem and the FOCs of the Entrepreneur

The utility function of the entrepreneur is:

$$\max_{b_{e,t},h_{e,t},L_t^{Savers},L_t^{Sub}} E_0 \sum_{t=0}^{\infty} \gamma^t \log(c_{e,t}), \tag{1.D.9}$$

where $b_{e,t}$ is the borrowing of firms, $h_{e,t}$ denotes their housing stock, L_t is the labor of households, and $c_{e,t}$ denotes firms' consumption.

The production function is:

$$Y_t = h_{e,t-1}^{\nu} L_t^{Savers\alpha(1-\nu)} L_t^{Sub(1-\alpha)(1-\nu)}, \tag{1.D.10}$$

where ν denotes the housing share in the production function and the parameter α controls for patient households' labor share in the production function.

The entrepreneurs' budget constraint is:

$$\frac{Y_t}{X_t} + b_{e,t} = c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t} b_{e,t-1} + w_t^{Savers} L_t^{Savers} + w_t^{Sub} L_t^{Sub}, \tag{1.D.11}$$

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

Entrepreneurs face a borrowing constraint:

$$R_{e,t} b_{e,t} \leq m E_t(q_{t+1} h_{e,t} \pi_{t+1}). \tag{1.D.12}$$

The FOCs of the entrepreneur are (denote by $\lambda_{e,t}$ the Lagrangian multiplier on the borrowing constraint):
w.r.t $b_{e,t}$

$$\frac{1}{c_{e,t}} = \gamma E_t\left(\frac{R_{e,t}}{c_{e,t+1}\pi_{t+1}}\right) + \lambda_{e,t} R_{e,t}, \tag{1.D.13}$$

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

$$\frac{q_t}{c_{e,t}} = E_t\left[\frac{\gamma}{c_{e,t+1}}\left(\nu \frac{Y_{t+1}}{X_{t+1} h_{e,t}} + q_{t+1}\right) + \lambda_{e,t} m q_{t+1} \pi_{t+1}\right], \tag{1.D.14}$$

w.r.t. labor:

$$w_t^{Savers} = \frac{\alpha(1-\mu-\nu)Y_t}{X_t L_t^{Savers}}, \tag{1.D.15}$$

$$w_t^{Sub} = \frac{(1-\alpha)(1-\mu-\nu)sY_t}{X_t L_t^{Sub}}. \tag{1.D.16}$$

1.D.4 Retailers

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:

$$Y_t^f = \left(\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} \, \mathrm{d}z \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{1.D.17}$$

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

$$P_t = \left(\int_0^1 P_t(z)^{1-\varepsilon} \, \mathrm{d}z \right)^{\frac{1}{1-\varepsilon}}. \tag{1.D.18}$$

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

The retailer maximizes the following equation:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,k} \left(\frac{P_t^*(z)}{P_{t+k}} - \frac{X}{X_{t+k}} \right) Y_{t+k}^*(z) \right\}, \tag{1.D.19}$$

where $\Lambda_{t,k} = \beta^k \left(\frac{c_t^{Savers}}{c_{t+k}^{Savers}} \right)$ is the patient household relevant discount factor, $X_t = \frac{P_t}{P_t^w}$ is the markup of final over intermediate goods and X denotes the steady state value of the markup.

The aggregate price level evolution is given by:

$$P_t = (\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon})^{\frac{1}{1-\varepsilon}}. \tag{1.D.20}$$

Combining the last two equations and log-linearizing leads to the following formulation of a forward-looking Phillips curve

$$\hat{\pi}_t = \beta E_t \hat{\pi_{t+1}} - \kappa \hat{X}_t, \tag{1.D.21}$$

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

1.D.5 All Baseline Model Equations

1. Aggregate demand block

$$Y_t = c_t^{Savers} + c_t^{Sub} + c_{e,t} + c_{b,t} + c_{bb,t} \tag{1.D.22}$$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{b,t}}{c_{b,t+1}\pi_{t+1}}) + (1-\tau\chi^{intb})G_t \tag{1.D.23}$$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{e,t}}{c_{b,t+1}\pi_{t+1}}) + (1-\tau\chi^{firm})G_t \tag{1.D.24}$$

$$\frac{1}{c_{b,t}} = \beta_b E_t(\frac{R_{d,t}}{c_{b,t+1}\pi_{t+1}}) + G_t \tag{1.D.25}$$

$$\frac{1}{c_t^{Savers}} = \beta E_t(\frac{1}{c_{t+1}^{Savers}\pi_{t+1}})R_{d,t} \tag{1.D.26}$$

$$\frac{1}{c_{e,t}} = \gamma E_t(\frac{R_{e,t}}{c_{e,t+1}\pi_{t+1}}) + \lambda_{e,t}R_{e,t} \tag{1.D.27}$$

$$\frac{1}{c_t^{Sub}} = \beta^{Sub} E_t(\frac{(1-\delta_{s,t})R_{s,t}}{c_{t+1}^{Sub}\pi_{t+1}}) + \lambda_t^{Sub}R_{s,t} \tag{1.D.28}$$

$$\frac{1}{c_{bb,t}} = \beta_b E_t(\frac{R_{s,t}(1-\delta_{s,t+1})}{c_{bb,t+1}\pi_{t+1}}) + (1-\tau^{Sub}\chi^{Sub})(1-\delta_s)GG_t \tag{1.D.29}$$

$$\frac{1}{c_{bb,t}} = \beta_b E_t(\frac{R_{b,t}}{c_{bb,t+1}\pi_{t+1}}) + GG_t \tag{1.D.30}$$

2. Aggregate supply

$$Y_t = h_{e,t-1}^{\nu} L_t^{Savers\alpha(1-\nu)} L_t^{Sub(1-\alpha)(1-\nu)} \tag{1.D.31}$$

$$w_t^{Savers} = \frac{\alpha(1-\mu-\nu)Y_t}{X_t L_t^{Savers}} \tag{1.D.32}$$

$$w_t^{Sub} = \frac{(1-\alpha)(1-\mu-\nu)sY_t}{X_t L_t^{Sub}} \tag{1.D.33}$$

$$\hat{\pi}_t = \beta E_t \hat{\pi_{t+1}} - \kappa \hat{X}_t \tag{1.D.34}$$

3. Housing market block

$$1 = h_t^{Savers} + h_t^{Sub} + h_{e,t} \tag{1.D.35}$$

$$\frac{q_t}{c_t^{Savers}} = \beta E_t(\frac{q_{t+1}}{c_{t+1}^{Savers}}) + \frac{j_t}{h_t^{Savers}} \tag{1.D.36}$$

$$\frac{q_t}{c_t^{Sub}} = \beta^{Sub} E_t(\frac{q_{t+1}}{c_{t+1}^{Sub}} + \lambda_t^{Sub} m^{Sub} q_{t+1}\pi_{t+1}) + \frac{j_t}{h_t^{Sub}} \tag{1.D.37}$$

$$\frac{q_t}{c_{e,t}} = E_t[\frac{\gamma}{c_{e,t+1}}(\nu \frac{Y_{t+1}}{X_{t+1}h_{e,t}} + q_{t+1}) + \lambda_{e,t} m q_{t+1}\pi_{t+1}] \tag{1.D.38}$$

4.Borrowing constraints

$$R_{s,t} b_t^{Sub} = m^{Sub} E_t(q_{t+1}\pi_{t+1}) h_t^{Sub} \tag{1.D.39}$$

$$R_{e,t} b_{e,t} = m E_t(q_{t+1} h_{e,t} \pi_{t+1}). \tag{1.D.40}$$

$$\tau = \frac{bb_t + b_{e,t} - d_t}{\chi^{Intb} bb_t + \chi^{Firm} b_{e,t}} \tag{1.D.41}$$

$$\tau^{Sub} = \frac{(1-\delta_s) b_t^{Sub} - bb_t}{\chi^{Sub}(1-\delta_s) b_t^{Sub}} \tag{1.D.42}$$

$$\delta_{s,t} = \delta_s - \phi_{s,h}(q_t - Q) \tag{1.D.43}$$

5. Budget constraints/ evolution of state variables

$$c_t^{Savers} + q_t(h_t^{Savers} - h_{t-1}^{Savers}) + d_t = R_{d,t-1} d_{t-1}/\pi_t + w_t^{Savers} L_t^{Savers} + F_t \tag{1.D.44}$$

$$\frac{Y_t}{X_t} + b_{e,t} = c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t} b_{e,t-1} + w_t^{Savers} L_t^{Savers} + w_t^{Sub} L_t^{Sub} \tag{1.D.45}$$

$$c_{b,t} + \frac{R_{d,t-1} d_{t-1}}{\pi_t} + bb_t + b_{e,t} = d_t + \frac{R_{b,t-1} bb_{t-1}}{\pi_t} + \frac{R_{e,t-1} b_{e,t-1}}{\pi_t}, \tag{1.D.46}$$

$$c_{bb,t} + b_t^{Sub} + R_{b,t-1} bb_{t-1}/\pi_t = bb_t + R_{s,t-1}(1-\delta_{s,t}) b_{t-1}^{Sub}/\pi_t \tag{1.D.47}$$

6.Shock processes and monetary policy rule

$$\ln j_t = \rho_j \ln j_{t-1} + \varepsilon_{j,t}, \tag{1.D.48}$$

$$R_{d,t} = (R_{d,t-1})^{r_R} E_t(\pi_{t-1}^{1+r_\pi}(\frac{Y_{t-1}}{Y})^{r_y} \bar{rr})^{1-r_R} e^{\varepsilon_{R,t}}. \tag{1.D.49}$$

1.E The Option Characteristics of the Tranching Problem

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 the 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, the economic agent bets on the increase of the underlying asset price. By selling a call option (having a short call position) or buying a put option (having a long put position), the investor bets on the fall in the underlying asset price. The holder of an equity tranche of MBS gets payoffs equal to the ones from a long put position - he invests in the hope that the default rate (which can be interpreted as the underlying asset) will decrease. Also, investing in a senior tranche of an MBS is profitable when the default rate decreases. Note that

$$P_s, t = min(S_t - fS_t, S_t - \delta_{s,t}S_t) = S_t(1-f) - max(S_t\delta_{s,t} - fS_t, 0) = \\ S_t(1-\delta_{s,t}) - max(fS_t - \delta_{s,t}S_t, 0). \tag{1.E.50}$$

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 in the case of the equity tranche and the senior tranche payoff, the face value of the MBS, S_t, can be factored out. The underlying asset for the investors of MBS tranches is the default of subprime loans $\delta_{s,t}$, whereas the exercise price of the options they trade equals f (the attachment point of senior tranche). Figure 1.21 visualizes the profit (on the vertical axis) of investing in a short call and long put position depending on the default of subprime loans (horizontal axis). The lower the default, the higher the profit of investors (or the lower the loss).

After a shock, payoffs are realized and it is known whether the loss was bigger than

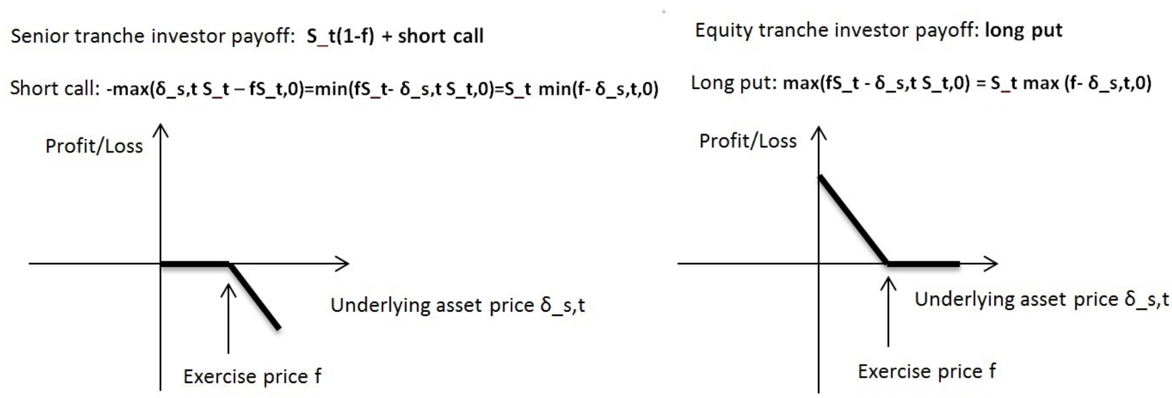


Figure 1.21: Option position of MBS investors

the size of the equity tranche. Thus, the investors get a well-known proportion of subprime cash-flows. However, while deciding about investing 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. 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. 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). There is a simple method to smoothly approximate a function with a kink, like the ones drawn above. The logistic function provides an approximation of maximum and minimum functions, which makes the solution tractable.[25] 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 $E_t[max(\delta_{s,t+1} - f, 0)] \approx E_t[-f - \frac{\delta_{s,t+1}+f}{1+e^{(-\delta_{s,t+1}+f)}}]$. Figure 1.22 provides a visualization of the approximation by the logistics function. The solid line presents the maximum function, while the dotted line its approximation. The x-axis corresponds to different values of δ - subprimers' default rate.

[25]Actually, the logistic function is used in one of the financial methods of estimating the value of securitized products. In finance, apart from the 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).

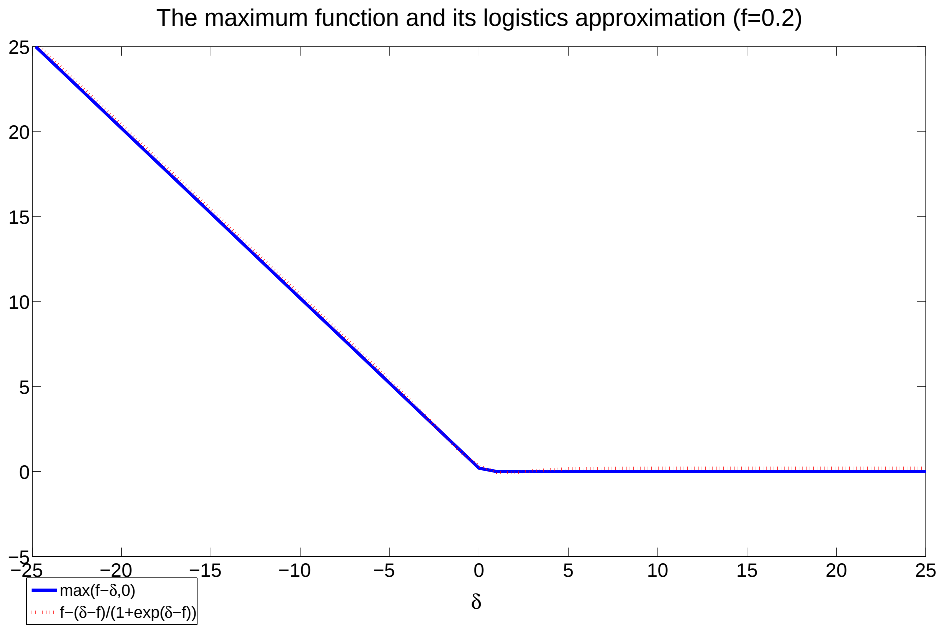


Figure 1.22: Logistics function as an approximation of the maximum function

Equation 1.E.50 shows three analogous representations of the 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 the expected payoffs of both tranche holders (for a long put). Having rewritten expected payoffs using the approximating function, one can log-linearize the conditions determining the behavior of the price of MBS tranches and consumption of the agents engaged in the transaction.

In what follows, I show that the solution of the model with the use of the logistics function to approximate the maximum functions denoting investors' payoffs yields qualitatively the same results as the easier model presented in the main part of the chapter, even though the approximation by the logistics function is not very exact near the model's steady state ($\delta = 0.05$ presented by the vertical dashed green line on the Figure 1.23).

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, I consider two cases. In the first case, I 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

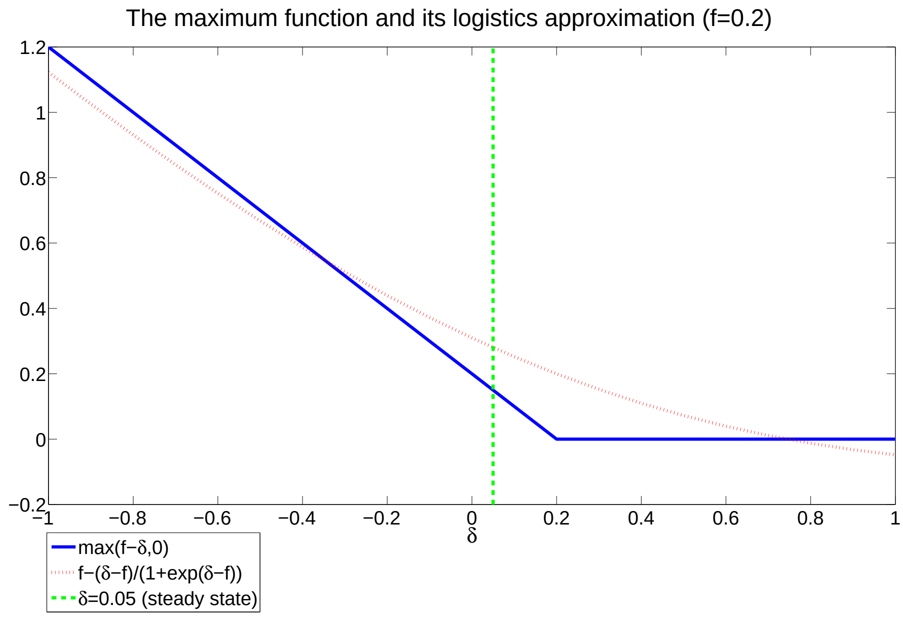


Figure 1.23: Logistics function as an approximation of the maximum function

impatience, they are more prone to acquire claims on the equity tranche). In the second case, I assume that the commercial bankers buy the senior tranche of 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 quantitatively stronger results). In both cases, subprime lenders retain a vertical fraction t of the issued security (equivalent to retaining a percentage t of cash flows).[26]

1.E.1 First Version: Patient Households and Entrepreneurs Invest in MBS Tranches

In the first version of the model with securitization of subprime loans, patient households invest in the senior tranche, and entrepreneurs in the equity tranche.

The budget constraints of investors change and a new term describing investment in the derivative security appears. First, denote the payoff of the senior tranche

[26] In general, the 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 present model's case, vertical slice retention generates the same payoff for the bank as equivalent exposure.

$E_t[min(S_{t+1} - fS_{t+1}, S_{t+1} - \delta_{s,t+1}S_{t+1})]$ 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):

$$c_t^{Savers} + q_t(h_t^{Savers} - h_{t-1}^{Savers}) + d_t + (1-t)p_{s,t}MBS_{s,t} = \\ R_{d,t-1}d_{t-1}/\pi_t + w_t^{Savers}L_t^{Savers} + F_t + (1-t)MBS_{s,t-1}. \quad (1.E.51)$$

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

$$\beta \frac{1}{c_{t+1}^{Savers}} = p_{s,t} \frac{1}{c_t^{Savers}}. \quad (1.E.52)$$

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:

$$\frac{Y_t}{X_t} + b_{e,t} + (1-t)MBS_{e,t-1} = \\ c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t}b_{e,t-1} + w_t^{Savers}L_t^{Savers} + w_t^{Sub}L_t^{Sub} + (1-t)p_{e,t}MBS_{e,t}. \quad (1.E.53)$$

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

$$\gamma \frac{1}{c_{e,t+1}} = p_{e,t} \frac{1}{c_{e,t}}. \quad (1.E.54)$$

The long-put approximation is given by the logistics function:

$$P_t = E_t[max(f - \delta_{s,t+1}, 0)] \approx E_t[f - \frac{\delta_{s,t+1} - f}{1 + e^{(\delta_{s,t+1} - f)}}] \quad (1.E.55)$$

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

Assets	Liabilities
Loans to subprime borrowers: tb_t^{Sub}	Interbank deposits bb_t
Loss reserve $-t\delta_s b_t^{Sub}$	

Thus, a Basel-type capital requirement, given exogenously, is now given by:

$$\tau^{Sub} \leq \frac{t(1-\delta_s)b_t^{Sub} - bb_t}{\chi^{Sub} t(1-\delta_s)b_t^{Sub}}. \tag{1.E.56}$$

The budget constraint of subprime lenders changes. Note that when it comes to the transfer of already realized cashflows, it holds that: $(1-t)[min(S_t - fS_t, S_t - \delta_{s,t}S_t) + max(fS_t - \delta_{s,t}S_t, 0)] = (1-t)[S_t(1-\delta_{s,t})] = (1-t)[R_{s,t-1}b_{t-1}^{Sub}(1-\delta_{s,t})/\pi_t]$. Yet, in the case of claims purchases 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 the subprime lender is:

$$c_{bb,t} + b_t^{Sub} + R_{b,t-1}bb_{t-1}/\pi_t - (1-t)[p_{s,t}MBS_{s,t} + p_{e,t}MBS_{e,t}] = \\ bb_t + tR_{s,t-1}(1-\delta_{s,t})b_{t-1}^{Sub}/\pi_t. \tag{1.E.57}$$

The prices of the tranches are determined by equations 1.F.66 and 1.F.62.

1.E.2 Second Version: 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 the entrepreneurs does not change with respect to the version of the model when patient households and entrepreneurs buy MBS tranches. The budget constraint of commercial bankers changes, as well as their balance sheet and capital requirement. I assume here that the risk weight on the senior tranche is as high as in the case of interbank deposits (since it is highly rated), whereas the risk weight on the equity tranche equals the risk weight of subprime loans.

The commercial bankers' balance sheet is:

Assets	Liabilities
Interbank loans : bb_t	Deposits d_t
Loans to entrepreneurs: $b_{e,t}$	Equity eq_t
MBS security - senior tranche: $(1-t)MBS_{s,t}$	

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

$$\tau \leq \frac{bb_t + b_{e,t} + (1-t)MBS_{s,t} - d_t}{\chi^{Intb} bb_t + \chi^{Firm} b_{e,t} + \chi^{Int}(1-t)MBS_{s,t}}. \tag{1.E.58}$$

The budget constraint of commercial bankers is now:

$$\begin{aligned} c_{b,t} + R_{d,t-1}d_{t-1}/\pi_t + bb_t + b_{e,t} + (1-t)p_{s,t}MBS_{s,t} = \\ d_t + R_{b,t-1}bb_{t-1}/\pi_t + R_{e,t-1}b_{e,t-1}/\pi_t + (1-t)MBS_{s,t-1}. \end{aligned} \tag{1.E.59}$$

New FOC:

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

$$\beta_b \frac{1}{c_{b,t+1}} = p_{s,t}\frac{1}{c_{b,t}} + (1-\tau\chi^{Int})G_t. \tag{1.E.60}$$

The problem of subprime lender is analogous to the case where patient households and entrepreneurs buy MBS tranches.

1.E.3 Results

For calibration, it is assumed that the attachment point $f = 0.2$. The attachment point of the senior tranche corresponds to the data average (Hull and White, 2010). Figure 1.24 shows the results of the baseline model (blue solid line) and the two models with securitization in which different agents buy MBS tranches (green dashed line - entrepreneurs buy the equity tranche, patient households buy the senior tranche; red dotted-dashed line - entrepreneurs buy the equity tranche, commercial bankers

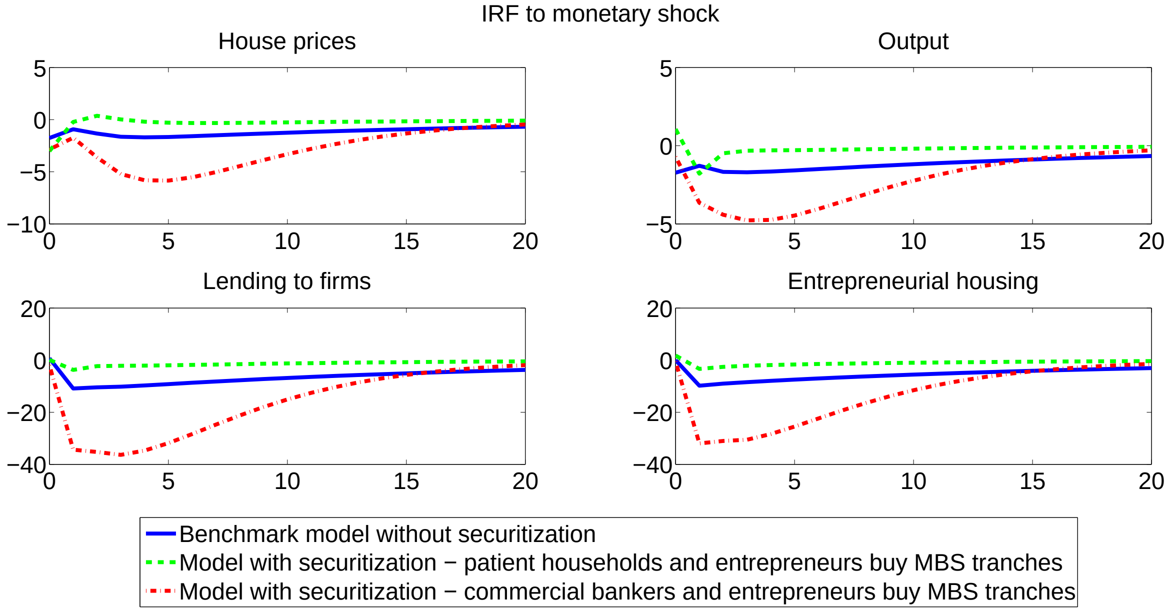


Figure 1.24: Impulse responses of model versions with and without securitization, monetary shock

buy the senior tranche) after the monetary shock, and Figure 1.25 shows the impulse response functions of chosen variables after the preference shock. The slightly different solution method from the one presented in the main part of the chapter does not affect qualitatively the results: when commercial bankers engage in the acquisition of MBS, the securitization has an amplifying effect on business cycles, while when only non-financial agents in the economy buy MBS tranches, the securitization dampens the response of lending and output to contractionary shocks.

1.F Three Versions of the Model with Securitization

1.F.1 First Version: Entrepreneurs Invest in MBS Tranches

In the first version of the model with securitization of subprime loans, entrepreneurs buy both the senior tranche and the equity tranche.

The budget constraint of investors changes and a new term describing investment in the derivative security appears. First, denote the payoff from the investment $(S_{t+1} - \delta_{s,t+1}S_{t+1})$ as $MBS_{e,t}$ and the price of tranches by $p_{e,t}$. Then, the budget

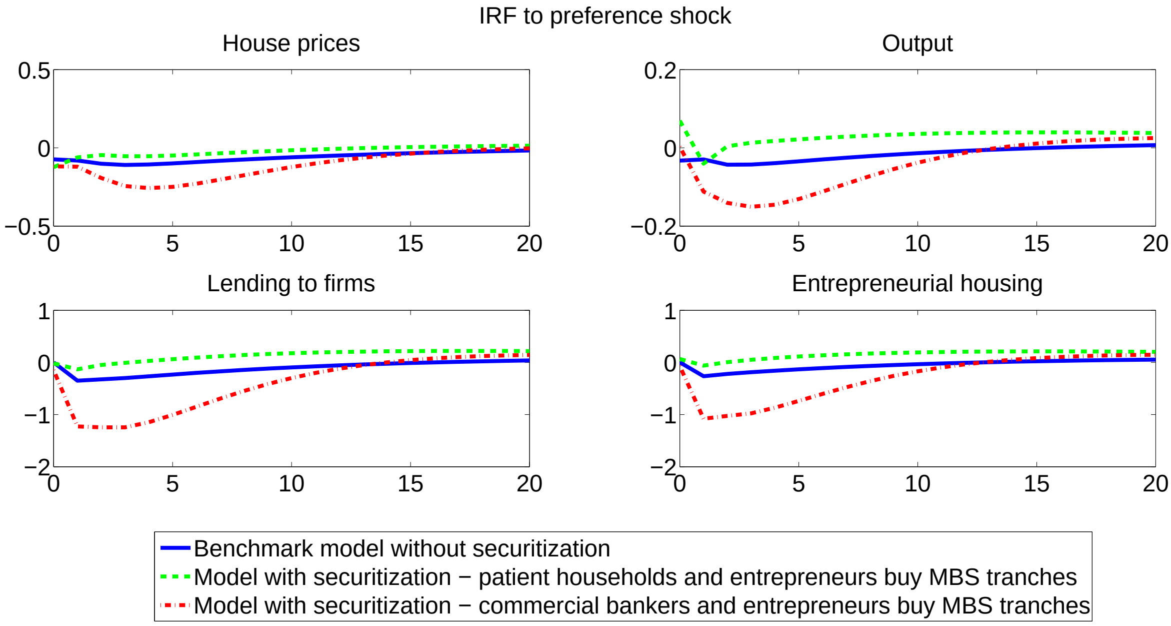


Figure 1.25: Impulse responses of model versions with and without securitization, preference shock

constraint of the entrepreneur is (remember that subprime lenders retain portion t of every tranche):

$$\frac{Y_t}{X_t} + b_{e,t} + (1-t)MBS_{e,t-1} =$$
$$c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + \frac{R_{e,t-1}}{\pi_t} b_{e,t-1} + w_t^{Savers} L_t^{Savers} + w_t^{Sub} L_t^{Sub} + (1-t)p_{e,t} MBS_{e,t}. \tag{1.F.61}$$

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

$$\gamma \frac{1}{c_{e,t+1}} = p_{e,t} \frac{1}{c_{e,t}}. \tag{1.F.62}$$

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

Assets	Liabilities
Loans to subprime borrowers: tb_t^{Sub} Loss reserve $-t\delta_s b_t^{Sub}$	Interbank deposits bb_t

Thus, a Basel-type capital requirement, given exogenously, is now given by:

$$\tau^{Sub} \leq \frac{t(1-\delta_s)b_t^{Sub} - bb_t}{\chi^{Sub} t(1-\delta_s)b_t^{Sub}}. \tag{1.F.63}$$

The budget constraint of subprime lenders changes. Recall that when it comes to the transfer of already realized cash-flows, it holds that: $(1-t)[min(S_t - fS_t, S_t - \delta_{s,t}S_t) + max(fS_t - \delta_{s,t}S_t, 0)] = (1-t)[S_t(1-\delta_{s,t})] = (1-t)[R_{s,t-1}b_{t-1}^{Sub}(1-\delta_{s,t})/\pi_t]$. The budget constraint of the subprime lender is:

$$c_{bb,t} + b_t^{Sub} + R_{b,t-1}bb_{t-1}/\pi_t - (1-t)p_{e,t}MBS_{e,t} = bb_t + tR_{s,t-1}(1-\delta_{s,t})b_{t-1}^{Sub}/\pi_t. \tag{1.F.64}$$

The price of the tranches is determined by equations 1.F.62.

1.F.2 Second Version: Patient Households Invest in MBS Tranches

Analogous to the problem described in the previous subsection, when patient households acquire MBS claims, their budget constraint changes. First, denote the payoff from the investment $(S_{t+1} - \delta_{s,t+1}S_{t+1})$ as $MBS_{s,t}$ and the price of tranches by $p_{s,t}$. Then the budget constraint of the patient households looks as follows:

$$\begin{aligned} c_t^{Savers} + q_t(h_t^{Savers} - h_{t-1}^{Savers}) + d_t + (1-t)p_{s,t}MBS_{s,t} = \\ R_{d,t-1}d_{t-1}/\pi_t + w_t^{Savers}L_t^{Savers} + F_t + (1-t)MBS_{s,t-1}. \end{aligned} \tag{1.F.65}$$

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

$$\beta \frac{1}{C_{t+1}^{Savers}} = p_{s,t} \frac{1}{C_t^{Savers}}. \tag{1.F.66}$$

The problem of the subprime lender is analogous to the case where entrepreneurs buy MBS tranches.

1.F.3 Third Version: Commercial Bankers Invest in MBS Tranches

In the third version of the model with securitization, commercial bankers invest in subprime loan proceeds. The budget constraint of commercial bankers changes, as well as their balance sheet and capital requirement. I assume here that the risk weight on both tranches in this version of the model is as high as in the case of interbank deposits, reflecting the fact that securitized assets were highly rated.

In this case, the payoff from the investment $(S_{t+1} - \delta_{s,t+1} S_{t+1})$ is denoted $MBS_{s,t}$ and the price of tranches by $p_{b,t}$

The commercial bankers' balance sheet is:

Assets	Liabilities
Interbank loans : bb_t	Deposits d_t
Loans to entrepreneurs: $b_{e,t}$	Equity eq_t
MBS security: $(1-t)MBS_{s,t}$	

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

$$\tau \leq \frac{bb_t + b_{e,t} + (1-t)MBS_{s,t} - d_t}{\chi^{Intb} bb_t + \chi^{Firm} b_{e,t} + \chi^{Int}(1-t)MBS_{s,t}}. \tag{1.F.67}$$

The budget constraint of commercial bankers is now:

$$\begin{aligned} c_{b,t} + R_{d,t-1} d_{t-1}/\pi_t + bb_t + b_{e,t} + (1-t) p_{b,t} MBS_{s,t} = \\ d_t + R_{b,t-1} bb_{t-1}/\pi_t + R_{e,t-1} b_{e,t-1}/\pi_t + (1-t) MBS_{s,t-1}. \end{aligned} \tag{1.F.68}$$

New FOC:

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

$$\beta_b \frac{1}{c_{b,t+1}} = p_{b,t} \frac{1}{c_{b,t}} + (1 - \tau\chi^{Int})G_t. \tag{1.F.69}$$

The problem of the subprime lender is analogous to the case where entrepreneurs and patient households buy MBS tranches.

1.G Extension: Impatient Prime Borrowers

Impatient prime borrowers consume, work and demand real estate.

They maximize a lifetime utility function given by

$$\max_{b_t^{Prime}, h_t^{Prime}, L_t^{Prime}} E_0 \sum_{t=0}^{\infty} \beta^{Prime^t} (\log c_t^{Prime} + j_t^{Prime} \log h_t^{Prime} - \frac{L_t^{Prime^{\eta^{Prime}}}}{\eta^{Prime}}) \tag{1.G.70}$$

The budget constraint of the impatient household looks as follows:

$$c_t^{Prime} + q_t(h_t^{Prime} - h_{t-1}^{Prime}) + 1/T \sum_{j=1}^{T} \frac{R_{T,t-j} b_{T,t-j}^{Prime}}{\prod_{i=0}^{j-1} \pi_{t-i}} = b_{T,t}^{Prime} + w_t^{Prime} L_t^{Prime}, \tag{1.G.71}$$

where $b_{T,t}$ is a loan contract with maturity T purchased at time t.

The setup differs from the Iacoviello (2005) version, because it is assumed that impatient prime households have access to more than one-period loans.[27] 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 Calza et al. (2013)). This assumption aims to capture the characteristics of a prime mortgage contract in the U.S., which is characterized by a fixed interest rate over a longer time period. It also distinguishes

[27] This issue has been addressed by Calza et al. (2013) 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 Calza et al. (2013), in the present model, borrowing in each period depends not only on the future value of housing prices, but also on the outstanding debt from previous periods.

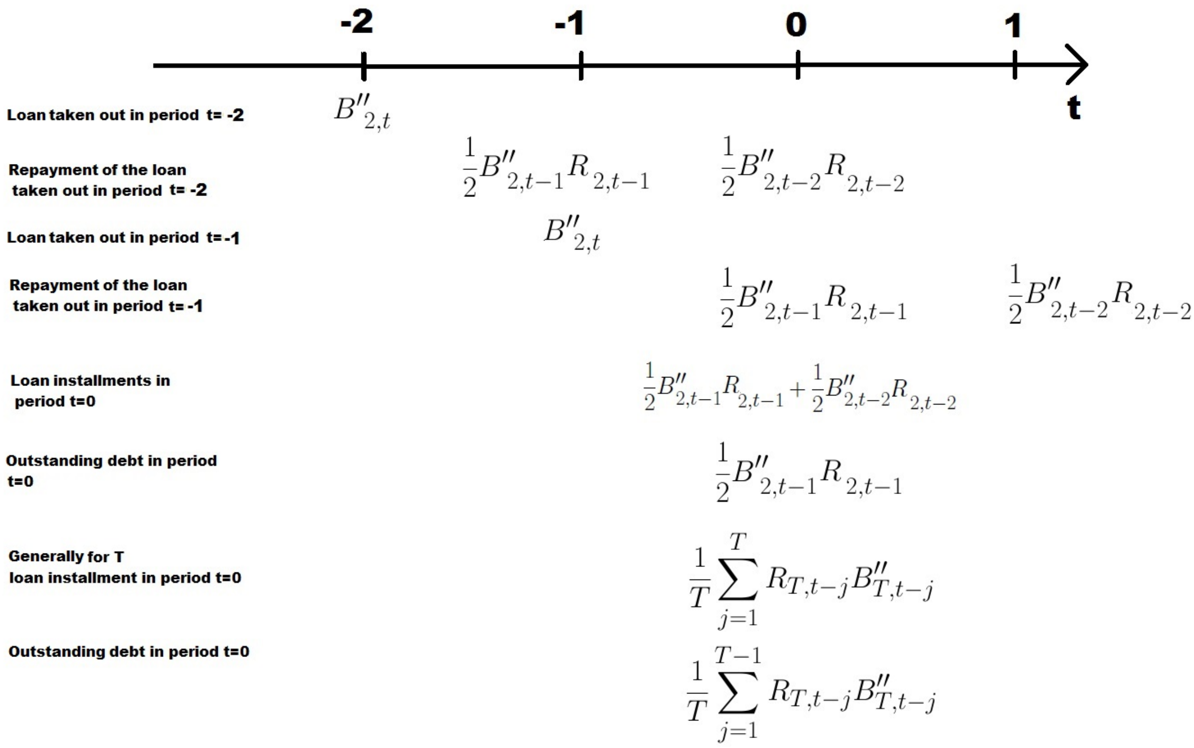


Figure 1.26: Installment payments of the prime borrower in the case of two-period contracts (in nominal terms)

prime borrowers from subprime ones who have only access to short-term, one-period loans.

They face a borrowing constraint (household commits to repay debt at time $t+T$):

$$R_{T,t}b_{T,t}^{Prime} \leq m^{Prime}E_t(q_{t+T})h_{t+T-1}^{Prime}\prod_{j=1}^{T}\pi_{t+j} - 1/T\sum_{j=1}^{T-1}\frac{R_{T,t-j}b_{T,t-j}^{Prime}}{\prod_{i=0}^{j-1}\pi_{t-i}}, \qquad (1.G.72)$$

The FOCs are (λ_t^{Prime} is the Lagrangian multiplier on the borrowing constraint): w.r.t. b_t^{Prime}

$$\frac{1}{c_t^{Prime}} = E_t(1/T\sum_{j=1}^{T}\beta^{Prime j}\frac{R_{T,t}}{c_{t+j}^{Prime}\prod_{i=0}^{j-1}\pi_{t+1-i}})+$$
$$\lambda_t^{Prime}R_{T,t} + E_t(1/T\sum_{j=1}^{T-1}\lambda_{t+j}^{Prime}\beta^{Prime j}\frac{R_{T,t}}{\prod_{i=0}^{j-1}\pi_{t+1-i}}), \qquad (1.G.73)$$

w.r.t. h_t^{Prime}

$$\frac{q_t}{c_t^{Prime}} = E_t(\beta^{Prime}\frac{q_{t+1}}{c_{t+1}^{Prime}} + \beta^{Prime^{1-T}}\lambda_{t+1-T}^{Prime}m^{Prime}q_{t+1}\prod_{i=0}^{T-1}\pi_{t+1-i}) + \frac{j_t}{h_t^{Prime}}, \tag{1.G.74}$$

w.r.t. L_t^{Prime}

$$w_t'' = L_t^{Prime^{\eta^{Prime}-1}}c_t^{Prime}, \tag{1.G.75}$$

w.r.t.λ_t^{Prime}

$$R_t b_t^{Prime} = m^{Prime}E_t(q_{t+1}\prod_{j=1}^{T}\pi_{t+j})h_t^{Prime} - 1/T\sum_{j=1}^{T-1}\frac{R_{T,t-j}b_{T,t-j}^{Prime}}{\prod_{i=0}^{j-1}\pi_{t-i}}. \tag{1.G.76}$$

For computation of the extended version, I assume that impatient prime borrowers differ from impatient borrowers in the following characteristics: their LTV ratio is lower ($m^{Prime} = 0.75$), they have access to 4-period loans, the risk-weight on their loans is lower than for subprime loans ($\chi^{Prime} = 0.5$), and they borrow from commercial bankers.

As stated in the main part of the chapter, the existence of prime borrowers does not change the conclusions from the model. The output response, presented in Figure 1.27, is less negative in the case where bankers invest in MBS compared to the baseline model without prime borrowers, because in this version of the model subprime borrowers constitute only a subsection of households' borrowing.

The logic behind the contraction of balance sheets applies also to the extended model, both for the preference and the monetary shock, presented respectively in Figure 1.28 and 1.29. Apart from the effect of securititzation on entrepreneurial borrowing and housing stock, in the model with prime borrowers, we observe also changes in prime borrowers' housing and borrowing responses.

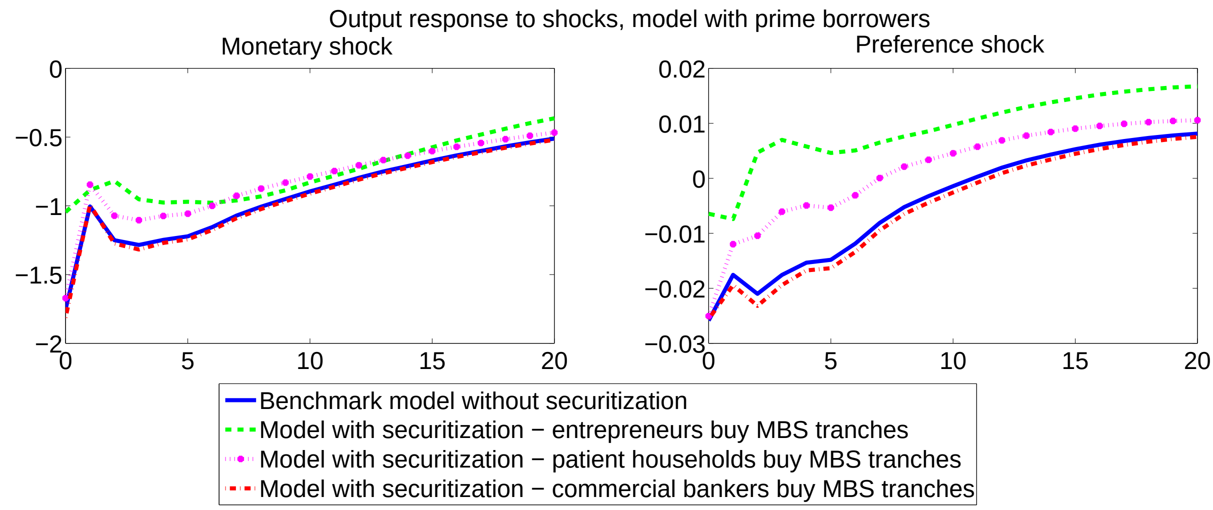


Figure 1.27: Output responses of model versions with and without securitization

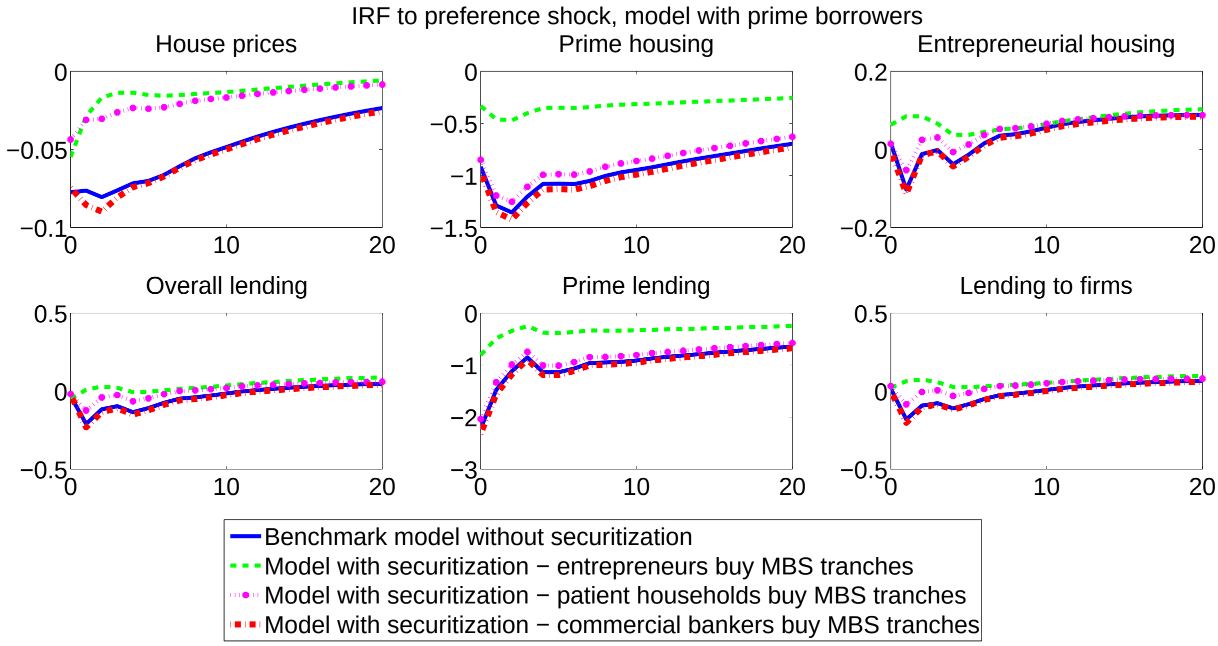


Figure 1.28: Impulse responses of model versions with and without securitization

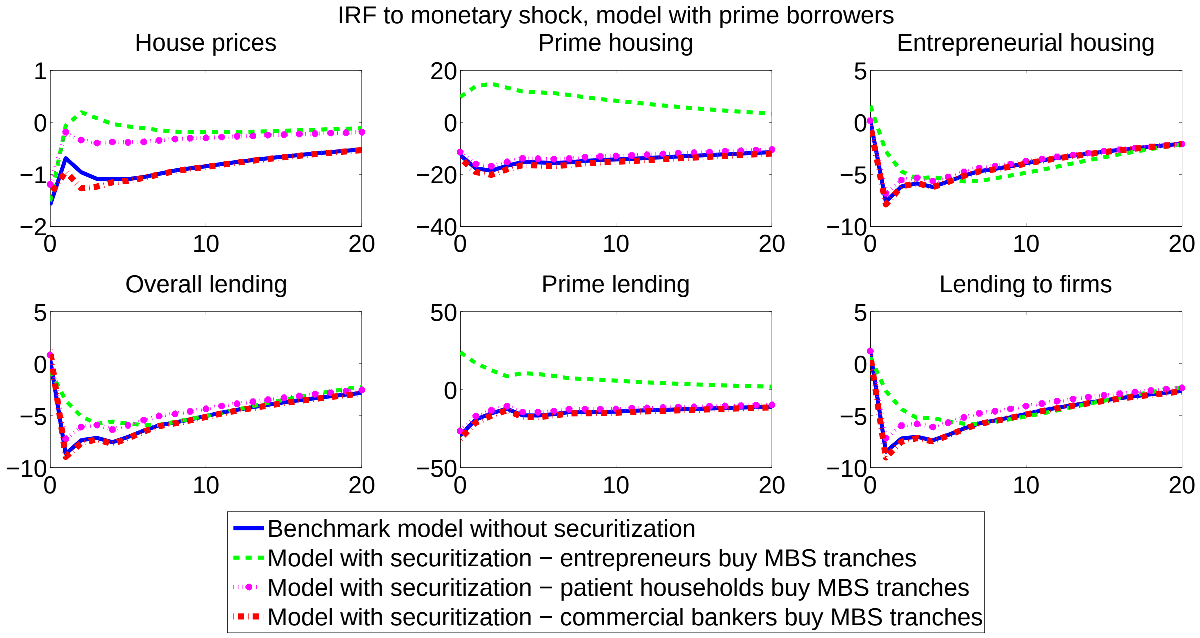


Figure 1.29: Impulse responses of model versions with and without securitization

Chapter 2

House Prices, Credit and Monetary Policy in the U.S. and the U.K.

2.1 Introduction

The Great Recession after the financial crisis of 2007 to 2009 dramatically demonstrated the importance of credit markets for economic developments. The notion that this crisis was triggered by turmoil in the market for U.S. housing debt, especially subprime mortgage loans, and the long-run empirical evidence on the relationship between booms in real house prices and financial crises (see Reinhart and Rogoff, 2009), ask for a joint analysis of developments in the credit and the housing market. The large credit growth observed in the decade preceding the crisis was accompanied by rising house prices in the United States. When the house prices began to drop in 2005 and 2006, credit growth stalled and ouput began to fall. In the U.S., regulation and tax changes were designed to increase the homeownership rate among U.S. citizens (see Temkin, Johnson, and Levy, 2002) and, along with the rising house prices which raised the value of loan collateral, contributed to a very large credit volume in the U.S. The combination of the recent experience of the crisis together with the long history of housing bubbles and financial crises, leads to a reconsideration of possible policy interventions. From the perspective of a policy-maker, it is especially important to know how different measures available to intervene in the market for housing credit differ in their effectiveness and in their consequences for the broader economy. In this chapter, we analyze the effects of two possible measures: a contractionary monetary policy shock and a negative credit supply shock, resulting from a decrease of the admitted loan-to-value (LTV) ratio for borrowers, which can be a measure from the set of macroprudential policies.

For our analysis, we estimate a vector autoregressive model (VAR). We identify the two structural shocks by imposing sign-restrictions on the impulse response functions as proposed by Uhlig (2005). The sign restrictions are derived from a structural dynamic stochastic general equilibrium (DSGE) model. We use the model by Iacoviello (2005), which is a natural starting point, as it delivers a straightforward and empirically plausible relation of credit and house prices. The model reflects important features of real world credit markets as houses are used as collateral for loans to households and entrepreneurs in the economy. We take this model, which has already a monetary shock built in, and add to the model a credit shock, defined as an exogeneous decrease in the LTV ratio for residential housing. We run the model for admissible parameter values and use the resulting impulse responses to generate sign restrictions for certain variables. Given these restrictions, we use the structural VAR model estimated with U.S. und U.K. data to analyze the effects of the considered shocks on house prices which are not robustly clear from the DSGE model. We use data from the U.S. because of the importance of its credit market in the global financial crisis. We focus also on the U.K. due to the ongoing debate about macroprudential measures in that country and the establishment of the Financial Policy Committee dealing with regulation and macroprudential policy as a part of the Bank of England in 2011. Moreover, having identified monetary and credit shocks in our model, we want to investigate the role of these shocks in the development of house prices and output. We find that a negative monetary shock leads to a clear and persistent decline in house prices, while the impact of a negative credit shock on house prices remains unclear for U.S. data. For the U.K., we find a short-term decline of house prices after a negative credit shock.

Of course, we are not the first who examine the effects of a credit shock to the economy in a VAR setup. However, our analysis with its joint focus on credit and house prices in combination with the use of sign restrictions derived directly from a structural DSGE model, has (to our knowledge) not been done before. Moreover we focus on the housing and residential mortgage market, not the total credit value or the corporate credit market, which is often done in other studies. Thus, our main contribution is the analysis of the effectiveness of different policy measures aimed at influencing the house price dynamics in an economy in which housing purchases are mainly financed through credit. We find it particularly interesting to examine the effects of monetary and macroprudential policies in mitigating house price growth in the U.S and the U.K. Which measure seems to be more effective in influencing house prices - changing the policy interest rate or altering the credit supply by introducing caps on the LTV ratio? Which of these two policies would have longer lasting effects? And are there differences in the effect on output in the economy after each of the two shocks? These are all important questions because several countries in the world experience house price booms that may not end up in a global crisis as the recent downturn in the housing market in the U.S., but may still have severe consequences for the economies of the affected countries. Using datasets for two different countries enables us a comparison of the results in the context of differences in their mortgage and financial markets.

The remaining part of the chapter is organized as follows: The next section, Section 2.2, briefly discusses the related literature. Section 2.3 outlines the employed estimation procedure and the data used in our analysis. In Section 2.4, we derive the sign restrictions used to generate our results, which in turn are presented in Section 2.5. We conclude with Section 2.6.

2.2 Related Literature

Naturally, the events of the Global Financial Crisis amplified the attention of economic researchers on subjects related to credit and housing. As Jordà, Schularick, and Taylor (2014) note, p. 1: "*to say that the recent crisis and its aftermath has led to a reassessment of the importance of the housing finance for the macroeconomy would be a distinct understatement.*" The Great Recession of 2007-2009 that had its roots in the subprime credit market in the U.S. again drew researchers' attention towards the role of credit markets in generating business cycles, as well as towards the importance of financial regulation and macroprudential policies. Recent empirical studies like Reinhart and Rogoff (2009) provide a long-run perspective on the empirical historical evidence. Schularick and Taylor (2012) observe that the previously stable relationship between money and credit growth broke down after the Great Depression and that credit growth can be a good predictor of financial crises.

Also the modern macroeconomic literature has studied the role of credit in the economy. Bernanke and Gertler (1995) deal with the credit channel of monetary transmission. In their seminal paper, Kiyotaki and Moore (1997) examine the role of collateral constraints that lead to the amplification and higher persistence of shocks. The financial accelerator model by Bernanke, Gertler, and Gilchrist (1999) also shows the propagation effect of credit for shocks in the economy. In light of the Global Financial Crisis, Devereux and Yetman (2010) and Dedola and Lombardo (2012) among others extend these approaches to open economy models and investigate the international propagation of financial shocks, while Kollmann, Enders, and Müller (2011) look at the effect of capital constraints for lending by an international bank in a macroeconomic model.

2.2.1 VAR Studies on Credit Shocks

There are several VAR studies examining the effects of credit shocks in the economy. Many of them investigate the role of credit shocks in the U.S. for the developments in the rest of the world. This is often done in a panel VAR framework. An example of such a study is Goodhart and Hofmann (2008) who perform an analysis for 17 industrialized countries in the period from 1973 to 2006. They include six variables in their VAR (GDP, CPI, short-term nominal interest rate, nominal house prices, nominal broad money, and nominal bank credit to the private sector) and identify the system by using a Cholesky decomposition, ordering the variables as stated before. Their main finding is that the effects of monetary and credit shocks on house prices are stronger when house prices are booming. They also refer to macroprudential policy, providing a descriptive analysis of LTV ratios in different countries. Assenmacher-Wesche and Gerlach (2008) perform a panel VAR study for 17 countries by identifying the system with a Cholesky decomposition and using data from 1986 to 2006 and six variables: consumer prices, real GDP, credit, three-month interest rates, residential property prices, and equity prices. They find that credit shocks do not have a large impact on property prices and that there is only weak evidence on the effects of U.S. credit shocks in other countries. These two papers are interesting from our point of view because they investigate the effects of a credit shock in a model with house prices. However, the authors use a Cholesky decomposition for identification, while we prefer to use sign-restrictions to generate interpretable structural shocks. In the case of the following papers, the opposite is the case. The methodology used by the authors is similar to ours, because they identify the VAR system by imposing sign restrictions, but their estimations do not include house prices which are, in our view, an important factor that should be included in the analysis.

Eickmeier and Ng (2015) perform a VAR study for 33 countries in the period from 1983 to 2009, using real and financial variables like GDP, inflation, short term interest rates, government and corporate bond yields, credit volume, equity prices and exchange rates. A credit supply shock is defined as an exogenous change causing a fall in output and credit volume, as well as a fall in credit volume to GDP, a rise in the credit interest rate, and the credit spreads. Their analysis of international economic linkages and the international propagation of credit supply shocks shows that negative U.S. credit supply shocks have stronger negative effects on domestic and foreign GDP, compared to credit supply shocks from the euro area and Japan. Domestic and foreign credit, as well as equity markets exhibit significant responses to the credit supply shocks.

Hristov, Hülsewig, and Wollmershäuser (2012) perform a panel VAR analysis for eleven eurozone countries for the period from 2003 to 2010, taking into account five variables: GDP, price level, loan volume, loan rate, short-term interest rate. Their approach is most similar to ours, because, before imposing sign restrictions, the authors examine results of different DSGE models. However, not all models considered by the authors deliver the same sign restrictions so ultimately the decision about imposed conditions is not derived systematically from any model, as opposed to our study. The authors identify four out of five shocks in the system, defining a credit supply shock as a shock causing a fall in real GDP, the money market rate, the loan volume, and a rise in the loan rate. The effect of the credit supply shock on the inflation rate that has been left unrestricted is unclear. The variance decomposition shows that the credit supply shock played an important role in output growth during the recent crisis, however, there are big differences among particular eurozone countries.

Helbling, Huidrom, Kose, and Otrok (2011) also investigate the effects of credit supply shocks in a global study, concentrating on global business cycles and the importance of the shocks originating in the U.S. They perform a VAR and a FAVAR analysis and their dataset includes quarterly series of credit, credit spread (measured by the yield difference on corporate bonds), default rate (on corporate speculative bonds), GDP, labor productivity, inflation, and the interest rates of the G-7 countries for the period from 1988 to 2009. The credit shock is identified as an exogenous disturbance leading to a decrease in credit and an increase in credit spreads, the authors also assume that productivity does not fall and the default rates do not rise. The results show that while the effects of credit supply shocks are generally not significant, they played an important role during the Great Recession.

2.2.2 Macroprudential Literature

Another strand of the economic literature considers different measures which can help prevent or alleviate housing bubbles. This is mainly research conducted by international organizations, such as the IMF (International Monetary Fund) or the BIS (Bank of International Settlements) that consider the effectiveness of macroprudential policies as opposite or complementary to monetary policy tools. Macroprudential instruments are implemented in order to reduce the systemic risk that might endanger the whole financial system. They include regulations on bank capital in the form of capital requirements, ceilings on the LTV ratios or the debt-to-income ratios and limits on borrowing in foreign currency.

In the wake of the crisis, some institutions suggested introducing stronger macroprudential policies (see IMF, 2011). Among the proposed measures there is a cap on the loan-to-value ratio for residential mortgages. The historical experience of Asian economies that implemented this macroprudential measure suggests that introducing limits on the LTV ratios leads to subdued house price growth and lower sensitivity of delinquency rates to house prices (see Wong, Fong, fai Li, and Choi, 2011). However, no such data is available for advanced economies.

The survey paper of Lim et al. (2011) shows that the effectiveness of macroprudential measures does not depend on the stage of economic development of a given country. Noticing that the use of macroprudential policies is at the centre of policy debate, Angelini, Neri, and Panetta (2011) build in two macroprudential measures into the macroeconomic model of Gerali, Neri, Sessa, and Signoretti (2010) which in turn is strongly based on Iacoviello (2005). They consider countercyclical capital requirements and changes in the LTV ratios that adjust to the economic situation. The authors discuss the impact of monetary and macroprudential policies in an economy, considering two cases - in the first case the authorities cooperate minimizing a common loss function, in the second they do not cooperate, minimizing their own loss functions. The results show that in normal times macroprudential policies do not contribute much to the stabilization in the economy and may be in conflict with monetary polices. Yet when a financial shock occurs, macroprudential policies become an important factor in stabilizing the economy. The authors do not discuss the effects of a credit shock in the economy.

Crowe, Dell'Ariccia, Igan, and Rabanal (2011) discuss different possibilities of preventing house price booms in the economy (fiscal policy, monetary policy, macroprudential tools) and include an LTV shock in a DSGE model. Unlike Iacoviello (2005) they find that including house prices in the Taylor rule of the central bank may increase the welfare of the economy's population. They also find that using taxation to reduce house-price volatility has only minor effects on the economy and is less effective than other policy tools. The LTV ratio shock temporarily reduces house prices and leads to a permanent decline in the credit volume. Countercyclical changes in the LTV ratio are found to be beneficial for the economy, and they should rather react to credit growth than house price developments. The authors conclude that the macroprudential measures are the best way to curb real estate prices and leverage.

2.3 Estimation and Data

A VAR model is given by:

$$y_t = \mu + B_{(1)}y_{t-1} + B_{(2)}y_{t-2} + ... + B_{(p)}y_{t-p} + u_t, \tag{2.3.1}$$

where y_t is a $k \times 1$ vector of observations in period t. Correspondingly, y_{t-1} to y_{t-p} are vectors of the same k variables in the p periods before t. $B_{(1)}$ to $B_{(p)}$ denote $k \times k$ matrices of coefficients and μ is a vector of constants. u_t is the $k \times 1$ vector of the one-step ahead prediction errors of the reduced form VAR model. The variance-covariance matrix of u_t is given by the $k \times k$ matrix $\Sigma = E\left[u_t u_t'\right]$.

To obtain shocks to the system that have a structural interpretation, one has to find the matrix A in the equation

$$u_t = Av_t, \tag{2.3.2}$$

which relates the reduced form errors to the vector of structural shocks v_t, with $E\left[v_t v_t'\right] = I_k$. While there are other approaches which directly impose restrictions on the matrix A to identify the structural shocks, we employ the approach by Uhlig (2005) that identifies a structural shock by imposing sign restrictions on the impulse-response functions of selected variables for a specified number of periods. To do so, we construct a large number of potential A matrices and check for each of them whether the resulting impulse-response functions fulfill the sign restrictions (outlined below) or not. The candidate matrices that pass this test are stored, while the others are discarded.

In our analysis we want to investigate the effects of two structural shocks: a negative credit shock and a contractionary monetary policy shock. To identify these two orthogonal shocks, we follow Mountford and Uhlig (2009) who explain that one has to identify a sub-matrix of A with a rank equal to the number of structural shocks one wants to identify. The matrix A has to satisfy $AA' = \Sigma$ and the identified sub-matrix can be written as

$$\left[a^{(1)}, a^{(2)}\right] = \tilde{A}\left[q^{(1)}, q^{(2)}\right]. \tag{2.3.3}$$

$a^{(1)}$ and $a^{(2)}$ are the $k \times 1$ impulse vectors of the two identified shocks. They are given by the product of $\tilde{A}$, which is the lower triangular Cholesky factor of Σ, and $q^{(1)}$ and $q^{(2)}$, which are the first two columns of a $k \times k$ matrix Q that consists of orthonormal columns.

As Uhlig (2005), we estimate the VAR with Bayesian methods using a Normal-Wishart prior. We use the algorithm described by Rubio-Ramirez, Waggoner, and Zha (2010) to implement the sign-restrictions: We take a draw of the coefficients of the matrix B and the variance-covariance matrix Σ from the Normal-Wishart posterior. To obtain Q in equation (2.3.3) we draw an arbitrary $k \times k$ matrix X with independent standard normal elements and use the QR-decomposition of X to get a Q satisfying $QQ' = I$ and $QR = X$. Given Q and the draw of Σ we can construct impulse vectors according to equation (2.3.3). If the impulse response functions implied by the impulse vectors fulfill all imposed sign restrictions, the draws are kept. In total, we collect 5000 draws that are consistent with our specification of the restrictions. The VAR for the U.S. is estimated including a constant, a trend and two lags of the variables. We choose the lags consistent with the indications of the

Hannan-Quinn Criterion (HQC) and the Schwarz Information Criterion (SIC). The VAR for the U.K. is estimated including one lag of the variables.[1]

For our analysis of the U.S. we employ data from the FRED (Federal Reserve Economic Data) database of the Federal Reserve Bank of St. Louis. The house prices are given by the index data (USSTHPI) provided by the Federal Housing Finance Agency.[2] We use quarterly series starting in the first quarter of 1987 to make the sample length equal to the one used for the U.K.[3] The sample includes the subprime mortgage crisis and ends with the fourth quarter of 2013.[4] In our estimation, we use six variables: the real gross domestic product (GDPC1), real consumption (PCECC96), inflation (calculated on the basis of the GDP deflator GDPDEF), the federal funds rate (FEDFUNDS), house prices and outstanding mortgage loans (REALLN). We take the natural logarithm of real GDP, real consumption, deflated mortgage loans and the deflated house price index. All data apart from the house prices and the federal funds rate is seasonally adjusted. Figure 2.1 shows the time series of the six variables over the considered period.

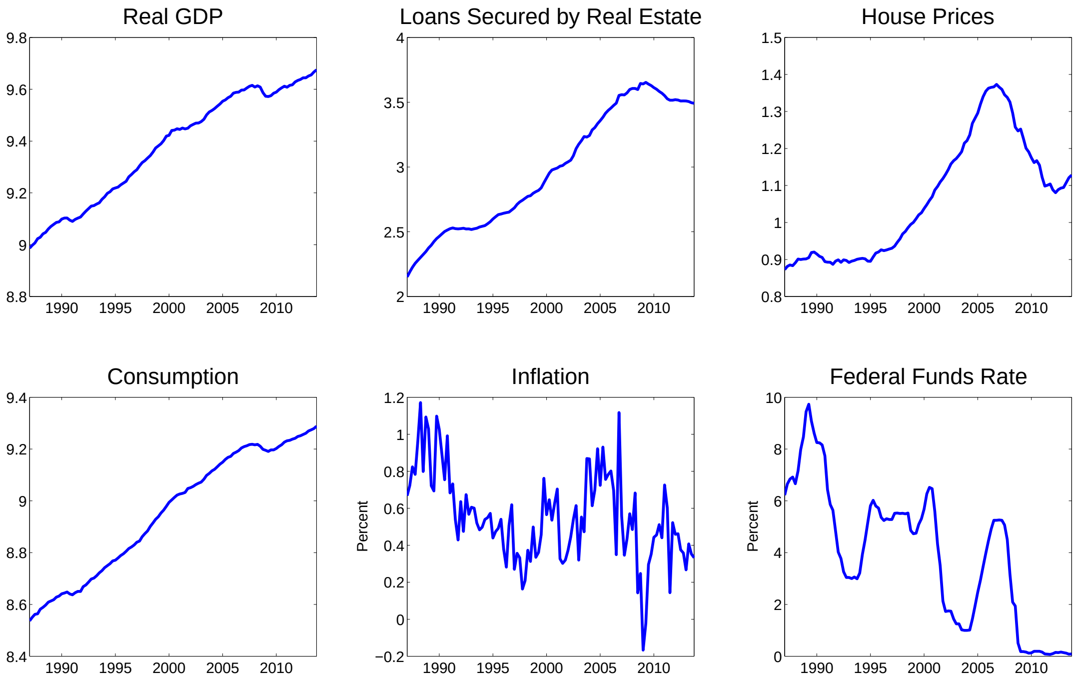
In the case of the U.K., we use the following data sources. The house price index is the Nationwide series for all U.K. houses. The nominal interest rate is the end of quarter official bank rate (IUQLBEDR) of the Bank of England. The data source for GDP and the GDP deflator are the International Financial Statistics (IFS) of the International Monetary Fund. The lending data is provided by the Bank of England (LPQB3SE). The series provides information on the quarterly amounts outstanding of monetary financial institutions' sterling net secured lending to individuals and housing associations. The data for U.K. households' consumption is provided by

[1]Another possibility suggested by the information criteria would be to estimate a model with four lags. We did this excercise too and our conclusions do not change.

[2]Another source for house price data in the U.S. is the S&P/Case-Shiller Home Price index. The USSTHPI index includes valuations from conforming conventional mortgages provided by Fannie Mae and Freddie Mac and refinance appraisals as well, while the S&P/Case-Shiller Home Price index includes purchase prices and uses information from county assessor and recorder offices, see `http://www.fhfa.gov/Media/PublicAffairs/Pages/Housing-Price-Index-Frequently-Asked-Questions.aspx`. To make sure that our results do not depend on the house price data we use, we repeat our analysis using the S&P/Case-Shiller Home Price index. Since the correlation of the series is around 99% over the considered period, our results are robust to this change.

[3]The lending data for the U.K. starts in the first quarter of 1987.

[4]Our sample includes the zero lower bound period that started in the U.S. in December 2008. We do a robustness check and perform our analysis also for the period until the 4th quarter of 2008. Our main conclusions remain the same.



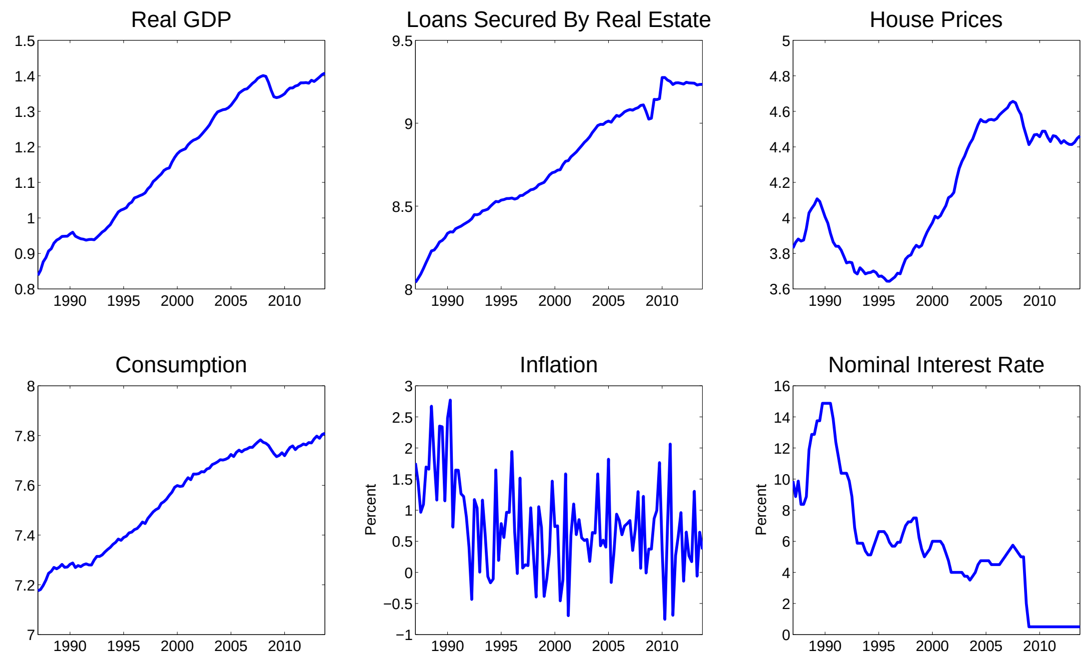
Notes: Data Sources: FRED and Federal Housing Finance Agency. The series of real GDP, deflated house price index, deflated loans backed by real estate and real consumption show the logarithm of the variables.

Figure 2.1: U.S. data series used in the analysis

Eurostat (namq_gdp_c). The data is seasonally adjusted and the nominal series are deflated with the GDP deflator (GDP, consumption, house price index and lending backed by mortages). Figure 2.2 shows the time series of the six variables over the considered period. There is a striking similarity between the charts for the U.S. and U.K. data, and the data series seem to follow the same patterns.

2.4 Establishing Sign Restrictions

To identify the structural shocks for our analysis, we have to establish sign restrictions that we impose on the impulse response functions. The restrictions should be uncontroversial in order to generate reliable results. We identify the two structural shocks of interest by using the impulse response functions from a dynamic stochastic



Notes: Data Sources: Bank of England, Eurostat, Nationwide and IMF. The series of the deflated GDP, deflated house price index, deflated loans backed by mortgages and deflated consumption show the logarithm of the variables.

Figure 2.2: U.K. data series used in the analysis

general equilibrium (DSGE) model in order to pin down robust sign restrictions. This approach is also used for example by Enders, Müller, and Scholl (2011), who study the effect of fiscal and technology shocks on the real exchange rate in the U.S. The DSGE-model that forms the basis of our analysis is the model by Iacoviello (2005).

In the following, we briefly outline the model by Iacoviello (2005) which is a New-Keynesian monetary business cycle model that includes nominal loans and collateral constraints tied to housing values. The model includes patient households, impatient households and entrepreneurs. Both, the impatient households (by definition) and the entrepreneurs are assumed to discount future consumption more heavily than the patient households. Consequently, in equilibrium they both borrow from the patient households. Borrowing is limited by a collateral constraint which relates the maximum amount borrowed to the stock of housing held by the borrower. 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 assets. Thus, lenders will make the amount of loans depend on the parameter m, which can be interpreted as the LTV ratio. Households have higher LTV ratios than entrepreneurs, which reflects the different riskiness of loans to the two types of agents. Output is produced by the entrepreneurs using labor provided by the households, capital, and the housing stock. Monetary policy is conducted by the central bank which sets the interest rate according to a policy rule responding to output and inflation. Iacoviello (2005) considers four different shocks to the model economy. An inflation shock, a technology shock, a monetary shock and a shock changing the preferences for housing. In addition to these four shocks, we define a (negative) credit shock as an exogenous decrease in the allowed loan-to-value ratio for the households.

In Iacoviello (2005), the impatient households face a collateral constraint given by:

$$R_t b''_t = m'' E_t(q_{t+1} h''_t \pi_{t+1}), \tag{2.4.1}$$

where R_t denotes the interest rate paid on loans, b''_t is the borrowing of the households, E_t is the expectation operator, q_t denotes the house price, h''_t the housing stock of impatient households, π_t the inflation rate, and the parameter m is a fixed LTV ratio. Entrepreneurs face a similar collateral constraint, but since we are interested in residential housing,[5] we consider only a shock to the LTV ratio of impatient households. We assume that the households' LTV ratio follows an autoregressive process given by:

$$m''_t = \rho_{m''} m''_{t-1} - e_{m'',t}, \tag{2.4.2}$$

where $\rho_{m''}$ describes the autocorrelation of the LTV ratio and $e_{m'',t}$ is an i.i.d. random innovation.

[5] We focus on the residential mortgages, which account for around 80% of all outstanding mortgages backed by real estate in the U.S. in the considered time period. Moreover, as the IMF (2009), p. 26, reports, residential properties' real estate prices experienced a more accentuated boom than that of commercial properties, whose prices only followed the developments on the residential property market.

2.4.1 Simulation for the U.S.

To be more confident about the robustness of the sign restrictions implied by the model, we follow Enders et al. (2011) who consider intervals of possible values for the different parameters of the model.[6] Table 2.1 shows the parameters of the Iacoviello (2005) model and the intervals we admit for each of them in the U.S. case. The model we use is exactly the model of Iacoviello (2005).

	Parameter	Range	Source/Target
β	discount factor - patient HHs	$[0.99, 0.9925]$	Iacoviello (2005), Iacoviello and Neri (2010)
β''	discount factor - impatient HHs	$[0.95, 0.97]$	Iacoviello (2005), Iacoviello and Neri (2010)
γ	discount factor - entrepreneurs	$[0.975, 0.98]$	Iacoviello (2005)
δ	capital depreciation rate	$[0.015, 0.03]$	Dueker et al. (2007)
μ	capital share in prod. function	$[0.3, 0.35]$	Iacoviello (2005), Iacoviello and Neri (2010)
ν	housing share in prod. function	$[0.03, 0.05]$	Iacoviello (2005), Iacoviello (2013)
m	LTV ratio for entrepreneurs	$[0.85, 0.9]$	Iacoviello (2005)
m''	LTV ratio for HHs	$[0.55, 0.7]$	Iacoviello (2005)
α	patient HHs' wage share	$[0.64, 0.88]$	Iacoviello (2005), Jappelli (1990b)
θ	probability fixed price	$[0.55, 0.75]$	Enders et al. (2011), Iacoviello (2005)
ψ	capital adjustment costs	$[1, 6]$	Smets and Wouters (2007)
X	steady state gross markup	$[1.01, 1.15]$	Iacoviello and Neri (2010)
η'	labor supply aversion p. HHs	$[1.01, 2]$	Iacoviello (2005)
η''	labor supply aversion imp. HHs	$[1.01, 2]$	Iacoviello (2005)
J'	weight on housing - p. HHs	$[0.08, 0.12]$	Iacoviello (2013), Iacoviello and Neri (2010)
J"	weight on housing - imp. HHs	$[0.08, 0.12]$	Iacoviello (2013), Iacoviello and Neri (2010)
$\rho_{m''}$	autocorr. of LTV shock	$[0.95, 0.99]$	high shock persistence
ρ_u	autocorr. of inflationary shock	$[0.85, 0.95]$	high shock persistence
ρ_j	autocorr. of preference shock	$[0.85, 0.95]$	high shock persistence
ρ_a	autocorr. of technology shock	$[0.85, 0.95]$	high shock persistence
ρ_π	weight of policy resp.. to inflation	$[0.2, 0.8]$	Clarida et al. (1999), Orphanides (2004)
ρ_r	weight of policy resp. to int.rate	$[0.7, 0.8]$	Iacoviello (2005), Clarida et al. (1999)
ρ_y	weight of policy resp. to output	$[0.1, 0.2]$	Iacoviello (2005), Clarida et al. (1999)

Notes: All parameter definitions but the LTV-Shock refer directly to the original model by Iacoviello (2005). HHs = households.

Table 2.1: Admitted intervals for model parameters in the U.S. case

The values of the discount factors of the different agents ensure that the patient households have the highest discount factor, and the impatient households the lowest. The discount factor of entrepreneurs is chosen to be smaller than that of the patient

[6] As we consider the entire range of plausible parameter values, we cannot exclude that some of the drawn combinations as a whole may be rather implausible. However, as we only use sign restrictions that are implied by all drawn combinations, the exclusion of the implausible ones would, if at all, only further restrict the possible impulse responses, leaving our identification valid.

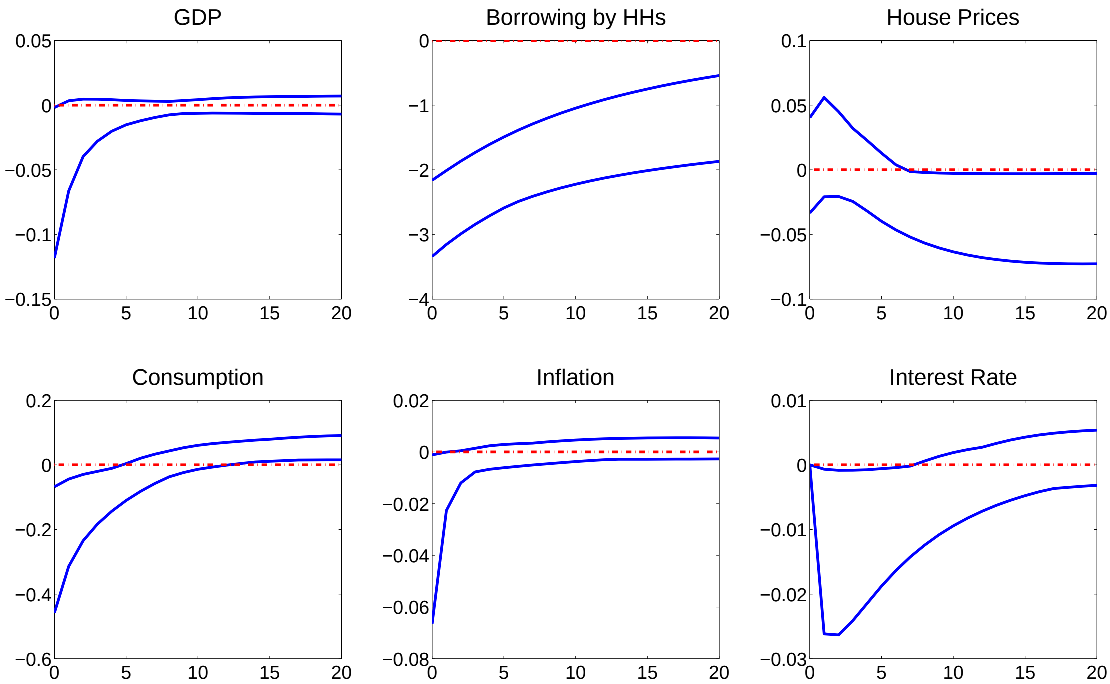
households. Such a choice implies that the borrowing constraints of the borrowing agents are always binding. The range for β, the patient households' discount factor, is chosen based on the literature. The lower value matches the parametrization of Iacoviello (2005) and the higher the parametrization of Iacoviello and Neri (2010). The values for β'', the impatient households' discount factor, have the same source. The lower value for the discount factor of entrepreneurs, γ, is chosen to be larger than that of impatient households and the higher value corresponds to the calibration of Iacoviello (2005). The values for the depreciation rate of capital, δ, are chosen in line with values commonly used in the literature. One of the lowest values for this parameter is 0.015 (see e.g. Dueker, Fischer, and Dittmar, 2007) which means that the capital depreciates at a rate of 6% per year, because the model period corresponds to a quarter. The higher value implies an annual depreciation at a rate of 12%. The range for the parameter μ describing the capital share in the production function is pretty standard and follows Iacoviello (2005) and Iacoviello and Neri (2010). The share of entrepreneurial housing stock in the production function, ν, is model-specific because it targets the steady-state value of commercial real estate over annual output. For the range, we choose values used by Iacoviello (2005) and Iacoviello (2013). Iacoviello (2005) estimates the steady state values of the LTV ratios as $m = 0.89$ for entrepreneurs and $m'' = 0.55$ for households. We believe that the estimated value for LTV of firms may be too high, whereas the LTV for households may be too low, so we enlarge the parameter sets downwards (for m) and upwards (for m"). The values of the patient housheholds' wage share correspond to the values used by Iacoviello (2005) and Jappelli (1990b).

The Calvo parameter θ determining the probability of a fixed price in a given period is chosen to include values yielding an average price duration of 6.7 to 9 months, based on Enders et al. (2011) and Iacoviello (2005). The parameter defining capital adjustment costs in the economy, ψ, is somehow controversial in the literature. Iacoviello (2005) calibrates it at 2, however also much lower and much higher estimates are common. We choose the lower value for the parameter to be fairly low to take into account small adjustment costs, and the higher value is 6, so that our range includes high adjustment costs estimated by Smets and Wouters (2007) for the U.S (5.75). Our range for the steady state gross markup X is chosen as to consider the minimum markup, it includes the Iacoviello (2005) calibration of 1.05 and goes up to the value used by Iacoviello and Neri (2010). For the labor supply aversion of patient and impatient households, η' and η'', Iacoviello (2005) uses the lowest bound implying a very high labor supply elasticity: 100. The upper bound for these parameters is set at 2, which implies the labor Frisch elasticity of 1, consistent with macroeconomic estimates as reported by Keane and Rogerson (2011). The weights on housing services in the utility function of the agents are usually chosen to match the stock of residential housing relative to annual output observed in the data. For our exercise, we choose a range basing on Iacoviello (2013) and Iacoviello and Neri (2010), including the calibrated value 0.1 used by Iacoviello (2005). We choose the range for parameters determining the autocorrelation of shocks in the model so as to consider fairly persistent shocks. The LTV shock is most persistent, as changing regulatory LTV is considered to be a rather permanent macroprudential measure.

The calibration of the parameters appearing in the backward-looking Taylor rule applied by the central bank considers the estimates of Iacoviello (2005) and enlarges them considerably. The value used by Iacoviello for ρ_π is 0.27, but we consider values ranging from 0.2 to 0.8. ρ_r is 0.73 in Iacoviello (2005), while we consider values from 0.7 to 0.8. Lastly, for ρ_y, which Iacoviello estimates at 0.13, we choose the range 0.1-0.2. Our ranges are in line with estimates by Clarida et al. (1999) and Orphanides (2004). For the standard deviation of all of the shocks, we consider one-percentage exogenous deviations from the steady state.

To generate the ranges of possible impulse response functions of the model, we follow the approach of Enders et al. (2011) and draw the vector of parameters many times assuming that they are independently uniformly distributed on the stated intervals. In total, we take 25000 draws. Figure 2.3 shows the resulting intervals for the model's impulse response functions to a negative exogenous shock to the households' LTV ratio. The lines denote the (pointwise) maxima and minima. The impulse responses are measured in percentage deviations from steady state.

We see that the shock generates a fall in the interest rate, inflation, GDP, borrowing by the households, and aggregate consumption. Whereas the contraction in borrowing is long-lasting, the decline of the other variables is observed only in the initial periods after the shock. With respect to house prices the response is not so clear. Intuitively one would expect a fall in house prices after a negative credit shock. However, we see that for some parameter values the response of house prices is positive, and for



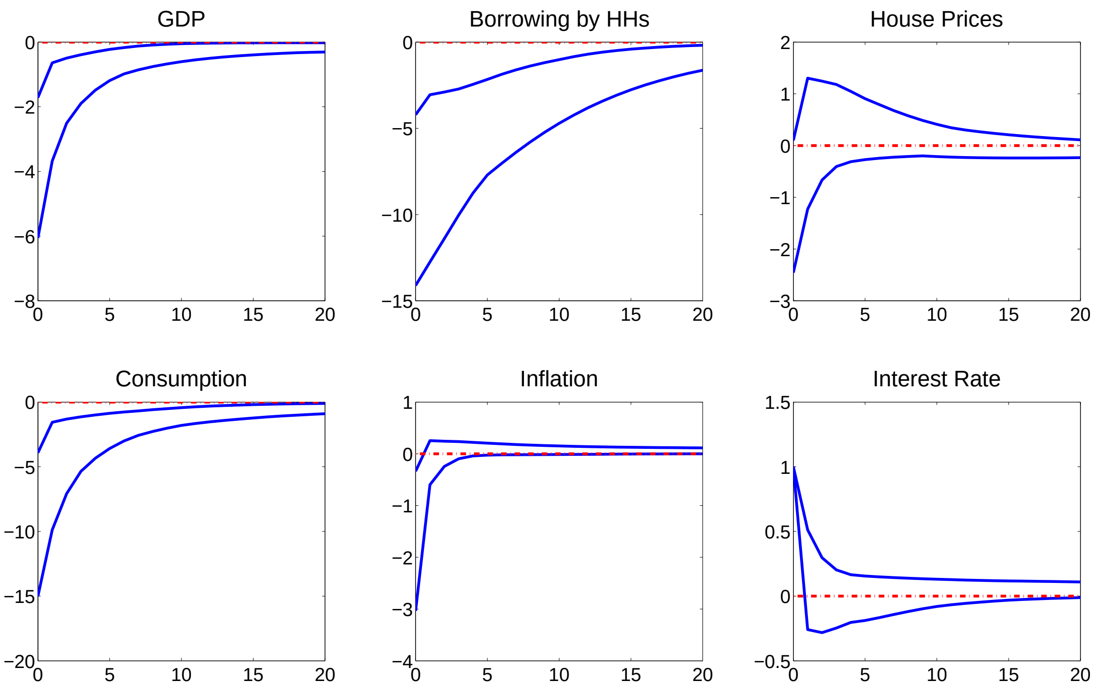
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in the LTV ratio. The impulse responses are measured in percentage deviations from steady state.

Figure 2.3: Credit Shock - Impulse response functions of the DSGE model (U.S.)

some negative. The benchmark Iacoviello (2005) calibration results in a negative house price response to a negative LTV shock, so it has to be our assumed range of certain parameters that yields the surprising result. We investigated which of the parameters is responsible for the positive response of house prices to our shock and the result is mainly driven by rho_y, the coefficient appearing in the Taylor rule that determines the weight of policy response to output. If the coefficient is low, as in the benchmark Iacoviello (2005) calibration, the house price response to a negative LTV ratio shock will be clearly negative. However, with rho_y attaining values higher than 0.15 the response of house prices may be positive. We see thus that the existence of a central bank in our model economy that reacts not only to the inflation rate but also to changes in output, may considerably affect the results of a purely macroprudential policy. If the central bank decides to offset the negative effects of the change in LTV ratio for the economy, it will lower the interest rates after a negative LTV ratio shock which might outweigh the negative direct effect of a lower LTV ratio on house prices. If, however, the monetary policy does not react strongly to the fall in output, the interest rates will be lowered by a smaller amount and the LTV ratio shock will have the effect that we expect on house prices.

Moreover, it is worth mentioning that the strong fall in households' borrowing after a negative LTV ratio shock (also after a monetary shock, which is visible in Figure 2.4) is due to a substantial decrease in the housing stock the households are holding. Since the households borrow up to a certain fraction of the future value of their housing stock, the fall in the housing stock directly affects the borrowing of credit-constrained agents.

Figure 2.4 shows the resulting intervals for the model's impulse response functions to a contractionary monetary policy shock. As in the case of a negative LTV ratio shock, we observe a fall in GDP, borrowing and aggregate consumption. Inflation and house prices also initially fall, whereas the interest rate exhibits an increase due to the nature of this shock.



Notes: Pointwise minima and maxima of the chosen variables after an exogenous increase in the policy interest rate. The impulse responses are measured in percentage deviations from steady state.

Figure 2.4: Monetary Shock - Impulse response functions of the DSGE model (U.S.)

We summarize the resulting sign restrictions in Table 2.2. In both cases we leave the response of house prices and output open, as this is our main point of interest. Table 2.2 is constructed to show that given our ranges of parameters, both monetary and LTV shocks are distinguishable and different from other shocks present in the Iacoviello (2005). Although we identify only two shocks in our VAR, we show the restrictions implied by our ranges also for the three other shocks to show that all shocks are well-identified given our parameter ranges. Specifically, the monetary shock differs from the LTV shock through the response of the nominal interest rate, r. The responses after both shocks distinguish them from the preference shock through the response of consumption c - otherwise the preference shock could be the mirror image of our shocks of interest. Thus, inclusion of consumption in our VAR analysis is crucial for the identification strategy. The consumption response distinguished also the responses after technology shock from the monetary shock and the LTV shock. The response of consumption helps to distinguish the inflation shock from the LTV shock, while the inflation response distinguishes it from the monetary shock. Appendix 2.A contains the impulse response functions for the remaining three shocks of the model presented in Table 2.2.

Shock	r	π	hpi	GDP	b	c
Monetary (int. rate up)	+	-	∅	∅	-	-
	(0)	(0)	(-)	(-)	(0-4)	(0-4)
LTV (down)	-	-	∅	∅	-	-
	(0-2)	(0)	(-)	(-)	(0-4)	(0-4)
Preference (up)	∅	∅	+	+	+	-
	(-)	(-)	(0-5)	(0-2)	(0-5)	(4-6)
Technology (up)	-	-	+	+	∅	+
	(1-5)	(0-5)	(0-5)	(1-5)	(-)	(2-5)
Inflation (up)	+	+	∅	-	∅	-
	(1-5)	(0-5)	(-)	(2-5)	(-)	(1-5)

Notes: The upper row defines the sign of the restriction and the lower row the periods for which the restriction is imposed. ∅ denotes unrestricted variables.

Table 2.2: Identifying sign restrictions for different shocks derived from the DSGE model (U.S.)

2.4.2 Simulation for the U.K.

We apply the same methodology as outlined above for the U.K. Table 2.3 shows the ranges for the parameters in the U.K. case. Some of the basic parameters, such as the discount rates of the agents, or model-specific parameters (utility weight on housing, housing share in the production function) are assumed to have the same ranges as in the U.S. case. However, there are certain parameters that vary substantially across countries and are worth to be discussed at this point. First of all, the LTV ratios for entrepreneurs are chosen to be lower in U.K. than in the U.S., following Hayes and Kane (2009). Cutler (2002) shows that the LTV ratio for U.S. buyers ranged below 0.7 in years 1981-2001; we choose the range 0.6-0.7. Moreover, there is evidence that both wage and price rigidities are less pronounced in the U.K. compared to the U.S. market. We thus have to adjust our θ, the probability of a fixed price, accordingly. The microdata evidence provided by Bunn and Ellis (2009) suggests that prices in the U.K. change every 4-5 months, which results in a range of [0.25,0.4] for our model's parameter. The last important change in ranges for parameter values in the U.K. case is visible in the weights used in the Taylor rule. Models estimating the Taylor rule coefficients for the U.K. give more narrow ranges for rho_{π}, ρ_r and ρ_y than in the U.S. case. However, as we will see in the figures showing the impulse responses of the DSGE model, the changes in the parameters do not lead to different conclusions about the possible sign restrictions for the VAR model.

The sign restrictions resulting from our simulation in the U.K. case are summarized in Table 2.4 and are based on the results presented in Figure 2.5 and Figure 2.6. Despite different parameter values, they very much resemble the sign restrictions that we applied in the U.S. case. Specifically, our imposed sign restrictions for the LTV shock and monetary shock are the same for the U.K. as in the U.S. case. As before, all shocks are distinguishable. Appendix 2.A contains the impulse response functions for the remaining three shocks of the model presented in Table 2.4.

To sum up, despite the differences in calibration, the identifying restrictions for our VAR analysis derived from the DSGE simulation in the case of the monetary and the credit shock are the same for the U.S. and the U.K. and are summarized in Table 2.5.

	Parameter	Range	Source/Target
β	discount factor - patient HHs	$[0.99, 0.9925]$	Iacoviello (2005), Iacoviello and Neri (2010)
β''	discount factor - impatient HHs	$[0.95, 0.97]$	Iacoviello (2005), Iacoviello and Neri (2010)
γ	discount factor - entrepreneurs	$[0.975, 0.98]$	Iacoviello (2005)
δ	capital depreciation rate	$[0.015, 0.03]$	Faccini et al. (2011)
μ	capital share in prod. function	$[0.3, 0.35]$	Iacoviello (2005), Iacoviello and Neri (2010)
ν	housing share in prod. function	$[0.03, 0.05]$	Iacoviello (2005), Iacoviello (2013)
m	LTV ratio for entrepreneurs	$[0.75, 0.8]$	Hayes and Kane (2009)
m''	LTV ratio for HHs	$[0.6, 0.7]$	Cutler (2002)
α	patient HHs' wage share	$[0.64, 0.88]$	Iacoviello (2005), Jappelli (1990b)
θ	probability fixed price	$[0.25, 0.4]$	Bunn and Ellis (2009)
ψ	capital adjustment costs	$[1, 6]$	Smets and Wouters (2007)
X	steady state gross markup	$[1.01, 1.15]$	Iacoviello and Neri (2010)
η'	labor supply aversion p. HHs	$[1.01, 2]$	Iacoviello (2005)
η''	labor supply aversion imp. HHs	$[1.01, 2]$	Iacoviello (2005)
J'	weight on housing - p. HHs	$[0.08, 0.12]$	Iacoviello (2013), Iacoviello and Neri (2010)
J"	weight on housing - imp. HHs	$[0.08, 0.12]$	Iacoviello (2013), Iacoviello and Neri (2010)
$\rho_{m''}$	autocorr. of LTV shock	$[0.95, 0.99]$	high shock persistence
ρ_u	autocorr. of inflationary shock	$[0.85, 0.95]$	high shock persistence
ρ_j	autocorr. of preference shock	$[0.85, 0.95]$	high shock persistence
ρ_a	autocorr. of technology shock	$[0.85, 0.95]$	high shock persistence
ρ_π	weight of policy resp.. to inflation	$[0.28, 0.59]$	DiCecio and Nelson (2007), Villa and Yang (2011)
ρ_r	weight of policy resp. to int.rate	$[0.54, 0.87]$	Faccini et al. (2011), DiCecio and Nelson (2007)
ρ_y	weight of policy resp. to output	$[0.34, 0.39]$	Faccini et al. (2011), Villa and Yang (2011)

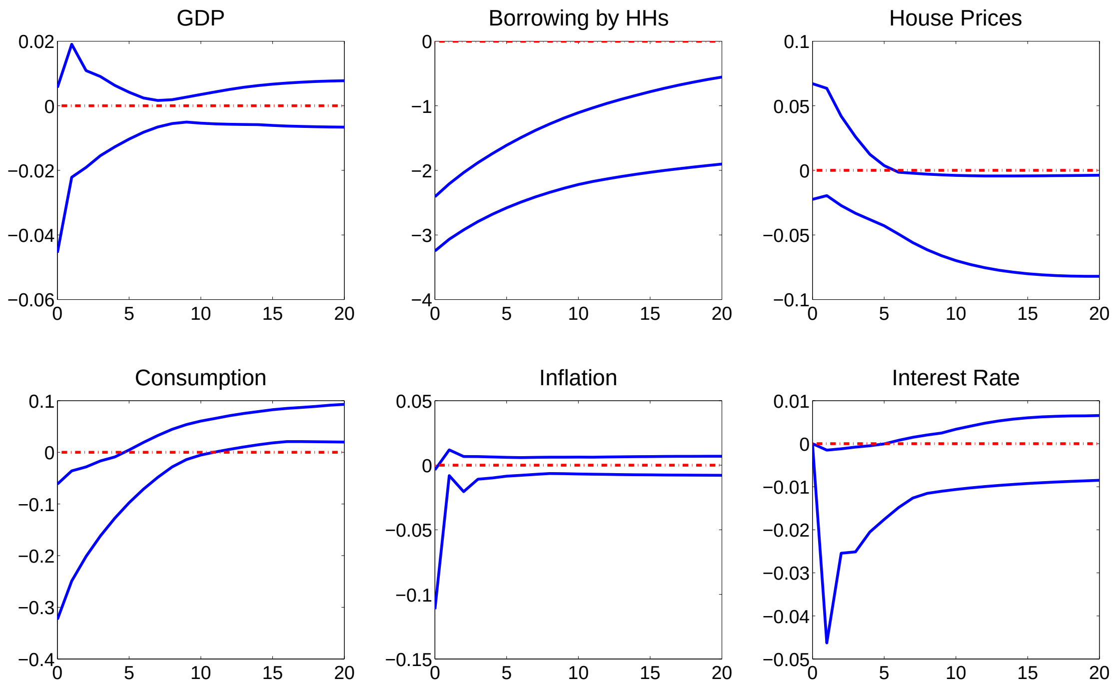
Notes: All parameter definitions but the LTV-Shock refer directly to the original model by Iacoviello (2005). HHs = households.

Table 2.3: Admitted intervals for model parameters for the U.K. case

Shock	r	π	hpi	GDP	b	c
Monetary (int. rate up)	+	-	∅	∅	-	-
	(0)	(0)	(-)	(-)	(0-4)	(0-4)
LTV (down)	-	-	∅	∅	-	-
	(0-2)	(0)	(-)	(-)	(0-4)	(0-4)
Preference (up)	∅	∅	+	+	+	-
	(-)	(-)	(0-5)	(0-4)	(0-5)	(0,4-6)
Technology (up)	-	-	+	+	∅	+
	(1-5)	(0,2-5)	(0-5)	(1-5)	(-)	(1-5)
Inflation (up)	+	+	-	-	∅	-
	(1-5)	(0,2-5)	(0-3)	(1-5)	(-)	(1-5)

Notes: The upper row defines the sign of the restriction and the lower row the periods for which the restriction is imposed. ∅ denotes unrestricted variables.

Table 2.4: Identifying sign restrictions for different shocks derived from the DSGE model (U.K.)



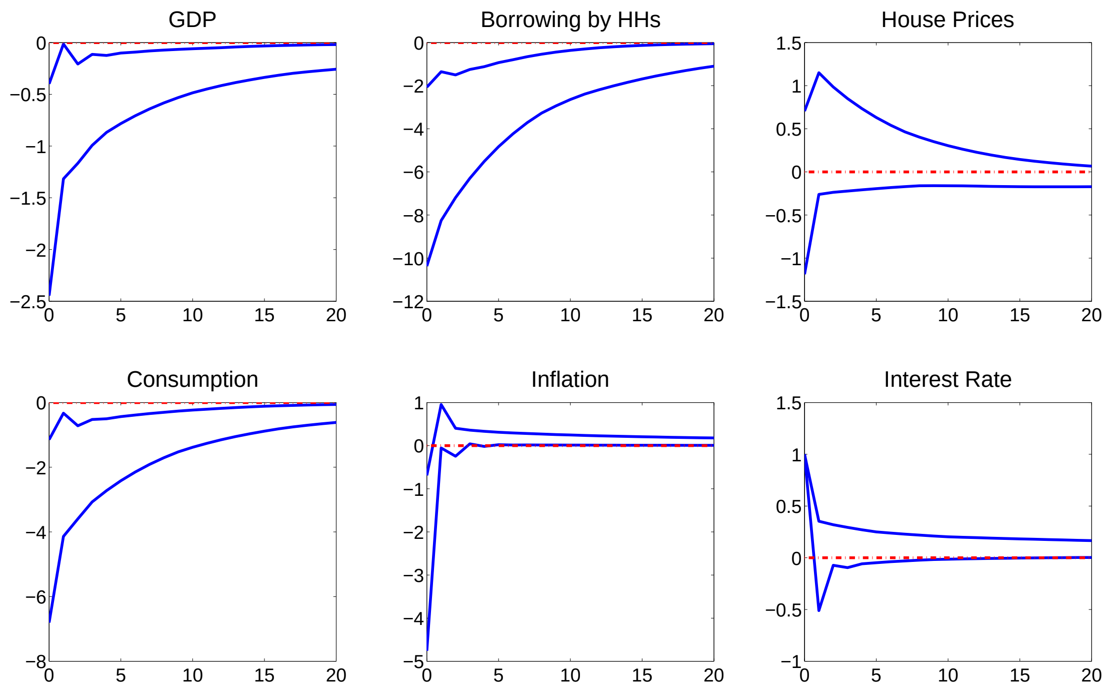
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in the LTV ratio. The impulse responses are measured in percentage deviations from steady state.

Figure 2.5: Credit Shock - Impulse response functions of the DSGE model (U.K.)

Shock	r	π	hpi	GDP	b	c
Monetary (int. rate up)	+	-	$\varnothing$	$\varnothing$	-	-
	(0)	(0)	(-)	(-)	(0-4)	(0-4)
LTV (down)	-	-	$\varnothing$	$\varnothing$	-	-
	(0-2)	(0)	(-)	(-)	(0-4)	(0-4)

Notes: The upper row defines the sign of the restriction and the lower row the periods for which the restriction is imposed. $\varnothing$ denotes unrestricted variables.

Table 2.5: Sign restrictions imposed on the VAR model (U.K. and U.S.)



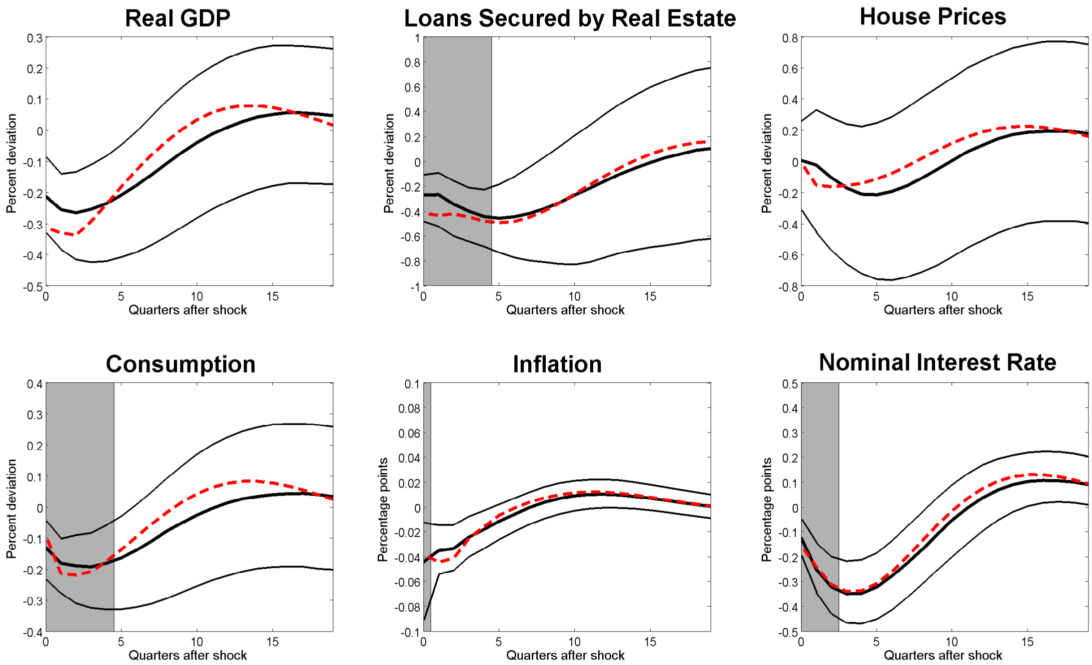
Notes: Pointwise minima and maxima of the chosen variables after an exogenous increase in the policy interest rate. The impulse responses are measured in percentage deviations from steady state.

Figure 2.6: Monetary Shock - Impulse response functions of the DSGE model (U.K.)

2.5 Results

2.5.1 The VAR Analysis for the U.S.

Using the sign restrictions outlined in the previous section, we employ the method explained in Section 2.3 to estimate the VAR for the U.S. data and compute the resulting impulse response functions of the considered variables to the identified structural shocks. Figure 2.7 shows the reaction of the six variables to a negative credit shock. In addition to the (pointwise) median of the impulse response functions



Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative credit shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

Figure 2.7: Estimated impulse responses to a credit shock (U.S.)

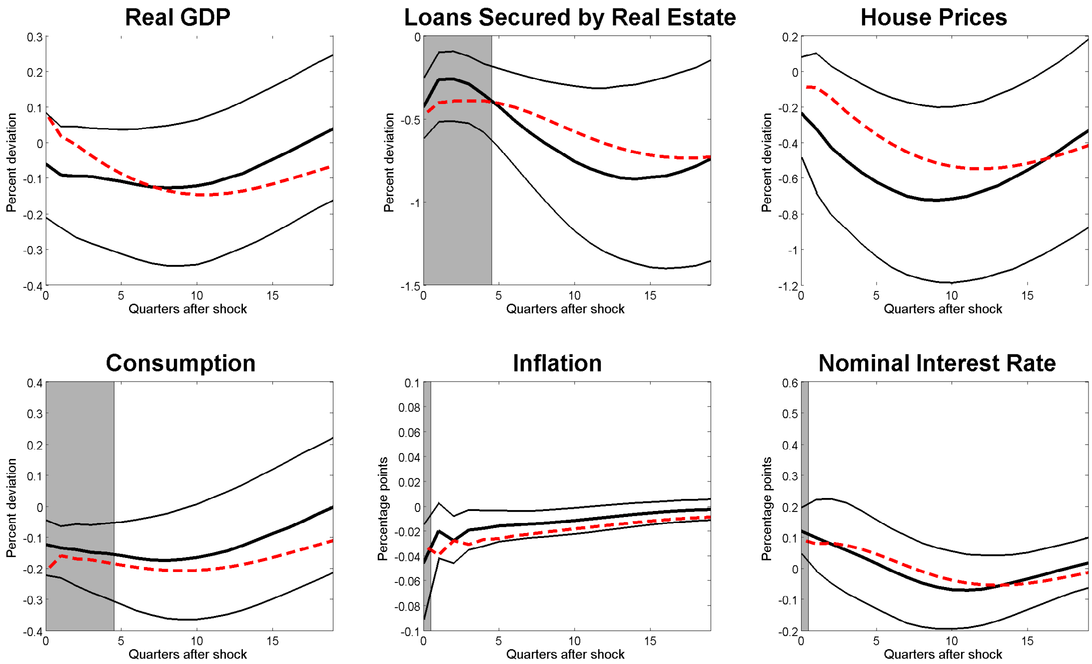
(continuous middle line), we also plot the impulse responses of the single model whose impulse response functions are the closest to the pointwise median (the dashed line). This approach is suggested by Fry and Pagan (2007) because for the median of the impulse response functions, it is neither certain that there is a single model that generates this shape, nor do the median responses necessarily represent orthogonal shocks, as they very likely stem from different admissible models. The dashed lines in Figure 2.7 and Figure 2.8 show the impulse responses of this single model. The shaded areas correspond to the periods for which the sign restrictions are imposed. Looking at the reaction of variables to a credit shock (Figure 2.7), we note that the response of house prices, which was left unrestricted, is not clear, although the mean and median model suggest a short-term contraction. The GDP exhibits a significant, but short-lived contraction. All other variables fall, which is consistent with the imposed sign restrictions, however, the contraction is rather short-lived.

Figure 2.8 shows the impulse responses resulting from a contractionary monetary shock. As in the case of the negative credit shock, we left the response of house prices unrestricted. Unlike the credit shock, a negative monetary shock induces a clear and persistent, although not immediate, decline in house prices. Moreover, we left the GDP response unrestricted and we see that the median response of output to a contractionary monetary shock is indeed contractionary, however, not all impulse responses deliver a clear negative result. With respect to the other variables, the effects of a monetary shock seem to be longer-lasting than those of a negative credit shock.

Figure 2.9 shows the forcast error variance decomposition of the median model for the house prices up to 20-quarter horizon. We see that the LTV shock accounts for a very small fraction of the forecast error variance of the house prices over the considered time period, while the monetary shock contributes up to 10% in the medium-term horizon. [7]

Given our estimates, we calculate the historical structural innovations of the two shocks for the considered time period. As Enders et al. (2011), we calculate four-quarter moving averages. The left panels of Figure 2.10 show the median and quantiles from our estimates. The middle panels compare the median from the left panel (solid line) with the innovations resulting from the the single “median” model a’ la Fry and Pagan (2007) identified above. The obtained structural innovations have a large volatility. However, we can identify some main spikes that should be confirmed in the data about LTV ratios in the U.S. and important macroeconomic episodes. The evidence suggests that the LTV ratio for first-time homebuyers was indeed fluctuating

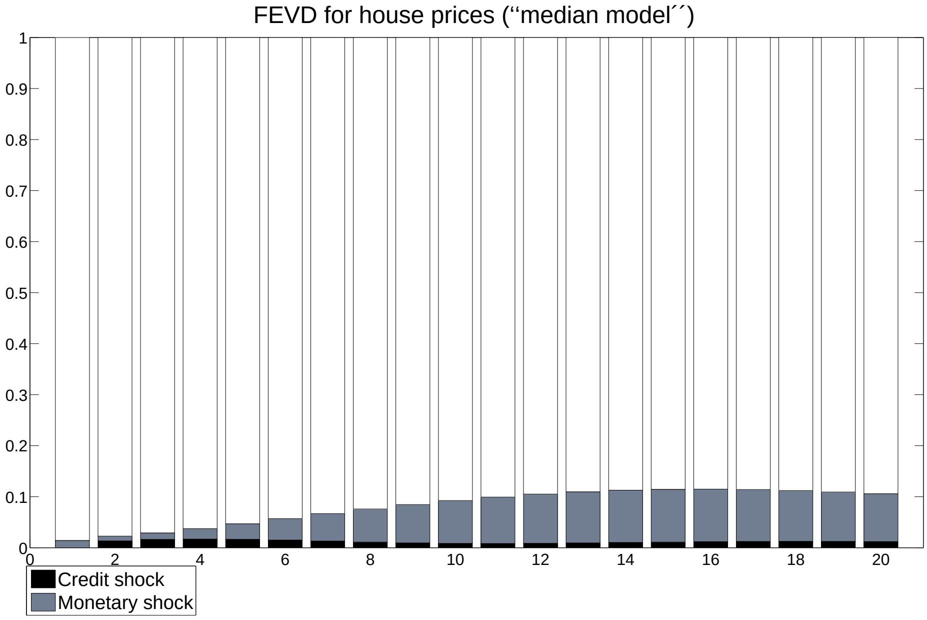
[7] Figure 2.21 in the Appendix 2.A shows how the FEVD of the median model compares to the FEVD of the full set of admissible models.



Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative monetary shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

Figure 2.8: Estimated impulse responses to a monetary shock (U.S.)

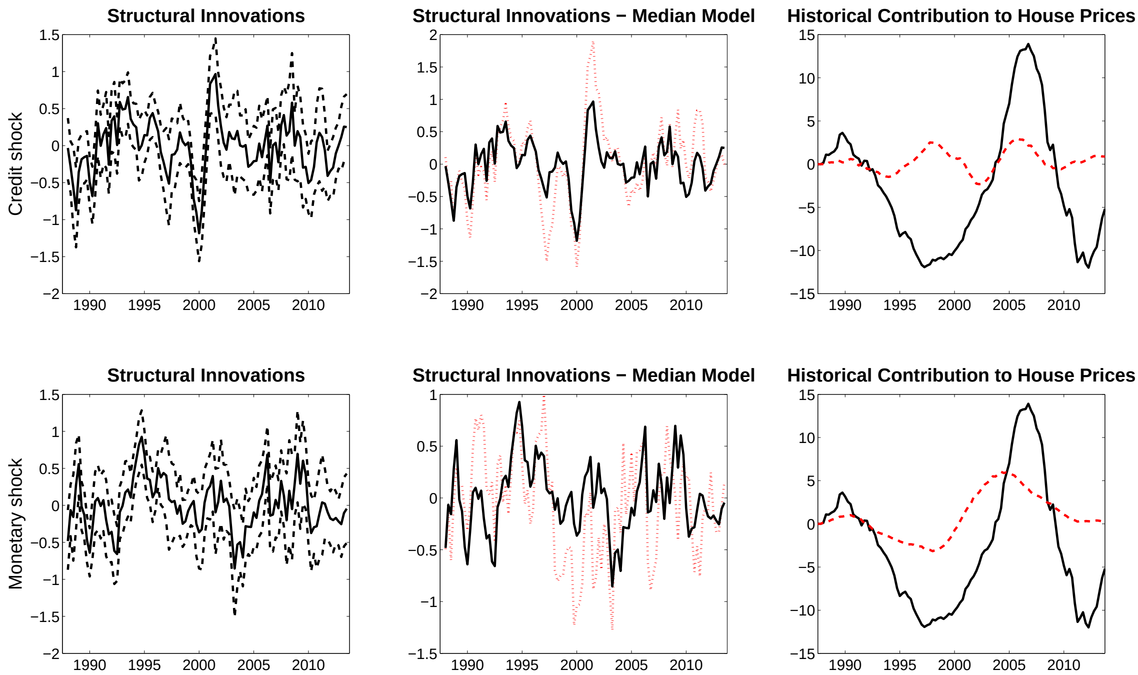
over the past three decades (Duca, Muellbauer, and Murphy, 2012). We focus on the innovations implied by the median model (red dashed line). Looking at the upper middle panel of Figure 2.10 we see that a big spike is observed at the beginning of the new century. Temkin et al. (2002) identify a liquidity crunch in the subprime market that started in 1998 and continued until 2000. During this time, prices of many Mortgage Backed Securities (MBS) decreased, the loan supply was reduced which may have led to lower average LTV ratios reflected in the rise on the graph depicting structural innovations. Several important hikes occur in 2008 and 2009, at the height of the Great Recession. The analysis of the lower middle panel of Figure 2.10 is more difficult due to the high volatility of innovations. However, the innovations can be related to existing narratives of the monetary policy over that time period. For example, the two hikes around 1995 correctly identify 'the preemptive strike against inflation', a change in monetary policy when authorities started to increase



Notes: The graph shows the shares of the forecast error variance explained by the credit shock (black) and the monetary shock (grey). The remaining share is explained by the unidentified other shocks.

Figure 2.9: Forecast error variance decomposition for house prices (U.S.)

interest rates after a period of falling and stable federal funds rate at the beginning of the 1990s (see Goodfriend, 2002). The beginning of the new century was a period of falling and low federal funds rate, the FOMC started to increase the rate from August 2004 on and did not start to lower the rate until September 2007, which is well captured by the last substantial hikes on the graph showing monetary shock innovations. The right panels of Figure 2.10 present the historical decomposition of house prices in the U.S. We see that monetary shocks contributed more to the development of house prices in the U.S. in the considered period.



Notes: The figure shows the estimated innovations associated with the two identified shocks (four-quarter moving averages). The left panels show the median and the 16% and the 84% quantile of the different draws. The middle panels show again the median (continuous line) and the innovation implied by the "median" model (dashed line). The right panels show the impact of the shocks on the predicted house prices: all shocks (solid line) versus the respective shock only.

Figure 2.10: Estimated innovations (U.S.)

2.5.2 The VAR Analysis for the U.K.

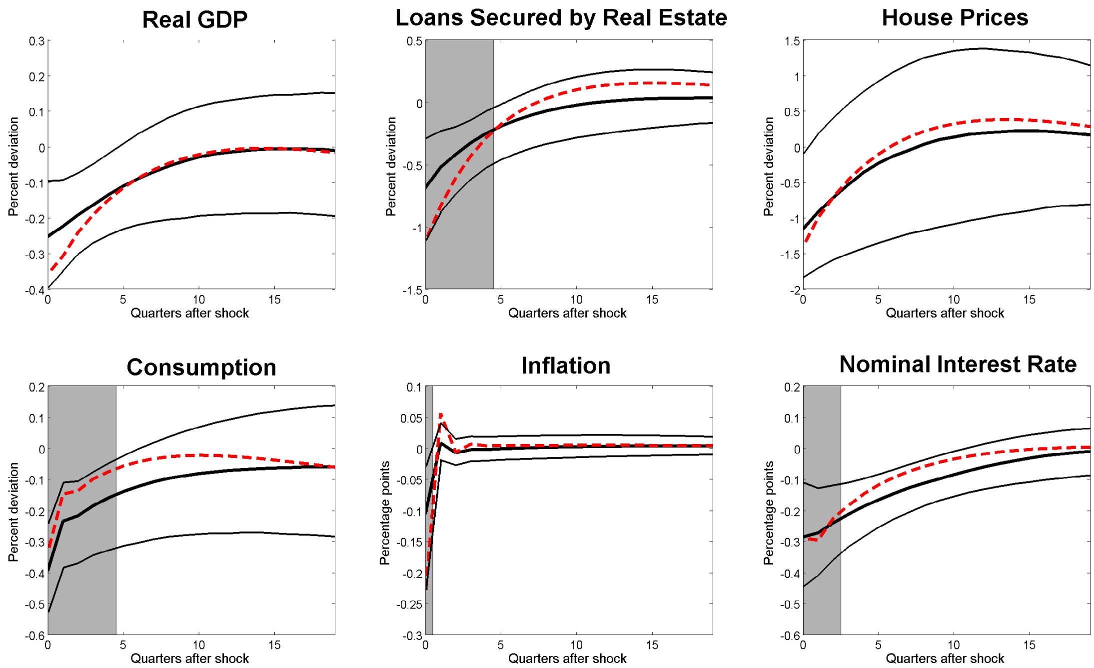
Turning to U.K. data, Figure 2.11 shows the impulse responses generated by the VAR after a LTV ratio shock. The sign restrictions are identical to the ones imposed on the U.S. data and indicated by shaded areas on the graph. Comparing Figure 2.11 with the analogous figure for the U.S. (Figure 2.7), we see that in the case of the U.K. the LTV ratio shock has a more substantial impact on the behavior of the considered variables, specifically on house prices and credit. Also, GDP and consumption go down significantly, but as in the case of the U.S., the contraction is rather short-lived.

Looking at the impulse responses to a monetary shock, which are depicted in Figure 2.12, we see that in contrast to the case of the U.S., the impulse responses for U.K. data do not generate a clear response of house prices. However, the median responses suggest a slight fall in house prices. The negative reaction is not immediate: it only realizes a few quarters after the monetary shock. However, when it does, the impact of the monetary shock is quite big and seems to be persistent. After an exogenous increase in the nominal interest rate, real GDP and consumption experience a fall over a longer period of time than in the case of the LTV shock. There is a strong and persistent fall in the volume of loans secured by real estate and only a short-term fall in the inflation rate.

Figure 2.13 shows the forcast error variance decomposition of the median model for the house prices up to 20-quarter horizon. We see that the LTV shock accounts for roughly 40% of the forecast error variance of the house prices in the first period, with a decreasing share over time, while the monetary shock has an approximately stable contribution of around 5%.[8]

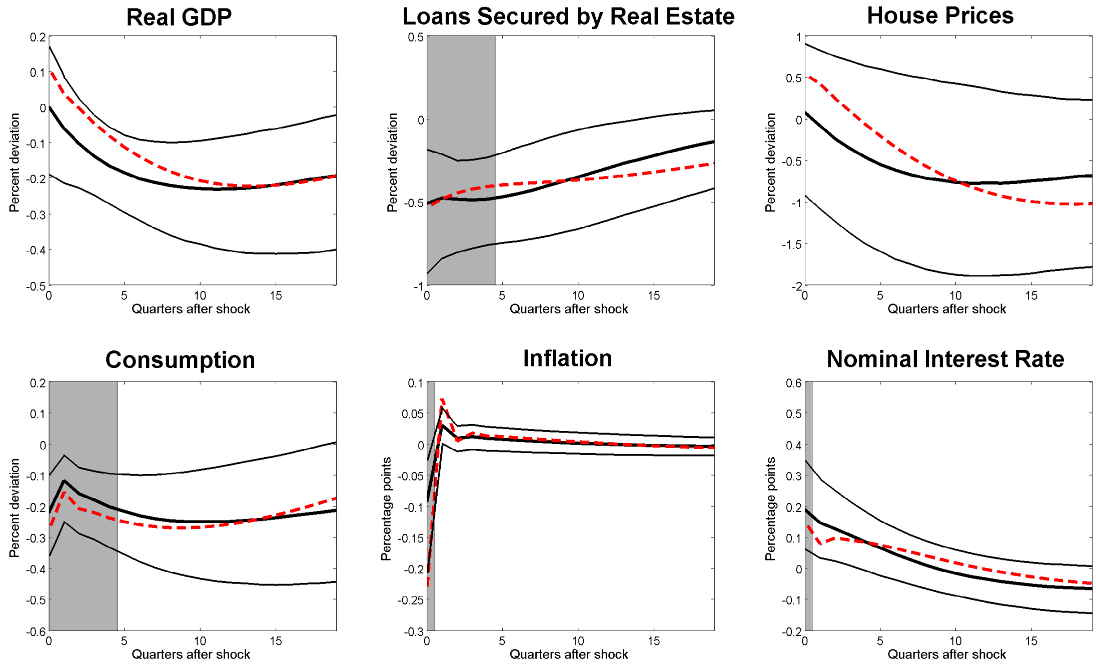
Figure 2.14 shows the structural innovations identified by our VAR model. As in the case of the U.S., we focus again on the indications of the median model, given by the dotted red line in the middle panels of the Figure. The largest spike in the middle upper graph corresponds to the peak of the recent financial crisis. The monetary shock innovations exhibit substantial volatility and indicate a large expansionary shock in the crisis period. The right panels of the figure present the historical decomposition of house prices in the U.K. We see that a fall in house prices in the recent crisis episode was substantially driven by a negative credit shock.

[8] Figure 2.22 in the Appendix 2.A shows how the FEVD of the median model compares to the FEVD of the full set of admissible models.



Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative credit shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

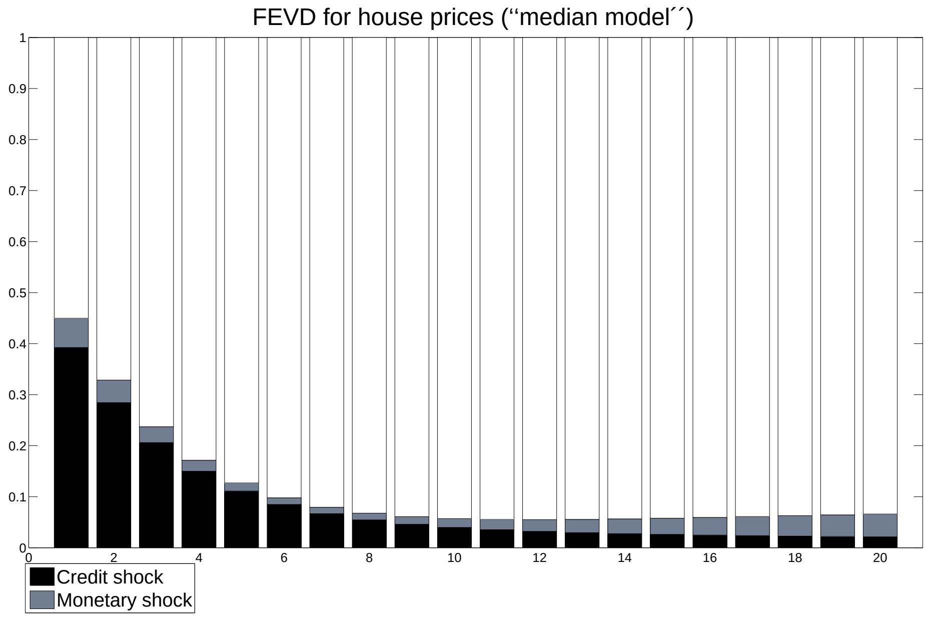
Figure 2.11: Estimated impulse responses to a credit shock (U.K.)



Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative monetary shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

Figure 2.12: Estimated impulse responses to a monetary shock (U.K.)

Comparing the results for U.K. and U.S. data, we may conclude that in both cases monetary policy has a longer-lasting effect than the credit shock. We find it particularly interesting to compare the strength of impulse responses in both countries that may reflect diverse transmission mechanisms and differences in their mortgage markets. Comparing the responses from the median model in Figure 2.12 with the ones in Figure 2.8, we see that for the median model the impact of a monetary shock on house prices in the U.K. is stronger and longer-lasting than in the U.S. One reason for that may be that the majority of mortgage loans in the U.S. are fixed interest rate contracts (65% of loans held by federal agencies have a fixed rate for 30 years, further 15% for 15 years, see Coles and Hardt (2000)), whereas in the U.K., the variable interest rate contracts prevail (60% of all contracts, the remaining ones often fixed only for 1-5 years, see Miles, 2004). On top of that, in the U.S. due to the Tax Reform Act of 1986, mortgage interest paid on the primary residence (as

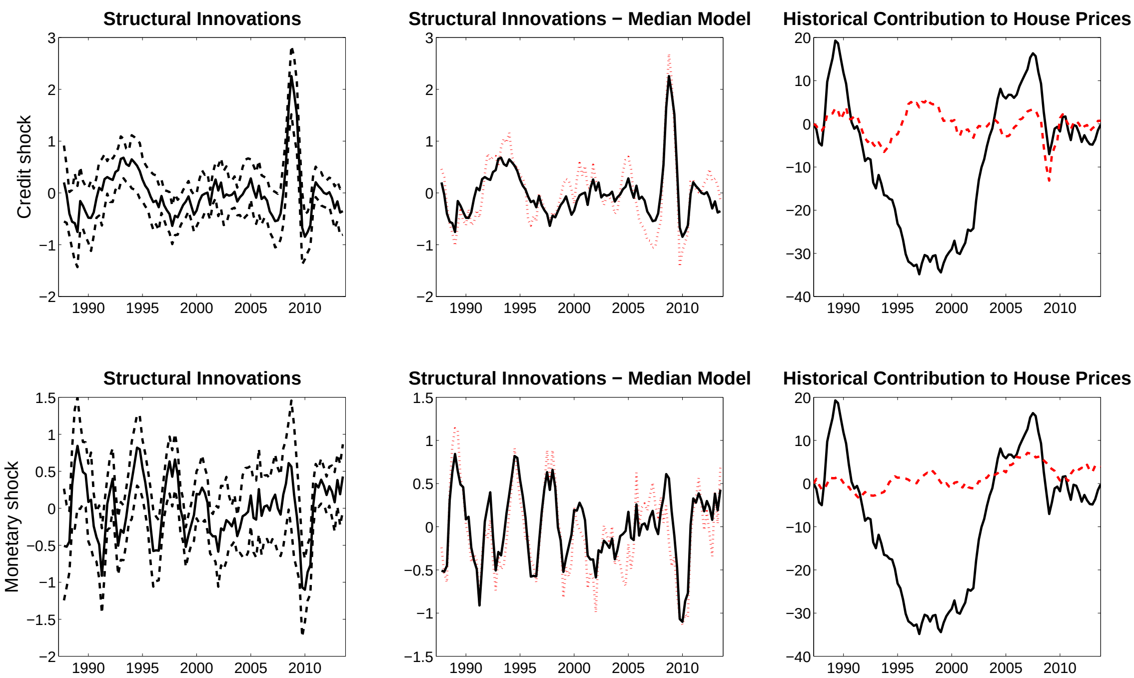


Notes: The graph shows the shares of the forecast error variance explained by the credit shock (black) and the monetary shock (grey). The remaining share is explained by the unidentified other shocks.

Figure 2.13: Forecast error variance decomposition for house prices (U.K.)

well as home equity loans) is tax-deductible. The taxation generally favors housing wealth as opposed to other forms of wealth and mortgage debt over other types of loan contracts (see Lehnert, 2006). Given that specific feature of the U.S. mortgage market, we would not expect a substantial change in households' demand for housing after an increase in the nominal interest rate. However, in the U.K. not only is the majority of mortgage contracts of variable interest rate type, but there is also no mortgage tax relief. This kind of tax exemption was available in the U.K. until 6 April 2000, when the relief was removed.[9] Given the absence of the tax provision, we would expect the changes in the nominal interest rates in the U.K. to have a more pronounced effect on lending and house prices than in the U.S., and this seems to be confirmed by our VAR results. The housing prices in the U.K. seem generally to be more susceptible to different exogenous changes due to the characteristics of its

[9]See http://www.hmrc.gov.uk/ria/miraswithdrawal.pdf



Notes: The figure shows the estimated innovations associated with the two identified shocks (four-quarter moving averages). The left panels show median and the 16% and the 84% quantile of the different draws. The middle panels shows again the median (continuous line) and the innovation implied by the "median" model dashed line). The right panels show the impact of the shocks on the predicted house prices: all shocks (solid line) versus the respective shock only.

Figure 2.14: Estimated innovations (U.K.)

housing market. The U.K. housing market is characterized by both limited supply because of the lack of suitable space and by strict planning laws (see HMTreasury, 2003).

2.5.3 Comparison with the Literature

Our results for the U.S. are consistent with the evidence provided by Assenmacher-Wesche and Gerlach (2008), despite a different method of VAR identification and the inclusion of equity prices instead of consumption as a VAR variable in Assenmacher-Wesche and Gerlach (2008). The credit shock in Assenmacher-Wesche and Gerlach

(2008) has only very short-lasting effects on the considered variables, and the house prices show no significant response. The effects of the monetary shock are clearer: the variables of interest exhibit a long-term contraction, even though it does not occur immediately after the shock. The contraction in credit is very long-lasting, while GDP recovers in our model relatively faster than in Assenmacher-Wesche and Gerlach (2008), although also after a long period of downturn. The decline of house prices after a monetary policy shock is also consistent with the results by Vargas-Silva (2008) who analyzes the effects of monetary policy on the U.S. housing market using a VAR identified by sign-restrictions. Also, Goodhart and Hofmann (2008) in their panel analysis for 17 countries find that a monetary shock has longer lasting effects on variables such as GDP, house prices and credit, compared to a credit shock. Musso et al. (2011), analyzing the VAR responses for the U.S. and euro area economy, show that a monetary policy shock has a large effect on housing market related variables, such as residential investment and real house prices. On the contrary, a negative credit supply shock, defined as an increase in the mortgage lending rate, does not lead to a robust response of house prices in the short and medium run and leads to a significant decrease in U.S. house prices only after around 12 quarters. This supports our findings about a clearer impact of monetary policy rather than a credit shock on house prices.

When it comes to the studies that do not include housing prices in their analysis, the results of Hristov et al. (2012) also confirm our findings in the euro area context: the effects of a loan supply shock on GDP and loan volume are shorter-lasting than the ones of a monetary shock. On the contrary, Helbling et al. (2011) find that following a global credit shock, global GDP increases initially but afterwards there is a long-lasting decline. However, the results are not statistically significant. For the U.S. credit shock, Helbling et al. (2011) find no significant effects on U.S. GDP.

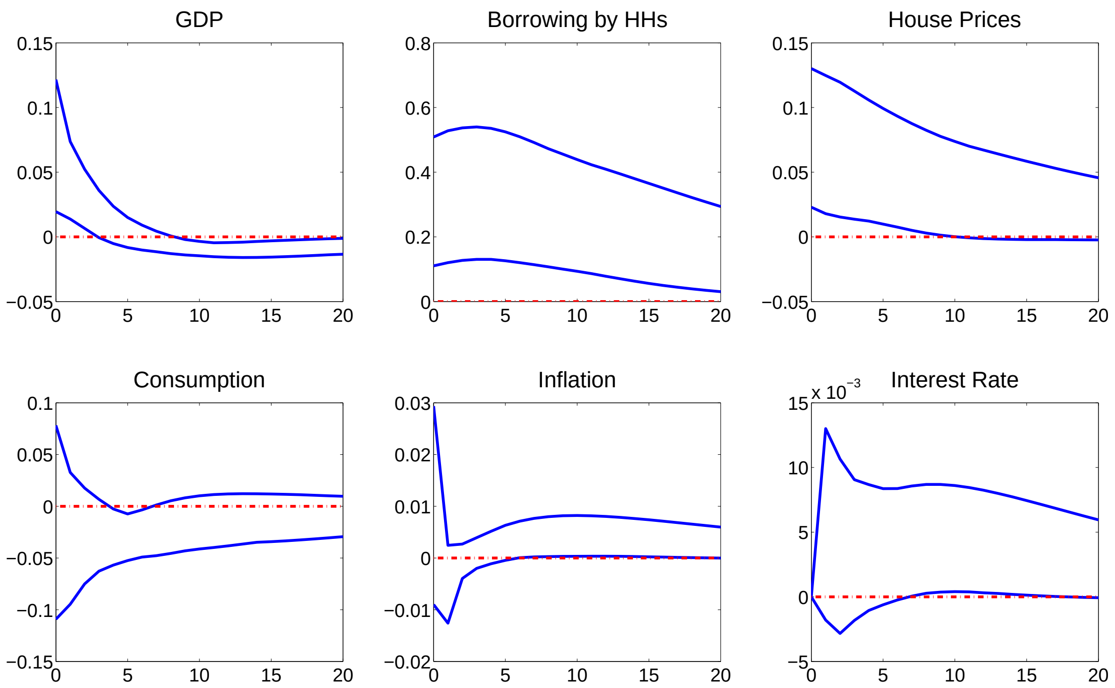
2.6 Conclusion

Estimating a VAR for U.S. and U.K. data using sign restrictions derived from a DSGE model, we analyze the effectiveness of monetary and credit policies in influencing house prices in the economy. For both countries, we find that a negative monetary shock has a stronger effect on house prices, while the impact of a negative credit shock on house prices is insignificant, which is in line with other studies including house prices in a VAR analysis. The comparison of the results for the U.S. and the U.K. suggests that both monetary and macroprudential policies are more effective in the U.K. This might be explained by the structure of the mortgage market and e.g. taxation rules.

As our sample also includes the time period of the financial crisis, we analyze the contribution of the considered shocks to the recent house price developments in both countries. The historical decomposition suggests that in the U.S. the monetary shocks played an important role in the build-up of house prices before the crisis. For the U.K., we find that the drop in the house prices during the crisis can be attributed to a large extent to a credit shock.

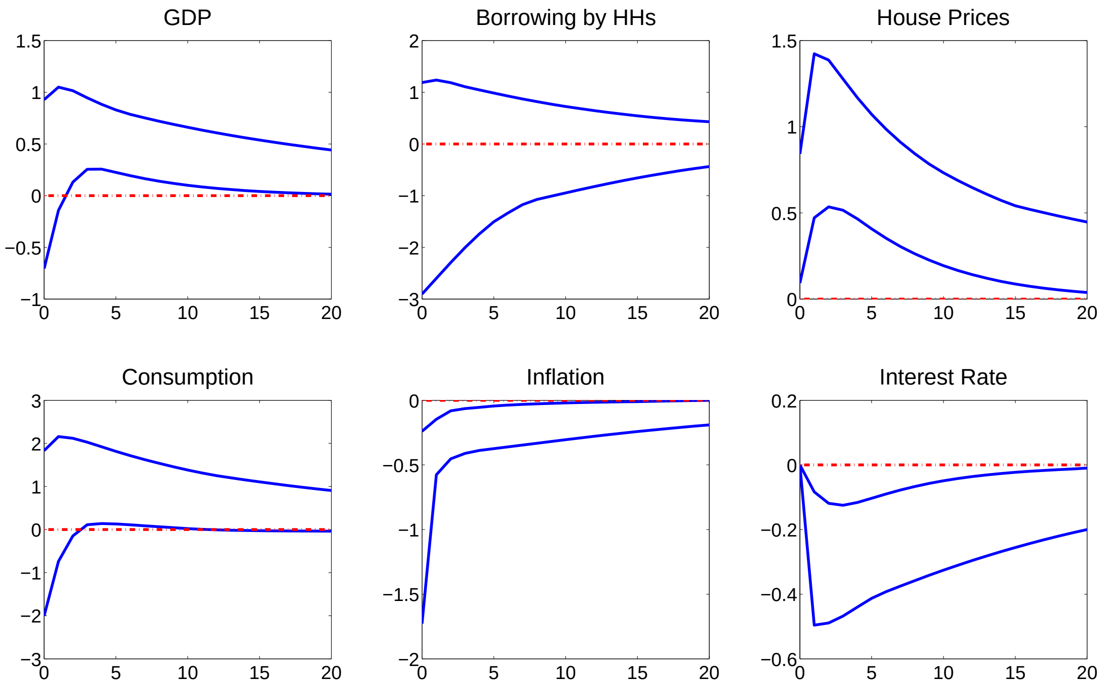
Appendix to Chapter 2

2.A Additional Graphs



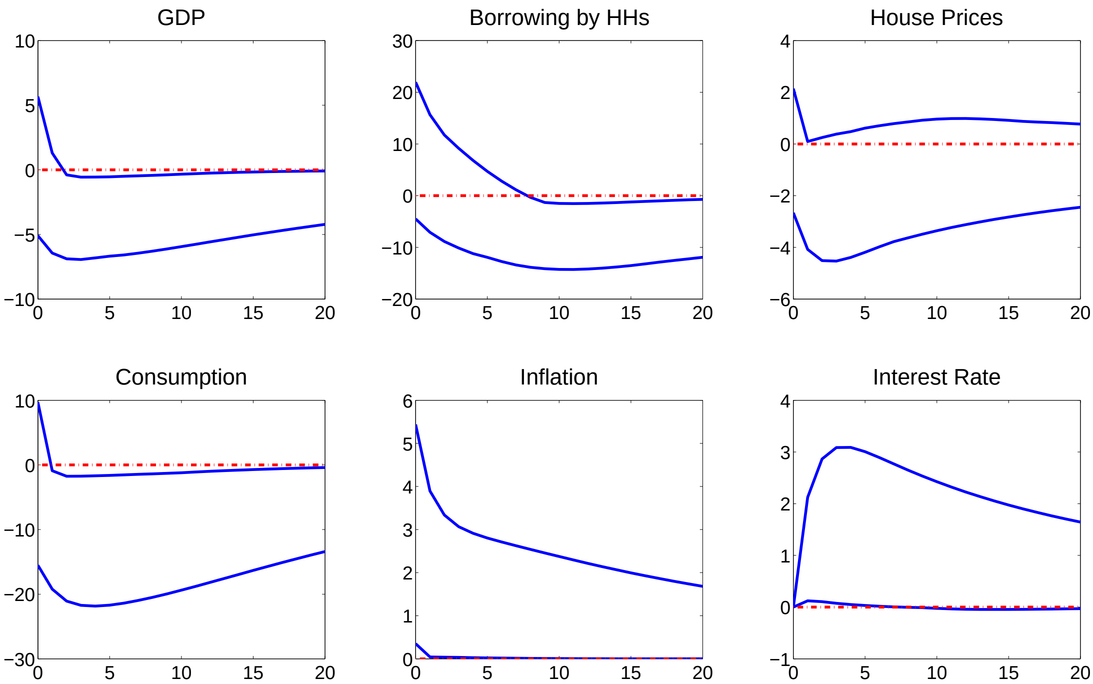
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in households' housing preference. The impulse responses are measured in percentage deviations from steady state.

Figure 2.15: Housing Preference Shock - Impulse response functions of the DSGE model (U.S.)



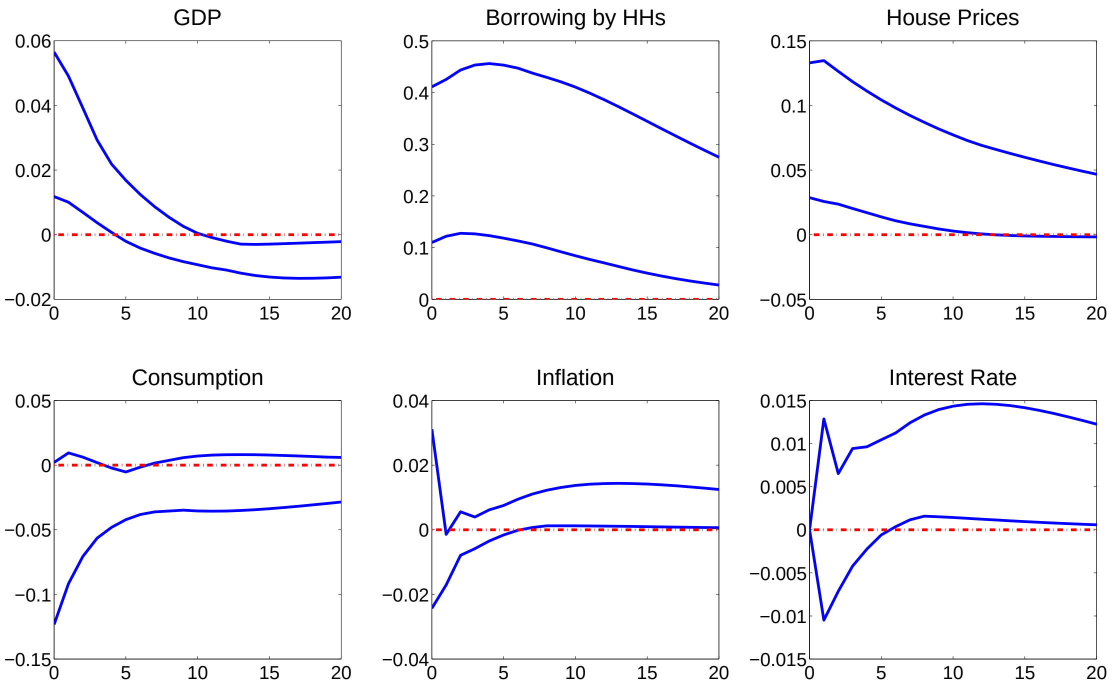
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the productivity. The impulse responses are measured in percentage deviations from steady state.

Figure 2.16: TFP Shock - Impulse response functions of the DSGE model (U.S.)



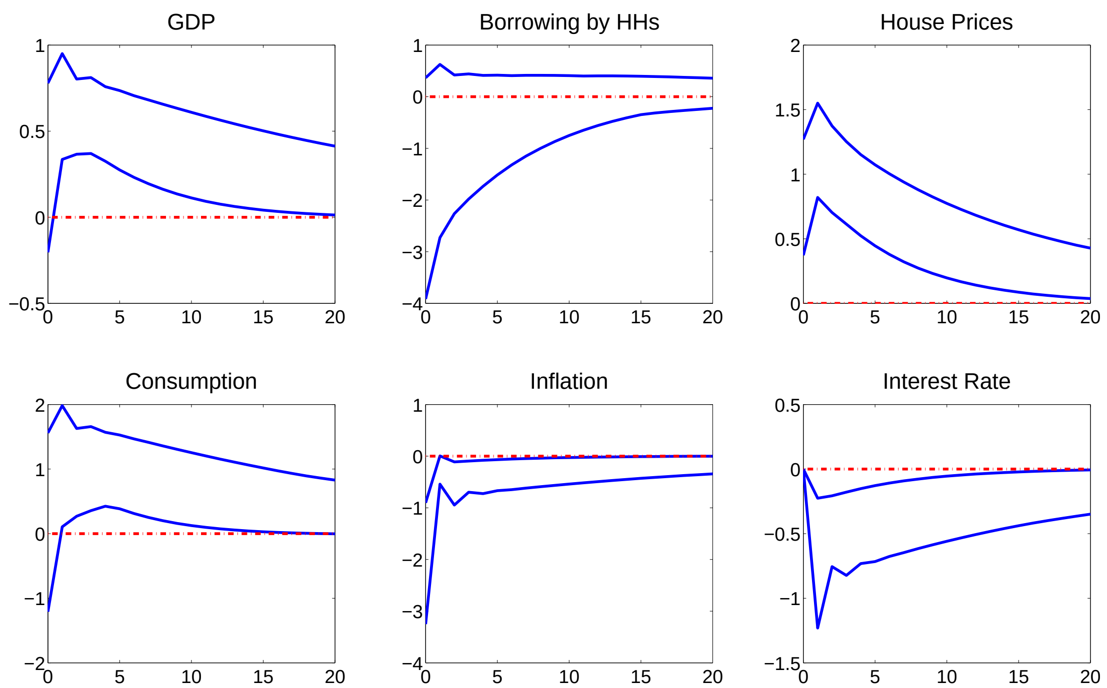
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage incease in the inflation. The impulse responses are measured in percentage deviations from steady state.

Figure 2.17: Inflation Shock - Impulse response functions of the DSGE model (U.S.)



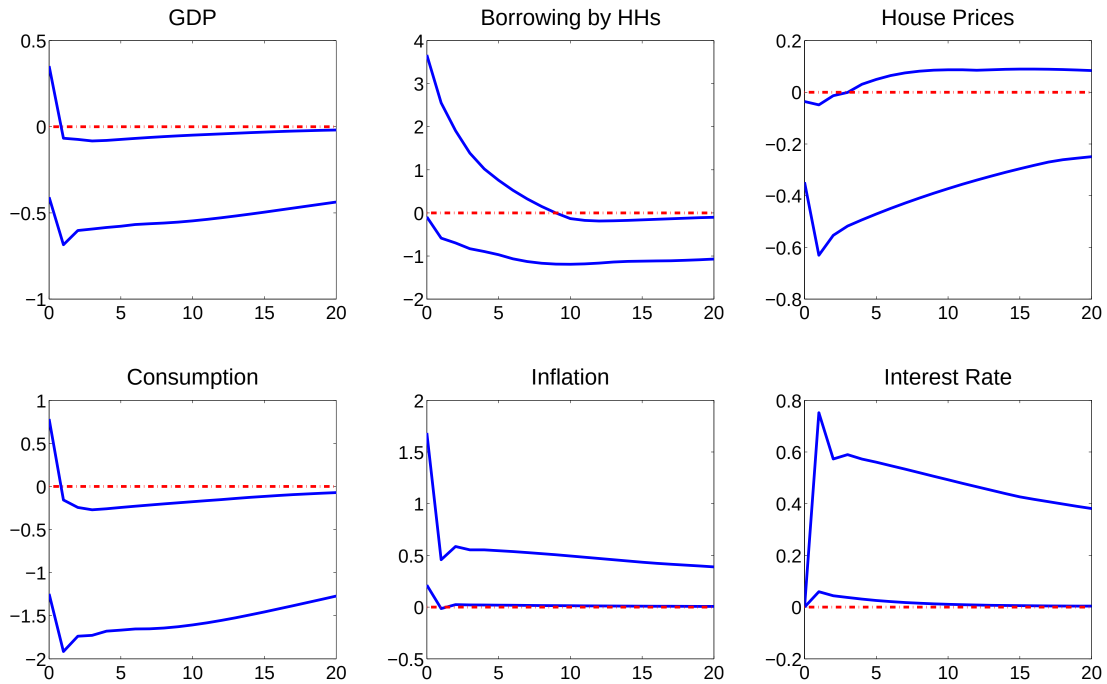
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in households' housing preference. The impulse responses are measured in percentage deviations from steady state.

Figure 2.18: Housing Preference Shock - Impulse response functions of the DSGE model (U.K.)



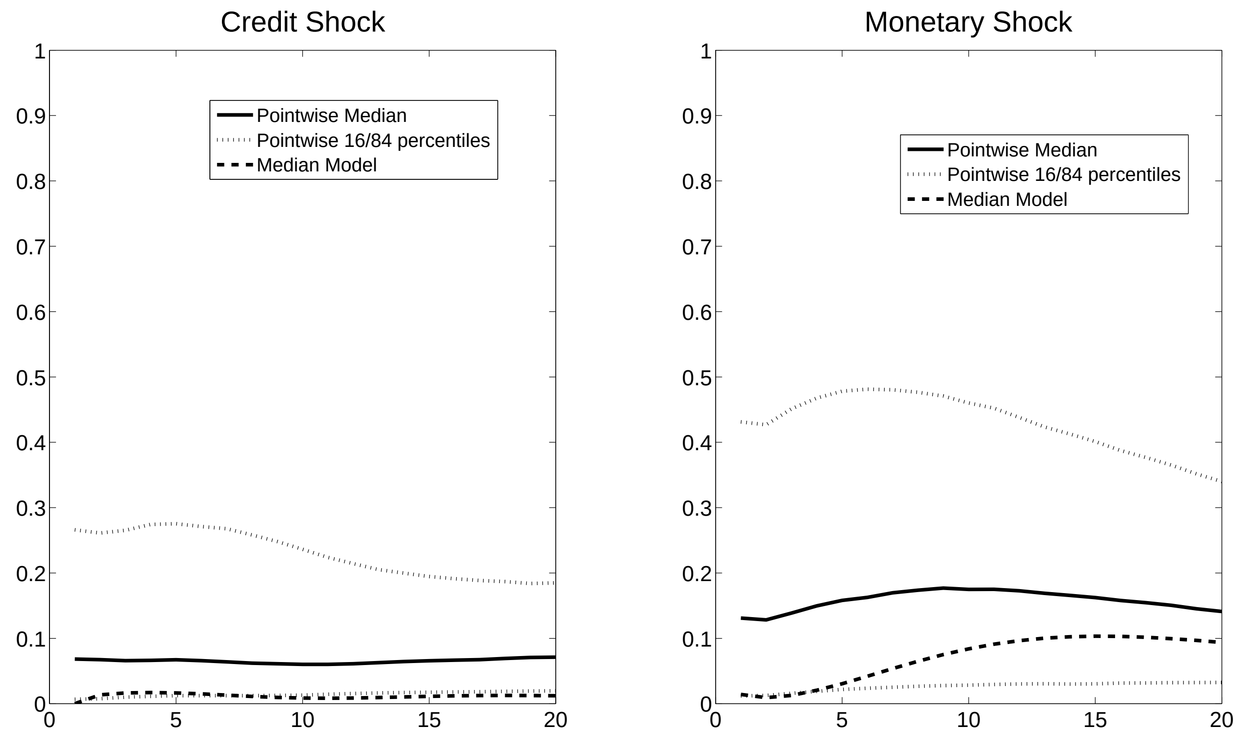
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the productivity. The impulse responses are measured in percentage deviations from steady state.

Figure 2.19: TFP Shock - Impulse response functions of the DSGE model (U.K.)



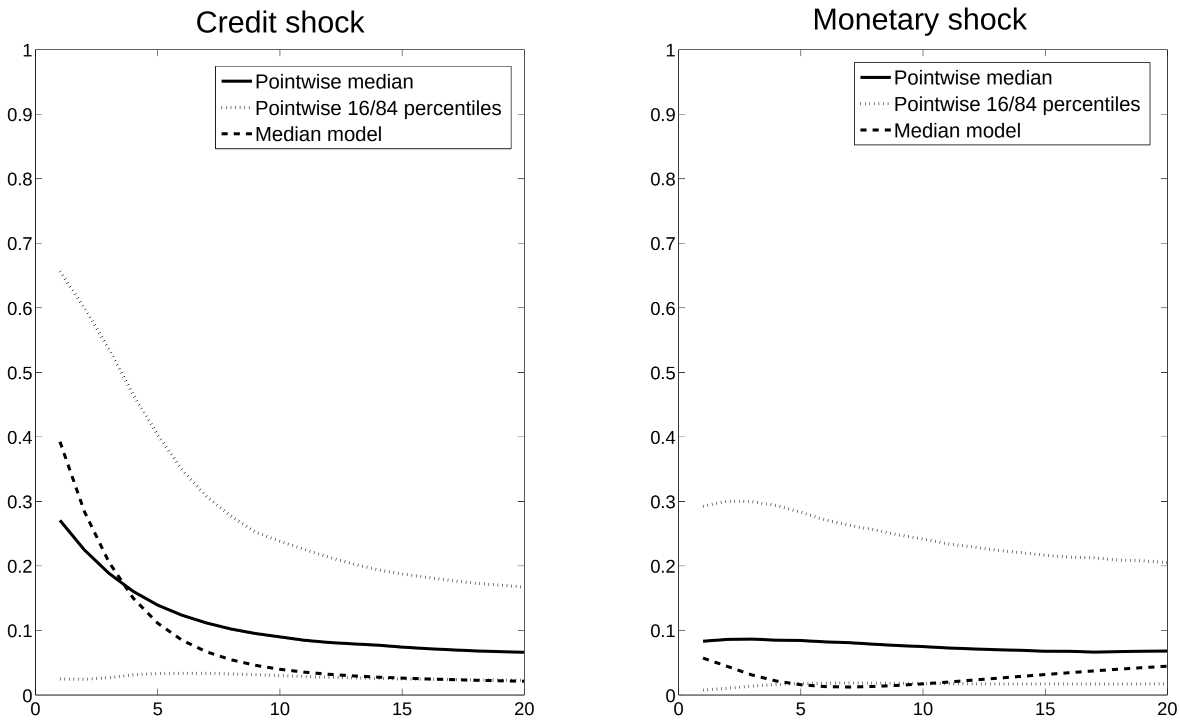
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage incease in the inflation. The impulse responses are measured in percentage deviations from steady state.

Figure 2.20: Inflation Shock - Impulse response functions of the DSGE model (U.K.)



Notes: Graphs show the share of the forward error variance of the house prices that is explained by the credit shock (left panel) and the monetary Shock (right panel). The dashed line results from the "median model". The continuous line denotes the pointwise median across all accepted models and the dotted lines denote the respective (pointwise) 16th and 84th percentiles.

Figure 2.21: Forecast error variance decomposition of house prices (U.S.)



Notes: Graphs show the share of the forward error variance of the house prices that is explained by the credit shock (left panel) and the monetary shock (right panel). The dashed line results from the "median model". The continuous line denotes the pointwise median across all accepted models and the dotted lines denote the respective (pointwise) 16th and 84th percentiles.

Figure 2.22: Forecast error variance decomposition of house prices (U.K.)

Chapter 3

The Price vs Quantity Debate: Climate Policy and Business Cycles

3.1 Introduction

Although the recent financial crisis primarily emphasized the significance of the financial and housing markets in business cycles, covered in the previous two chapters of this dissertation, it also renewed interest in the optimal design of environmental policies, particularly in the European Union.[1] As economic agents rarely internalize the costs of their polluting activities, addressing the problem of climate change remains an important challenge for policymakers.

Two classical alternatives for regulating pollutants considered by the literature are a cap-and-trade system (present e.g. in the European Union) and a tax (present e.g. in Norway or certain Canadian provinces); the former is a quantity instrument and the latter is a price instrument. It seems that there is no consensus on the superiority of one instrument over another. In this chapter, we contribute to this debate by analyzing the optimal instrument design in the face of uncertainty stemming from unexpected changes in economic circumstances.

The literature that compares the relative performance of price and quantity instruments under uncertainty starts with the seminal contribution of Weitzman (1974) who analyzes the optimal instrument choice in a static partial equilibrium framework.

[1]The European Union's Emissions Trading System (EU ETS) works under a 'cap and trade' principle, setting the level of greenhouse gases' emissions to a certain level. It came unter scrutiny during the crisis, as the price of emissions allowances plunged due to the weak economic activity and an oversupply of allowances. Currently, the European Comission is working on improving the EU ETS system, addressing the problem of allowances surplus, which arose "largely as a result of the economic crisis", as we can read on its website, `http://ec.europa.eu/clima/policies/ets/reform/index_en.htm`.

He shows that, under uncertainty about the abatement costs, the relative slopes of the marginal benefit (damage) function and the marginal cost functions determine which instrument is preferred. If the expected marginal benefit function from reducing emissions is flat relative to the marginal cost of abatement, a price instrument is preferred. If, however, the marginal benefit function is steeper, a quantity instrument is preferred.[2] The literature has extended Weitzman (1974)'s framework to a dynamic (but still partial equilibrium) setting (e.g. Hoel and Karp, 2002; Newell and Pizer, 2003; Karp and Zhang, 2005).[3] This literature emphasizes that, for stock pollutants such as greenhouse gases, the total stock of pollution changes little from one year to another, so that the marginal benefit function is basically flat in the short-run. Thus, in the case of the CO2, price instruments are preferable.

In this chapter, we extend this line of research by analyzing the optimal design of environmental policy in a business cycle framework. Given the long-term impact of climate change, the analysis of environmental policies in a rather short-term business cycle setup may come as a surprise. However, a vast literature on the design of environmental policies in such a setup has recently emerged. It is summarized by Fischer and Heutel (2013). In his paper, Heutel (2012), p. 244, provocatively writes: "*Environmental policy (...) typically has not been designed to respond to business cycles, likely because the scale of most environmental policies is small relative to the economy. However, addressing global climate change will require policies that dwarf conventional environmental policies in scale and scope. Can climate policy designers continue to ignore business cycles, or does climate policy require a more explicit integration with macroeconomic fluctuations?*".

The main difference between the papers in the real business cycle literature and the earlier works is that the latter consider instruments which are fixed at least for some time, while the real business cycle models feature instruments which are

[2] Another implication of Weitzman's result is that benefit uncertainty, unless it is correlated with cost uncertainty, does not affect the net benefit under both price and quantity controls and thus, does not affect the optimal choice between carbon taxes and emissions caps. As a result, many followers of Weitzman (1974) have primarily focused on uncertainty arising from shocks to abatement costs of firms, with a key exception of Stavins (1996) who shows that under reasonable conditions, the correlation between costs and benefits can reverse the conclusions drawn on the basis of the relative-slope rule.

[3] Weitzman's original analysis has been also extended to analyze the performance of hybrid policies that combine elements of taxes and cap-and-trade schemes (e.g., Roberts and Spence, 1976) and to indexed-instruments (e.g., Newell and Pizer, 2003).

state-contingent and adjusted each period. Earlier studies established the result that for stock pollutants, such as carbon dioxide, price instruments are preferable, because of the relatively flat benefit function from the reduction of pollution. Given the short-term character of business cycles and the fact that the pollution stock does not change much over the business cycle, one would expect this result to be even stronger in a real business cycle framework. A carbon tax imposed on the pollution externality can be interpreted as a Pigovian tax, and thus should be set equal to the marginal damages from the pollution stock. As damages are approximately constant in the short-term, so should be the imposed carbon tax in order to correct this externality. Surprisingly, Heutel (2012) finds that, in the response to a productivity shock, the optimal response of carbon taxes is procyclical, and that taxes fluctuate more than emissions, which may suggest that a quantity restriction is preferred over a price instrument. (Lintunen and Vilmi, 2013) continue this line of research by investigating the conditions for the procyclicality of carbon taxes.

Thus, models analyzing fixed policies and state-contingent policies yield different policy recommendations. We investigate the reasons for this divergence, starting from the most recent literature on the subject. Our theoretical framework is an extension of the real business cycle model in Heutel (2012). We incorporate labor and distortionary fiscal policy into his setup to show that the surprising result of carbon tax procyclicality can be explained by tax-incompleteness. We calibrate the model to the U.S. economy and use it to investigate the design and dynamics of optimal carbon tax and cap-and-trade policies. The policies considered in the business cycle framework are state-contingent policies that can be adjusted every period. In practice, regulators usually choose single-order, fixed, instruments due to difficulty in implementation. We see state-contingent policies as instruments in an idealized world, in which policymakers can readjust their decisions every period. These policies serve as benchmarks in our analysis. We contrast their welfare implications, comparing them with non-state-contingent policies, which are respresented in our model by either a carbon tax or a cap on emissions fixed at their corresponding steady-state values.

Simulations of the model produce several results. First, we demonstrate that, in an idealized world in which planners can continually adjust instruments to reflect current contingencies of the state of the economy, the expected welfare outcome and stock of greenhouse gases are very similar irrespective of whether a regulator uses a baseline price or a quantity instrument. Second, we show that the carbon tax remains approximately constant over the business cycle. If a quantity restriction is chosen, then the optimal quantity varies more over the business cycle relative to the volatility of carbon tax in the model with environmental taxation. Third, we observe that, if a regulator cannot continually adjust instruments and must choose either a fixed price instrument or a fixed quantity instrument, taxes are the more efficient instrument. Intuitively, if under idealized conditions, as discussed above, the carbon tax is approximately constant and emissions vary more, then the welfare costs associated with fixing the instrument at its steady-state value should generate smaller losses under the former than under the latter policy. Our estimates of such welfare losses confirm this intuition: we find that a fixed tax policy leads to a welfare loss of USD 232.83 per capita per annum, as opposed to the fixed quantity instrument that generates a loss of USD 258.22 per capita per annum.

Our main finding that the carbon tax is almost constant and fluctuates less than emissions in response to a TFP shock contrasts with the result presented in Heutel (2012). The reason is that, in Heutel's framework, the tax system is incomplete and the regulator uses the carbon tax partly to offset revenue fluctuations over the course of the business cycle. If, as in our model, the carbon tax is used solely to address the environmental policy problem, the procyclicality disappears. Heutel's result is obtained, therefore, due to a violation of Tinbergen's optimal policy principle, i.e. that each policy problem should be attacked with a specific policy instrument (see Tinbergen, 1952).

The rest of the chapter is organized as follows. Section 3.2 describes the core model. Section 3.3 discusses the model's calibration. Section 3.4 presents and discusses the results under price and quantity instruments when the regulator can continuously adjust instruments to reflect current states of nature. The same section presents the results for the version of the model when the economy is hit by two correlated shocks - productivity and shock to abatement technology; it also discusses policy implications of our main results. Section 3.5 discusses what drives divergence in our results when compared to those of Heutel (2012). Section 3.6 concludes.

3.2 Real Business Cycle Model with Distortionary Taxes and Climate Externality

The baseline model used in this chapter extends Heutel (2012)'s real business cycle model with climate externalities by introducing distortionary fiscal policy. The economy consists of households, firms, and the government. Households obtain utility from the consumption of both public and private goods, as well as from leisure. Goods are produced using private capital and labor. Following Heutel (2012), production causes greenhouse gas emissions, which accumulate in the atmosphere and lead to climate change that causes damages by reducing output according to a damage function. As in Heutel (2012), we assume that firms can counteract the adverse productivity effect of climate change by increasing spending on abatement. The government levies emissions, output and labor taxes on firms. The revenues from these taxes are used to finance public good provision and the public debt.

3.2.1 Households

A representative household maximizes:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t, g_t). \tag{3.2.1}$$

In this utility function, c_t and g_t represent private and public consumption and l_t is the number of hours worked by the household. The representative household faces the following budget constraint:

$$c_t + i_t + \rho_{Bt} b_{t+1} = w_t l_t + r_t k_{t-1} + \pi_t + b_t, \tag{3.2.2}$$

where i_t is private investment, π_t is firm profits, b_{t+1} denotes one-period government bond purchases and ρ_{Bt} is the price of one-period bonds. Households derive income from supplying labor and capital to firms at rental rates w_t and r_t. The private capital stock is accumulated according to:

$$k_t = (1-\delta)k_{t-1} + i_t. \tag{3.2.3}$$

First-order conditions of the household maximization problem imply:

$$w_t = -\frac{u'_L(t)}{u'_c(t)}, \tag{3.2.4}$$

$$u'_c(t) = \beta E_t u'_c(t+1)[1 - \delta + r_{t+1}], \tag{3.2.5}$$

$$u'_c(t)\rho_{Bt} = \beta E_t u'_c(t+1). \tag{3.2.6}$$

Equation (3.2.4) equates the marginal rate of substitution of leisure for consumption to real wages and defines the household's labor supply. Condition (3.2.5) is a standard stochastic Euler equation, which determines intertemporal allocation: it equates the intertemporal marginal rate of substitution in consumption to the real rate of return on private capital. Condition (3.2.6) is the counterpart of equation (3.2.5) for domestic bonds.

3.2.2 Final Goods Production

Output y_t is produced by identical firms, and can be used for consumption, investment, abatement or government spending:

$$y_t = (1 - d(x_t))f(k_{t-1}, l_t; a_t), \tag{3.2.7}$$

where a_t represents an exogenous productivity shock that follows a stationary stochastic process:

$$\ln a_t = \rho \ln a_{t-1} + \varepsilon_t, \varepsilon_t \sim N(0, \sigma_\varepsilon^2), \mid \rho \mid < 1. \tag{3.2.8}$$

We assume that the stock of pollution in the atmosphere, denoted by x_t, adversely affects output through the damage function $d(x_t)$. The formulation of climate damages as a fraction of output lost as in (3.2.7) was introduced by Nordhaus (1991) and since then has been extensively used in the literature. The mapping of emissions to economic damage can be thought as comprising two steps. First, emissions increase the concentration of greenhouse gases leading to climate change, and, second, climate change causes economic damages. Some papers, e.g., Barrage (2014) follow Nordhaus's approach and model two steps of mapping from carbon concentration to damages. We follow the equally common specification of Heutel (2012) and Golosov et al.

(2014) who map CO2 concentration to damages in one step.[4] The specification (3.2.7) assumes that climate change affects output directly. Such a specification is standard in climate change modeling and represents the dependence of the production of many goods on climate conditions, such as production of agricultural goods, forestry, fisheries etc.

Profits of firms are defined as:

$$\pi_t = (1 - \tau_t)y_t - w_t(1 + \tau_{Lt})l_t - \tau_{Et}e_t - r_t k_{t-1} - z_t, \tag{3.2.9}$$

where τ_{Lt} is payroll (labor) tax, τ_t is output tax, τ_{Et} is tax on emissions, e_t are emissions, which are by-products of production, and z_t is spending on abatement by firms. Private abatement spending is assumed to abate the μ_t fraction of emissions via the following relation:

$$\frac{z_t}{y_t} = m(\mu_t), \tag{3.2.10}$$

so that firms face the emissions constraint given by:

$$e_t = (1 - \mu_t)h(y_t), \tag{3.2.11}$$

where $h(y_t)$ determines total emissions from producing y_t output. Following Heutel (2012), we assume that a climate change externality arises because firms do not take into account their emissions' impact on the pollution stock and thus on productivity. In other words, firms take x_t as a given. Optimality conditions of the firm imply:

$$r_t = (1 - d(x_t))f'_k[1 - \tau_t - \tau_{Et}(1 - \mu_t)h'(y_t) - m(\mu_t)], \tag{3.2.12}$$

$$w_t(1 + \tau_{Lt}) = (1 - d(x_t))f'_L[1 - \tau_t - \tau_{Et}(1 - \mu_t)h'(y_t) - m(\mu_t)], \tag{3.2.13}$$

[4] The two stage mapping would have introduced a set of lags in the effect of current-emissions on output, but would have not changed our results. This is because cyclical changes in emissions levels have very little effect on the pollution stock due to the long-lived nature of CO2, and thus it is relatively immaterial whether a ton of carbon dioxide is emitted today or a few periods later. We demonstrate in the Appendix 3.A that the damages from pollution do not change significantly with business cycles.

$$\tau_{Et} = \frac{y_t m'(\mu_t)}{h(y_t)}. \tag{3.2.14}$$

Equation (3.2.12) is an optimality condition for the demand for capital. It implies that the return associated with an increase in capital stock by one unit is equal to the marginal product of capital. The marginal product of capital is net of additional tax payments on increased emissions and net of additional spending on abatement to clean a given fraction μ of extra emissions. Equation (3.2.13) is the counterpart of equation (3.2.12) for labor demand. Finally, equation (3.2.14) says that firms react to the carbon tax by choosing the level of abatement (equivalently the level of emissions) such that the tax on emissions equals the marginal cost of emissions reduction.

3.2.3 Government

The government budget constraint is given by:

$$g_t + b_t = w_t \tau_{Lt} l_t + \tau_{Et} e_t + \tau_t y_t + \rho_{Bt} b_{t+1}, \tag{3.2.15}$$

where the government raises revenues by taxing labor income and emissions and levying output tax to finance public debt b_t and provision of public goods, g_t. The government can issue one-period bonds b_{t+1}. The government budget constraint (3.2.15) incorporates market clearing for bonds which requires that households' demand for bonds and government supply for bonds are equated.

3.2.4 Carbon Cycle

Following Heutel (2012), we assume that in each period carbon dioxide emissions by domestic and foreign firms increase the existing pollution stock which decays at a linear rate η:

$$x_t = \eta x_{t-1} + e_t + e_t^{row}, \tag{3.2.16}$$

where e_t are current-period domestic emissions that are related to the output produced and fraction μ_t that is abated, while e_t^{row} is current-period emissions from the rest of the world and η is the fraction of the pollution stock that remains in the atmosphere.[5]

[5] The atmosphere is not the only reservoir of carbon dioxide. Even without industrial emissions there exists a natural carbon cycle encompassing flows of carbon dioxide among different reservoirs: the

3.2.5 Equilibrium

We solve the model by constructing a Ramsey problem since our main interest lies in specifying optimal governmental policies that lead to a second-best outcome in the presence of environmental externalities. It is well known that the existence of enivronmental externality breaks the equivalence between the outcome of the social planner's problem and the decentralized economy (see Xepapadeas, 2005). However, the social optimum can still be approached by an appropriate design of taxation. We model a decentralized economy in which the Ramsey planner finds optimal fiscal policies so as to internalize the externalities. To construct the Ramsey problem, we reorganize some of the constraints in order to reduce the number of choice variables and to obtain a compact expression for the household budget constraint. In particular, combining (3.2.2),(3.2.9) and (3.2.15) gives the following resource constraint for the economy:

$$c_t + k_t - (1-\delta)k_{t-1} + z_t + g_t = y_t. \tag{3.2.17}$$

Next, by adding and substituting for w_t from (3.2.4), we rewrite the government's budget constraint as follows:

$$g_t + b_t = -\frac{u'_L(t)}{u'_c(t)}\tau_{Lt} l_t + \tau_{Et}(1-\mu_t)h(y_t) + \tau_t y_t + \rho_{Bt} b_{t+1}. \tag{3.2.18}$$

Substituting (3.2.4) into (3.2.13) gives:

$$-\frac{u'_L(t)}{u'_c(t)}(1+\tau_{Lt}) = (1-d(x_t))f'_L[1-\tau_t-\tau_{Et}(1-\mu_t)h'(y_t) - m(\mu_t)]. \tag{3.2.19}$$

3.2.6 Ramsey Problem

The Ramsey planner maximizes the utility of households:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t, g_t) \tag{3.2.20}$$

atmosphere, oceans etc., present e.g. in Nordhaus (2008). In this model, we leave the flows between the atmosphere and other carbon reservoirs aside and model the effect of industrial activity on the atmosphere. The one-dimensional representation of the carbon cycle based on the stock of pollution in the atmosphere only has been also utilized in Golosov et al. (2014).

subject to (3.2.5), (3.2.14), (3.2.17), (3.2.18), (3.2.19) and

$$y_t = (1 - d(x_t))f(k_{t-1}, l_t; a_t), \tag{3.2.21}$$

$$x_t = \eta x_{t-1} + (1 - \mu_t)h(y_t) + e_t^{row}, \tag{3.2.22}$$

where we also use function (3.2.12) for the definition of r_t.

The government chooses c_t, μ_t, k_t, y_t, x_t, l_t, τ_{Lt}, τ_{Et}, τ_t, g_t and b_{t+1} to maximize (3.2.20) subject to the constraints specified above.

The Lagrangian for this problem is given by:

$$\begin{aligned}
L \quad = \quad & E_0 \sum_{t=0}^{\infty} \beta^t \{ u(t) + \lambda_t \left[-u'_c(t) + \beta u'_c(t+1)(1 - \delta + r_{t+1}) \right] + \\
& + \Omega_t [c_t + k_t - (1-\delta)k_{t-1} + m(\mu_t)y_t + g_t - y_t] + \\
& + \chi_t [\tau_{Et} h(y_t) - y_t m'(\mu_t)] + \\
& + \Lambda_t [-g_t - b_t - \frac{u'_L(t)}{u'_c(t)} \tau_{Lt} l_t + \tau_{Et}(1-\mu_t)h(y_t) + \tau_t y_t + \rho_{Bt} b_{t+1}] + \\
& + \lambda_{pt} [y_t - (1 - d(x_t)) f(k_{t-1}, l_t, k_{Gt-1})] + \\
& + \varsigma_t \left[-\frac{u'_L(t)}{u'_c(t)}(1 + \tau_{Lt}) - (1 - d(x_t)) f'_L(t)(1 - \tau_t - \tau_{Et}(1-\mu_t)h'(y_t) - m(\mu_t)) \right] + \\
& + \Phi_t [x_t - \eta x_{t-1} - e_t^{row} - (1-\mu_t)h(y_t)] \}.
\end{aligned}$$

The first-order conditions of the Ramsey problem are given in Appendix 3.C.

3.3 Calibration

To calibrate the model, we select parameter values that enable the theoretical model to generate features that are (as closely as possible) consistent with the main features of the U.S. economy. We assign values to structural parameters using values that are common in business cycle studies of fiscal policy and macroeconomic models with climate change externalities. To calibrate the climate part of the model, we draw on the estimates and parameter values used in Heutel (2012). Baseline parameter values of the model are summarized in Table 3.1, while Table 3.2 reports macroeconomic ratios implied by the theoretical model as well as the corresponding values for the

U.S. data. Data sources employed in these calculations are summarized in Appendix 3.B.

Parameter	Value	Definition
α	0.36	private capital share in the production function
ρ	0.95	persistence of the TFP shock
σ_ε	0.007	standard deviation of the TFP shock
δ	0.025	private capital depreciation rate (quarterly)
β	0.98	subjective discount factor (quarterly)
κ	1.6	coefficient of relative risk aversion
θ	0.236	weight of public consumption in utility
$1/\psi$	0.4	Frisch elasticity of labor supply
η	0.9979	pollution decay
d_2	5.2096e-10	damage function parameter
d_1	-1.2583e-06	damage function parameter
d_0	1.3950e-3	damage function parameter
θ_1	0.05607	abatement cost equation parameter
θ_2	2.8	abatement cost equation parameter
$1-\nu$	0.696	elasticity of emissions with respect to output

Table 3.1: Baseline parameter values

A time period represents one quarter. The production function is given by

$$f(k_{t-1}, l_t; a_t) = a_t k_{t-1}^{\alpha} l_t^{1-\alpha}. \tag{3.3.1}$$

We set α to 0.36, which is a value commonly used in the standard RBC literature. For the TFP process, we assume that $\rho = 0.95$ and $\sigma_\varepsilon = 0.007$, where the value of the standard deviation is as in Heutel (2012) and is similar to the value 0.0056 as in Schmitt-Grohe and Uribe (2007). We show below that our results are not sensitive to changes in the value of ρ. The private capital depreciation rate, δ, is set to 0.025 (Heutel, 2012). We set the discount factor β to 0.98.

For the quantitative analysis, we consider the following form of the households' utility function:

$$u(c_t, l_t, g_t) = \frac{c_t^{1-\kappa} - 1}{1-\kappa} + \theta \frac{g_t^{1-\kappa} - 1}{1-\kappa} - \frac{l_t^{1+\psi}}{1+\psi}, \tag{3.3.2}$$

with the coefficient of relative risk aversion, κ, set to 1.6, which implies that the value of the intertemporal elasticity of substitution (EIS) is 0.625. The standard value of κ in the literature is 1 (see, e.g., Golosov et al., 2013). We set the value of ψ such that the Frisch elasticity of labor supply is 0.4, in line with macroeconomic estimates reported by Rogerson and Wallenius (2009). The weight of public consumption in the utility function, θ, is set to 0.236 to match the average labor tax observed in the U.S. Our steady state labor tax is a function of government spending, indirectly governed by the value of θ, see equation 3.2.15.

Following Heutel (2012), the pollution stock in the atmosphere evolves according to the following equation: $x_t = \eta x_{t-1} + e_t + e_t^{row}$. We set the value of η to 0.9979 as in Heutel (2012), who calibrates this parameter assuming that 83 years represent the half-life of atmospheric carbon dioxide.[6]

The emissions produced by the rest of the world, e_t^{row} are set to 4 times the steady state level of domestic emissions. According to data by the U.S. Environmental Protection Agency (EPA), the U.S. accounted for 19% of global CO2 emissions from fossil fuel combustion in 2008, which means that global emissions were four times higher than those in the U.S.[7]

The loss of potential output due to pollution is governed by the function $d(x) = d_2 x^2 + d_1 x + d_0$. We set the values of d_2, d_1, d_0 respectively to 5.2096e-10, -1.2583e-06, 1.3950e-3, following Heutel (2012), who calibrates these values to match the damages from carbon dioxide in the atmosphere estimated by papers in the environmental literature. Heutel (2012) bases this estimation on Nordhaus (2008). Our baseline calibration gives damages of 0.59%.

The abatement cost function is taken directly from Nordhaus (2008) and has the form $m(\mu) = \theta_1 \mu^{\theta_2}$. We set $\theta_1 = 0.05607$ and $\theta_2 = 2.8$, following Heutel (2012).

[6] In actuality, there is no single number that describes the lifetime of carbon dioxide in the atmosphere because it is a weighted sum of exponential decays at different rates. Carbon dioxide is not destroyed in the air, but is instead exchanged between the atmosphere, the ocean, and land. For other greenhouse gases, lifecycle estimation is possible, see the report of Intergovernmental Panel on Climate Change (2001). Thus, the values used by different studies vary. Following Archer (2005), Golosov et al. (2014) we alternatively calibrate the half-life of CO2 to 150 years. Assuming a half-life of 150 years would lead to $\eta = 0.9988$ in our model. Our model's results are not sensitive to changes in η - the decay parameter influences quantitative responses of only three variables (emissions, stock of pollution and fraction of emissions abated), while the responses of all other variables remain the same.

[7] `http://www.epa.gov/climatechange/ghgemissions/global.html`

Symbol	Variable	Model	Data
c/y	personal consumption/output	0.58	0.68
g/y	government consumption/output	0.26	0.15
i/y	private domestic investment/output	0.16	0.16
e/y	emissions/output	0.76	0.60
b/y	public debt/output	0.77	0.77
μ	fraction of emissions abated, %	0.54	1.85
τ_E	tax on emissions, %	0.002	-
τ_L	labor tax, %	15.4	15.4
τ	output tax, %	21.25	35
$\tau_E e/y$	revenue from carbon tax, % of GDP	0.0013	0.7 (estimate)

Table 3.2: Structure of the theoretical economy and the data

Given our baseline parametrization, the theoretical model implies a very low level of carbon taxes in the steady-state, 0.002% (for comparison, Heutel's model implies 0.0487%), and respectively a very low share of carbon tax revenues in GDP, only 0.0013% of GDP. In most countries with carbon taxation, the revenue from environmental taxes does not exceed 1%. Different estimates for the U.S. evaluate the possible net revenue in the range 0.51-0.8% of U.S. GDP (Table 2 in Gale et al., 2013). As Gale et al. (2013) report, in 2007 the carbon tax raised revenues were equivalent to 0.3% of GDP in Finland and Denmark and 0.8% of GDP in Sweden. In Australia carbon tax revenue in 2012-2013 accounted to 1.2% of GDP.[8]

Finally, output is mapped into emissions through $h(y_t) = y^{1-\nu}$, with $e_t = (1 - \mu_t)h(y_t)$, where $1 - \nu$ represents the elasticity of emissions with respect to output. We set the value of $1 - \nu$ at 0.696, which is the estimate from a (seasonally adjusted) ARIMA regression of the log of emissions of CO2 on the log of GDP for U.S. data in years 1981-2003, presented in Heutel (2012). We solve the model by log-linearizing around the steady-state.

[8] http://www.treasury.gov.au

3.4 Simulation Results

3.4.1 Results under Baseline Price Instrument Policy

Figure 3.1 shows the impulse responses (IR) of the key variables to a 1% increase in productivity under both carbon tax and cap-and-trade policies. All variables are expressed in terms of percentage deviations from the steady state, except for the tax rates, for which responses are expressed as absolute deviations from their steady-state values.[9] Given the objectives of the chapter, we report plots of the impulse response functions only for key variables related to our analysis, but the results for the remaining variables are available upon request. The continuous line represents the model with baseline carbon tax policy, and the dashed line represents the model with baseline cap-and-trade policy. We start with discussing the results under baseline carbon tax policy in this section and discuss the results under baseline cap-and-trade policy in the next section.

Impulse responses obtained from simulations of the baseline model yield the following key qualitative results. First, in line with the findings of other studies on optimal carbon tax over the business cycle (e.g. Heutel, 2012), emissions increase in the periods following a positive productivity shock. Given the long-lived nature of carbon dioxide, increased emissions result in a higher pollution stock over the medium term, and increase by around 0.0085% in 25 years time. We demonstrate in the Appendix 3.A that this number is quite small, by estimating increases in mean global temperature and sea levels associated with this rise in atmospheric greenhouse gases. Second, the labor tax increases by 1.66 percentage points (10.77 percent), the output tax decreases by 1.22 percentage points (5.75 percent), while the tax on emissions is raised by only 0.000014 percentage points, corresponding to 0.7 percent relative to the steady-state value in response to the shock.

The small fluctuations in the carbon tax rate can be explained drawing on the intuition of the "price versus quantity" literature. Given the long-lived nature of greenhouse gases, the additional damage from each additional ton of carbon emissions is constant in the short-run. In terms of the model presented in section 3.2, the

[9]Please note that for each time period t, we plot the values of those stock variables which enter the current production process, namely x_t and k_{t-1}. Since e_t affects x_t contemporaneously, x_t jumps in response to the shock, while k_{t-1} does not.

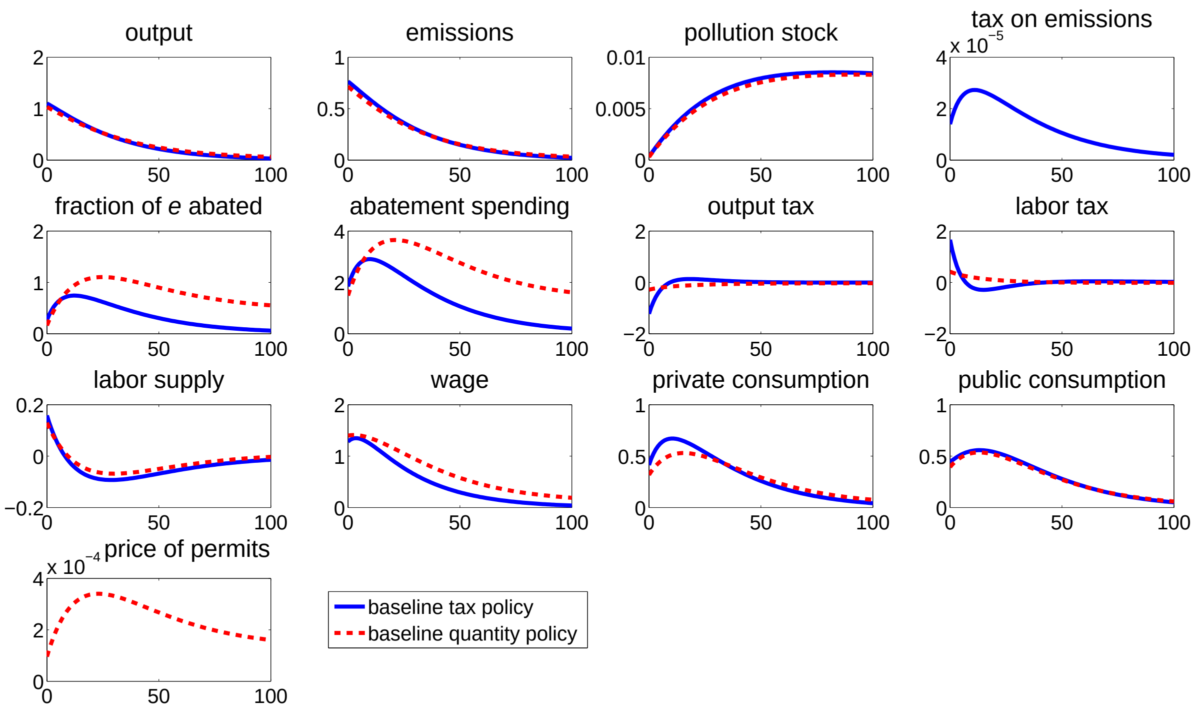


Figure 3.1: Impulse responses under baseline carbon tax and cap-and-trade policies to a positive TFP shock

concentration of CO2 emissions in the atmosphere $x_t = \eta x_{t-1} + e_t + e_t^{rpw}$, $x_t \sim x_{t-1}$, as well as damages $d(x_t) = d_2 x^2 + d_1 x + d_0$ remain essentially constant over the business cycle. Following Pigou's principle, the private sector's marginal cost - carbon tax under baseline policy - must correspond to the level of marginal damages, which are "flat" in the short-run. This explains why the optimal carbon tax is essentially constant over the business cycles.

3.4.2 Results under Baseline Quantity Instrument Policy

Following Heutel (2012), we introduce a cap-and-trade scheme into our framework by assuming that the government mandates the level of emissions a firm can produce, q_t. In other words, the government allocates permits to each firm (one representative firm) for free, so that it does not generate revenue. The setting is an example of the simplest cap-and-trade scheme that does not allow for policies similar to a "safety valve", in which firms are allowed to purchase an unlimited number of permits at a set price (see Pizer, 2002); we also abstract from incorporating active banking of permits, which would allow firms to shift obligations across time in response to periods of unexpectedly high or low marginal costs (see e.g. Fell et al., 2012).[10] In addition, since the theoretical framework features one representative firm, the quantity constraint is equivalent to a cap-and-trade scheme.

An individual's budget constraint and FOC in this setting remain as in the baseline model. There are only changes in the firm's problem and in the government's budget constraint. Specifically, firms do not pay taxes and consequently, the government budget omits revenues from taxing emissions. Profits of the firms are defined as:

$$\pi_t = (1-\tau_t)y_t - w_t(1+\tau_{Lt})l_t - r_t k_{t-1} - z_t \tag{3.4.1}$$

subject to the emissions constraint $q_t = (1-\mu_t)h(y_t)$ and abatement spending $z_t = m(\mu_t)y_t$. The government budget constraint is:

$$g_t + b_t = w_t\tau_{Lt}l_t + \tau_t y_t + \rho_{Bt}b_{t+1}. \tag{3.4.2}$$

Optimality conditions of the firm imply:

$$r_t = (1-d(x_t))f'_k[1-\tau_t - m(\mu_t) - \frac{m'(\mu)y_t}{h(y_t)}(1-\mu_t)h'(y)], \tag{3.4.3}$$

$$w_t(1+\tau_{Lt}) = (1-d(x_t))f'_L[1-\tau_t - m(\mu_t) - \frac{m'(\mu)y}{h(y)}(1-\mu_t)h'(y)], \tag{3.4.4}$$

$$q_t = (1-\mu_t)h(y_t). \tag{3.4.5}$$

Equation (3.4.5) is a constraint on the quantity of emissions produced. Equations (3.4.3)-(3.4.4) are analogous to equations (3.2.12)-(3.2.13) under tax policy, and they are optimal conditions of demand for capital and labor, respectively. They also demonstrate that the price of permits - the shadow price of a unit of emissions under quantity policy - is $p_{Et} \equiv m'(\mu)y_t/h(y_t)$. For comparison, under a price instrument,

[10] Active banking of permits can make the cap-and-trade scheme more flexible in terms of intertemporal allocation of abatement decisions by firms. As a result, in the face of temporary uncertainty in costs, under cap-and-trade with banking and borrowing, emissions fluctuate period-by-period and prices are relatively constant (Parsons and Taschini, 2013).

as shown in equation (3.2.14), firms reduce emissions until the marginal cost of reductions equal the tax, i.e. the price of carbon.

The simulation results of the baseline carbon tax (continuous line) and baseline cap-and-trade policies (the dashed line) are reported in Figure 3.1. There are two important results we want to emphasize. First, both baseline policies lead to very similar welfare and emissions outcomes in the medium-term under uncertainty driven by the same productivity shock. Second, the optimal restriction under a cap-and-trade policy is procyclical. These results can be explained as follows.

Our baseline policies are state-contingent, meaning that after the shock is realized, the regulator updates the regulatory instrument (either the value of the tax or cap on emissions) along with other policy instruments to reflect the new conditions of the state of the economy and to facilitate the adjustment to the shock. It is then intuitive that state-contingent policies under the *same* shock yield the same expected welfare outcome. After uncertainty is resolved, the marginal costs are certain, but they change with the business cycles. They tend to increase during booms and to fall during recessions. That is, every period will be associated with a different level of marginal costs. As the private sector's cost, the shadow price of carbon, must correspond to the marginal damages of pollution (Pigou, 1920), with essentially constant damages in the short-run and varying the marginal costs, the optimal quantity control must vary with business cycles to deduce a shadow price that is not only consistent with the target for emissions, but also internalizes externalities. This explains why the optimal restriction under state-contingent cap-and-trade is procyclical.

3.4.3 Fixed Price and Fixed Quantity Based Policies and Welfare

As discussed above, when the regulator can continually readjust the policies, the choice of the optimal instrument - price or quantity - becomes irrelevant as both policies lead to the same expected welfare outcome. However, state-contingent policies are difficult, if not impossible, to implement in practice because they involve continuous readjustment of policies and require complete knowledge of the distribution of the shocks affecting the economy. Baseline state-contingent policies in our analysis serve as benchmarks to assess the relative performance of fixed price and quantity policies, which is done by comparing welfare losses from fixing instruments at their steady state levels.

Following the procedure of Schmitt-Grohe and Uribe (2007), our measure of welfare is the amount of baseline steady-state policy consumption a household would be willing to give up to be as well off under the alternative specification as under the baseline policy. The results are shown in Table 3.3. For the consumption-equivalence, a number of, e.g., 0.64 means that the alternative environmental tax policy reduces welfare by 0.64% of consumption on average.

Welfare in consumption-equivalents, %	
Model with fixed emissions tax	0.64
Model with fixed quantity	0.71

Table 3.3: Welfare effects of alternative tax policies

We express welfare costs associated with single order instruments in monetary value, using the 2013 U.S. annual personal consumption expenditure,[11] which stood at USD 11,496.2 bn. By using this data, and converting it to per capita terms,[12] we find that a fixed tax instrument leads to a lower welfare loss compared to the fixed quantity instrument: USD 232.83 per person with taxes vs. USD 258.22 under quantity controls.[13]

It is important to note that under fixed environmental regulation policies, the rest of the economy still continually readjusts after the shock is realized. Moreover, as the impulse responses reveal (Figures 3.2 and 3.3), pronounced differences in the adjustment paths of the variables under fixed policies vs. state-contingent policies appear at the firm level, through adjustment in abatement spending and respectively in the fraction of emissions abated. The negligible differences in responses of other variables explain why the welfare costs of basic policies relative to baseline are relatively small.

[11] Data source is the NIPA table, see Appendix 3.B for more details.

[12] Population in the U.S. in 2013 stood at 316.1 million people.

[13] The uncertainty in our model arises from temporary shocks and our results are not sensitive to changes in the persistence of the shocks. See Figure 3.5 in Appendix 3.A that presents the IRFs under different values of the persistence of the shock under carbon tax policy. The welfare ranking of the instruments also remains unchanged and the results are available upon request. Yet, in general, the dynamic structure of cost uncertainty can affect the choice between a price or quantity control, as shown in Parsons and Taschini (2013). Specifically, by using reduced form specification in tradition of the early price-quantity literature, they show that temporary shocks to abatement cost favor the use of a price control, while the permanent shocks favor a quantity control.

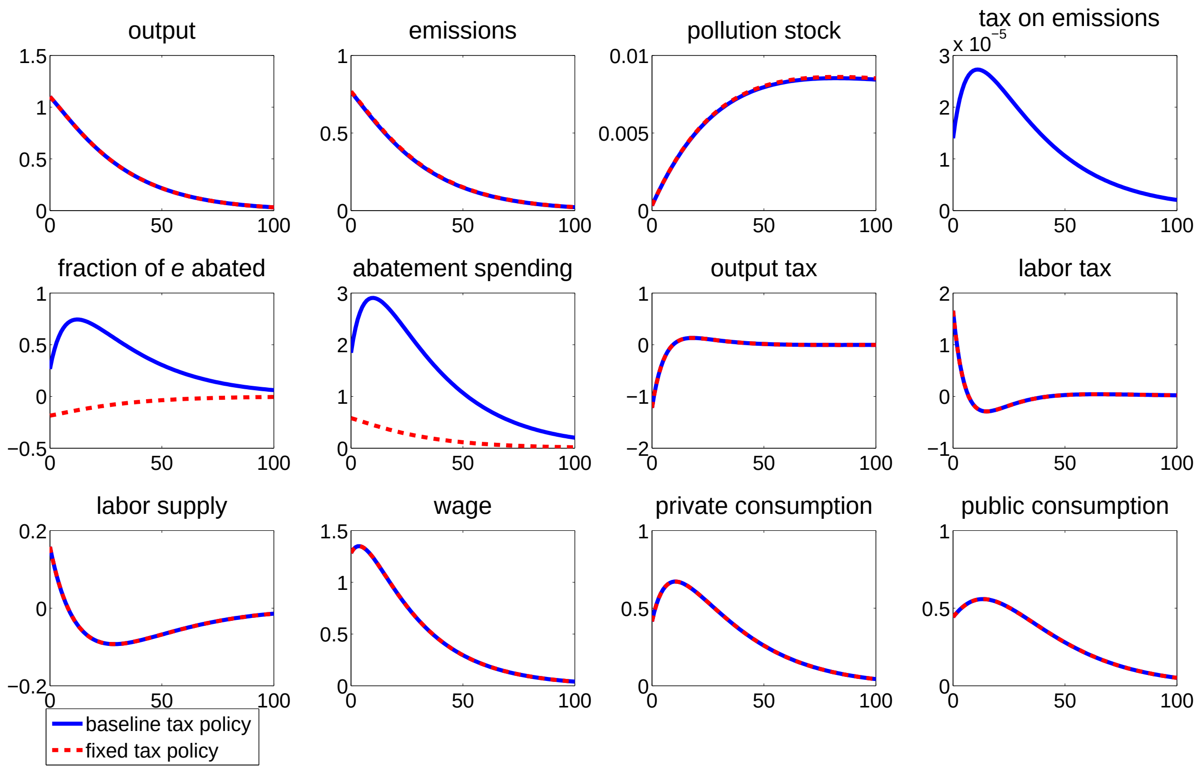


Figure 3.2: Responses under baseline carbon tax and fixed carbon tax policies to a positive TFP shock

Finally, some other studies also find very small differences in the welfare gains from contrasting different policy instruments, even though those estimates are not directly comparable with ours. In particular, Pizer (1999) investigates the relative performance of taxes versus rate controls (which hold the fractional reduction in emissions constant) in an integrated climate-economy model under uncertainty which is modeled including thousands of different states of nature. He finds that uncertainty leads to a preference for taxes over control rates, with the optimal rate control generating welfare gains[14] equivalent to a USD 73 increase in current per capita consumption, while the optimal tax policy generates a USD 86 increase.

[14]The source of such a gain is due to those states of the nature in which the marginal costs of reduction of emissions are low, while the marginal benefits are high, which favors more stringent policies. Opposing states of nature favor less stringent policies and thus generate losses from more stringent policies, but such losses are not as significant as the gains, resulting in an overall improvement in welfare. In other words, policies more stringent than the optimal control rate policy ignoring uncertainty improve welfare.

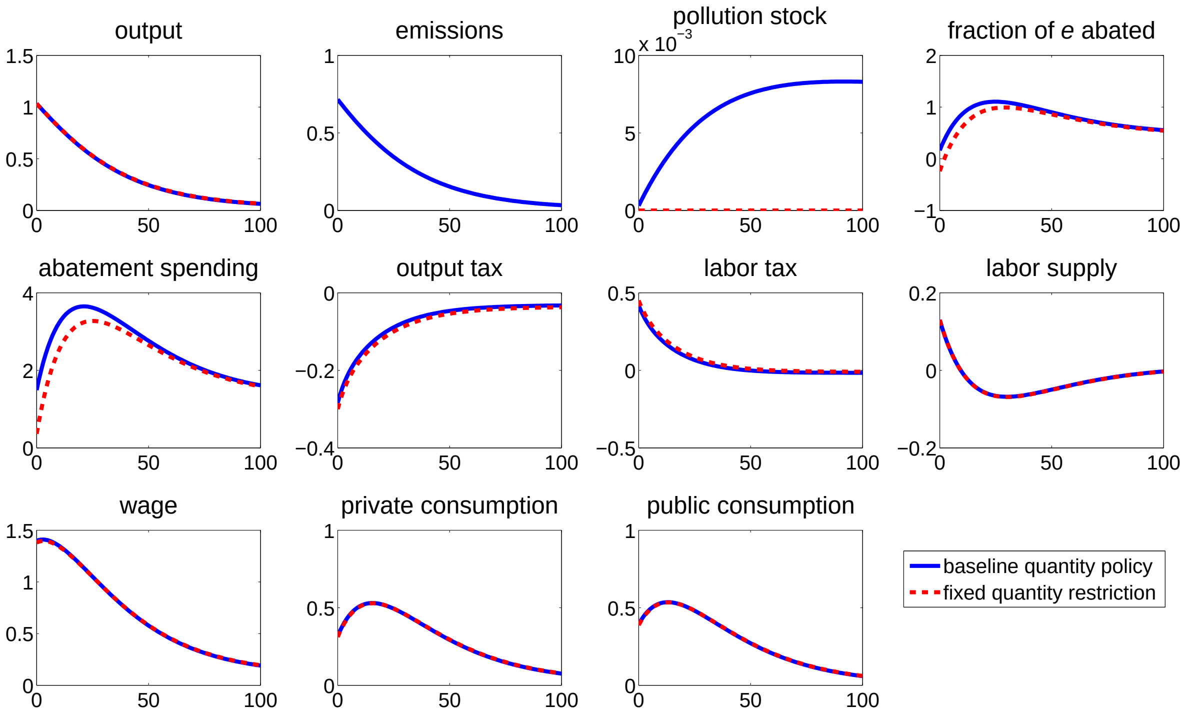


Figure 3.3: Responses under baseline cap-and-trade and fixed quantity restriction policies to a positive TFP shock

3.4.4 Associated Shocks to Abatement Technology

In this section, we discuss the simulation results of the scenario under which the economy is affected by two correlated shocks, a productivity shock and a shock to the abatement technology. This experiment is motivated by the following considerations. In our baseline model, uncertainty comes from the productivity shock. The existing "price versus quantity" literature, however, models a reduced form of the abatement cost function with mean-zero random shocks to marginal abatement costs. The shocks to the reduced form of abatement costs may originate (indirectly) from productivity shocks or directly from business cycles. In our framework, we can differentiate between these two types of shocks to abatement costs by considering a productivity shock and an abatement shock. We introduce an abatement shock as a shock to the abatement technology $\varepsilon_{ab,t}$:

$$\frac{z_t}{y_t} = m(\mu_t)\varepsilon_{ab,t} \tag{3.4.6}$$

which is assumed to follow an AR(1) process, defined as:

$$\ln \varepsilon_{ab,t} = \rho_{\varepsilon_{ab,t}} \ln \varepsilon_{ab,t-1} + \rho_{ab}\varepsilon_t, \tag{3.4.7}$$

where ε_t is the shock to productivity, and $\rho_{ab}\varepsilon_t$ is a shock to abatement technology. We assume $\rho_{ab} > 0$, which means that during expansions stemming from a positive productivity shock, abatement of a given fraction of emissions μ associated with a given output becomes more costly. As mentioned earlier, there are two new values in this extension that we need to parametrize, the value of the persistence of the shock to the abatement technology, and the value of the correlation between the shocks to productivity and the shocks to abatement. Since we assume that abatement costs vary with business cycles, we can set the value of persistence of the shock to abatement technology equal to the one of productivity shock. As the value of the correlation between productivity and abatement a priori is unknown, we experiment with two values of ρ_{ab}: 0.4 and 0.7.

Comparison of the impulse responses under the baseline policy and under the correlated shock case (Figure 3.4) reveals that adjustment to the shock to abatement technology happens through changing the total spending on abatement, without any notable effects on the behavior of the remaining variables. As a result, the firm produces the same level of emissions and abates the same fraction of emissions. This exercise illustrates that adjustment to some shocks, particularly those affecting abatement technology, is better dealt with at the firm level. This, as we discuss in the next section, provides an underpinning behind our argument in favor of price over quantity regulation in the real world.

3.4.5 Assumptions and Policy Implications

Our theoretical framework assumes a genuine uncertainty that exists not only for the regulator but also for producers. In Weitzman's (Weitzman, 1974) original analysis and in most studies that have followed, it is assumed that uncertainty in the marginal costs function is an information gap on the side of the regulator - randomness known to a producer but unknown to a regulator.[15] In this section we discuss how

[15] Laffont (1977) provides a detailed discussion of the information structure present in policy choice problems by a regulator choosing between prices or quantities in tradition of the original Weitzman's

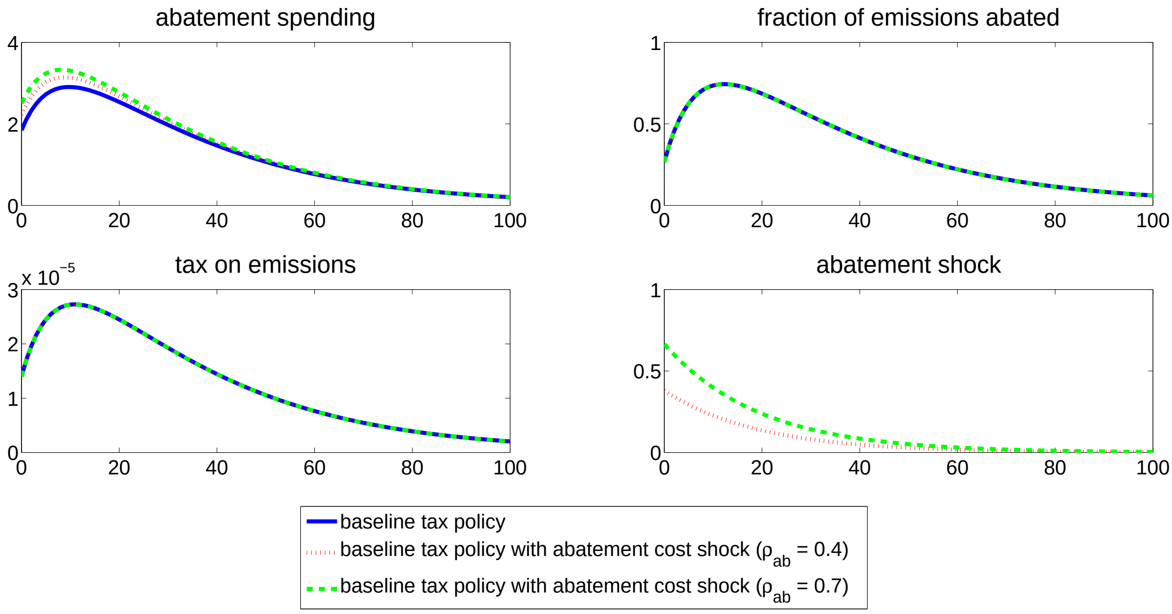


Figure 3.4: Responses to a TFP shock and to a TFP shock correlated with a shock to abatement technology

the presence of information asymmetry as in previous studies can affect the result on the relative preference of price over quantity and we conclude by drawing policy implications.

We do not model information asymmetry explicitly in our framework, but we believe that some of our results can provide arguments in favor of price over quantity instruments in the presence of information gap described above. In particular, we have shown that optimal adjustment to some type of shocks, such as shocks to abatement technology, occurs at the firm level. Thus, our results can imply that even in the more "ideal" situation with the absence of information asymmetry, it is more optimal for firms to find their own efficient solutions. In a world with such an uncertainty gap, it may be even more desirable to provide firms and businesses with the flexibility to innovate and find their best adjustment solutions, while not requiring the regulator to face the difficult task of estimating the marginal costs of abatement by firms. This is because firms possess better information about abatement costs than the regulator as they are closer to the actual production process. That is why we believe that

analysis.

the presence of information gap further reinforces our argument in favor of price instruments.

This line of reasoning echoes more general arguments about the superiority of price over quantity instruments in the face of shocks to growth and technology outlined by Pizer (2003), p. 19:[16]

> *"Rather than attempting to hit a fixed quantity target at any cost, we should instead price emissions at our best guess concerning their rate of marginal damage. Since there is a real risk that the costs of hitting a fixed quantity target can be extremely high - depending on growth and technology - such targets make little sense."*

3.5 Carbon Taxes and Business Cycles

We have shown that the optimal carbon tax is approximately constant over the business cycle. Our results are in contrast with the findings of Heutel (2012) who finds a procyclical behavior of optimal carbon taxes. In this section, we explain what drives the divergence of our results.

We start with reporting the standard deviations of carbon tax, output and emissions and their ratios in the two models in Table 3.4. Following Heutel (2012), the statistics are obtained by simulating the economy for 100 periods, and the reported standard deviation is the mean of over 10,000 draws from the distribution of the productivity shock. To compute statistics in Heutel's original model, we use the replication codes available on his webpage.

Two results emerge from the table. First, the standard deviation of the optimal carbon tax is about the same as the standard deviation of output, and just slightly higher than the standard deviation of emissions in Heutel's original model. Second, the table shows that the extension of Heutel's model with distortionary fiscal policy which equips the regulator with additional instruments to accommodate the business cycles (our model), plays an important role in reducing overall volatility. Most

[16] Pizer (2003) tests the robustness of the claim that under the possibility of catastrophic damages, a quantity instrument is the preferred instrument. The existence of some thresholds of climate change is one of the arguments for quantity-based regulations. For more comprehensive discussions of the advantages of carbon tax vs cap-and-trade, see, e.g., Hepburn (2006) and Goulder and Schein (2013).

importantly, the volatility of carbon taxes declines, and is reduced by more than those of output and emissions. Furthermore, the relative volatility of emissions to output is the same across the two models.

	Standard deviation (%)		
Model	τ_E	y	e
Heutel's	2.02%	2.04%	1.4%
ours	0.48%	0.77%	0.53%
ratio	4.2	2.6	2.6

Table 3.4: Standard deviations of carbon tax, output and emissions

To explain the procyclicality result of carbon taxes in Heutel's model, we present the optimal conditions of the firms and household's Euler equations from his model:

$$r_t = (1 - d(x_t))f'_k[1 - \tau_{Et}(1 - \mu_t)h'(y_t) - m(\mu_t)], \tag{3.5.1}$$

$$\tau_{Et} = \frac{y_t m'(\mu_t)}{h(y_t)}, \tag{3.5.2}$$

$$u_{c,t} = \beta E_t u_{c,t+1}[1 - \delta + r_t]. \tag{3.5.3}$$

Equation (3.5.2) is identical to the equation in our model (3.2.14) and represents the role of carbon taxes internalizing the climate externality. The setting of the theoretical framework in Heutel's model, however, implies that carbon taxes, in addition to internalizing climate externality, facilitate the intertemporal allocation of consumption across periods (equations (3.5.1) and (3.5.3)). Intuitively, as abatement is more costly during economic expansions, the carbon tax rises to prompt firms to avoid producing more emissions during expansions; the opposite is true during recessions. This implies an intertemporal trade-off in emissions and consequently in consumption: emit (consume) relatively less today during booms, but be compensated for that with relatively higher emissions (consumption) during recessions. In line with this, Heutel (2012), p.261 , points out that: *"It is this variance in consumption, not in the pollution stock, that leads to the variance in the emissions tax"*. In such a way, carbon taxes end up doing double duty by accommodating the business cycles. Such a "non-standard" outcome usually appears in the optimal taxation literature when the tax system is *incomplete*. We demonstrate below that incompleteness of the tax system is in fact present in Heutel's model but is not an issue for the model of this chapter.

Chari and Kehoe (1998) define a tax system as incomplete, if, for at least one pair of goods, the government has *no* tax instruments that drive a wedge between the marginal rate of substitution (MRS) and the marginal rate of transformation (MRT) for those goods. A tax system is said to be complete when this is not the case. Incomplete tax systems can lead to"non-standard" policy prescriptions because some instruments end up substituting for the ability to create certain wedges that cannot be created in a decentralized economy.[17] Chari and Kehoe (1998) argue that optimal taxation is best understood in terms of the optimal wedges between the MRS and the corresponding MRT. There is one independent MRS/MRT pair in Heutel's model summarized as follows:

$$MRS_{c_t,c_{t+1}} \equiv \frac{\beta u_{c,t+1}}{u_{c,t}}; \;\; MRT_{c_t,c_{t+1}} \equiv \frac{1}{y_{k,t+1}+1-\delta}. \tag{3.5.4}$$

MRS and MRT above have the standard interpretation: the MRS is a ratio of marginal utilities, while the MRT is a ratio of the marginal products of an appropriate production possibilities frontier. The intertemporal MRT can be interpreted by using the economy-wide intertemporal budget constraint as follows. If consumption today is reduced by one unit, then the economy gains one additional unit of capital k_{t+1} (holding output of all other goods constant), which increases c_{t+1} via next period production. Thus, a unit reduction in c_t leads to a gain of $y_k(t+1)+1-\delta$.

A (first-best) socially efficient allocation is characterized by a "zero wedge" condition:

$$E_t \frac{MRS_{c_t,c_{t+1}}}{MRT_{c_t,c_{t+1}}} = 1, \tag{3.5.5}$$

while in Heutel's model, carbon taxes introduce a wedge between MRS and MRT as MRT is a function of carbon taxes; and carbon taxes thus affect the intertemporal consumption allocation over business cycles:

$$E_t \frac{MRS_{c_t,c_{t+1}}}{MRT_{c_t,c_{t+1}}(\tau_{Et})} = 1 \tag{3.5.6}$$

[17] Correia (1996) provide examples in which an incomplete tax system results in non-zero capital-income taxation. See also Aruoba and Chugh (2010) for further discussion.

in addition to correcting the externality as captured by equation (3.5.1). Thus, to ensure completeness of the tax system in the framework similar to the one in Heutel, it is necessary to introduce one additional *distortionary* tax. However, since we also introduce labor and as a result, carbon taxes can affect the labor-leisure choice in our setting, we need to introduce two distortionary taxes: on labor and production[18], and under such setting the carbon tax only plays the role it was originally introduced for - correction of climate externality. Specifically, the counterpart of the condition (3.5.6) in our model is:

$$E_t \frac{MRS_{c_t,c_{t+1}}}{MRT_{c_t,c_{t+1}}(\tau_{Et},\tau_t)} = 1 \tag{3.5.7}$$

and our model also features another MRS/MRT pair summarized as follows:

$$MRS_{c,l} \equiv \frac{u_c(t)}{u_L(t)}; MRT_{c,l} \equiv -y_L(t) = -\frac{w_t(1+\tau_{Lt})}{1-\tau_t-\tau_{Et}(1-\mu_t)h'(y_t)-m(\mu_t)}. \tag{3.5.8}$$

The conditions that characterize the allocation in the absence of distortionary taxes include (3.5.5) and:

$$\frac{MRS_{c,l}}{MRT_{c,l}} = 1, \tag{3.5.9}$$

but in our model, tax on labor drives a wedge between the MRS and the MRT between consumption and work (or between consumption and leisure with the opposite sign):

$$\frac{MRS_{c,l}}{MRT_{c,l}} = -\frac{1+\tau_{Lt}}{1-\tau_t-\tau_{Et}(1-\mu_t)h'(y_t)-m(\mu_t)}. \tag{3.5.10}$$

In sum, conditions (3.5.7) and (3.5.10) prove that the regulator in our model has two tax instruments, tax on labor and tax on output for each wedge between the MRS and the MRT, which proves the completeness of the tax system. The carbon tax internalizes the climate externality through (3.2.14). The introduction of additional

[18]Introducing an output tax is not the only option to distort the intertemporal allocation of consumption; another option would be a tax on capital income. We have experimented with a version of the model with both capital and labor taxes; our results go through but the welfare cost differences under fixed tax and fixed cap-and-trade policies become much smaller. Intuitively, with another set of instruments which can potentially "better" cushion the economy against the shocks, the policy framework becomes equivalent to the certainty case under which there is simple duality between price and quantity instruments. For our objective, it is does not matter which model is presented, but since the model with capital tax is a bit more cumbersome as it requires re-writing the Ramsey problem in a time-consistent way, we present the model with output tax. The results for another model are available upon request.

taxes is in line with Tinbergen (1952) who notes that the number of policy instruments needs to be equal to the number of policy targets. However, in the case of policy instruments with side-effects, supplementary instruments may be needed to control these side-effects. This is the case in our model.

The above discussion raises a question which has important policy implications: should environmental policies, carbon taxes in particular, be used as instruments to stabilize the economy in the face of shocks to economic activity? Our analysis suggests that carbon taxation is unlikely to be justified on the grounds other than to target climate externalities. This logic is similar to the conclusion of the optimal taxation theory applied to the taxation of energy and energy-related products: pure revenue raising is best done with wide-base taxes, such as VAT or taxes on labor, rather than carbon taxes, and carbon taxation should not be pursued merely in order to raise public revenues.

3.6 Conclusion

The analysis of the optimal policy instrument to control CO2 emissions under uncertainty from business cycles has recently gained relevance and importance, particularly in the aftermath of the financial and economic crisis of 2008. The debate is under way on how the EU ETS system needs to be reformed to make the system more resilient to unanticipated shocks, in particular stemming from changes in economic circumstances. Within academic literature, there are two strands of research, price vs. quantity literature and studies that analyze the optimal design of environmental policies over the business cycle; which yield different implications for the behavior of carbon taxes in response to fluctuations in economic activity.

This chapter contributes to the existing literature by analyzing the optimal design and the relative performance of two distinct instruments - price and quantity - over the business cycles. We analyze both state-contingent and “basic” regulations (with price or quantity fixed at their steady state levels) within a dynamic general equilibrium framework with distortionary fiscal policy. Our focus is on price-based and quantity-based policies, most frequently contrasted in the literature, but we acknowledge that it is possible to form hybrid instruments, a combination of price and quantity mechanisms. We take into account the simplest form of a cap-and-trade mechanism when considering quantity based regulation, and in particular, we abstract from the so-called banking or borrowing of emission permits, which in a dynamic setting, can make quantity policies more flexible.

We find that the optimal state-contingent policy in response to a productivity shock turns out to be a carbon tax that fluctuates very little, while emissions fluctuate more. We note that the marginal abatement costs that vary with business cycles are a reason why the optimal quantity regulation under state-contingent cap-and-trade policy is procyclical. Using state-contingent policies as ideal instruments, we argue that the same dynamics of the marginal abatement costs make fixed quantity policies disadvantageous over fixed price based regulations. We also explain what causes divergence in our results from the ones in Heutel (2012), suggesting that carbon taxes in his framework play double duty by accommodating business cycles, leading to procyclical responses to business cycle shocks.

Our results lend support to the findings of Pizer (1999), Hoel and Karp (2002) and others who argue in favor of a price rather than quantity instrument in controlling CO2 emissions in the short-run, when damages from climate changes remain relatively "flat".

Appendix to Chapter 3

3.A Productivity Shock and Associated Increase in the Stock of Pollution

In our baseline model a 1% TFP shock results in an increase in the pollution stock of about 0.0085% over 25 years. How does this number relate to reality? The Mauna Loa Observatory[19] provides monthly information on the concentration of the atmospheric carbon dioxide. The concentrations are expressed in parts per million (ppm), which give the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. The Carbon Dioxide Information Analysis Center[20] provides conversion tables that enable us to convert this measure of atmospheric CO2 concentration into gigatons of carbon. 1 ppm by volume of atmosphere CO2 equals to 2.13 GtC. This measure does not count the mass of oxygen in the CO2 molecule, but since the atom weight of carbon (12 units) and of CO2 (44 units), one unit of GtC is equivalent to 44/12=3.67 GtCO2 (see Dessler and Parson, 2010, p.201), and 1ppm is therefore equivalent to 2.13 GtC and 7.82 GtCO2.

As of January 2015, the concentration of CO2 in atmosphere stood at 399.85 ppm or equivalently at 851.68 GtC or 3126.83 GtCO2. If we treat this value as our steady state, an additional increase of 0.0085% in the pollution stock over 25 years time period, as suggested by impulse response function, corresponds to 0.034 ppm, or 0.07 GtC and 0.27 GtCO2 increase in the concentration of CO2 in atmosphere. World CO2 emissions in 2013 stood at 35.3 GtCO2. Assuming that the level of yearly emissions does not change, over a period of 25 years the world will emit 882.5 GtCO2 meaning that an additional increase in the CO2 stock due to a TFP shock constitutes only 0.03% of all emissions over a 25-year period.

Intergovernmental Panel on Climate Change (2007) reports a table (Table 5.1, p. 67) that relates CO2 concentration in the atmosphere to the global temperature and average sea level increase above pre-industrial levels. At CO2 concentrations of 350-400 ppm (current level), global temperature increase above pre-industrial levels ranges from 2.0-2.5°C, and the global average sea level rises above the pre-industrial

[19] http://co2now.org/
[20] http://cdiac.ornl.gov/pns/convert.html

level from 0.4-1.4 m. For the 400-440 ppm range the corresponding numbers are: 2.4-2.8°C and 0.5-1.7°C. Thus an increase in CO2 concentration from the current level to 440 ppm (by 40 ppm) could lead to a maximal increase in the temperature above pre-industrial levels of 0.4°C (2.8°C-2.4°C) and the maximum sea rise level of 0.3 m (1.7m-1.4m). Treating these estimates as our reference, we can conclude that an additional increase in CO2 concentrations of 0.034 ppm would correspond to an increase in temperature by 0.00034°C and an additional increase in the sea level by 0.000255m over 25 years interval following the productivity shock.

3.B Data Sources

In this section we describe data sources and U.S. data entry components into Table 3.2.
Data from the NIPA tables are for year 2013.

- GDP - from the NIPA Table 1.5.5. Gross Domestic Product, Expanded Detail, line 1.

- Personal consumption expenditure - from the NIPA Table 1.5.5. Gross Domestic Product, Expanded Detail, line 2.

- Government consumption expenditure - from the NIPA Table 1.5.5. Gross Domestic Product, Expanded Detail, line 55+line 58+line 61.

- Government gross investment - from the NIPA Table 1.5.5. Gross Domestic Product, Expanded Detail, line 56+line 59+line 62.

- Gross private domestic investment - from the NIPA Table 1.5.5. Gross Domestic Product, Expanded Detail, line 26.

- Emissions per unit of total GDP - for 2012 for the U.S. from the United States Environmental Protection Agency (2013), p.ES-24, Table ES-9.

- Fraction of emissions abated: derived from author's calculations with original data from Creyts et al. (2007), who provide estimates of potential abatement projections for greenhouse gases in the U.S. They estimate that the U.S. would potentially abate cumulative 3GtCO2 of emissions for the period 2005-2030. Assuming the same amount of emissions abated every year during 25 years time period, from 2005 to 2030, and given that total greenhouse gas emissions amounted to 6.5GtCO2 by the U.S. in 2012 (United States Environmental Protection Agency (2013)), we obtain 1.85%, an estimate of the fraction of emissions abated in 2012.

- Abatement Spending - from the U.S.Census Bureau (2008), Table 1 (Pollution Abatement Operating Costs) and Table 2 (Pollution Abatement Capital Expenditures). U.S.Census Bureau (2008) is a survey of a sample of 20000 manufacturing plants, which, according this survey, spent 20677.6 mln USD on pollution abatement operating costs and 5907.8 mln USD on pollution abatement capital expenditures in 2005. By combining these data with the U.S. GDP data for 2005, USD 13095.4 bln, we obtain estimate of the fraction of abatement spending in GDP, 0.2%, reported in the main part of the chapter.

- Labor tax - OECD, Taxing Wages 2014 (May 2014), `http://www.oecd-ilibrary.org/taxation/taxing-wages-2014_tax_wages-2014-en`

- Output tax - gross receipt tax, similar to a sales tax, but levied on the seller of goods rather than on consumers. It is in place in several states in the U.S., e.g. Washington, Ohio, Texas. We use the calculations of the Tax Foundation[21] that converted the gross receipt taxes into an effective corporate income tax, taking into account also the burden of the federal tax imposed on corporations.

- Revenue from environmental taxes - Congressional Budget Office (2013) estimates potential tax revenues from carbon taxes at 1.2 trillion USD in a 10 years period. Assuming a yearly revenue of 0.12 trillion USD, we calculate it as a fraction of US GDP in 2013 and obtain the estimate 0.7% of GDP.

- Steady state value of government bonds as relation to output - based on Table B79 (federal debt held by public as percent of gross domestic product) from Council of Economic Advisers (2013).

[21] `http://taxfoundation.org/article/us-states-lead-world-high-corporate-taxes`

3.C First-order Conditions of the Ramsey Problem

The first-order conditions of the Ramsey problem outlined in section 3.2.6 are given by:

$$u_c'(t) - \lambda_t u_{cc}''(t) + \lambda_{t-1} u_{cc}''(t)(1-\delta+r_t) + \Omega_t - (\Lambda_t \tau_{Lt} l_t - \varsigma_t(1+\tau_{Lt}))\frac{u_{Lc}''(t)u_c'(t) - u_L'(t)u_{cc}''(t)}{(u_c'(t))^2} = 0 \tag{3.C.1}$$

$$\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial \mu_t} + \Omega_t m'(\mu)y_t - \chi_t y_t m''(\mu) - \Lambda_t \tau_{Et} h(y_t) + \varsigma_t(1-d(x_t))f_L'[\tau_{Et}h'(y_t) - m'(\mu_t)] + \Phi_t h(y_t) = 0 \tag{3.C.2}$$

$$\begin{aligned} &\lambda_t \beta u_c'(t+1)\frac{\partial r_{t+1}}{\partial k_t} + \Omega_t - \beta(1-\delta)\Omega_{t+1} - \lambda_{pt+1}\beta(1-d(x_{t+1}))f_k'(t+1) + \\ &+\beta\varsigma_{t+1}(1-d(x_{t+1}))f_{kL}(t+1) * \\ &*[1-\tau_{t+1} - \tau_{Et+1}(1-\mu_{t+1})h'(y_{t+1}) - m(\mu_{t+1})] = 0 \end{aligned} \tag{3.C.3}$$

$$\begin{aligned} &\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial y_t} + \Omega_t(m(\mu_t)-1) + \chi_t[\tau_{Et}h'(y_t) - m'(\mu_t)] + \Lambda_t[\tau_{Et}(1-\mu_t)h'(y_t) + \tau_t] + \\ &+\lambda_{pt} + \varsigma_t(1-d(x_t))f_L'[-\tau_{Et}(1-\mu_t)h''(y_t)] - \Phi_t(1-\mu_t)h'(y_t) = 0 \end{aligned} \tag{3.C.4}$$

$$\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial x_t} + \lambda_{pt}d'(x_t)f(t) - \varsigma_t d'(x_t)f_L'[1-\tau_t - \tau_{Et}(1-\mu_t)h'(y_t) - m(\mu_t)] + \Phi_t - \beta\eta\Phi_{t+1} = 0 \tag{3.C.5}$$

$$\begin{aligned} &u_L' - \lambda_t u_{cL}'' + \lambda_{t-1}u_{cL}''(1-\delta+r_t) + \lambda_{t-1}u_c'\frac{\partial r_t}{\partial l_t} + \\ &+\Lambda_t[-\frac{u_L'}{u_c'}\tau_{Lt} - \tau_{Lt}l_t\frac{u_{Lc}''u_c' - u_L'u_{cc}''}{(u_c')^2}] - \lambda_{pt}(1-d(x_t))f_L' + \varsigma_t(1+\tau_{Lt})\frac{u_{Lc}''u_c' - u_L'u_{cc}''}{(u_c')^2} + \\ &+\varsigma_t(1-d(x_t))f_{LL}''[1-\tau_t - \tau_{Et}(1-\mu_t)h'(y_t) - m(\mu_t)] = 0 \end{aligned} \tag{3.C.6}$$

$$\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial \tau_{Lt}} - \Lambda_t\frac{u_L'}{u_c'}l_t + \varsigma_t\frac{u_L'}{u_c'} = 0 \tag{3.C.7}$$

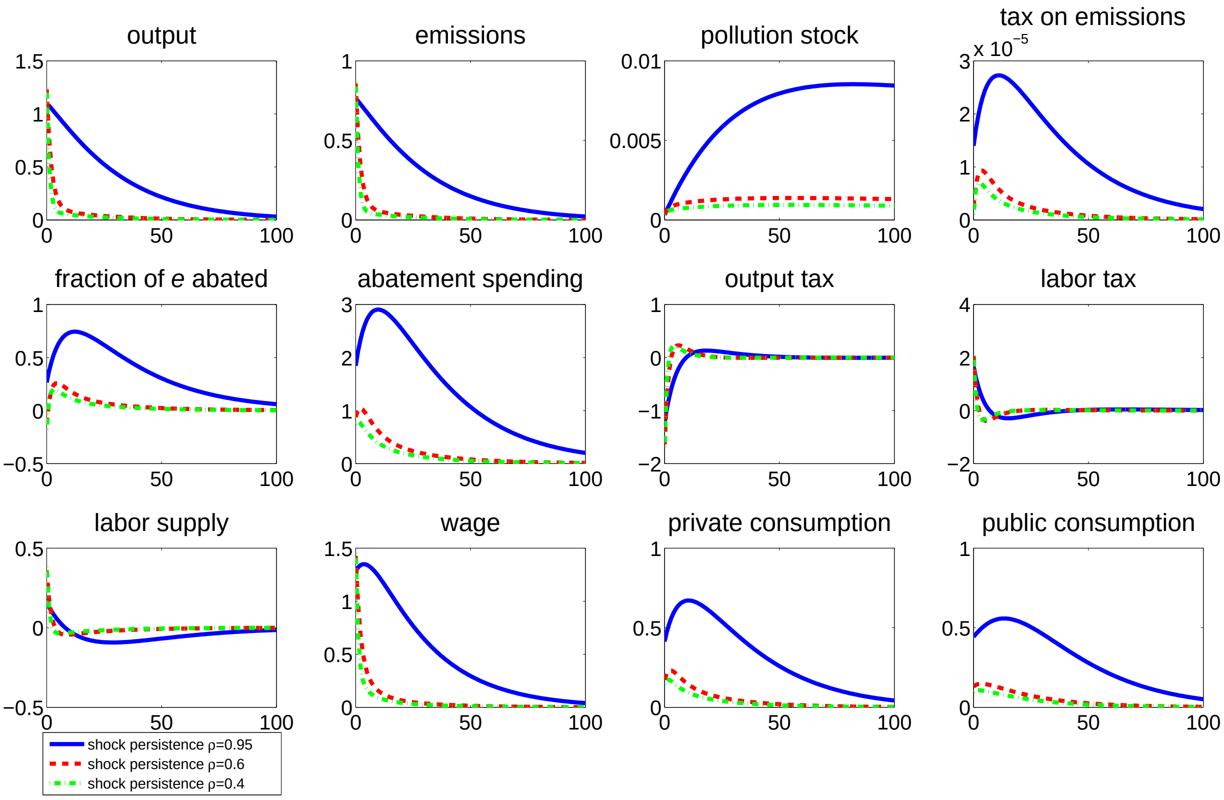


Figure 3.5: Responses to a TFP shock under different values of the persistence of the shock ρ

$$\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial \tau_{Et}} + \chi_t h(y_t) + \Lambda_t(1-\mu_t)h(y_t) - \varsigma_t(1-d(x_t))f_L'(1-\mu_t)h'(y_t) = 0 \tag{3.C.8}$$

$$\lambda_{t-1}u_c'(t)\frac{\partial r_t}{\partial \tau_t} + \Lambda_t y_t - \varsigma_t(1-d(x_t))f_L' = 0 \tag{3.C.9}$$

$$\Lambda_t \rho_{Bt} - \beta\Lambda_{t+1} = 0 \tag{3.C.10}$$

$$u_g' - \lambda_t u_{cg}'' + \lambda_{t-1}u_{cg}''(1-\delta+r_t) - \Lambda_t + \Omega_t + (\varsigma_t(1+\tau_{Lt}) - \Lambda_t\tau_{Lt}l_t)\frac{u_{Lg}''u_c' - u_L'u_{cg}''}{(u_c')^2} = 0 \tag{3.C.11}$$

Bibliography

ADRIAN, T. AND H. S. SHIN (2010): "Liquidity and leverage," *Journal of Financial Intermediation*, 19, 418–437.

——— (2011): "Financial Intermediary Balance Sheet Management," *Annual Review of Financial Economics*, 3, 289–307.

AMROMIN, G. AND A. PAULSON (2010): "Default rates on prime and subprime mortgages: differences & similarities," *Profitwise*, 1–10.

ANGELINI, P. (2000): "Are Banks Risk Averse? Intraday Timing of Operations in the Interbank Market," *Journal of Money, Credit and Banking*, 32, 54–73.

ANGELINI, P., S. NERI, AND F. PANETTA (2011): "Monetary and macroprudential policies," *Bank of Italy Working Paper*.

ARCHER, D. (2005): "Fate of fossil fuel CO2 in geologic time," *Journal of Geophysical Research: Oceans*, 110, n/a–n/a.

ARUOBA, S. AND S. CHUGH (2010): "Optimal fiscal and monetary policy when money is essential," *Journal of Economic Theory*, 145, 1618–1647.

ASSENMACHER-WESCHE, K. AND S. GERLACH (2008): "Monetary policy, asset prices and macroeconomic conditions : a panel-VAR study," *National Bank of Belgium Working Paper*.

BARRAGE, L. (2014): "Optimal dynamic carbon taxes in a climate-economy model with distortionary fiscal policy," *working paper, University of Maryland.*

Bernanke, B. S. and M. Gertler (1995): "The Credit Channel of Monetary Policy Transmission," *Journal of Economic Perspectives*, 9, 27 – 48.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999): "Chapter 21 The financial accelerator in a quantitative business cycle framework," Elsevier, vol. 1, Part C of *Handbook of Macroeconomics*, 1341 – 1393.

Bunn, P. and C. Ellis (2009): "Price-setting behaviour in the United Kingdom: a microdata approach," *Bank of England Quarterly Bulletin*, Q1, 28–36.

Calza, A., T. Monacelli, and L. Stracca (2013): "Housing Finance And Monetary Policy," *Journal of the European Economic Association*, 11, 101–122.

Chari, V. V. and P. Kehoe (1998): "Optimal Fiscal and Monetary Policy," *Research Department Staff Report 251, Federal Reserve Bank of Minneapolis*.

Clarida, R., J. Gali, and M. Gertler (1999): "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature*, 37, 1661–1707.

Coles, A. and J. Hardt (2000): "Mortgage markets: why US and EU markets are so different," *Housing Studies*, 15.

Congressional Budget Office (2013): *Effects of a Carbon Tax on the Economy and the Environment*.

Correia, I. (1996): "Should Capital Income be Taxed in the Steady State?" *Journal of Public Economics*, 60, 147–151.

Council of Economic Advisers (2013): *Economic Report of the President*, United States Government Printing Office.

Creyts, J., A. Derkach, S. Nyquist, K. Ostrowski, and J. Stephenson (2007): *Reducing U.S. Greenhouse Gas Emissions: How Much at What Costs*, U.S. Greenhouse Gas Abatement Mapping Initiative.

Crowe, C., G. Dell'Ariccia, D. Igan, and P. Rabanal (2011): "How to Deal with Real Estate Booms: Lessons from Country Experiences," *IMF Working Paper*.

Cutler, J. (2002): "UK house prices - an accident waiting to happen?" *CML Housing Finance*, 55, 11–25.

Dedola, L. and G. Lombardo (2012): "Financial frictions, financial integration and the international propagation of shocks," *Economic Policy*, 27, 319–359.

Demyanyk, Y. and O. V. Hemert (2011): "Understanding the Subprime Mortgage Crisis," *Review of Financial Studies*, 24, 1848–1880.

Dessler, A. and E. A. Parson (2010): *The Science and Politics of Global Climate Change: A Guide to the Debate*, Cambridge University Press.

Devereux, M. B. and A. Sutherland (2010): "Country portfolio dynamics," *Journal of Economic Dynamics and Control*, 34, 1325–1342.

Devereux, M. B. and J. Yetman (2010): "Leverage Constraints and the International Transmission of Shocks," *Journal of Money, Credit and Banking*, 42, 71–105.

Dhyne, E., L. J. Alvarez, H. L. Bihan, G. Veronese, D. Dias, J. Hoffmann, N. Jonker, P. Lunnemann, F. Rumler, and J. Vilmunen (2006): "Price Changes in the Euro Area and the United States: Some Facts from Individual Consumer Price Data," *Journal of Economic Perspectives*, 20, 171–192.

DiCecio, R. and E. Nelson (2007): "An Estimated DSGE Model for the United Kingdom," *Federal Reserve Bank of St. Louis Review*, 89, 215–31.

Duca, J. V., J. Muellbauer, and A. Murphy (2012): "Credit standards and the bubble in US house prices: new econometric evidence," *BIS Papers: Property markets and financial stability*, 83–89.

Dueker, M., A. Fischer, and R. Dittmar (2007): "Stochastic Capital Depreciation and the Co-movement of Hours and Productivity," *The B.E. Journal of Macroeconomics*, 6, 1–24.

Eickmeier, S. and T. Ng (2015): "How do {US} credit supply shocks propagate internationally? A {GVAR} approach," *European Economic Review*, 74, 128 – 145.

Enders, Z., G. J. Müller, and A. Scholl (2011): "How do fiscal and technology shocks affect real exchange rates?: New evidence for the United States," *Journal of International Economics*, 83, 53 – 69.

Faccini, R., S. Millard, and F. Zanetti (2011): "Wage rigidities in an estimated DSGE model of the UK labour market," *Bank of England Working Paper*.

Faia, E. (2011): "Credit Risk Transfers and the Macroeconomy," *Kiel Working Papers*.

Fell, H., I. A. MacKenzie, and W. A. Pizer (2012): "Prices versus quantities versus bankable quantities," *Resource and Energy Economics*, 34, 607–623.

Fischer, C. and G. Heutel (2013): "Environmental Macroeconomics: Environmental Policy, Business Cycles, and Directed Technical Change," *Annual Review of Resource Economics*, 5, 197–210.

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

Fry, R. and A. Pagan (2007): "Some issues in using sign restrictions for identifying structural VARs," *National Centre for Econometric Research Working Paper*, 14.

Gale, W. G., S. Brown, and F. Saltiel (2013): *Carbon Taxes as Part of the Fiscal Solution*.

Geithner, T. (2011): "Macroeconomic effects of risk retention requirements," *mimeo*.

Gerali, A., S. Neri, L. Sessa, and F. M. Signoretti (2010): "Credit and Banking in a DSGE Model of the Euro Area," *Journal of Money, Credit and Banking,*, 62, 107–141.

Golosov, M., J. Hassler, P. Krusell, and A. Tsyvinski (2014): "Optimal Taxes on Fossil Fuel in General Equilibrium," *Econometrica*, 82, 41–88.

Golosov, M., M. Troshkin, A. Tsyvinski, and M. Weinzierl (2013): "Preference heterogeneity and optimal income taxation," *Journal of Public Economics*, 97, 160–175.

Goodfriend, M. (2002): "The phases of U.S. monetary policy : 1987 to 2001," *Economic Quarterly*, 1–17.

Goodhart, C. and B. Hofmann (2008): "House prices, money, credit, and the macroeconomy," *Oxford Review of Economic Policy*, 24, 180–205.

Gorton, G. B. (2008): "The Panic of 2007," *Yale School of Management Working Papers*.

Gorton, G. B. and N. S. Souleles (2007): "Special Purpose Vehicles and Securitization," in *The Risks of Financial Institutions*, National Bureau of Economic Research, Inc, NBER Chapters, 549–602.

Goulder, L. H. and A. Schein (2013): "Carbon taxes vs. cap and trade: a critical review," *NBER working paper 19338*.

Grodecka, A. (2013): "Subprime borrowers, securitization and the transmission of business cycles," *Bonn Econ Discussion Papers*.

Grodecka, A. and K. Kuralbayeva (2014): "The Price vs Quantity Debate: Climate policy and the role of business cycles," *OxCarre Working Papers*.

Hayes, P. and G. Kane (2009): "Deleveraging commercial real estate in Europe," *Prudential Real Estate Investors*.

Helbling, T., R. Huidrom, M. A. Kose, and C. Otrok (2011): "Do credit shocks matter? A global perspective," *European Economic Review*, 55, 340 – 353.

Hellwig, M. (2009): "Systemic Risk in the Financial Sector: An Analysis of the Subprime-Mortgage Financial Crisis," *De Economist*, 157, 129–207.

Hepburn, C. (2006): "Regulation by prices, quantities, or both: a review of instrument choice," *Oxford Review of Economic Policy*, 22 (2), 226–247.

Heutel, G. (2012): "How Should Environmental Policy Respond to Business Cycles? Optimal Policy under Persistent Productivity Shocks," *Review of Economic Dynamics*, 15, 244–264.

HMTreasury (2003): "Housing, consumption and EMU," .

Hobijn, B. and F. Ravenna (2010): “Loan Securitization and the Monetary Transmission Mechanism,” Tech. rep.

Hoel, M. and L. Karp (2002): “Taxes versus quotas for a stock pollutant,” *Resource and Energy Economics*, 24, 367–384.

Hristov, N., O. Hülsewig, and T. Wollmershäuser (2012): “Loan supply shocks during the financial crisis: Evidence for the Euro area,” *Journal of International Money and Finance*, 31, 569 – 592.

Hull, J. and A. White (2010): “The Risk of Tranches Created from Mortgages,” *Financial Analysts Journal*, 66, pp. 54–67.

Hutchinson, J. M., A. W. Lo, and T. Poggio (1994): “ A Nonparametric Approach to Pricing and Hedging Derivative Securities via Learning Networks,” *Journal of Finance*, 49, 851–89.

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

——— (2013): “Financial Business Cycles,” *mimeo.*

——— (2014): “Financial Business Cycles,” *forthcoming in Review of Economic Dynamics.*

Iacoviello, M. and S. Neri (2010): “Housing Market Spillovers: Evidence from an Estimated DSGE Model,” *American Economic Journal: Macroeconomics*, 2, 125–64.

IMF (2009): “World Economic Outlook,” .

——— (2011): “Global Financial Stability Report,” .

Intergovernmental Panel on Climate Change (2001): *Climate Change 2001: The Scientific Basis*, Cambridge University Press.

——— (2007): *Climate Change 2007: Synthesis Report.*

Jaffee, D., A. Lynch, M. Richardson, and S. Van Nieuwerburgh (2009): "Mortgage Origination and Securitization in the Financial Crisis," *Financial Markets, Institutions & Instruments*, 18, 141–143.

Jappelli, T. (1990a): "Who Is Credit Constrained in the U.S. Economy?" *The Quarterly Journal of Economics*, 105, 219–34.

——— (1990b): "Who Is Credit Constrained in the U.S. Economy?" *The Quarterly Journal of Economics*, 105, 219–34.

Jones, D. (2000): "Emerging problems with the Basel Capital Accord: Regulatory capital arbitrage and related issues," *Journal of Banking and Finance*, 24, 35–58.

Jordà, O., M. H. Schularick, and A. M. Taylor (2014): "Betting the House," NBER Working Papers 20771, National Bureau of Economic Research, Inc.

Jovanoviè, M. N. (2013): *The Economics of European Integration*, Edward Elgar Publishing Limited.

Karp, L. and J. Zhang (2005): "Regulation of stock externalities with correlated abatement costs," *Environmental and Resource Economics*, 32, 273–299.

Keane, M. P. and R. Rogerson (2011): "Reconciling Micro and Macro Labor Supply Elasticities: A Structural Perspective," NBER Working Papers 17430, National Bureau of Economic Research, Inc.

Kiyotaki, N. and J. Moore (1997): "Credit Cycles," *Journal of Political Economy*, 105, 211–48.

Kliff, J. and P. S. Mills (2007): "Money for Nothing and Checks for Free: Recent Developments in U.S. Subprime Mortgage Markets," *IMF Working Papers*.

Kollmann, R., Z. Enders, and G. Müller (2011): "Global banking and international business cycles," *European Economic Review*, 55, 407–426.

Kuncl, M. (2014): "Securitization under Asymmetric Information over the Business Cycle," *CERGE-EI Working Papers*.

Laffont, J. J. (1977): "More on Prices vs. Quantities," *Review of Economic Studies*, 44(1), 177–182.

Lehnert, A. (2006): "Overview of US Mortgage Markets," *Bank of International Settlements*.

Liebowitz, S. (2009): "ARMs, Not Subprimes, Caused the Mortgage Crisis," *The Economists' Voice*, 6, 1–5.

Lim, C., F. Columba, A. Costa, P. Kongsamut, A. Otani, M. Saiyid, T. Wezel, and X. Wu (2011): "Macroprudential Policy: What Instruments and How to Use Them? Lessons from Country Experiences," *IMF Working Paper*, 105, pp. 211–248.

Lintunen, J. and L. Vilmi (2013): "On optimal emission control - Taxes, substitution and business cycles," Research Discussion Papers 24/2013, Bank of Finland.

Miles, D. (2004): "The UK Mortgage Market: Taking a Longer-Term View," Final report and recommendations, HM Treasury.

Moench, E., J. Vickery, and D. Aragon (2010): "Why Is the Market Share of Adjustable-Rate Mortgages So Low?" *Current Issues in Economics and Finance*, 16, 1–11.

Mountford, A. and H. Uhlig (2009): "What are the effects of fiscal policy shocks?" *Journal of Applied Econometrics*, 24, 960–992.

Musso, A., S. Neri, and L. Stracca (2011): "Housing, consumption and monetary policy: How different are the US and the euro area?" *Journal of Banking & Finance*, 35, 3019 – 3041.

Newell, R. G. and W. A. Pizer (2003): "Regulating stock externalities under uncertainty," *Journal of Environmental Economics and Management*, 45, 416–432.

Nishiyama, Y. (2007): "Are Banks Risk-Averse?" *Eastern Economic Journal*, 33, 471–490.

Nordhaus, W. D. (1991): "To slow or not to slow: the economics of the greenhouse effect," *The Economic Journal*, 101(407), 920–937.

——— (2008): *A question of balance*, Yale University Press.

Orphanides, A. (2004): "Monetary Policy Rules, Macroeconomic Stability, and Inflation: A View from the Trenches," *Journal of Money, Credit and Banking*, 36, 151–75.

Parsons, J. E. and L. Taschini (2013): "The role of stocks and shocks concepts in the debate over price versus quantity," *Environmental and Resource Economics*, 55, 71–86.

Peterman, W. B. (2012): "Reconciling micro and macro estimates of the Frisch labor supply elasticity," .

Pigou, A. C. (1920): *The economics of welfare*, London: Macmillan.

Pizer, W. A. (1999): "The optimal choice of climate change policy in the presence of uncertainty," *Resource and Energy Economics*, 21, 255–287.

——— (2002): "Combining price and quantity controls to mitigate global climate change," *Journal of Public Economics*, 85(3), 409–34.

——— (2003): "Climate change catastrophes," *RFF, discussion paper 03-31.*

Ratti, R. A. (1980): "Bank Attitude toward Risk, Implicit Rates of Interest, and the Behavior of an Index of Risk Aversion for Commercial Banks," *The Quarterly Journal of Economics*, 95, 309–31.

Reinhart, C. M. and K. S. Rogoff (2009): *This Time Is Different: Eight Centuries of Financial Folly*, vol. 1 of *Economics Books*, Princeton University Press.

Roberts, M. J. and M. Spence (1976): "Effluent charges and licences under uncertainty," *Journal of Public Economics*, 5, 193–208.

Rogerson, R. and J. Wallenius (2009): "Micro and macro elasticities in a life cycle model with taxes," *Journal of Economic Theory*, 144, 2277–2292.

Rubio-Ramirez, J. F., D. F. Waggoner, and T. Zha (2010): "Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference," *The Review of Economic Studies*, 77, 665–696.

Schmitt-Grohe, S. and M. Uribe (2007): "Optimal simple and implementable monetary and fiscal rules," *Journal of Monetary Economics*, 54, 1702–1725.

Schularick, M. and A. M. Taylor (2012): "Credit Booms Gone Bust: Monetary Policy, Leverage Cycles, and Financial Crises, 1870-2008," *American Economic Review*, 102, 1029–61.

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

Stavins, R. N. (1996): "Correlated uncertainty and policy instrument choice," *Journal of environmental economics and management*, 30, 218–232.

Temkin, K., J. E. H. Johnson, and D. Levy (2002): "Subprime markets, the role of GSEs, and risk-based pricing," U.S. Department of Housing and Urban Development's Office of Policy Development and Research.

Tinbergen, J. (1952): *On the Theory of Economic Policy*, North-Holland Publishing Company; Amsterdam.

Uhlig, H. (2005): "What are the effects of monetary policy on output? Results from an agnostic identification procedure," *Journal of Monetary Economics*, 52, 381 – 419.

United States Environmental Protection Agency (2013): *Draft inventory of U.S. greenhouse gas emissions and sinks:1990-2012*, National Service Center for Environmental Publications.

U.S.Census Bureau (2008): *Pollution Abatement Costs and Expenditures: 2005,*.

Vargas-Silva, C. (2008): "Monetary policy and the US housing market: A VAR analysis imposing sign restrictions," *Journal of Macroeconomics*, 30, 977 – 990.

Villa, S. and J. Yang (2011): "Financial intermediaries in an estimated DSGE model for the United Kingdom," *Bank of England Working Paper*.

Weitzman, M. L. (1974): "Prices vs quantities," *Review of Economic Studies*, 45(2), 229–238.

Wong, E., T. Fong, K. fai Li, and H. Choi (2011): "Loan-to-value ratio as macro-prudential tool - Hong Kong's experience and cross-country evidence," *Hong Kong Monetary Authority Working Paper*.

Xepapadeas, A. (2005): "Chapter 23 Economic growth and the environment," in *Economywide and International Environmental Issues*, ed. by K.-G. Maler and J. R. Vincent, Elsevier, vol. 3 of *Handbook of Environmental Economics*, 1219 – 1271.