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Introduction

This thesis consists of three chapters which analyze macroeconomic topics that drew much attention in the years of financial and economic crisis since 2007. Chapter 1 and Chapter 2 deal with the topic of sovereign default. Chapter 3 provides an analysis of the effects of monetary policy and credit shocks on house prices.

In the decades since the aftermath of the Second World War, sovereign default was mainly an issue of very poor countries or emerging market economies. However, in the years since 2009, also advanced European countries experienced a substantial increase in the spread between the interest rate on their governments' bonds and the yield of a supposedly riskless benchmark, like the German government's debt.

One policy reaction to this development was to establish European institutions, like the European Stability Mechanism (ESM), that can (and did) provide financial assistance to troubled countries. Providing financial assistance is also one of the tasks of the International Monetary Fund (IMF), which operates on a global level. The IMF exists already since 1945 and has provided loans to many countries in several crisis events, before also participating in the programs for the European countries in the recent crisis. Using a quantitative model of sovereign default, Chapter 1 of this thesis analyzes how the existence of such official lending institutions affects the likelihood of a sovereign default of a country, which has access to financial assistance.

An important insight on sovereign debt crises is the feature that they might not only be caused by fundamental reasons, such as high debt levels and low output, but that they also might be caused by self-fulfilling runs by investors. Such non-fundamental defaults are one main argument for the provision of financial assistance and hence are also considered in the analysis in Chapter 1.

While the quantitative analysis in Chapter 1 is done for the example of Argentina, a standard case of the sovereign default literature, Chapter 2 turns to an European example. The Chapter applies a model of sovereign default, that includes long-term debt and run-driven defaults, to analyze the crisis experience of Italy in the recent years, where the spread between Italian and German government bonds rose up to more than four percentage points.

Chapter 3 turns to a different topic that has played an important role in the analysis of the financial and economic crisis. The chapter provides an empirical analysis of the effects of monetary policy shocks and credit shocks on house prices. The shocks are identified using sign-restrictions from a theoretical model. The results obtained for data from the U.S. and the U.K. can inform on the effectiveness of policies to influence house prices while accounting for side-effects on the broader economy.

In the following each chapter is introduced in more detail:

Chapter 1 builds on joint work with Ronald Rühmkorf. In this chapter, a quantitative model of sovereign default is used to analyze the impact of the availability of loans by official international lenders on the probability of a country to default on its government debt. The official lender in the model captures important features of the IMF. Financial assistance is provided subject to conditionality for the government, modeled in form of debt targets, and seniority of the bailout loans over market debt. The possibility to receive financial assistance during times of crisis can provide the government with the funds necessary to fulfill its debt obligations and might hence help to avoid a default. The model considers a default as the optimal decision of the government and allows for fundamental crisis due to very low output realizations as well as for self-fulfilling crises due to runs by international investors. Runs by investors might occur in the so called crisis zone, where the decision of the investors to let the country roll over its debt decides on whether the country defaults or not. A failure of the investors to coordinate on a rollover of the country's debt induces a default. Using a sunspot variable to determine which equilibrium is selected the model can provide quantitative results for the question at hand.

For the quantitative analysis, the model is calibrated to match Argentinean data. The model simulations show that the probability of a default on market debt increases when financial assistance is available. This result can be explained by the fact, that the financial assistance works as an insurance for the investors. For given fundamentals the government is less likely to default when it has the possibility to receive financial assistance. However, there is a counteracting general equilibrium effect. Given the smaller default risk, the investors are willing to pay a higher price for government bonds. This in turn induces the government to borrow more. The resulting higher average debt levels then lead to more defaults in equilibrium.

Chapter 2 also deals with the topic of sovereign default. It analyzes to what extent a standard quantitative model of sovereign default can explain the developments of sovereign interest rate spreads observed for European countries during the crisis in the recent years. The chapter applies the model of sovereign default by Chatterjee and Eyigungor (2012) to analyze the situation of Italy in the time of the crisis on the European sovereign debt markets. The model features default as the optimal decision of the government, includes long-term debt and allows for self-fulfilling default crises. For the quantitative analysis the model is calibrated to match important moments of the Italian data. The analysis shows that while the model is able to match some aspects of the data, it predicts a counterfactual default in the early periods of the crisis, when output was extremely low. Furthermore, the quantitative results suggest that the development of the interest rate spreads are influenced by other factors than only the Italian fundamentals. Interestingly, the long maturity of Italian debt leaves only little room for self-fulfilling crises as considered in the model.

Chapter 3 is based on joint work with Anna Grodecka. The chapter provides an empirical analysis of the effects of monetary policy shocks and credit shocks on house prices and the broader economy. The analysis is conducted estimating vector autoregressive (VAR) models for time series of U.S. and U.K. data. The shocks are identified using sign restrictions derived from the impulse response functions of a dynamic stochastic general equilibrium (DSGE) model that includes house prices and collateralized credit. The empirical analysis shows that in the U.S. a negative monetary shock leads to a decline in house prices, while there is no such effect for the U.K. data. The credit shock, in contrast, has no significant effect on house prices for the U.S. data, but its effect is negative for the U.K. A reason for the differences in the strength of the effects of the two shocks in the two countries might amongst others be found in differences in the structure of mortgage contracts in the two countries. The chapter also provides a historical decomposition to shed light on the role of credit and monetary shocks for house price developments.

Chapter 1

Sovereign Borrowing, Financial Assistance, and Debt Repudiation[1]

1.1 Introduction

Does the availability of financial assistance help to avoid sovereign defaults? In the light of the European sovereign debt crisis this question has again become a pressing concern for policymakers. The overall impact of the availability of financial assistance is a priori unclear as it leads to two counteracting effects. On the one hand, financial assistance as provided e.g. by the International Monetary Fund (IMF) or the European Stability Mechanism (ESM) can counter runs by investors due to self-fulfilling default expectations and bridge deficits in times of low output and high debt levels. On the other hand, by providing insurance the availability of financial assistance lowers risk premia for troubled countries on international capital markets for a given debt level. Such a downward shift in borrowing costs might induce governments to raise debt levels and thus increase default incentives. We analyze the implications of the availability of financial assistance quantitatively using a model of sovereign default. The model features defaults due to bad fundamentals, runs by investors due to multiple equilibria, and an official lending facility that captures the main characteristics of actual international financial institutions. Runs on sovereign debt markets constitute a major threat for indebted governments as they can push countries into default that have in principle sound fundamentals and would not default otherwise. An official lending facility can help to prevent the possible coordination failure as financial assistance supplies the government with funds even when there

[1]This chapter is based on joint work with Ronald Rühmkorf (Kirsch and Rühmkorf, 2013). The final publication of this paper is available at link.springer.com, DOI: 10.1007/s00199-015-0945-0.

might be a run by private investors on the market for government debt.

The model is based on the standard sovereign default model à la Eaton and Gersovitz (1981) and builds on Cole and Kehoe (2000) by considering multiple equilibria due to runs by investors. The government of a small open economy can borrow both from private international investors and from an official lending facility. Each period the government decides whether to repay its debt or to default on its obligations. A default entails exclusion from international financial markets and a loss in output. As reported by Roubini and Setser (2004) bailout loans are de facto senior to market debt. We include this characteristic into the model: The government can either default on its market debt only or jointly on both types of debt.[2] In addition to defaults by the government that are caused by bad fundamentals, the private debt market is prone to self-fulfilling runs, in which the investors refuse to provide new credit and the government defaults. Market debt is priced endogenously by risk neutral international investors acting on perfectly competitive markets. In contrast, bailout loans are always provided according to a fixed price schedule that contains a surcharge on the risk-free interest rate. Using financial assistance is therefore unattractive for a country that can borrow at the risk-free rate from international investors. However, when default risk and risk premia are high, turning to bailout loans becomes relatively more attractive. In exchange for loans, the official lending facility demands policy adjustments ('conditionality') from the government: The government has to restrict deficits as long as it keeps making use of financial assistance.

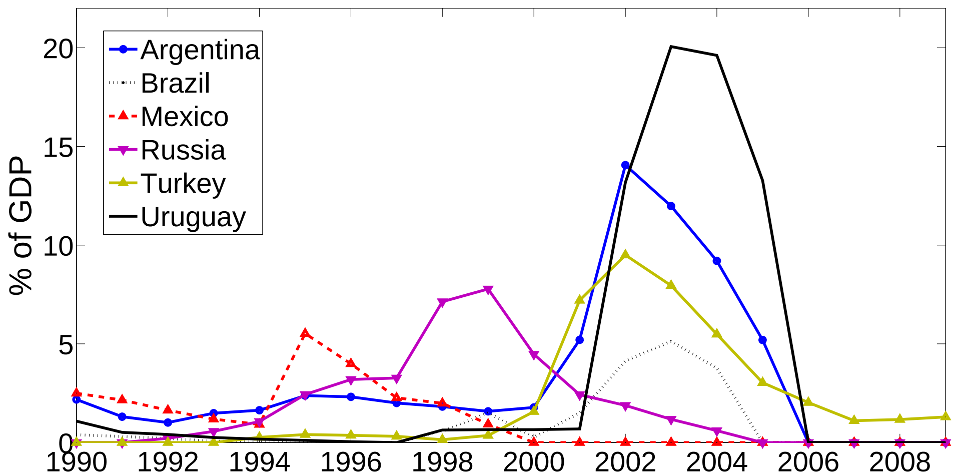
For the quantitative analysis we calibrate the model to match the data around the Argentinean default in 2001. During this crisis Argentina resorted to the IMF for financial assistance. At its peak in 2002, the use of IMF loans by Argentina reached close to 15 percent of GDP, which is at the upper end of the observed ratios for the crisis events in emerging economies between 1994 and 2002 (see Figure 1.1).[3] The model captures key features of Argentinean business cycle statistics. To analyze the effect of the presence of the official lending facility on the default probability we

[2] In the following the term 'market debt' denotes credit provided by private international investors on international debt markets. We use the terms 'bailout loans' or 'financial assistance' for credit provided by the official lending facility.

[3] A detailed empirical account of default events in several emerging markets economies in the 1990s and early 2000s is provided by Sturzenegger and Zettelmeyer (2006), while Roubini and Setser (2004) examine the crisis events of that time with a special focus on the implications regarding crisis resolution policies.

compare the benchmark model and a version of the model without bailout loans. We find that the availability of financial assistance reduces the frequency of run-driven defaults. However, its presence leads to substantially higher debt levels and a small *overall increase* in the default probability. For a given level of market debt the presence of financial assistance reduces the probability of a default by providing credit at comparatively low interest rates when international investors charge prohibitively high interest rates. At the same time it reduces the size of the *crisis zone*. The crisis zone consists of combinations of output and debt levels for which a self-fulfilling debt run can occur due to a coordination failure among investors. The reduction of the size of the crisis zone leads to a decrease in the number of run-driven defaults. Hence, defaults on market debt become, all else equal, less likely. This insurance effect of the financial assistance reduces the interest rates charged by international investors. Lower interest rates in turn induce the country to increase its borrowing. This general equilibrium effect leads to larger average debt stocks compared to the model without financial assistance. Larger debt stocks make a government default more likely. For our benchmark calibration we find that the general equilibrium effect outweighs the insurance effect and the default probability is higher in the presence of the official lending facility.

Figure 1.1: Use of IMF credit relative to GDP of selected countries in financial crises



Data source: Worldbank.

The model builds on the strand of literature that analyzes the incentives of governments to default on their debt when bond contracts are unenforceable. Eaton and Gersovitz (1981) show that when default is punished, certain levels of government debt can be sustainable in equilibrium even when bond contracts are not enforceable. The government chooses not to default on its debt as long as the costs associated with a default are higher than the utility gains due to the omitted repayment. Arellano (2008) studies the quantitative implications of this model by applying it to the Argentinean default event in 2001 and shows that a calibrated version of the model is able to replicate important features of the Argentinean data. Multiple equilibria in models of sovereign default have been analyzed by Calvo (1988) and Cole and Kehoe (1996, 2000). In the Cole and Kehoe model there exists an interval of debt levels, the crisis zone, for which the government finds it optimal to default only in case it cannot issue new debt because of a run on the sovereign debt market.

This chapter is also related to recent work by Boz (2011), Fink and Scholl (2011), and Roch and Uhlig (2014) who study bailouts in a model of optimal default.[4] Boz (2011) includes bailout loans supplied by a third party (the IMF) along with market debt held by foreign private investors. She assumes that IMF credits are repaid for sure and shows that her model is able to reproduce the countercyclical use of IMF loans while market debt is used procyclically.[5] Fink and Scholl (2011) model bailout loans as a grant that is constantly available to the government and associated with a restriction on government spending. Their model is able to mimic the empirical duration and frequency of bailout programs. In contrast to our model, both papers do not consider self-fulfilling runs on side of the investors and model bailouts differently. Roch and Uhlig (2014) embed multiple equilibria into an Arellano-type model and analyze a bailout agency that possesses a sufficient amount of funds to guarantee the actuarially fair price of the sovereign debt at all times. Considering this theoretical bailout mechanism, the model illustrates the effect of a bailout agency that can distinguish between fundamental crisis and runs and eliminates self-fulfilling runs

[4] Aguiar and Gopinath (2006) briefly discuss an unconditional bailout grant in a sovereign default model with trend shocks. Benjamin and Wright (2009) analyze the impact of bailout grants in a model of debt renegotiation.

[5] Dellas and Niepelt (2011) show in a two-period model that a debt agreement with a lending partner that possesses a better enforcement technology can be beneficial both for the lending and the borrowing country, and that the bilateral loans are used more during times of crises than in times with good economic conditions and low interest rates on the private market.

completely. Similar to Roch and Uhlig (2014) we allow for runs by investors in an Arellano-type model. The focus of our model is however different as we model the official lending facility such that it captures the main characteristics of observed official lending. One of the key problems of official lenders is to identify whether the demand for bailout loans derives from a run on sovereign debt markets or from bad fundamentals. We incorporate this property into the model by the assumption that the official lending facility always provides financial assistance according to a fixed price schedule. Furthermore, we model conditionality and seniority associated with bailout loans.

Bailout loans are also considered in the literature using global games methods. Corsetti, Guimarães, and Roubini (2006) develop a three-period model to analyze bailouts and the implications of the liquidity support on moral hazard. They find that limited contingent liquidity support can help to prevent liquidity runs by raising the number of investors willing to lend to the country. Moreover, they identify circumstances in which official lending actually strengthens a government's incentive to implement desirable but costly policies. Morris and Shin (2006) find similar results.

The rest of this chapter is organized as follows: Section 1.2 describes the benchmark model used for the analysis. Section 1.3 discusses the calibration of the model and describes the employed solution method. Section 1.4 presents the results of the quantitative analysis and Section 1.5 concludes.

1.2 Model

1.2.1 Preferences and endowments

Our analysis is set in a small open economy with an infinite time horizon. The preferences of the representative household of the small open economy are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t\right), \tag{1.2.1}$$

where c_t is consumption in period t, $\beta \in (0,1)$ is the discount factor, and E_0 is the expectation operator. The period utility function $u(\cdot)$ is strictly increasing and strictly concave and hence implies risk aversion.

The country receives a stochastic stream of endowments which follows a Markov process. In each period the benevolent government of the small open economy decides on the debt policy of the country in order to maximize the discounted sum of the household's utility by borrowing or lending on international financial markets. The government can trade bonds with international investors and has access to a limited amount of bailout loans. The bailout loans are provided by a supranational official lending facility which represents an International Financial Institution (IFI) like the IMF or bilateral agreements with other countries. All loans have a maturity of one period.[6] As long as the government repays all of its debt, the country faces the following resource constraint:

$$c = y + q^d\left(d', h', y\right) d' - d + q^h\left(h'\right) h' - h. \tag{1.2.2}$$

where y is the country's endowment income, d denotes the country's outstanding debt (i.e. positive values of d imply that the government is indebted), and q^d is the price the government receives for newly issued market bonds (next period's variables are indicated by a prime). The variable h denotes the amount of bailout loans borrowed from the official lending facility and q^h is the price of these loans.

In our model we allow for self-fulfilling crises during which a run by the investors triggers a government default. As we discuss in the next section, a sunspot shock ζ can be used to determine whether a run by the investors realizes. Similar to Cole and Kehoe (2000), the timing of actions within each period is assumed to be as follows:

1. The endowment income and the sunspot variable ζ are realized and the states are d, h, y, ζ, and the credit-standing of the government.

2. The government, taking the price schedules q^d and q^h as given, chooses d' and h'.

3. The international investors, taking q^d as given, provide d'.

[6] One period bonds are also used e.g. by Arellano (2008) and Boz (2011). Chatterjee and Eyigungor (2012) and Hatchondo and Martinez (2009) analyze long term loans with a fixed maturity while only considering one type of debt. While our model features bailout loans with a maturity of one period, the country always has the possibility to roll over the previous stock of bailout loans at the same (constant) conditions in every period which is similar to the case of bailout loans with a longer maturity.

4. The government decides whether or not to default.

5. The government receives financial assistance h' and households consume.

1.2.2 International investors

We assume that international investors are acting in perfectly competitive markets. They can borrow and lend at world financial markets at a risk-free interest rate r and are risk neutral.[7] Given that in a certain period there is no run, the international investors' profit maximization implies the following bond price equation, which ensures zero profits in expectation:

$$q^d\left(d', h', y\right) = E_{\zeta', y'|y}\left[\frac{1-\delta\left(d', h', y', \zeta'\right)}{1+r}\right]. \tag{1.2.3}$$

The investors price the bond by forming expectations over the sunspot shock ζ' and next period output y' which, along with the government debt level, influence the default decision $\delta\left(d', h', y', \zeta'\right)$. As output is assumed to follow a Markov process, expectations about next period output are formed conditional on the current output level. The indicator variable δ denotes the default decision of the government in the next period. If the government either defaults on market debt only or on both types of debt, δ takes a value of one. If there is no default and the government fulfills all its debt obligations, δ equals zero. Anticipating the government's default decision, the investors take into account the probability of a default for a given choice of d' and h' and adjust the bond price accordingly. The equilibrium interest rate on sovereign debt held by private international investors hence rises with the risk of a default as the investors demand a risk premium for compensation.

As we will explain in more detail in Section 1.2.4, there are certain combinations of the state variables d, h, and y for which self-fulfilling crises become possible. In this crisis zone there are two possible equilibria: In one equilibrium, the investors are willing to provide new lending, the government rolls over its debt, and there is no default. In the other equilibrium, the investors expect the government to default and hence do not provide new credit for a rollover of the outstanding government

[7] See Lizarazo (2013) for a model of sovereign default with risk averse lenders.

debt and the sovereign defaults. We use the sunspot variable ζ to determine which of these two equilibria realizes. ζ is assumed to be i.i.d. over time and takes a value of one with probability π and a value of zero with probability $(1-\pi)$. If the country is in the crisis zone, a realization of $\zeta = 1$ induces a run by the investors. The investors anticipate the probability of a run-driven default by the government in the next period which depends on the realization of ζ'. If there is a run already in the *current* period (induced by $\zeta = 1$), the investors are not willing to provide any lending to the government at a positive bond price. Thus the bond price in the current period is equal to zero and no longer given by equation (1.2.3).

1.2.3 Official lending facility

As long as the country is in good credit standing, it can make use of financial assistance from an official lending facility. We assume that the lending facility always provides financial assistance, independent of whether the country's demand for bailout loans derives from a run or high interest rates that are driven by bad fundamentals. Following Boz (2011), the price of bailout loans q^h is not determined by a market mechanism, but set by the official lending facility according to an exogenously fixed schedule. Hereby we capture the fact that the lending conditions of the official lending facility are rather guided by political decisions (which we do not model) than by pure profit considerations. Consistent with the actual price schedule of IMF loans, we assume that the price depends on the amount of bailout loans demanded.[8] The exogeneity of the bond price for bailout loans makes it necessary to impose a maximum h_{max} on the amount of bailout loans. Otherwise a country in good credit standing could always borrow arbitrarily large amounts before declaring default in the next period.[9] To capture important characteristics of actual official lending we model bailout loans to be senior to market debt (see Section 1.2.4). Furthermore,

[8] According to the IMF's lending policies for the so called 'stand-by arrangements', the effective total interest rate demanded from borrowers consists of a number of different fees and charges that are added to the riskless interest rate (IMF, 2015). Some of the additional charges are independent of the size of the loans (e.g. there is a 50 basis points service charge). Other surcharges on the interest rate are increasing with the size of the demanded IMF loans, as e.g. the 'surcharge for large loans' of 200 basis points for loans sizes above 300 percent of the country's quota.

[9] This problem does not exist when the bond price is determined on the private debt market. In this case, international investors assess the default probability and the bond price falls to zero when the default probability approaches one.

we assume that the official lending facility possesses a better punishment technology than the private international investors, i.e. the punishment after a default on bailout loans is stronger than the punishment after a default on market debt only. This seems plausible as a default on bailout loans might lead to an even stronger loss of reputation. Moreover, the official lenders might use political measures like sanctions, which are not available to international investors, to punish the defaulting country.

The government can only borrow from the official lending facility if it complies with conditionality obligations set by the facility. The IMF provides loans to troubled countries conditional on certain policy adjustments. The requirements of this conditionality are aimed at resolving the balance of payment and government debt problems of the borrower. They include macroeconomic and structural measures (Bird, 2007). An additional rationale for imposing conditionality is to alleviate debtor moral hazard problems (Guitián, 1995). A large part of these measures is related to fiscal policy and may include amongst others limits on the budget deficits and on the level of external debt (IMF, 2002). We capture important program features by assuming that a government that is borrowing from the official lending facility has to follow a debt adjustment program. As long as the government holds positive amounts of bailout loans, its decision on new debt is bounded by the following constraint on total new borrowing:

$$d' + h' \leq \lambda \left(d + h \right). \tag{1.2.4}$$

The parameter λ determines the strictness of the conditionality: For λ above one, the total debt of the country is still allowed to increase, but at most by $(\lambda - 1) \times 100$ percent per period. For a λ below one, total debt has to decrease by $(1 - \lambda) \times 100$ percent per period. For the case of a default on market debt we assume $\lambda = 1$ which implies that the country may not increase its amount of bailout loans.

1.2.4 Decision problem of the government

In each period the government decides on its debt policy. The government has to decide whether to default or not and, in case it does not default on its old debt, the government has to choose the amount of new debt (market debt and bailout loans). We assume that the country can either default on market debt only or on both market debt and bailout loans at the same time. We allow for the former option because historical evidence shows that countries defaulted on their debt obligations to private international investors while receiving IMF support (see e.g. Sturzenegger and Zettelmeyer, 2006). However, a default on bailout loans without simultaneous default on market debt is not allowed as loans from the IMF are de facto senior to market debt (see Roubini and Setser, 2004).

The government's choice between the different options depends on the specification of the respective consequences. As commonly assumed in the literature, default always occurs on the full amount of outstanding debt.[10] After a default, the country is excluded from financial markets for a limited time and incurs an output cost $l(y) \geq 0$.[11] During the exclusion period the country can thus only consume its endowment net of the output cost: $y_t^{def} = y_t - l(y_t)$. A country that has defaulted on its debt only regains access to financial markets with a certain probability. While we assume the output cost to be the same for both types of default, the average exclusion length depends on the type of default. A country that defaults on market debt only is modeled to have a shorter average exclusion length than a country that defaults on both market debt and bailout loans simultaneously. We therefore distinguish between the probability to return to financial markets after a default on market debt only, θ, and the probability to return to financial markets after a default on both types of debt, θ_H, with $\theta \geq \theta_H$. Both probabilities are assumed to be constant over time. The difference in average exclusion length reflects that the official lending facility has a stronger commitment to punish a defaulting sovereign than a private creditor.

The value function of being in good credit-standing $V^o(d, h, y, \zeta)$ depends on the amount of outstanding debt (market debt and bailout loans), the income state, and the sunspot variable ζ. It is given by the maximum of the three possible options of repayment or default:

$$V^o(d, h, y, \zeta) = \max\left\{V^c(d, h, y, \zeta), V^{defD}(h, y), V^{defDH}(y)\right\}. \tag{1.2.5}$$

[10] An exception is Yue (2010), who considers a model of debt renegotiation where the haircut is determined in a Nash bargaining between debtor and creditor. Other exceptions include Benjamin and Wright (2009), Bi (2008) and D'Erasmo (2011).

[11] For a discussion of the empirical evidence see Panizza, Sturzenegger, and Zettelmeyer (2009).

V^c is the value function of repayment of both types of debt. In this case the country fulfills its contractual obligations, i.e. it pays back its outstanding debt (market debt and bailout loans), and chooses the optimal level of new market debt and bailout loans. V^{defD} is the value function of defaulting on market debt only and consequently continuing without access to private credit markets. V^{defDH} is the value function of defaulting on both market debt and bailout loans and losing access to both types of borrowing.

For the implementation of self-fulfilling default crises we follow Chatterjee and Eyigungor (2012) by assuming that in case of a default in the current period the government has to return new loans d' without any interest payments to the international investors. The value function V^{defD} is therefore independent of the amount of new loans d'. Nevertheless, runs by the international investors as in Cole and Kehoe (2000) are possible as any international investor would loose interest earnings in case she provides new loans and the government defaults in the same period.[12]

The value function associated with a default on market debt only, V^{defD}, is given by:

$$\begin{aligned} V^{defD}(h,y) = \max_{\{h'\}} \Bigg\{ & u\left(y^{def} + q^h(h')\,h' - h\right) \\ & + \beta \int_{y'} \Big[\theta\Big[(1-\pi)\,V^o(0,h',y',0) + \pi V^o(0,h',y',1)\Big] \\ & + (1-\theta)\,V^{defD}(h',y')\Big] f(y',y)\,dy' \Bigg\} \end{aligned} \tag{2.6}$$

subject to

$$\begin{aligned} & c \geq 0 \\ & h' \leq h \qquad \text{if} \quad h > 0 \\ & 0 \leq h' \leq h_{max}. \end{aligned}$$

[12]The detailed within-period timing of actions that leads to the potential emergence of self-fulfilling crisis is outlined in Section 1.2.1.

In this case, the country still fulfills its contractual obligations with the official lending facility, but has zero market debt as it just defaulted. The value function V^{defD} is therefore independent of d and the sunspot shock ζ. With probability θ the country can return to international financial markets in the next period. π is the probability that the sunspot variable takes a value of one. $f(y', y)$ denotes the transition probability to income state y' in the next period given income state y in the current period.

After a default on both types of debt the country has no access to further borrowing and the households can only consume the endowment. The value function for a default on both types of debt, V^{defDH}, is given by:

$$V^{defDH}(y) = u\left(y^{def}\right) + \beta \int_{y'} \Big[\theta_H \big[(1-\pi) V^o(0,0,y',0) + \pi V^o(0,0,y',1) \big] + (1-\theta_H) V^{defDH}(y') \Big] f(y', y)\, dy'. \quad (2.7)$$

The value function of debt repayment, V^c, is given by:

$$V^c(d,h,y,\zeta) = \max_{\{d',h'\}} \Big\{ u\Big(y + q^d(d',h',y)\, d' - d + q^h\left(h'\right) h' - h\Big) + \beta \int_{y'} \Big[(1-\pi) V^o(d',h',y',0) + \pi V^o(d',h',y',1) \Big] f(y',y)\, dy' \Big\} \quad (2.8)$$

subject to

$$c \geq 0$$
$$(d' + h') \leq \lambda (d + h) \qquad \text{if} \quad h > 0$$
$$0 \leq h' \leq h_{max}.$$

For certain combinations of the state variables the government prefers to repay its debt only if it has access to new borrowing but it defaults if it cannot roll over its maturing debt. In this case self-fulfilling debt runs can emerge due to a coordination failure among international investors. Given that there is a run by the investors, the country has no access to new market debt ($d' = 0$). To facilitate the following exposition, we introduce V^c_{run} to denote the value function of repayment *in case of a run*, i.e. V^c_{run} is V^c for combinations of the state variables that imply a run. V^c_{run} is given by:

$$
\begin{aligned}
V^c_{run}\left(d, h, y, 1\right) = \max_{\{h'\}} \Bigg\{ & u\Big(y - d + q^h\left(h'\right) h' - h\Big) \\
& + \beta \int_{y'} \Big[\left(1 - \pi\right) V^o\left(0, h', y', 0\right) + \pi V^o\left(0, h', y', 1\right) \Big] f\left(y', y\right) dy' \Bigg\}
\end{aligned} \tag{2.9}
$$

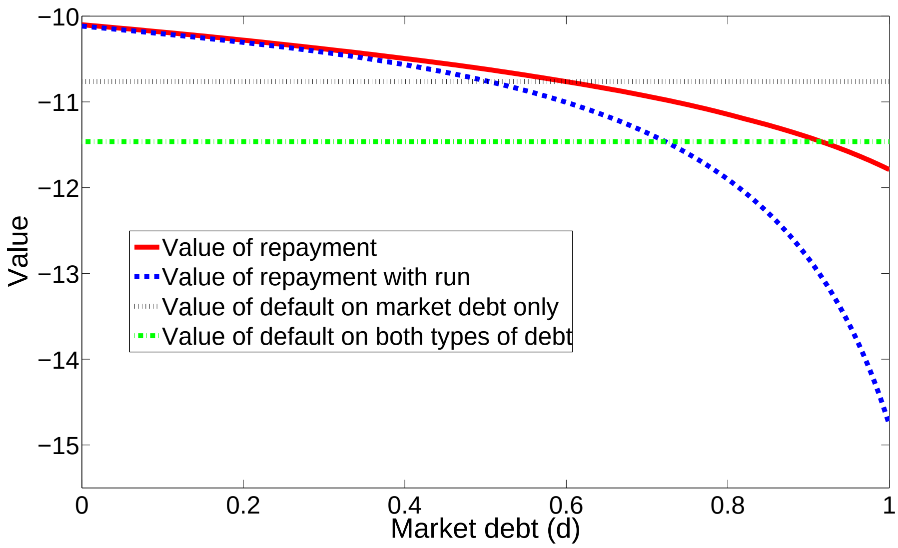
subject to

$$
\begin{aligned}
c &\geq 0 \\
h' &\leq \lambda\left(d + h\right) \qquad \text{if} \quad h > 0 \\
0 \leq h' &\leq h_{max}.
\end{aligned}
$$

Figure 1.2 illustrates the decision problem of the government. It shows the four different value functions for an intermediate output level in a situation where the government has no outstanding bailout loans. The two value functions of repayment decrease in the level of outstanding debt as the funds repaid to the investors cannot be consumed by the households.[13] For low levels of market debt, both the value of repayment without a run, $V^c\left(d, h, y, 0\right)$, and the value of repayment with a run, $V^c_{run}\left(d, h, y, 1\right)$, lie above the value of default, which does not depend on the level of outstanding debt. In this region the government would not default even if there was a run by the investors. Anticipating this, the investors would not run in the first place and no self-fulfilling crisis is possible for the given state combination. However, with increasing levels of outstanding debt the distance between $V^c\left(d, h, y, 0\right)$ and

[13]For this illustration, we compute $V^c_{run}\left(d, h, y, 1\right)$ also for levels of outstanding market debt for which in equilibrium no run occurs. $V^c\left(d, h, y, 0\right)$ is always larger or equal to $V^c_{run}\left(d, h, y, 1\right)$, as a run restricts the options of the government. Without a run the government could always choose $d' = 0$ and be at least as well off as in the case of a run.

Figure 1.2: Values of possible government choices for given levels of market debt



Notes: Values are calculated for a government without outstanding bailout loans and an intermediate output level. Computations are based on the benchmark calibration outlined in Section 1.3.

$V^c_{run}(d, h, y, 1)$ increases and for an interval of intermediate amounts of outstanding debt $V^c(d, h, y, 0)$ lies above $V^{defD}(h, y)$, while $V^c_{run}(d, h, y, 1)$ lies below $V^{defD}(h, y)$. This is the crisis zone where self-fulfilling crises become possible as the government only prefers to default in case of a run. Rational investors anticipate the behavior of the government. Consequently, if an individual investor expects the other investors *not* to roll over the debt, she will anticipate a government default and will not be willing to lend to the government either as this would lead to the loss of interest earnings. Given that the investors are not willing to roll over the debt, the government defaults. However, in case an individual investor expects all other investors to roll over the debt, she knows that the government will not default and she is also willing to buy new bonds. Given that the government can roll over its debt, it does not default in equilibrium. Therefore, there exist combinations of the state variables for which there are two possible equilibria, one with rollover and no default and one without rollover and a default by the government. Which of these equilibria is actually realized is determined by the realization of the sunspot variable ζ. For high levels of debt not only $V^{c}_{run}(d,h,y,1)$ but also $V^{c}(d,h,y,0)$ is lower than the value of default $V^{defD}(h,y)$. In this case the government defaults for sure, independent of the rollover decision of the investors.[14]

Definition: Given the parameters, the output process, and the price schedule for bailout loans, the recursive equilibrium for this economy is defined by the set of policy functions c, d', h', the default decision function of the government, and the bond price function $q^{d}(d',h',y)$ such that:

1. Given the government's policies, the country's resource constraint is satisfied.
2. Taking as given the bond price schedule $q^{d}(d',h',y)$ and possible runs by the investors, the government's policies d', h', and its default decision solve the government's optimization problem.
3. The bond price $q^{d}(d',h',y)$ reflects the default probabilities and ensures zero profits in expectation for the investors. When there is a self-fulfilling run, the bond price $q^{d}(d',h',y)$ is equal to zero.

1.3 Calibration

We solve the model numerically. Therefore, we need to assume specific functional forms and assign parameter values. The utility function of the representative household is a constant relative risk aversion utility function given by:

$$u(c) = \frac{c^{1-\sigma}}{1-\sigma}. \tag{1.3.6}$$

The income process is given by an AR(1) process for $\log(y)$:

$$\log(y_t) = \rho \log(y_{t-1}) + \eta_t \tag{1.3.7}$$

[14] The position of $V^{defDH}(y)$ relative to $V^{defD}(h,y)$ depends on the level of outstanding bailout loans. The government chooses the default option that yields the higher value. The emergence of the three regions holds independent of which of the two values of default is the higher one.

where $\eta_t \sim N\left(0, \sigma_\eta^2\right)$. The output costs are modeled as in Chatterjee and Eyigungor (2012) by a non-linear function:

$$l\left(y\right) = \max\left\{0, l_0 y + l_1 y^2\right\}. \tag{1.3.8}$$

where $l_1 \geq 0$. This convex cost function implies that a default is more costly in the case of a high output realization than in a period with low output.[15] The state-dependence of the output cost function is necessary to generate a sufficient number of defaults in equilibrium by inducing a strong relation between the default decision and the output level.[16] If a good income state is likely for the next period, bond prices are high and the country can accumulate high debt stocks on which it defaults when the output level is low.

In line with the interest rate schedule of the IMF, the price for the bailout loans is assumed to depend on the borrowed amount. As in Boz (2011) the official lending facility demands a linearly increasing surcharge $\psi\left(h'\right)$ on the risk-free interest rate:

$$q^h(h') = \frac{1}{1 + r + \psi\left(h'\right)}, \tag{1.3.9}$$

where

$$\psi\left(h'\right) = \psi_{min} + \frac{\psi_{max} - \psi_{min}}{h_{max}}\, h'. \tag{1.3.10}$$

We calibrate the model at quarterly frequency using data for the Argentinean economy before its sovereign default in 2001. As Chatterjee and Eyigungor (2012) point out, from 1993 to 2001 Argentina was at the same time in a currency board regime pegging the Argentinean Peso to the US Dollar and borrowing via marketable bonds on international credit markets. This makes this time period especially suitable for the analysis of the model. The parameter values of our benchmark calibration are stated in Table 1.1.

The relatively low discount factor β can be interpreted as indicating the strong impatience of the government of the economy which is mainly concerned about the

[15] The convexity of the cost function can also be generated endogenously in a production economy with working capital loans for foreign intermediate inputs (see Mendoza and Yue, 2012).

[16] Arellano (2008) shows that even without (state-dependent) output costs as in equation (1.3.8) default incentives are decreasing in the endowment.

Table 1.1: Calibration

Parameter		Value	Target/Source	Value
Discount factor	β	0.9005	Debt-to-GDP-ratio	0.46
Risk aversion	σ	2	Literature	
Autocorrelation $\log(y_t)$	ρ	0.945	Argentinean Data	
Std. dev. output shock	σ_η	0.025	Argentinean Data	
Risk-free rate	r	0.01	Literature	
Prob. of reentry - defD	θ	0.125	Avg. exclusion length	2 years
Prob. of reentry - defDH	θ_H	0.025	Estimate	
Output costs	l_0	-2.34	Default probability	3.1%
Output costs	l_1	2.508	Std. dev. of interest spread	4.58
Max. of bailout loans	h_{max}	0.25	Observed max. in data	0.2
Debt adjustment	λ	1.01	Max. annual deficit (% of GDP)	1.85
Interest surcharge	ψ_{min}	0.00125	IMF service charge	0.5% p.a.
Interest surcharge	ψ_{max}	0.113	Mean h/y	0.053
Prob. of run in crisis zone	π	0.16	Corr(y, $\Delta d/y$)	0.141

short-run. β is set to match the average ratio of market debt to quarterly GDP and lies in the range of values considered in the literature. To compute Argentinean debt levels, we use data on external public debt provided in the World Bank's Global Development Finance Database. As the series is annual and our model is quarterly we have to transform the data. At yearly frequency, the average ratio of debt held by private international investors to GDP in the years from 1993 to 2000 is 16.3 percent which implies a quarterly value of approximatively 65.2 percent. Following Chatterjee and Eyigungor (2012) we target only 70 percent of this debt-to-GDP ratio as this was roughly the size of the haircut after the Argentinean default.[17] Consequently, only this share of the debt (46.0 percent of quarterly GDP) is considered as the unsecured and hence defaultable debt stock.

The parameter of risk aversion σ is set to 2, which is a standard value in the literature. The output process is estimated using Argentinean data from the 20 years before the default event, taken from the dataset by Neumeyer and Perri (2005). We take the logarithm of deseasonalized quarterly real GDP data and detrend the series with a linear trend. The risk-free rate is equal to one percent per quarter, which implies an annual real rate of roughly four percent, a standard value in the real business cycle literature.

The value of the reentry probability after a default on market debt only, θ, lies

[17] See Sturzenegger and Zettelmeyer (2008) for an estimate of the size of the haircuts in several default events.

in the range of values used in the literature and is consistent with the estimates of Gelos, Sahay, and Sandleris (2011), who report only short periods of exclusion from international financial markets. Specifically, the median duration of exclusion after a sovereign default in the 1990s was two years. There is no empirical counterpart for θ_H as until now there has been no outright default on IMF credits of an emerging market economy. The value of θ_H employed in our calibration implies on average 10 years of exclusion and is an estimate based on the fact that Argentina still has not fully returned to international financial markets since its default in 2001, which involved major disagreements between the Argentinean government and the IMF. In Section 1.4.5 we show that our results are robust against considering a higher value of θ_H, i.e. a shorter average exclusion after a default on both types of debt. The first parameter of the output cost function, l_0, is set to match the default frequency of 3.1 percent (in annual terms) observed in Argentina.[18] The second parameter, l_1, is set to match the standard deviation of the interest rate spread which is 4.58 in the data.[19]

The values of h_{max} and λ are consistent with past IMF programs. We choose a h_{max} of 25 percent of average output, which is slightly higher than the largest amount of IMF loans used by Argentina, which was around 20 percent of pre-crisis output (see Roubini and Setser, 2004). The debt adjustment of $\lambda = 1.01$ is equivalent to a maximum debt increase of 3.9 percent per year which is approximately equal to an allowed deficit of 1.85 percent of GDP per year.[20] The minimum surcharge, ψ_{min}, is set to 0.00125, which equals a 50 basis points service charge (annually) demanded by the IMF. The maximum value of the linearly increasing interest rate surcharge, ψ_{max}, is set to match the mean ratio of bailout loans to quarterly GDP which is 0.053 for

[18]To obtain this estimate, we use the default and rescheduling events documented by Reinhart and Rogoff (2009), which can be clustered to six default episodes from Argentinean independence in 1816 until 2011.

[19]The spread is calculated as the difference between the Argentinean interest rates reported by Neumeyer and Perri (2005) and the rate of a 3-month U.S. Treasury bill in the period from 1993Q1-2001Q4.

[20]See IMF (2003) for actual targets of the Argentinean program. Specifically, allowed deficits for the first two years of the program were 2.3 percent and 1.4 percent of GDP. One can transform the deficit targets (measured in percent of GDP) into maximum debt increases by dividing them by the debt-to-GDP level targets for the respective year (which have been 0.477 and 0.473 in 2000 and 2001). Dividing the deficit targets by the actual debt-to-GDP of the respective years or the pre-crisis debt-to-GDP results in the same value for λ.

the period from 1970 to 2000.[21]

The probability of a run in the crisis zone, π, cannot be observed in the data. We set the parameter to match the correlation of output with the change in market debt relative to output, corr(y, $\Delta d/y$). This correlation has a value of 0.141 and is calculated for the time period 1993-2000, which is not affected by debt restructuring or default. Defaults that are caused by runs occur both at relatively high and at low output levels. Increasing π leads to a rise in the number of run-driven defaults and thereby decouples the risk of a default and consequently the bond price from the output level. This yields a decrease in the correlation. In our benchmark calibration π is set equal to 0.16. Furthermore, in Section 1.4.5 we show that the main results of the model remain valid when we consider different values of π.

We solve the model by value function iteration. Starting with a guess for the bond price schedule we compute the optimal policies of the government. Given these policies we compute the probabilities of a default in the next period depending on the choices of new loans (market debt and bailout loans) and the given output realization. These probabilities then enter into an update of the bond price function. This procedure is repeated until convergence. We discretize the state space by approximating the log output process with the Tauchen algorithm using 31 grid points. The mean of the log output process is set to zero. For the dimension of market debt we use a grid of 300 points within the interval [-0.1; 1.0] that spans the asset space from ten percent assets to hundred percent debt relative to a quarterly output of unity. For the dimension of bailout loans the grid consists of 40 points within the interval [0; 0.25].

[21] The mean ratio of IMF loans to GDP in annual data is 0.0132, which implies a quarterly value of approximatively 0.053.

1.4 Results

1.4.1 Business cycle statistics

To assess the performance of the model, we simulate the model and compare the resulting business cycle statistics with the corresponding statistics from Argentinean data.[22] Table 1.2 shows that the results for the benchmark calibration are in line with the data. Consumption is more volatile than output. All of the correlations have the correct signs: Consumption and output show a strong co-movement, while the interest rate spread (on market debt) and the trade balance are both countercyclical. We target an overall default probability of 3.1 percent. The resulting probability of a run-driven default is 0.9 percent, which means that more than a quarter of the defaults is caused by runs. For the benchmark calibration there are no joint defaults on both market debt and bailout loans. The model nearly matches the number of periods that the country uses bailout loans. We calibrate our model to match the average debt stock of Argentina. In accordance with the data, the model implies that market debt is used procyclically, while the use of bailout loans is countercyclical.

1.4.2 Effects of financial assistance

Given that the model successfully matches the data, we turn to answering our initial question of how the presence of financial assistance affects the probability of a government default. We compare the outcome of our benchmark model with the results obtained by simulating a version of our model that does not feature the official lending facility. For this comparison we apply the parameter values of the benchmark calibration in both models. The results summarized in Table 1.3 show that without the availability of bailout loans the overall default probability is slightly lower than in the benchmark model (2.95 vs. 3.11 percent). This overall default probability is partly caused by run-driven defaults. Without the lending facility there are substantially more run-driven defaults (1.4 vs. 0.9 percent). We find that the model without the lending facility exhibits on average a lower total debt level than the benchmark model

[22] We simulate the model for one million quarters and exclude default and exclusion periods. Additionally, similar to Chatterjee and Eyigungor (2012), we exclude two years after redemption as the country counterfactually returns to financial markets with zero debt. We calculate the business cycle statistics over the more than 870,000 remaining episodes.

Table 1.2: Business cycle statistics

Variable	Benchmark model	Data
Std. dev. Output	6.82	7.68 *
Std. dev. Consumption	9.29	8.38 *
Std. dev. Interest rate spread	4.58	4.58 **
Std. dev. Trade balance	4.48	1.50 **
Corr(Output, Interest rate spread)	-0.42	-0.79 **
Corr(Output, Trade balance)	-0.31	-0.81 **
Corr(Output, Consumption)	0.88	0.98 *
Corr(Interest rate spread, Trade balance)	0.61	0.82 **
Default prob. market debt	3.1%	3.1%
→ of which due to runs	0.9%	-
Default prob. market debt and financial assistance	0.0	0.0
Prob(h>0)	0.55	0.60
Average market debt (% of GDP)	46.0	46.0
Average financial assistance (% of GDP)	5.3	5.3
Average spread market debt	3.85	8.15
Corr(y, $\Delta d/y$)	0.141	0.141
Corr(y, $\Delta h/y$)	-0.06	-0.15

Notes: Data on output, consumption, interest rates, and trade balance from Neumeyer and Perri (2005). Spreads are calculated based on the rate of 3-month U.S. Treasury bills (data from FRED). Data on bailout loans from World Bank and International Financial Statistics (IFS), market debt from World Bank. Calculations are for 1980Q1-2001Q4 (*) and 1993Q1-2001Q4 (**). Prob(h>0) is calculated for 1946Q1-2011Q4. Debt levels are at quarterly frequency. For calculation of default probability, debt levels, and spread see Section 3. Due to limited data availability corr(y, $\Delta d/y$) is reported for annual data. corr(y, $\Delta h/y$) and the other correlations and std. dev. are reported for quarterly data. The average spread on market debt is reported in annualized terms.

(35 vs. 51 percent of quarterly GDP). While, by definition, there are no bailout loans in the model without the lending facility also the average level of debt borrowed from private international investors is lower than in the benchmark model. Our results imply that an official lending facility can in fact help to reduce the probability of runs by the investors. However, it also substantially decreases the incentive for countries to limit their debt levels. In total, the probability of default is higher when financial assistance is available. This results from the fact that the increase in the default incentives due to higher debt levels outweighs the lower probability of run-driven defaults.

Table 1.3: Effect of financial assistance on default probability and debt levels

Variable	Benchmark model	Without financial assistance
Default probability market debt	3.11%	2.95%
→ of which due to runs	0.91%	1.40%
Average market debt (% of GDP)	46.0	35.2
Average financial assistance (% of GDP)	5.3	-

1.4.3 Model dynamics

Turning to the underlying economic mechanisms of the model, we find that it preserves several important features of standard sovereign default models. First, the incentive to default is growing with the amount of debt as higher debt levels increase the possible gain of not repaying. Second, given a low realization of output repaying a certain amount of debt leads to lower consumption than repaying the same amount given a high realization of output. Therefore, default incentives are stronger for low output states than for high output states. Figure 1.3 depicts the default decision of a government that has no outstanding financial assistance (left panel) and of a government that already uses the maximum amount of available financial assistance (right panel). The black areas indicate combinations of output realizations and market debt holdings for which the government decides to default on its market debt. The government refrains from a default when output is high and debt is low (white area). The crisis zone (gray area) is located between the two areas in which the government always or never defaults. Self-fulfilling runs by the investors can only materialize when the default decision of the government depends on the decision of the investors to run. For high market debt and low output the government always prefers to default, independent of a possible run by the investors. Likewise, the government would always prefer to repay its debt in low debt and high output combinations, even if there was a run by the investors (which would have the consequence that the government could not roll over its debt). With rising debt levels and decreasing output a default becomes more and more attractive for the government. A run by the investors can then become decisive for whether or not the government defaults. This leads to the emergence of self-fulfilling expectations by the investors. A comparison of the left and the right panel of Figure 1.3 illustrates that the crisis and default zones are larger when the country already uses the maximum amount of financial assistance. This reflects the fact that the insurance effect of financial assistance is stronger the more of financial assistance is still available. Moreover, default incentives are stronger when the country borrows from the official lending facility in addition to its market debt as it has to pay back a larger total amount of debt.

Figure 1.3: Default decision of the government

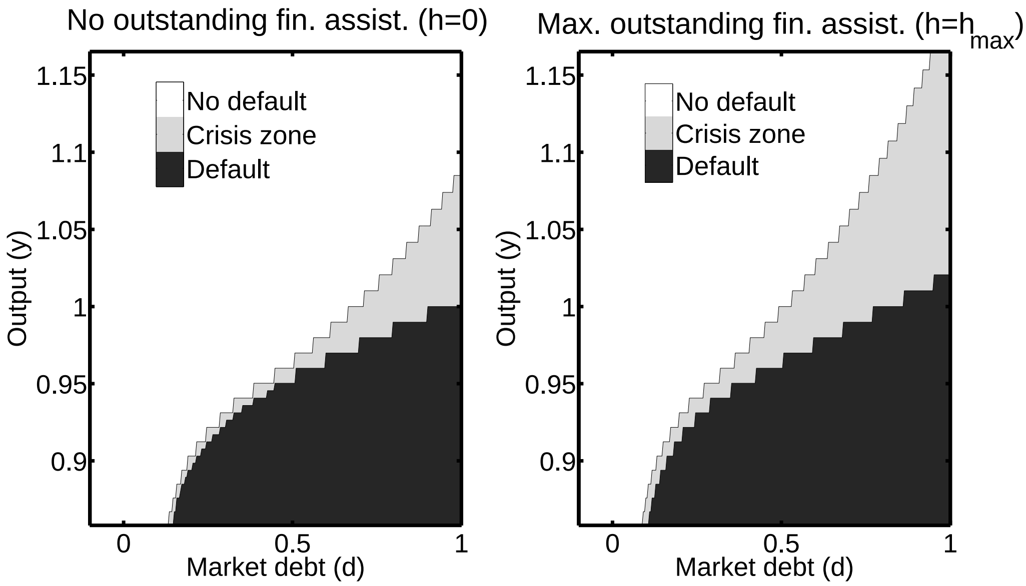
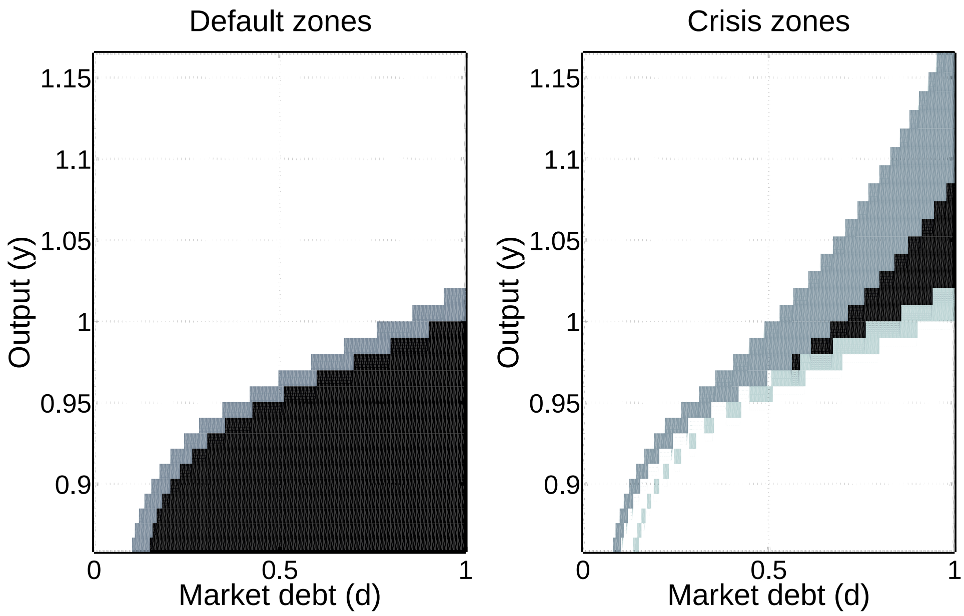


Figure 1.4 compares the default decision of the government in our benchmark model with the default decision of the government in the model in which no bailout loans are available. The left panel of Figure 1.4 shows that the default region is larger in the model without bailout loans. While the black area in the left panel of Figure 1.4 indicates where the default zones of the two models overlap, the gray area denotes combinations of output and debt for which the government defaults only in the model without the official lending facility. The availability of bailout loans also reduces the size of the crisis zone as illustrated in the right panel of Figure 1.4. The figure shows the crisis zone in the benchmark model for a government that has no outstanding bailout loans and compares it to the crisis zone in the model without bailout loans. While for certain state combinations the crisis zone prevails in both models (black area), the dark gray area to the left of the black area indicates those state combinations for which self-fulfilling crises occur only in the model without the official lending facility. For a few state combinations there exists a crisis zone only in the model with bailout loans (light gray area to the right of the black area).

However, in the model without the official lending facility the government defaults in this area for sure. The overall reduction in the size of the crisis zone is substantial. Once the country uses all of the available bailout loans this effect vanishes and the crisis zones are almost identical in the two model versions (right panel of Figure 1.8 in the appendix to this chapter). Both the reduction in the size of the default region and the crisis region make a default of the government for a given debt level less likely due to the insurance effect of financial assistance.

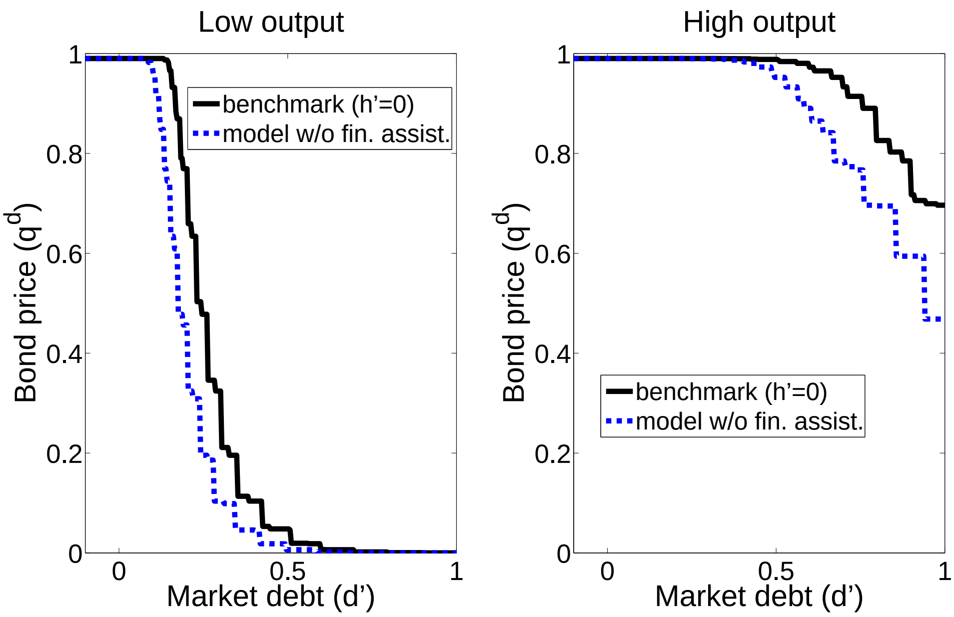
Figure 1.4: Comparison of default zones (left panel) and crisis zones (right panel)



Notes: black areas: zones overlap, gray areas: default/crisis only when no financial assistance is available, bright gray area: crisis zone only in the model with financial assistance.

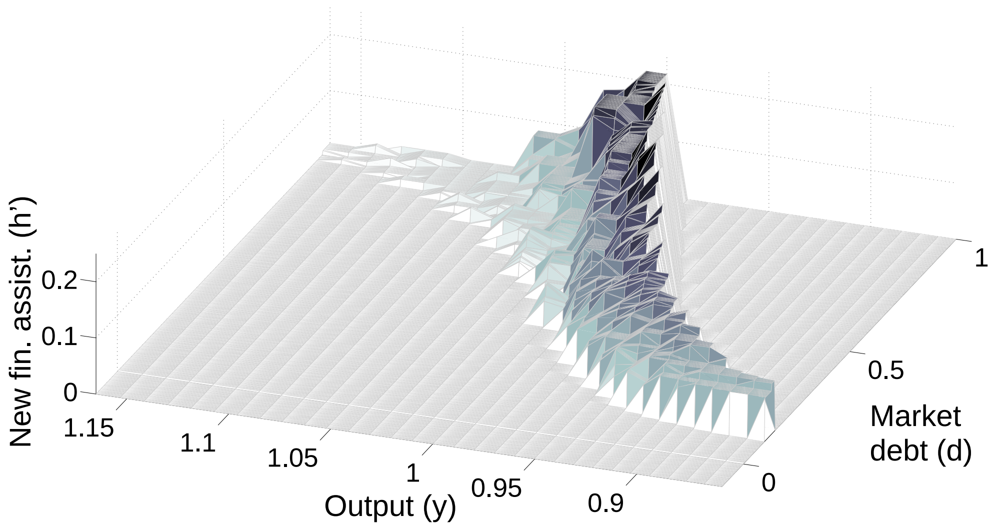
As defaults are less likely (for a given debt level) when the official lending facility is present, the international investors charge lower interest rates than when no financial assistance is available. Figure 1.5 illustrates the resulting shift in the bond price schedule. The bond price drops as debt levels increase. The continuous (black) lines denote the bond price schedule in the benchmark model for a government that has no outstanding bailout loans, but has them at its disposal. The dashed (blue) lines denote the schedule for a government in the model without the official lending facility. The availability of financial assistance shifts the bond price schedule to the right, resulting in lower interest rates for the government. The effect is present both at low output levels (left panel) and at high output levels (right panel). Facing a more favorable interest rate schedule, the government on average borrows a larger amount of debt when the official lending facility is present. Figure 1.5 also shows that the fall of the bond price occurs at lower debt levels when the output realization is low (left panel in comparison to right panel). Taking into account that default incentives increase for bad output realizations, investors charge higher interest rates for any amount of market debt demanded. The interest rate of market debt therefore follows a countercyclical pattern. The government reacts by demanding less market debt when output is low and by demanding more market debt when output is high. Hence, the government borrows procyclically on private bond markets (see also Table 1.2).

Figure 1.5: Comparison of equilibrium bond price schedules for market debt



The smaller size of the default and crisis zone in the benchmark model stems from the fact that the government turns to official lending instead of choosing an outright default. Figure 1.6 shows the demand for financial assistance of a government that has no outstanding bailout loans. The chosen volume of bailout loans increases for lower output realizations and for higher levels of outstanding market debt. For very low output and high market debt the demand for bailout loans is again zero as in this case the government prefers to default on market debt without using bailout loans. The region in which the demand for bailout loans spikes corresponds to the reduction of the crisis zone in the right panel of Figure 1.4. While the bond price for market debt falls rapidly when output levels are low (see Figure 1.5), the interest rate schedule of bailout loans is fixed independent of output levels. The government therefore substitutes market debt by bailout loans when output realizations are relatively low. However, due to the additional charges and fees of bailout loans, in good output states market debt is cheaper and the government demands no bailout loans. As a consequence the resulting demand for bailout loans is countercyclical.

Figure 1.6: Choice of financial assistance (for $h = 0$)



1.4.4 Welfare

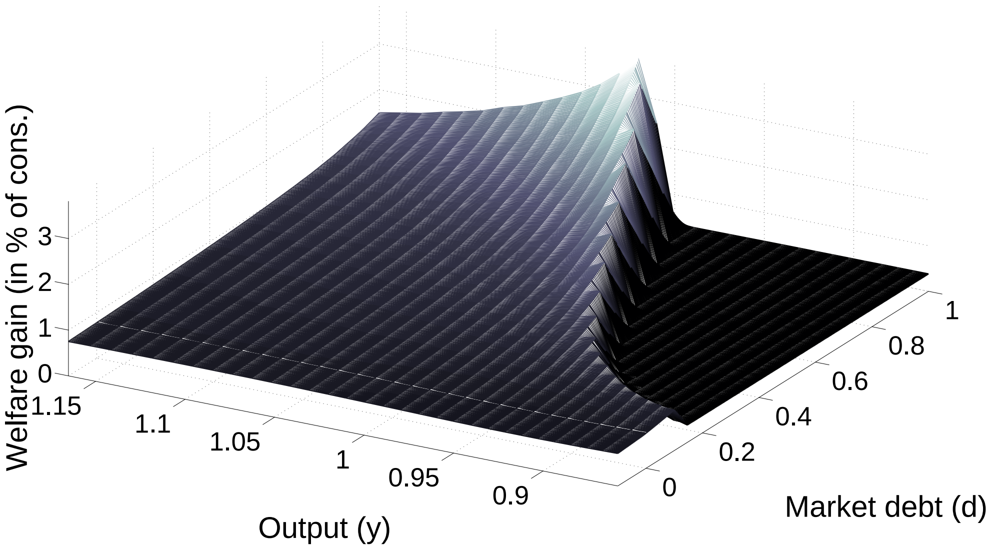
Despite the fact that the presence of the official lending facility is associated with a higher default probability, the welfare implications of bailout loans are a priori unclear. Having an additional borrowing opportunity can potentially improve the country's welfare. Also, there is a possible welfare gain as the official lending facility helps to (partly) resolve the inefficiency generated by the coordination failure of private international investors. The limited commitment of the sovereign and the presence of incomplete markets might, however, lead to a situation in which the country is worse off if financial assistance is available. Without the official lending facility the government has only one defaultable (i.e. state-contingent) bond at its disposal. Having an additional borrowing opportunity, however, changes the default incentives and hence influences the endogenous price schedule. The shift of the price schedule changes the constraints of the optimization problem of the government and it chooses much higher equilibrium debt levels which are also associated with higher interest rate payments. To assess the welfare implications numerically, we compare the certainty equivalent consumption in the benchmark model and in the model without financial assistance. More precisely, we compute the amount of additional consumption that is necessary to make households indifferent between living in the model with financial assistance and without financial assistance.[23]

As a first step, we conduct a state by state comparison. This comparison is similar to establishing a new official lending facility in a world without financial assistance. Figure 1.7 displays the resulting welfare gain (in percent of certainty equivalent consumption) due to the availability of financial assistance. The country benefits from the additional borrowing opportunity in case it has no outstanding bailout loans. Outstanding bailout loans automatically imply higher total repayment obligations and therefore have an impact on utility levels. Consequently, the state by state comparison is only meaningful for a government that currently does not have outstanding bailout loans. The state-dependent welfare gain depicted in Figure 1.7 lies in the range from 0.3 percent to 3.8 percent of certainty equivalent consumption and depends both on the level of market debt and the output level. The highest welfare gain occurs at high market debt levels and intermediate output. The regions with high welfare gains correspond to the reduction in the sizes of the crisis and default zones as illustrated in Figure 1.4. There is only a small welfare gain in the default zone where the sovereign has no direct benefit from the shift in the bond price schedule as it defaults despite the presence of the official lending facility.

The state by state comparison, however, does not take into account the general equilibrium effect of living in a world with financial assistance instead of living in a world without financial assistance. To account for the general equilibrium effect, we simulate both models and weigh the state-dependent values with the endogenous probabilities of being in the according state combination. A comparison of the

[23]For the welfare comparison we solve for g in the equation $g^{1-\sigma}V^{FA}\left(d,h,y,\zeta\right) = V^{no\ FA}\left(d,y,\zeta\right)$, where V^{FA} is the country's value function of being in the benchmark model with financial assistance and $V^{no\ FA}$ the value function of being in the model without financial assistance.

Figure 1.7: State-dependent welfare gain from the availability of financial assistance (for $h = 0$)



resulting values shows that the certainty equivalent consumption in the model with official lending facility is 0.48 percent lower than in the model without lending facility. This indicates that the negative effects of the higher default probability and higher debt service outweigh the benefits associated with financial assistance in terms of better consumption smoothing and lower borrowing costs. The international investors are not affected by the presence of the lending facility because they are risk neutral and always make zero profits in expectation due to perfect competition. There are no defaults on the bailout loans for the benchmark calibration. Therefore, the official lending facility does not incur any losses due to its lending activity, but generates profits by charging the surcharge on the riskless rate.

1.4.5 Robustness

To check the robustness of the results we vary the parameter values that govern the official lending facility, namely the strictness of the conditionality, λ, and the probability of returning to international financial markets after a default on financial assistance, θ_H. In the first column of Table 1.4 we restate the results of the benchmark calibration to facilitate comparison. In columns two to four we vary λ, while column five shows the results of changing θ_H. Our main result that the probability of default increases when financial assistance is available is robust against changes in λ and θ_H. Furthermore, the reduction of the probability of run-driven defaults and the increase of the average level of market debt are basically unaffected by the changes in λ or θ_H.

In the benchmark calibration we use a value of $\lambda = 1.01$, which is implied by the IMF program in Argentina. To further evaluate the impact of the strictness of the conditionality we first set λ equal to 0.95. This corresponds to a very strict conditionality as it enforces annual government budget surpluses of 8 percent of GDP during the time that bailout loans are used.[24] Furthermore, λ is set to one which is equivalent to a zero deficit target as in this case no further increase of the total amount of debt is allowed when the country is borrowing from the official lending facility. Finally, we allow for a laxer conditionality by changing λ to 1.1 which corresponds to an annual deficit target of 21 percent. The robustness checks demonstrate that increasing the strictness of the conditionality to $\lambda = 0.95$ results in a decrease in the average level of financial assistance and a strong reduction of the frequency of the use of bailout loans. The total debt level of the country slightly decreases as also the level of market debt falls. The stricter conditionality increases the correlation of output with the change in market debt relative to output, corr(y, $\Delta d/y$). The change of the correlation occurs because the government cannot increase its level of market debt when output is low and it is already borrowing from the official lending facility. Decreasing the strictness of the conditionality to $\lambda = 1.1$ has the opposite effect. The average levels of financial assistance and market debt and the frequency of the use of financial assistance increase. This results in a slightly higher probability of default. With laxer conditionality the government still increases its borrowing from private international investors while using financial assistance. This causes a slight reduction of the correlation of output with the change in market debt relative to output. Strict conditionality leads to a lower default probability and higher welfare than the benchmark case and lax conditionality. Lax conditionality results in higher debt levels and a higher default probability, which is detrimental to the country's welfare.

For the benchmark calibration we employ a value of $\theta_H = 0.025$ which corresponds to an average of ten years of exclusion after a default on financial assistance. To verify

[24]The correspondence between λ and the deficit target is presented in Footnote 20.

Table 1.4: Sensitivity of the results: Parameters of the official lending facility

	Benchmark	$\lambda = 0.95$	$\lambda = 1$	$\lambda = 1.1$	$\theta_H = 0.0625$
Default prob. market debt	3.11%	3.03%	3.11%	3.16%	2.93%
→ of which due to runs	0.91%	0.86%	0.90%	0.92%	0.87%
Default prob. market debt and fin. assist.	0.0	0.0	0.0	0.0	0.16%
→ of which due to runs	0.0	0.0	0.0	0.0	0.01%
Prob(h>0)	0.55	0.39	0.53	0.77	0.53
Average market debt (% of GDP)	46.0	45.8	46.0	46.2	46.0
Average financial assistance (% of GDP)	5.3	4.2	5.1	5.9	5.0
Average spread market debt	3.9	3.7	3.8	3.9	3.9
Corr(y, $\Delta d/y$)	0.141	0.146	0.142	0.136	0.142
Corr(y, $\Delta h/y$)	-0.06	-0.05	-0.06	-0.06	-0.06
Welfare gain due to financial assistance	-0.48%	-0.44%	-0.47%	-0.51%	-0.61%

to what extent our results depend on the chosen value of θ_H, we solve the model for $\theta_H = 0.0625$, which implies on average four years of exclusion after a default on financial assistance. Column five of Table 1.4 shows the resulting statistics. While the probability to default on both market debt and financial assistance is now positive, the overall probability of default remains basically unaffected. Also, the debt stocks are similar to the benchmark. Our results are therefore robust to shortening the average exclusion spell after a default on both types of debt. Defaults on both types of debt, which are present for the higher value of θ_H, imply that the government's total repayment obligations are reduced stronger than in the case of a default on market debt only. However, in this case the government also looses access to new bailout loans. Overall, we find that welfare declines when the country faces a shorter exclusion and defaults on both market debt and bailout loans occur.

To determine how the results of the model depend on the influence of the calibration of the probability of a run in the crisis zone π we also vary this parameter. The first column of Table 1.5 restates the results of the benchmark calibration in which π is set equal to 0.16 for both the benchmark model and the model without financial assistance. The next columns present the respective results when changing π to different values ranging from $\pi = 0.05$ to $\pi = 0.5$.[25] While the magnitude of the

[25]Note that for this exercise only the value of π is varied, while all other parameters remain at their benchmark values. As described in Section 1.3 in the benchmark calibration π is set to match the

effects vary, for all considered values of π the availability of financial assistance reduces the number of defaults which occur due to self-fulfilling runs by private investors but raises average debt levels causing an overall increase of the probability of default. The main result of the model is therefore robust for different assumptions about the value of π. Moreover, this robustness check also reveals that higher values of π lead to a larger number of defaults due to self-fulfilling runs accompanied by declining average debt levels thereby leading to an overall decrease of the default probability.

Table 1.5: Sensitivity of the results: Probability of a run in the crisis zone π

	Benchmark ($\pi = 0.16$)	$\pi = 0.05$	$\pi = 0.1$	$\pi = 0.2$	$\pi = 0.5$
Benchmark model					
Default prob. market debt	3.11%	3.22%	3.15%	3.12%	2.77%
→ of which due to runs	0.91%	0.59%	0.75%	0.99%	1.24%
Default prob. market debt and fin. assistance	0.0	0.0	0.0	0.0	0.0
→ of which due to runs	0.0	0.0	0.0	0.0	0.0
Prob(h>0)	0.55	0.52	0.57	0.55	0.55
Average market debt (% of GDP)	46.0	48.7	47.1	45.6	42.8
Average financial assistance (% of GDP)	5.3	5.4	5.4	5.3	5.4
Average spread market debt	3.9	4.0	4.0	3.9	3.4
Corr(y, $\Delta d/y$)	0.141	0.147	0.144	0.139	0.135
Corr(y, $\Delta h/y$)	-0.06	-0.06	-0.06	-0.06	-0.06
Without financial assistance					
Default prob. market debt	2.95%	3.20%	3.11%	2.88%	2.75%
→ of which due to runs	1.4%	0.97%	1.29%	1.44%	1.57%
Average market debt (% of GDP)	35.2	38.3	36.7	34.6	32.5
Average spread market debt	3.6	3.94	3.8	3.5	3.3

As a further robustness check we change the benchmark model by eliminating the option to default on financial assistance. We find that the simplified model leads to the same results as the benchmark model. Given that there are no state combinations for which a default on both types of debt occurs in equilibrium for the benchmark calibration, an exclusion of this option has no effects on the results of the model.

correlation of output with the change in market debt relative to output, corr(y, $\Delta d/y$) which is equal to 0.141.

1.4.6 Comparison to related studies

Comparing our results with related findings in recent quantitative studies we find important differences. Boz (2011) and Fink and Scholl (2011) also include financial assistance into a model of sovereign default. However, both studies have a focus different to ours and do not consider the full set of channels through which financial assistance affects the probability of default in our model. The presence of an official lending facility raises average debt stocks of the government in our model. Total debt of the government increases by 16 percentage points (which is an increase of 50 percent). A rise of equilibrium debt levels is also present in the model by Fink and Scholl (2011), while Boz (2011) finds the opposite effect. In contrast to our results both studies find that the inclusion of financial assistance increases the default probability strongly. In Boz (2011) the number of defaults rises drastically from 5.8 to 64.6 per 10,000 quarters and in Fink and Scholl (2011) the default probability increases from 2.88 to 5.00 percent. One important reason for this difference is the presence of defaults due to self-fulfilling crisis in our model. The official lending facility is able to decrease the occurrence of this type of default substantially. In the two other models this channel is excluded and the potential impact of bailout loans is hence restricted. Another reason for the difference might be found in the exact modeling of the official lending facility. In Boz (2011) the IFI provides unlimited amounts of non-defaultable loans to the country, which is consequently still able to smooth consumption relatively effectively after a default on market debt. This reduces the costs associated with a default relative to a version of the model without bailout loans. While there might be doubts about the commitment of the IFI to stop lending to a country in crisis, we think that our modeling choice of restricting the amounts of official lending is in line with actual policies. Roch and Uhlig (2014) consider a (basically unlimited) bailout guarantee that completely eliminates runs by private investors. In a preliminary numerical exercise they find a lower overall default probability when the guarantee is present. In difference to Roch and Uhlig (2014) in our model the government holds bailout loans in equilibrium which are senior to market debt. The associated repayment obligations affect the default incentives of the government. Considering an endogenous debt structure of both market debt and bailout loans we find that the presence of financial assistance leads to a slightly higher default probability in equilibrium.

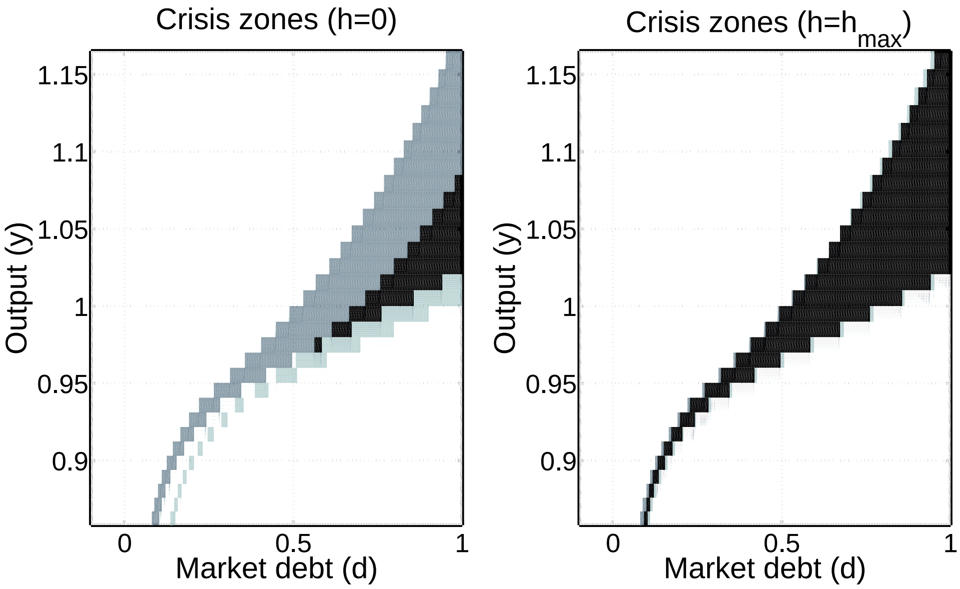
1.5 Conclusion

We construct a quantitative model of sovereign default to study the effects of the availability of financial assistance on the occurrence of defaults. The calibrated model yields business cycle statistics in line with Argentinean data. Simulating the benchmark model with financial assistance and a model version without financial assistance, we find that the presence of the official lending facility increases the probability of a default of the government on its market debt. At the same time the model version with this facility displays a higher average debt level than a model version without bailout loans. The insurance effect of bailout loans, which makes defaults less likely for a given level of debt, is therefore dominated by the general equilibrium effect of the resulting lower interest rates. The shift in the bond price schedule leads to higher equilibrium debt levels of the government and makes defaults again more likely. While the official lending facility is successful in reducing the number of defaults that are caused by runs of the investors it does not reduce the overall default probability. These results are robust against variations in the strictness of the conditionality and shortening the average exclusion spell after a default also on bailout loans. A welfare comparison shows that certainty equivalent consumption is lower in the model with financial assistance than in the model without financial assistance. Stricter conditionality leads to a higher welfare than lax conditionality as it results in lower total debt levels. The recent increase in official lending underscores the importance of understanding its impact on default incentives and welfare. Our results suggest that, while financial assistance can help to avoid defaults in the short run, it might entail substantial unintended consequences in the long run.

Appendix to Chapter 1

1.A Additional Figure

Figure 1.8: Comparison of crisis zones



Notes: black areas: zones overlap, gray areas: crisis only when no financial assistance is available, bright gray areas: crisis zone only in the model with financial assistance.

Chapter 2

The “Crisis Zone” in Europe - A Quantitative Analysis of the Case of Italy

2.1 Introduction

The experience of the crisis in European sovereign debt markets in the years after the financial crisis in 2009 has brought the topic of sovereign defaults back to the very top of the economic and political agenda. Several European countries faced high interest rate spreads on their government bonds, bailout programs for some countries (Ireland, Greece, Portugal, Cyprus and Spain) were set up, and Greece restructured its debt in 2012. The sudden emergence of high spreads on government bonds of advanced economies led to a debate on the underlying causes. Especially the distinction between fundamental economic factors, like high debt levels, low output (growth) and weak political institutions on the one hand, and reasons rather not founded in hard economic data like self-fulfilling run dynamics on the other hand, was (and still is) a prominent theme in the discussion.

While there had been no sovereign default in advanced economies since the aftermath of World War 2, there have been several defaults and debt crises in emerging economies. To analyze these events, economists have developed and applied theoretical models. Quantitative versions of these models are able to reproduce key features of default events. This chapter uses a calibrated version of a state-of-the art model of sovereign default to analyze the recent situation in Italy. While Italy did not receive an official bailout and fulfilled all its debt obligations, it is one of the countries that came under substantial pressure on the sovereign bond markets in the course of the European debt crisis. Interest rate spreads of Italian government bonds (relative to German bonds) rose above four percentage points at the end of 2011.

Using a structural model, in this case the one developed by Chatterjee and Eyigungor (2012), can help to better understand the events and to shed light on the relevance of different explanations. Chatterjee and Eyigungor (2012) model sovereign default in the tradition of Eaton and Gersovitz (1981) and Arellano (2008) as the optimal decision of a government. The model by Chatterjee and Eyigungor (2012) is especially useful for the exercise at hand, as it allows, in addition to the importance of fundamentals for the default decision, for defaults resulting from self-fulfilling crises on the international market for government bonds in the spirit of the "crisis zone" in Cole and Kehoe (2000). In the quantitative analysis conducted in this chapter, the model is calibrated to match the Italian data for the period under consideration, i.e. from the first quarter of 2010 to the last quarter of 2014. While the model is able to reproduce some features of the data, it clearly fails to fully account for the total evolution of the Italian interest rate spread over the time period. A main contrast between model and data is the fact that the model suggests that the spread should already have been high in the early periods of the sample, where output was still very low after the deep recession in 2009. In the data, however, the steep increase of the spread is observed only later in 2011 when output had already increased again. This observation might be seen as support for the argument (supported by empirical estimations) by De Grauwe and Ji (2013) that there was a change in the relationship between fundamentals and the interest rate spreads in Europe.

Of course there are many factors (potentially) influencing the European bond markets that are absent in the model. For example, the model does not include external bailouts by the European governments via the European Stability Mechanism (ESM) or its predecessors, and the bond purchasing programs by the European Central Bank (ECB), which (potentially) affected the prices of government bond over the sample period. Still, some findings are surely interesting for the debate. For example the quantitative analysis suggests, that runs by investors (at least those that are captured by the theoretical game outlined in Cole and Kehoe, 2000) only play a very minor role given the long maturity of debt found in the data and the associated relatively low amounts of debt to be rolled over each period.

The rest of the chapter is organized as follows: Section 2.2 provides a very brief overview of the developments of the crisis in the eurozone. Section 2.3 summarizes the model by Chatterjee and Eyigungor (2012) which is used in the quantitative analysis. Section 2.4 outlines the calibration of the model. Section 2.5 shows the results of the analysis and provides some discussion on the robustness. Section 2.6 provides further discussion of the results and relates them to the existing literature. Section 2.7 concludes.

2.2 The crisis in Europe

This section provides a brief account of the crisis events in Europe which constitute the background of the developments in Italy that are analyzed in this chapter. After the convergence of interest rates in the run-up to the introduction of the Euro in 1999, the cross-sectional variance of government bond yields of the participating countries had remained very low for almost a decade. Only after the financial crisis of 2008 non-negligible spreads showed up again. In the course of 2010, the spreads between the interest rates on government debt of several eurozone member countries (especially Greece, Ireland, Italy, Portugal, and Spain) and those of German government bonds escalated.[1] In the following some relevant aspects of the crisis developments in the eurozone are discussed briefly.[2]

With the introduction of the Euro, the borrowing costs especially for the southern European countries now participating in the common currency declined. In the following years Greece, Ireland, Italy, Portugal, and Spain experienced a substantial credit boom, yielding roughly a doubling of the ratios of private credit to GDP from 1998 to 2007 (see Lane, 2012). The ratio of government debt to GDP, however, only increased in Greece and Portugal, while it was declining in Ireland, Italy, and Spain. During the first decade of the 2000s the southern European countries Greece, Portugal, and Spain were running substantial current account deficits. While possibly being justified by economic convergence, large and sustained external deficits carry

[1] See Figure 2.9 and Figure 2.10 in the appendix of this chapter.

[2] For a more detailed analysis of the crisis in Europe see for example Lane (2012) or Shambaugh, Reis, and Rey (2012). Eichengreen, Jung, Moch, and Mody (2014) provide a historical comparison of the current crisis in Europe with the crisis episodes in Latin America in the 1980s and Asia in the 1990s.

significant risks for the country borrowing from the rest of the world. As summarized by Lane (2012), these risks include distortions in the economic structures of the domestic economy, which decrease the growth potential in the medium term, and the vulnerability to a sudden stop of external funding, which implies drastic and costly adjustment processes.

The credit boom, which was paralleled by the credit boom in the United States, came to an end in the global financial crisis after 2007. Based on their empirical analysis, Mody and Sandri (2012) describe the interaction of stress in the financial sectors and problems for public finances in the ensuing crisis in Europe. First, the global financial shock was transmitted to Europe and indicators of financial stress and sovereign spreads increased in many countries. In the phase after the nationalization of Anglo Irish (an Irish bank) in January 2009, Mody and Sandri (2012) observe that sovereign spreads react specifically to stress in the respective country's financial sector. This can be explained by a reassessment of public debt levels in the light of the expensive rescue measures provided to the banking sector. Since the beginning of 2009, the authors find a contemporaneous interaction of sovereign spreads and financial sector stress and a dramatic increase in spreads and a strong differentiation between the countries. The financial position of sovereigns was weakened by a downward revision of growth expectations due to the unfolding Great Recession and a correction of the previously expected growth paths of the respective countries which were now considered as unsustainable. In this phase, the weak financial sector limits the growth potential of the country, undermining the government's financial position, which in turn feeds back stress to the financial sector, which is an important holder of domestic government bonds. A crucial point in the intensification of the crisis was the release of dramatically higher fiscal deficit figures by the newly elected government after the general elections in Greece in 2009. The forecast for the fiscal deficit in 2009 was revised upwards from 6.0 to 12.7 percent of GDP (see Lane, 2012). Also the fiscal position of the other countries worsened as their revenues declined due to the economic crisis and the end of housing and asset booms.

To counter the developing crisis, different policy measures were used. The European countries set up different funds to provide credit to troubled countries.[3] In most of these lending programs, which were provided conditional on agreed economic reform

[3]See Lane (2012) for a compact description of the events.

measures, the International Monetary Fund (IMF) was also involved and provided further credit. Within the eurozone, Cyprus, Greece, Ireland, Portugal, and Spain received bailout programs. In 2012 the Greek debt was restructured as part of a second adjustment program and private investors suffered a haircut of over 60 percent of value.[4] While Ireland and Portugal concluded their programs with the EFSF (European Financial Stability Facility) and Spain ended its program with the ESM (European Stability Mechanism), Greek continued to have tremendous difficulties to return to private financial funding and in the course of the summer of 2015 a new (the third) assistance program is in preparation.

Next to the actions by the member states of the eurozone, also the European Central Bank (ECB) applied some important measures to ensure the functioning of the monetary policy transmission and the stability of the eurozone.[5] Most importantly, it bought government bonds under the "Securities Markets Programme" (SMP), and by introducing the so called "Outright Monetary Transactions" (OMT), which replaced the limited SMP, the ECB committed to buy, if necessary, on secondary markets without ex ante quantitative limit government bonds of eurozone countries that are in a conditional program with the ESM. De Grauwe (2013) argues that, by introducing OMT, the ECB accepted its role as a lender-of-last-resort in the markets for sovereign bonds of the member states of the eurozone. Without an institution like this, he sees the eurozone member states to be prone to liquidity crises, a threat which countries with their own currency and their own central bank standing ready to buy bonds would not face.

The deep recession and the ongoing weakness of economic growth in most of the member states of the eurozone led to a large debate on the right approach of fiscal adjustment policies and how to deal with the high debt levels. Mody (2013) and Whelan (2013) describe the evolution of the official positions on a sovereign default by a member state of the eurozone. At the beginning of the crisis a default was excluded, among other reasons due to the risk of contagion and the feeling that, as advanced economies, eurozone member states would be able to deal with the crisis without defaulting. But in the course of the crisis the view evolved that (especially) the Greek

[4] See Zettelmeyer, Trebesch, and Gulati (2013) for a detailed analysis of the Greek debt restructuring and the estimation of the haircut.

[5] See Krishnamurthy, Nagel, and Vissing-Jorgensen (2013) for a description and an analysis of the applied policies.

debt was unsustainable and "private sector involvement" became the official position. However, as Mody (2013) argues, as the policy decision were taken on an ad-hoc basis and each case was treated as a special and individual one, there was a lot of uncertainty surrounding the safety of the governments' debt, which kept the crisis going.

While Italy, neither defaulted nor received a bailout by its European partner countries, it still is one of the countries that repeatedly were in the focus of the discussions on the crisis. Given the size of its economy, the third largest in the eurozone, the economic stability of Italy is of great relevance for the rest of Europe. However, the country's high government debt level, its low economic growth, and political instabilities let to doubts about the sustainability of Italy's debt. One symptom of Italy's political instability was a rapid change of governments during the years of the crisis. Many commentators were very doubtful about the handling of the crisis by the government headed by Silvio Berlusconi. In November 2011, at the height of the crisis, Berlusconi resigned and its government was replaced by a "technocratic" government led by Mario Monti. Monti in turn resigned at the end of 2012 and after general elections in 2013 Enrico Letta took office a prime minister.[6] In February 2014 Letta's government again was replaced by a new government led by Matteo Renzi.

2.3 Model

The quantitative analysis in this chapter is conducted using the model of Chatterjee and Eyigungor (2012) in which a sovereign default is the optimal decision of the government. The model is an extension of the quantitative analysis of the Eaton and Gersovitz (1981)-framework by Arellano (2008) and includes long-term debt instead of one-period bonds and allows for self-fulfilling debt crises due to runs by international investors à la Cole and Kehoe (2000). To make the exposition of the analysis in this chapter self-contained, this section provides in the following a brief outline of the model by Chatterjee and Eyigungor (2012).[7]

[6] See Falagiarda and Gregori (2015) for an analysis of the different impact fiscal policy announcements by these three different governments had on the Italian sovereign spread.

[7] For further details, proofs, and information on the computational algorithm see Chatterjee and Eyigungor (2012) and the associated appendices thereof.

2.3.1 Preferences and endowments

The model framework consists of a small open economy with an infinite time horizon. Time is discrete and the preferences of the representative household of the small open economy are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t\right), \tag{2.3.1}$$

where c_t denotes consumption in period t. $\beta \in (0,1)$ is the discount factor, and E_0 is the expectation operator. The period utility function $u(\cdot)$ is strictly increasing and strictly concave and hence implies risk aversion.

The country receives a stochastic stream of endowments. For computational reasons Chatterjee and Eyigungor (2012) split the endowment x_t in two components:

$$x_t = y_t + m_t, \tag{2.3.2}$$

where y_t is a persistent component which follows a Markov process and m_t is a transitory component which is drawn independently each period from a continuous mean zero probability distribution.

2.3.2 Bond contracts

The government of the small open economy can trade bonds with international investors and has the option to default on its outstanding obligations. In contrast to the first generation of quantitative models of sovereign default in which all bonds had a maturity of one period,[8] the model of Chatterjee and Eyigungor (2012) allows to consider bond contracts with a maturity of multiple periods.[9] To keep the number of state variables tractable, only one type of bond is considered.[10] An outstanding unit of debt is assumed to mature each period probabilistically with probability λ. Units of debt that do not mature in a given period pay out a coupon payment z. By construction this payment structure is the same for any outstanding unit of debt independent of the date of its issuance. Assuming that each unit of debt is

[8] See e.g. Arellano (2008) and Aguiar and Gopinath (2006).

[9] Long-term loans with a fixed maturity are also analyzed by e.g. Hatchondo and Martinez (2009).

[10] Arellano and Ramanarayanan (2012) allow for an endogenous choice between short term and long-term bonds.

infinitesimally small implies that in a given period a government with $-b$ units of outstanding debt is with certainty obliged to pay $-\lambda b$ as principal and $-z \cdot (1-\lambda)\, b$ as coupon payments.[11]

In case of a default, which is assumed to comprise the full amount of debt, the government is excluded from financial markets and hence from further borrowing. A country in autarky may return to financial markets in a given period with probability ξ.

2.3.3 International investors and self-fulfilling runs

International investors are assumed to act in perfectly competitive markets. They can borrow and lend unlimited amounts at world financial markets at a risk-free interest rate r and are risk neutral.[12] In equilibrium the bond price hence has to reflect the probability of a default to ensure in expectations zero profits for the investors.

The need to roll over a substantial share of its debt each period exposes the government to the threat of self-fulfilling debt crises due to runs by investors. In certain situations the government's decision to default depends on its access to new loans, i.e. it chooses to default only if it does not receive new funding. In this case two possible equilibria emerge. In the first equilibrium all investors are willing to provide new lending and the government does not default. In the second equilibrium, however, each individual investor refuses to provide new loans because she fears that the other investors might refuse to roll over the debt yielding a loss of her investment due to the resulting default of the government. Without the new funds the government then chooses indeed to default in equilibrium. Cole and Kehoe (2000) provide a detailed theoretical explanation of this type of debt crisis.

To include run-driven defaults into the quantitative model outlined above, Chatterjee and Eyigungor (2012) make one simplifying assumption: In case of a run, the government has to return the new loans to the investors that did not refuse to lend. This assumption makes the value of default independent of the indetermined amount of new loans. The incentive structure of the individual investors, however, remains

[11] Following the notation of Chatterjee and Eyigungor (2012) negative values of b denote debt of the country.
[12] See Lizarazo (2013) for a model of sovereign default with risk averse lenders.

the same, as they miss interest payments they would have earned if they had invested on world financial markets.

2.3.4 The government's decision problem

In each period the benevolent government of the small open economy decides on the debt policy of the country in order to maximize the discounted sum of the households' utility. As long as the country is in good credit standing this implies that the government chooses either to default or to honor its debt obligations and to continue to be able to borrow on international financial markets. Consequently, the default decision results from comparing the value of default, X, with the value of repaying the debt, V.

The value function of default is given by:

$$X\left(y,m\right)=u\left(c\right)+ \\ \beta\left\{[1-\xi]E_{(y'm')|y}X\left(y',m'\right)+\xi E_{(y'm'\omega')|y}W\left(y',m',0,\omega'\right)\right\} \tag{2.3.3}$$

subject to

$$c=y-\phi\left(y\right)-\bar{m}, \tag{2.3.4}$$

with $'$ denoting next period's variables. The household can consume the endowment and with probability ξ the country will return to good credit standing in the next period. W denotes the value function of a country in good credit standing that has the option to default and ω is a sunspot variable, which is explained below. The resource constraint (2.3.4) reflects that during autarky the economy occurs an output cost of $\phi\left(y\right)$. Additionally, in the period of default the transitory component of m_t is set to its lowest possible value, $-\bar{m}$.

Due to the possibility of runs by the investors, one has to consider two different cases for the value function of repayment: First, the government honors its obligations while having new borrowing at its disposal. Second, the government honors its obligations despite having no access to new credit.

The value function of the first case is given by:

$$V^{+}(y,m,b) = \max_{b' \in B} u(c) + \beta E_{(y'm')|y}[(1-\pi) W(y',m',b',0) + \pi W(y',m',b',1)] \tag{2.3.5}$$

subject to

$$c = y + m + [\lambda + (1-\lambda) z]b - q(y,b')[b' - (1-\lambda) b] \tag{2.3.6}$$

where B denotes the set of possible debt choices and $q(y,b')$ is the price of newly issued bonds. The government pays principal and coupon payments for the outstanding bonds b and chooses the new amount of bonds b'.

π is the probability that the random variable ω takes a value of 1. The sunspot variable ω assumed to be i.i.d. and is introduced to determine which equilibrium is realized in case both equilibria explained above are possible for the given combination of state variables. A realization of $\omega = 1$ chooses the self-fulfilling debt crises default equilibrium.

The value function in case of a run by the investors is given by:

$$V^{-}(y,m,b) = \max_{b' \in B} u(c) + \beta E_{(y'm')|y}[(1-\pi) W(y',m',b',0) + \pi W(y',m',b',1)] \tag{2.3.7}$$

subject to

$$c = y + m + [\lambda + (1-\lambda) z]b - q(y,b')[b' - (1-\lambda) b] \tag{2.3.8}$$

and

$$b' \geq (1-\lambda) b, \tag{2.3.9}$$

where the last constraint (2.3.9) states the fact that without new lending by the investors the debt can not increase above the level of non-maturing debt at the beginning of the period.

In the presence of multiple equilibria, the realization of the sunspot variable is an additional state and W, that is the value of being in good standing, is given by:

$$W(y,m,b,\omega) = \begin{cases} V^{+}(y,m,b) & if\ X(y,-\bar{m}) \leq V^{-}(y,m,b) \text{ and } \omega \in \{0,1\} \\ X(y,-\bar{m}) & if\ V^{+}(y,m,b) < X(y,-\bar{m}) \text{ and } \omega \in \{0,1\} \\ V^{+}(y,m,b) & if\ V^{-}(y,m,b) < X(y,-\bar{m}) \leq V^{+}(y,m,b) \text{ and } \omega = 0 \\ X(y,-\bar{m}) & if\ V^{-}(y,m,b) < X(y,-\bar{m}) \leq V^{+}(y,m,b) \text{ and } \omega = 1. \end{cases} \tag{2.3.10}$$

This functional form results from the fact that the existence of multiple equilibria divides the state-space into three regions. In the first region, corresponding to the first case of equation (2.3.10), the government always prefers to honor its debt obligations, even without new loans. In this case the investors do not fear a default, always provide new loans, and no self-fulfilling defaults are possible. In the second region, corresponding to the second case of equation (2.3.10), the government always prefers to default, even if there is no run by the investors. The third region is the so-called "crises-zone". This is the region of multiple equilibria in which the sunspot variable ω determines whether there is no run and no default (the third case of equation (2.3.10)) or there is a run and a default (the fourth case of equation (2.3.10)).

2.3.5 Equilibrium bond price

Given the optimal decisions of the government and the international investors, the equilibrium price function for the government bond is given by:

$$q(y,b') = E_{(y'm'\omega')|y}\left[\left[1-d(y',m',b',\omega')\right]\frac{\lambda+[1-\lambda]\left[z+q(y',a(y',m',b',\omega'))\right]}{1+r}\right], \tag{2.3.11}$$

where the indicator function d denotes the default decision of the government, depending on the state variables. If the government decides to default d takes a value of one, otherwise it equals zero. The function a denotes the government's choice of debt given the state variables. The price function ensures in expectations zero profits for the investors, who receive either zero in case of a default in the next period or receive coupon and principal payments and hold the remaining stock of bonds if no default occurs. Chatterjee and Eyigungor (2012) show that this equilibrium price function exists. Additionally they show that the bond price is increasing in b', i.e. that interest rates are increasing with the chosen level of debt.

2.4 Calibration

For the quantitative application the model is calibrated to match relevant moments of the Italian data. In order to use the model for a quantitative analysis a number of functional forms have to be specified. The chosen functional forms are the same as in Chatterjee and Eyigungor (2012): First, as it is commonly done in the literature, the utility function of the households is assumed to be of the CRRA-form (constant relative risk aversion) and given by:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma}. \tag{2.4.1}$$

Second, the stochastic process of the country's output is specified as follows: The persistent component of the output process, y_t, is assumed to follow an AR(1)-process in logs, that is:

$$\ln y_t = \rho \ln y_{t-1} + \epsilon_t, \qquad \text{with} \quad \rho \in (0,1) \qquad \text{and} \quad \epsilon_t \sim N\left(0, \sigma_\epsilon^2\right). \tag{2.4.2}$$

The transitory component of the output process, m_t, is drawn each period from a truncated normal distribution, i.e.

$$m_t \sim \ trunc\ N\left(0, \sigma_m^2\right) \qquad \text{with points of truncation} \quad -\bar{m} \quad \text{and} \quad \bar{m}. \tag{2.4.3}$$

Third, the output cost of default depends on the realization of the output process and is given by the convex function

$$\phi(y) = \max\left\{0, d_0 y + d_1 y^2\right\}, \qquad \text{with} \quad d_0 < 0 < d_1. \tag{2.4.4}$$

The model is calibrated to match Italian data for the time period from the first quarter of 2010 to the fourth quarter of 2014. One time period in the model is equivalent to one quarter. Table 2.1 and Table 2.2 give an overview of the model's parameters and their values chosen for the analysis. A first set of parameters (listed in Table 2.1) is set directly given evidence from Italian data or common practice in the literature. The values of the remaining three parameters (listed in Table 2.2) are chosen by matching statistical moments from model simulations to the corresponding moments of the Italian data.

Table 2.1: Parametrization

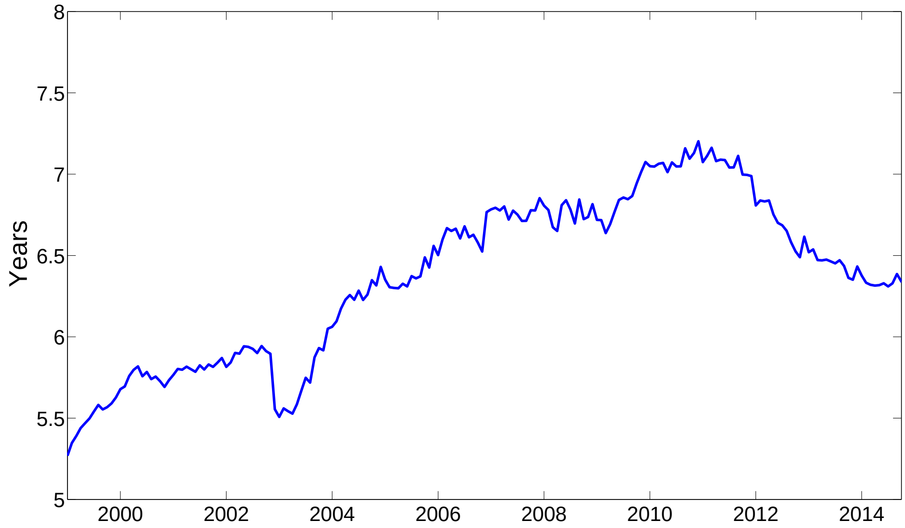
Parameter		Value	Source
Autocorrelation output	ρ	0.8811	Estimation - Italian data
Standard deviation of ϵ	σ_ϵ	0.0065	"
Standard deviation of m	σ_m	0.001	Predefined value
Bound on m	$\bar{m}$	0.002	"
Relative risk aversion	γ	2	Literature
Risk free interest rate	r	0.00085	Average quarterly real interest rate on German bonds
Maturity (inverse)	λ	0.037	Average residual life of Italian government debt
Coupon	z	0.007	Bonds roughly trade at par
Redemption probability	ξ	0.0532	Average exclusion of 4.7 years (Gelos et al., 2011)
Probability of run in "crisis zone"	π	0.1	Predefined value

The output process is estimated using seasonally-adjusted quarterly data on the Italian real GDP from 1999-Q1 to 2014-Q4, i.e. the time period since the introduction of the euro. The data is provided by Eurostat. After taking logs of the original series, the data is detrended using the Hodrick-Prescott filter (with a smoothing parameter of 1600). The parameters of the AR(1)-process, ρ and σ_ϵ, are estimated taking into account the transitory component which is assumed to follow a normal distribution with standard deviation $\sigma_m = 0.001$.[13] For the model solution the persistent component is approximated by a Markov chain with 200 states covering three standard deviations, σ_ϵ, above and below the zero mean. The normal distribution of the transitory component is truncated at +/- two standard deviations of m, σ_m.

The parameter of relative risk aversion in the utility function is set to $\gamma = 2$,

[13]The standard deviation of the the detrended log GDP series is 0.014. $\sigma_m = 0.001$ hence implies that the transitory component accounts for 0.51% of the variance of log output.

Figure 2.1: Average Residual Life of Italian Government Debt



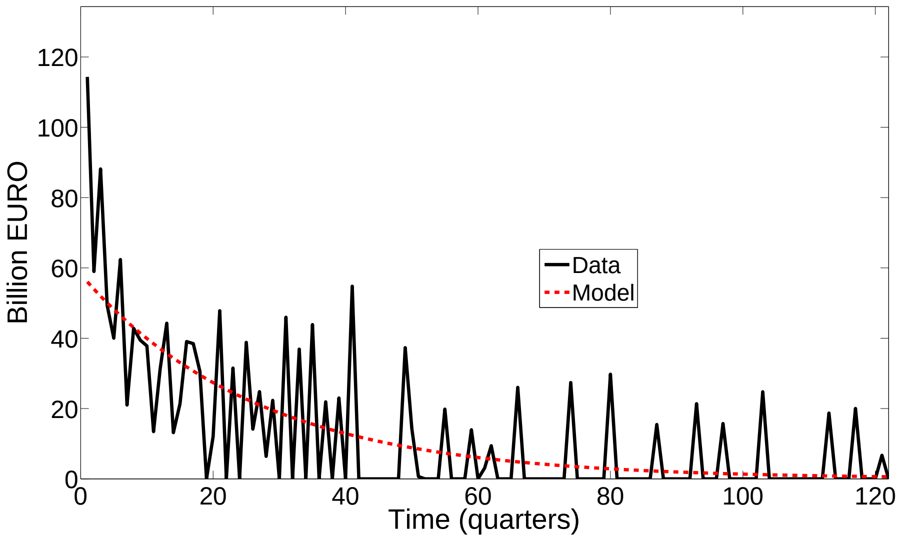
Data source: Dipartimento del Tesoro, Italy.

a standard value in the literature. The quarterly risk free interest rate is set to $r = 0.00085$ which corresponds to the average of the real interest rate of German government bonds over the time period considered.[14]

The inverse of the average maturity of the government bonds, λ, is set as to match the average maturity of Italy's government debt. Figure 2.1 shows the evolution of the average residual life of Italian government debt since the introduction of the Euro. The value of $\lambda = 0.037$ results from an average of 26.9 quarters (6.73 years) over the time period from the first quarter of 2010 to the last quarter of 2014. The way long-term debt is modeled in Chatterjee and Eyigungor (2012) implies that each period the same share of debt matures. Figure 2.2 and Figure 2.3 show how the repayment structure implied by the model compares to the actually scheduled amounts of repayment taken from data from the Italian treasury. The theoretical amount is calculated given the total amount of debt outstanding at a given point in time using a value of $\lambda = 0.037$ as implied by the value of the average maturity.

[14] From 2010-Q1 to 2014-Q4 the average annual nominal interest rate on German 10-year government bonds is 1.92%. Average annual euro area HICP-inflation over that period is 1.58%. This implies an (ex-post) real interest rate of 0.34% in annual terms.

Figure 2.2: Amount to be paid from 2011-Q2 onwards

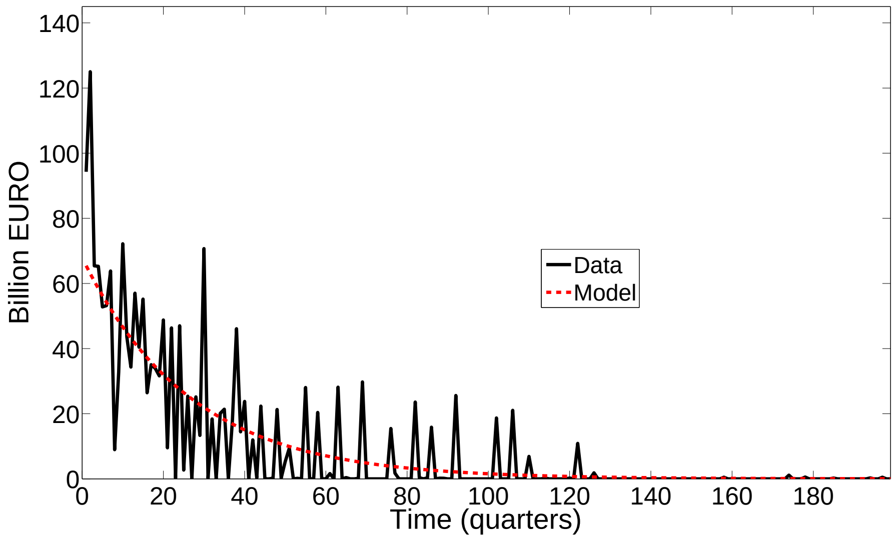


Notes: Amount of debt to be paid back in future quarters. The continuous black line shows the actual data from the Italian Dipartimento del Tesoro. The dashed red line shows the amount implied by the repayment structure in the model, given the total amount of repayments from the data and the calibrated value of the inverse of the average maturity, $\lambda = 0.037$.

Figure 2.2 shows the series from the perspective of the second quarter of 2011, just before the crisis intensified with interest spreads of Italian bonds rising to values above three percentage points in the third quarter of 2011. Figure 2.3 shows the same series for the first quarter of 2014. Overall the fit of the series is quite good, however, given the skewed distribution of the maturities of the different bonds in reality, the model underestimates the amounts to be paid in the first periods. To account for this, a robustness check with a higher value of lambda (i.e. a lower value for the average maturity) is shown in Section 2.5.3. Additionally, the data exhibits a certain seasonality due to the schedule for the issuance of bonds over the calendar year, which is not present in the model.

Probably the most important indicator of sovereign debt crisis is the interest rate spread that a government has to pay on its bonds. Figure 2.4 shows the series of the interest rates of Italian and German government bonds and the spread between the two. The series exhibit the by now well known pattern that there was only a very low spread from the introduction of the Euro until the global financial crisis around 2008,

Figure 2.3: Amount to be paid from 2014-Q1 onwards



Notes: See Figure 2.2

followed by a steep increase of the spread in 2011 and a decline, however not fully back to the old level, after summer 2012. The average spread over the time period from 2010-Q1 to 2014-Q4 is 2.516%. The value of the coupon parameter, z, is set equal to a value of 0.007. Given the targeted average annualized spread of 2.516% and the (annualized) value of the risk free rate of 0.34%, this value implies that on average the bonds in the model roughly trade at par.

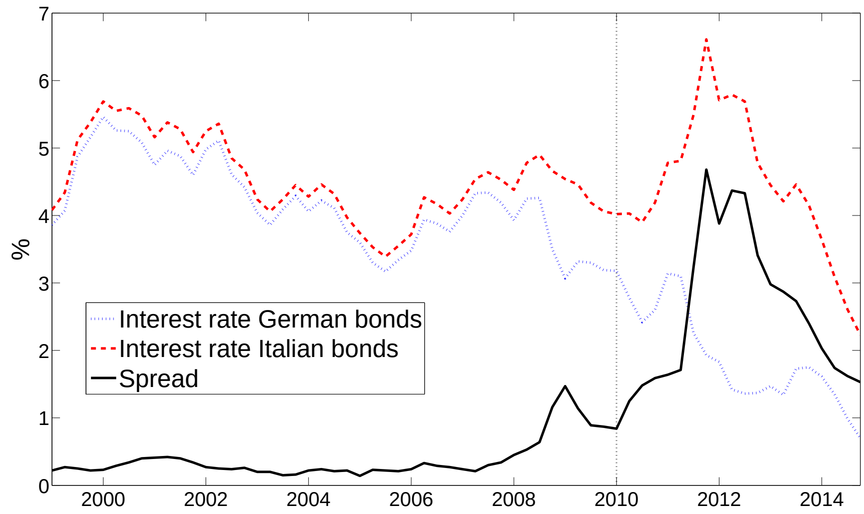
The redemption probability, i.e. the inverse of the expected length of the exclusion from credit from international financial markets, is set to $\xi = 0.0532$. This corresponds to the average exclusion of 4.7 years found by Gelos, Sahay, and Sandleris (2011) for a sample of default events in the time from 1980 to 2000.

The parameter π which denotes the probability of a run in the "crisis zone" is set to 0.1. As this parameter is hard to determine empirically it is set at this value in the benchmark calibration and varied in a sensitivity analysis in Section 2.5.3.

The remaining three parameters (see Table 2.2) are set by matching three moments from simulations of the model to moments of the Italian data.[15] Specifically, the

[15]See Chatterjee and Eyigungor (2012) for a detailed discussion of the interaction of the three

Figure 2.4: Interest rates and spread



Notes: data: "EMU convergence criterion bond yields" provided by Eurostat. The vertical line denotes the beginning of the sample period for the quantitative analysis.

discount factor is set to $\beta = 0.9732$ in order to match the average spread of 2.516%. The standard deviation of the spread, which equals 1.155 over the sample period (see Figure 2.4), is matched by setting the second parameter in the cost function, d_1, equal to a value of 6.231.

Table 2.2: Calibration

Parameter		Value	Target	Value
Discount factor	β	0.9732	Average spread	2.516%
Parameter in cost function	d_0	-6.0990	Debt-to-GDP-ratio	1.714
Parameter in cost function	d_1	6.2310	STD spread	1.155

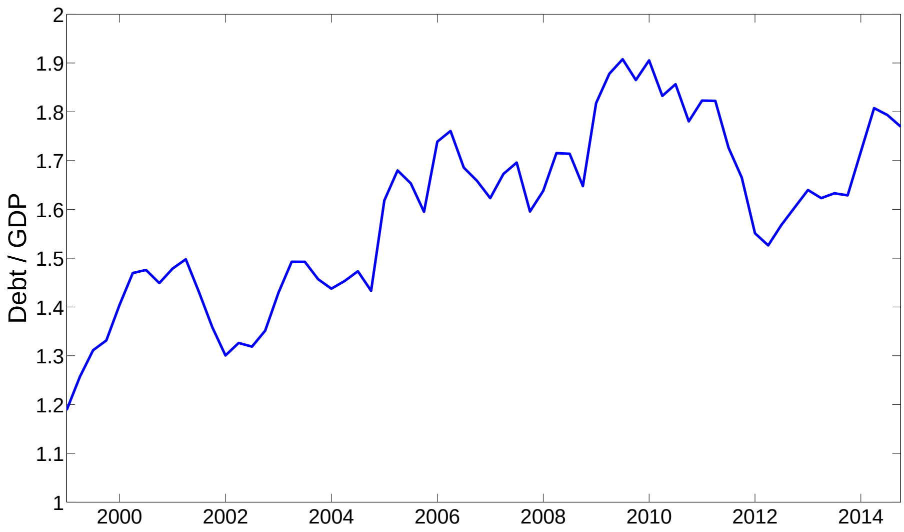
The value of the first parameter in the cost function, d_0, is set to -6.099 in order to match the average ratio of debt to GDP.[16] The debt measure chosen for the calibration

parameters.

[16]Note that the values of the two parameters of the cost function found in the calibration imply a very high output cost of default and autarky (up to forty percent of the average output if the highest values of the output shock are realized). While this might seem implausible, there is no clear empirical observation of the costs of an outright sovereign default in a modern advanced economy, that could inform about the actual costs.

is the ratio of gross government debt held by non-residents relative to nominal GDP. The data on this type of debt is available from the Bank of Italy. Figure 2.5 shows the evolution of this measure since the introduction of the Euro. Over the sample period since 2010 the average ratio of debt to (quarterly) GDP is 1.714. The specific measure of debt is chosen as, on the one hand, it is as in the model held by investors outside the country and, on the other hand, it can directly be related to the interest rate spread observed in the data and the decision of the government.

Figure 2.5: Italian Debt



Notes: Italian gross government debt held by non-residents relative to quarterly GDP. Data: Banca d'Italia.

2.5 Results

2.5.1 Business cycle statistics

One way to judge the model's performance is to compare business cycle statistics from model simulations with the corresponding moments from the actual Italian data.[17] Table 2.3 shows the results for the benchmark calibration of the model. The three moments at the bottom of Table 2.3 are direct targets that are matched by choosing three parameters of the model (see Section 2.4). The model is calibrated to match the data for the crisis period from 2010 to 2014. The rightmost column of Table 2.3 shows the moments of the Italian data for the full sample period since the introduction of the Euro in 1999.

Table 2.3: Business cycle statistics

Variable	**Model** (Benchmark Calibration)	**Data** (2010Q1-2014Q4)	**Data** (1999Q1-2014Q4)
$\sigma(y)$	0.008	0.009	0.014
$\sigma(c)/\sigma(y)$	2.726	1.228	0.555
$\sigma(nx/y)/\sigma(y)$	2.278	2.411	1.068
$corr(c,y)$	0.858	0.769	0.693
$corr(nx/y,y)$	-0.631	-0.297	0.133
$corr(spread,y)$	-0.567	0.014	-0.052
Default frequency	2.09%	0	0
Run driven default freq.	0.009%	0	0
$Mean(spread)$	2.838%	2.516%	1.045%
$\sigma(spread)$	0.924	1.155	1.208
$Mean(d/y)$	1.738	1.714	1.595

Notes: Data on output (y), consumption (c) and trade balance (nx) from the OECD. The spread is calculated as the difference between Italian bond yields and the German bond yields using data from Eurostat and is reported in annualized terms. The series of log output and log consumption are detrended using the HP-filter with smoothing parameter 1600. The debt level is Italian government debt held by the rest of the world (data provided by Banca d'Italia) and is reported relative to quarterly GDP. Except for the default frequencies, the statistics from the model are calculated considering only periods outside default and autarky.

The upper part of Table 2.3 shows data moments from the model simulation that are no direct targets in the calibration of the model. While consumption is too

[17] To obtain the statistics, the model is simulated several times over many periods. The statistics then are computed as averages over these simulations. As in Chatterjee and Eyigungor (2012) 20 quarters after the return to financial markets are excluded, as, in contrast to the data, the country reenters the markets with zero debt.

volatile in the model simulation compared to the data, the fact that it is more volatile than output is consistent with the data from the crisis period since 2010. The high relative volatility of consumption is a feature that is also found for Argentinian data before the default in 2001 (see Arellano, 2008; Chatterjee and Eyigungor, 2012), but is in contrast to the usual finding for advanced economies, that consumption tends to be less volatile than output[18] (as it is the case for Italy for the longer time span since the introduction of the euro). The model matches very well the high (relative) volatility of the trade balance during the period since 2010. Both, model and data show a high positive correlation between output and consumption. The trade balance is negatively correlated with output. This is again consistent with the Italian data from the crisis period and the Argentinian experience, but not with the longer sample of Italian data which shows a positive correlation. The model produces a strong negative correlation between the interest rate spread and output. However, in the Italian data since 2010 there is basically no correlation between the two variables, if at all it is slightly positive. For the benchmark calibration the model implies a default frequency of two percent per year, out of this, only 0.009 percentage points are due to run-driven crisis events.

2.5.2 The "crisis zone" and the evolution of the crisis

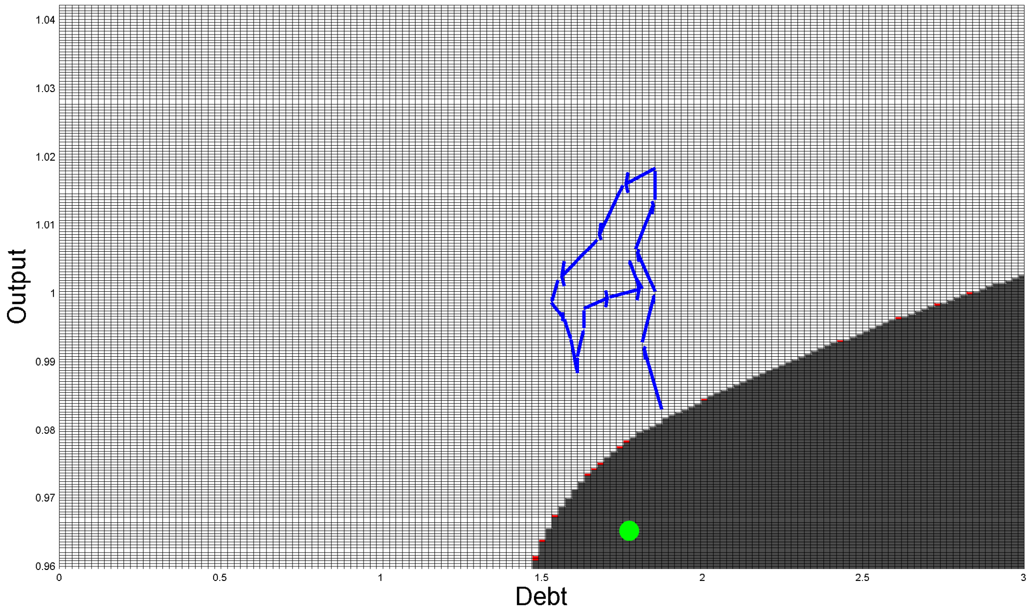
Figure 2.6 shows the default decision of the government in the model. The dark area shows the state combinations for which the government chooses to default. The model specification implies that this is the case when the outstanding debt is very high and output is relatively low. The red area denotes the "crisis zone", i.e. state combinations for which the decision of the international investors to provide new funding to the country determines its default decision. As can be seen from Figure 2.6 this region is very small for the benchmark calibration. This corresponds to the finding from the model simulations in the previous subsection that run-driven default events are very unlikely. One main driver of this finding is the long average maturity assumed in the benchmark calibration (see Section 2.5.3 for further discussion).

The blue arrows in Figure 2.6 show the actual evolution of the Italian fundamentals over the sample period (2010-Q1-2014-Q4).[19] Starting close to the default region

[18]See e.g. Neumeyer and Perri (2005).

[19]The output values are given by the values of the detrended GDP series. (As in the calibration the

Figure 2.6: The Crisis in Italy - Default Decision



Notes: Default decision of government for each combination of output realization (vertical axis) and outstanding debt (horizontal axis, measured relative to the output level given by the mean of the shock process). Dark gray area denotes the decision to default, the white area denotes repayment of outstanding debt and the red area denotes the “crisis zone”. The blue arrows denote the actual movement of Italian fundamentals in the sample Period from 2010-Q1 to 2014-Q4. The green dot denotes the Italian fundamentals in the first quarter of 2009.

there was an improvement in (detrended) output that moved the Italian fundamentals away from a default decision. Despite variations, the Italian debt level remained at levels for which a very low output realization might have induced the government to default on its debt obligations.

The green dot in Figure 2.6 denotes the combination of output and debt of Italy in the first quarter of 2009. This was the quarter where output dropped massively in the great recession after the financial crisis. The fact that the green dot lies in the default region illustrates the failure of the model to fully account for the whole

detrending is done applying the HP-filter to the series of log real GDP for the full sample from 1999-Q1 to 2014-Q4. The debt level in debt units of the model is determined by matching each period the ratio of debt to GDP in model units to the one observed in the data (see Figure 2.5).

evolution of the Italian default risk. While the model clearly predicts a default for this situation, the actual data shows indeed an uptick in the spread, however, the value of the spread is very small compared to the spreads observed in later periods (see Figure 2.4). Given the extreme drop in output in 2009, it is impossible for the calibrated model, which implies a close relationship between output and the spread, to reproduce the moments and the evolution of the spread data but not to imply the counterfactual default at that period.[20]

Acknowledging this obvious failure of the model, it is still interesting to see how the model does in explaining the development of the Italian spread in the period after the first deep recession. This period (2010-Q1 to 2014-Q4) comprises most of the time span of what is often referred to as “the Euro crisis” (the debt crisis of several European countries, which probably can not be said to be over at the moment of writing). The calibration outlined in Section 2.4 is made exactly for this time period. Figure 2.7 shows the evolution of output, the debt level and the interest rate spread over the time period under consideration. The graph shows the series of the variables taken from the data (dashed blue lines) and the ones obtained by simulating the model given the actual Italian output series as the realizations of the exogenous output shock (continuous red lines). The simulation is initialized in the first period with the debt level that corresponds to the actual Italian debt to GDP ratio. In the first periods of the simulation, the debt series from the model fits the data relatively well. Then, however, it does not match the decline of external debt observed in the data.[21] In the last quarters of the sample period, the two series are again relatively close. The rightmost panel of Figure 2.7 shows the series of the interest rate spread. In the beginning of the sample period, the spread series implied by the model deviates substantially from the one from the data. Given the still very low output at the beginning of 2010 the model implies a huge interest rate spread of more than 14 percentage points, while in the data the spread is below one percentage point. The fit of the two series in the rest of the sample is not too bad, but the strong

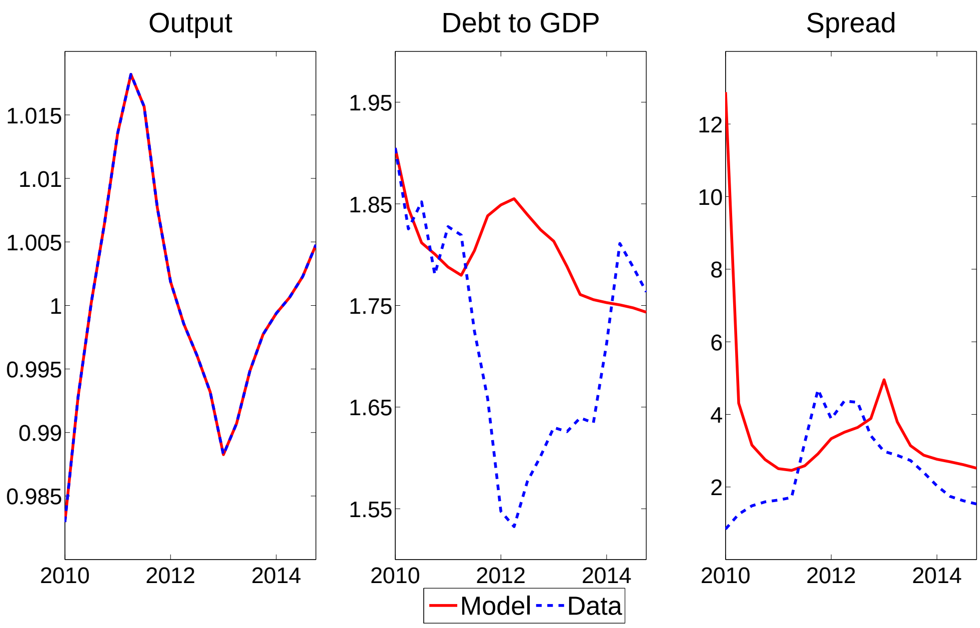
[20] Given the model mechanics, a model that implies this default would also be useless to analyze the periods following the default as the country would be excluded from financial markets and no bond price would exist.

[21] Remember that the debt considered in the analysis is externally held government debt, i.e. a decline in the debt measure does not automatically imply a decline in overall government debt. See Brutti and Sauré (2013) for an analysis of the repatriation of sovereign debt in the Euro area during the crisis.

deviation in the first period raises doubts that the model is indeed the explanation of the observed data.

Taken together, the analysis of the results from the model solution and simulations suggests that the developments in the Italian debt market in the last years can rather not be (fully) explained by a standard model of sovereign default, calibrated in the standard way. On the one hand, the observation that despite high debt levels there has been no default at the through of the recession in 2009 is at odds with the model's predictions. On the other hand, even in an analysis that excludes the recession period, the model, in which the interest rate spread is to a large extend driven by the development of the country's output, can not (fully) account for the sharp increase and the observed path of the spread in the later periods.

Figure 2.7: The Crisis in Italy - Output, Debt and Spread



Notes: The plots show the series from the model simulation (continuous red line) and the actual Italian data (dashed blue line). The Output series is fed into the model as exogenous shock series.

2.5.3 Robustness

One important finding of the analysis is that the calibrated model suggests that there is little room for run-driven defaults. This can be seen from the 'small' "crisis zone" depicted in Figure 2.6 and the very few run-driven default events in the model simulations (see Table 2.3). An important factor for this result is the long average maturity of the Italian debt. The long maturity implies that the amount of debt the country has to roll over each period is relatively small. Hence, a run driven denial of refinancing by the investors has only little impact on the government's decision to default. Figure 2.8 shows how the size of the "crisis zone" increases when the value of λ is increased, i.e. when the average maturity of the debt is lower.[22] While the "crisis zone" implied by the benchmark calibration only comprises a very small set of state combinations, the "crises zone" reaches a substantial size, when the average maturity is reduced to a few quarters.

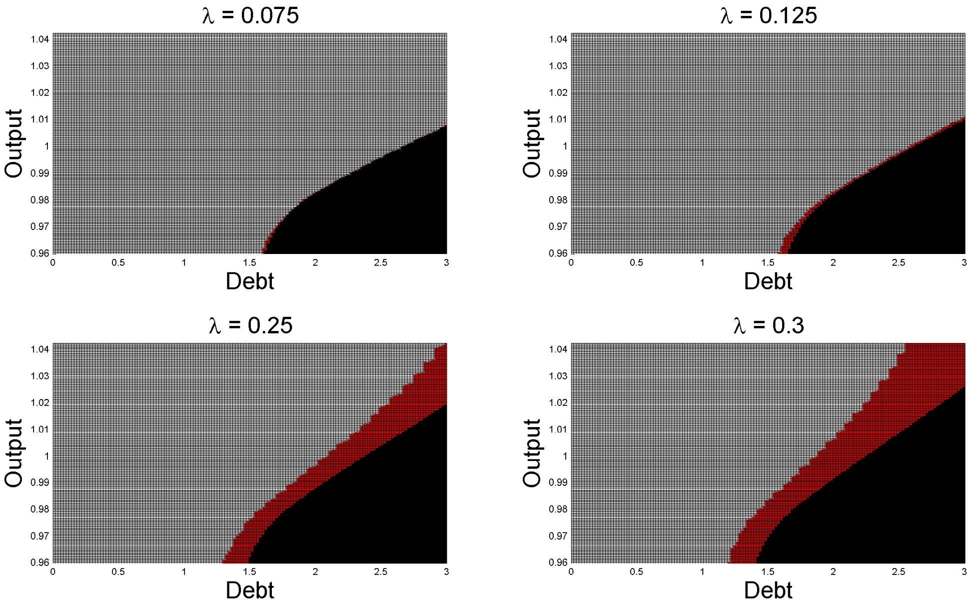
As illustrated by Figure 2.2 and Figure 2.3, using the average maturity of debt implies a relatively good fit of the payment schedule, but underestimates the payments in the early periods. To correct for this failure, a first robustness check is to calibrate the average maturity to match the repayment obligations in the first period. By dividing the amount to be paid in the third quarter of 2011 by the total amount of outstanding debt in the second quarter of 2011, one obtains a value of $\lambda = 0.075$. Hence, with this parametrization, the model matches the important repayment share in the very next period. However, the difference to the benchmark value of $\lambda = 0.037$ is relatively small (for the other example, the first quarter of 2014 (Figure 2.3) the implied lambda is also only 0.053) and hence the "crisis zone" which is depicted in the upper right panel of Figure 2.8 is only slightly larger than the one implied by the benchmark calibration. The remaining three panels of Figure 2.8 show that for a substantially shorter average maturity there is a significant increase in the size of the "crisis zone".

An increase in the size of the "crisis zone" raises the probability of run-driven defaults. Table 2.4 shows how the probabilities of default implied by the different model parametrization. The results clearly show how the importance of self-fulfilling

[22]For this comparison only the parameter λ is varied, while all other parameters remain at their values from the benchmark calibration. Hence, with these parametrizations the model does not match the targeted moments.

crises increases with a shorter average maturity of the debt.[23]

Figure 2.8: Varying average maturity of debt



Notes: Default decision of government for each combination of output realization (vertical axis) and outstanding debt (horizontal axis, measured relative to the output level given by the mean of the shock process). Black area denotes the decision to default, the white area denotes repayment of outstanding debt and the red area denotes the "crisis zone".

Table 2.4: Varying average maturity of debt

	$\lambda = 0.037$ (Benchmark)	$\lambda = 0.075$	$\lambda = 0.125$	$\lambda = 0.25$	$\lambda = 0.3$
Default frequency	2.09%	1.09%	0.75%	0.50%	0.39%
Run driven default frequency	0.0091%	0.07%	0.21%	0.48%	0.39%
→ Share of run driven defaults	0.43%	6.08%	28.06%	95.63%	99.73%

[23]Chatterjee and Eyigungor (2012) show that the threat of self-fulfilling crises is a reason for the government to prefer long-term debt over one-period short-term debt.

Table 2.5: Varying probability of run in "crisis zone"

Variable	$\pi = 0$	$\pi = 0.05$	$\pi = 0.1$ (Benchmark Calibration)	$\pi = 0.3$	$\pi = 0.5$
$\sigma(y)$	0.008	0.008	0.008	0.008	0.008
$\sigma(c)/\sigma(y)$	2.656	2.654	2.726	2.652	2.658
$\sigma(nx/y)/\sigma(y)$	2.207	2.210	2.278	2.209	2.217
$corr(c, y)$	0.834	0.833	0.858	0.834	0.834
$corr(nx/y, y)$	-0.588	-0.586	-0.631	-0.586	-0.588
$corr(spread, y)$	-0.605	-0.601	-0.567	-0.601	-0.600
Default frequency	2.11%	2.08%	2.09%	2.10%	2.11%
Run driven default frequency	0	0.004%	0.009%	0.029%	0.034%
$Mean(spread)$	2.829%	2.827%	2.838%	2.827%	2.825%
$\sigma(spread)$	0.913	0.915	0.924	0.911	0.909
$Mean(d/y)$	1.732	1.732	1.738	1.732	1.731

Notes: The spread is reported in annualized terms. The series of log output (y) and log consumption (c) are detrended using the HP-filter with smoothing parameter 1600. The debt level is reported relative to quarterly GDP. Except the default frequencies, statistics from the model are calculated considering only periods outside default and autarky.

As mentioned in Section 2.4, one has to assign a value to the probability that a run by the investors occurs, given that the country's fundamentals are in the "crisis zone". In the benchmark calibration this probability is set to $\pi = 0.1$. Table 2.5 provides a robustness analysis for this parameter choice. For this exercise only the value of π is varied, while the other parameters remain at their benchmark values. Unsurprisingly given the small size of the "crisis zone" in the benchmark calibration, the size of the value of π does not influence the results significantly. For relatively high values of π ($\pi = 0.3$ and $\pi = 0.5$) the frequency of run driven defaults somewhat increases, but it still remains a very rare event and the other statistics are basically unaffected. If one uses the bond price functions from the model solutions for the three different parametrizations with $\pi = 0, 0.1, 0.5$ the maximum difference in the spread implied by the actual path of Italian output and debt between the different parametrizations is only 0.1 percentage points.

2.6 Discussion

The failures and successes of the quantitative model to account for the observed Italian data provide some interesting insights that can be related to the debate on the events and to the existing literature. A first point that could be made is the interpretation that the model results lend support to the observation that after the financial crisis and the great recession something has changed in the relationship between the perceived sovereign risk (as expressed in the interest rate spread) and the economic fundamentals of countries in the eurozone. This observation is the conclusion of several empirical studies using panel-data e.g. De Grauwe and Ji (2013) or Beirne and Fratzscher (2013). As it has been pointed out in Section 2.5, relying on the model it is hard to understand why there was no default in 2009 given the substantial spreads observed in later periods with more favorable fundamentals. One way to interpret this finding is to argue, as De Grauwe and Ji (2013) do, that the high spreads since 2010 are not funded by the fundamentals, but the result of a self-fulfilling crisis mechanism that threatens members of a monetary union. Another possibility is to consider the spreads before the crisis, which were low and to a lesser degree influenced by the fundamentals, as the result of some form of neglect of the possibility of default risk or the assumption of an incredible no-bailout-policy. The rise in the spreads and their dependence on fundamentals then can be seen as the result of a "wake-up call" at the beginning of the crisis (see for example Bordon et al., 2014).

In the model considered in this chapter the default risk, and hence the interest rate spread, is to a large extend driven by the realization of the output shock. While this allows the model to produce steep increases in the interest rate spread and the resulting series of the spread somehow resembles the data after 2010 (see Figure 2.7), the substantial negative correlation of output and spread present in the model is not observed in the data (see Table 2.3). This raises doubt whether the model is really the explanation of the observed developments. According to the model also the decline in the spread after 2012 is only explained by the improvement in the output. However, in September 2012 the European Central Bank (ECB) decided to establish the Outright Monetary Transaction (OMT) program, that is to stand ready to buy (under certain circumstances) government bonds on the secondary market. Empirical research quantifies the effect of this announcement on the spreads of troubled European countries to be in the range of one to two percentage points (see for example Altavilla et al., 2014; Casiraghi et al., 2013). Additionally, in September 2012 the eurozone countries established the European Stability Mechanism, an institution which can provide credit to troubled countries. As analyzed in the first chapter of this thesis or in Roch and Uhlig (2014), the availability of official funding and guarantees in times of crisis should (for given fundamentals) also have contributed to a decrease in the Italian spread.[24]

Other differences between the model and reality include (among others) the fact that in the model the debt is completely held by external investors as only this implies payments that reduce domestic utility. To be consistent with this, the debt measure used in the calibration is also only debt held by the rest of the world. Insofar as also domestically held debt is relevant for the spread, the model neglects this.[25] The debt in the model is in real terms. For Italy as a member of the eurozone this is a plausible assumption. However, given the relative importance of the Italian economy, one might think that it influences to a certain degree the policy of the European Central Bank which could render a joint analysis of default and inflation useful (see e.g. Corsetti and Dedola, 2013). At the same time, the observation by De Grauwe and Ji (2013) that there are substantial differences in the relationship between fundamentals and bond yields for countries in the eurozone and countries that have their own currency supports the focus on real debt in this chapter.[26]

Moreover, given that the debt is denominated in Euro but there are fears of a break-up of the eurozone, the spread might include a compensation for denomination risk (see e.g. Kriwoluzky et al., 2014; De Santis, 2015). Other aspects discussed in the literature but absent in the model are the interactions between the European countries, for example regarding their fiscal policies within a monetary union (see Aguiar et al., 2014) or their default and renegotiation policies (see Arellano and Bai, 2013).

[24]Steinkamp and Westermann (2014) discuss the role creditor seniority plays for the effects of the different programs on the government bond yields.

[25]See Reinhart and Rogoff (2011) for an historical analysis of default on domestic debt.

[26]This debate corresponds to the discussion of the “original sin”, i.e. (emerging) countries that (have to) borrow in foreign currency.

One key aspect of the policy discussion is the possibility of multiple equilibria and self-fulfilling crises. The model used in this chapter uses an adapted version of the Cole and Kehoe (2000)-framework, where a failure to roll-over the debt due to a run by investors induces a default.[27] While in this case a realization of the "bad equilibrium" implies an immediate default, the expectation of this type of default to occur increases the spread also in other periods. The literature has also pointed out other mechanisms leading to self-fulfilling crises. For example, building on early work by Calvo (1988), Lorenzoni and Werning (2013) provide a different motivation of multiple equilibria in debt markets that can lead to high spreads and what they call "slow moving debt crisis". They assume that a country can not commit to the amount of bonds that are sold but needs are certain amount of revenue from its bond auctions. This gives rise to multiple equilibria with the possibility that the government has to pay high interest rates due to the realizations of a "bad equilibrium". The high interest rate payments in turn increase the danger of a default. Combined with long-term debt this mechanism can yield to the occurrence of high spreads over several periods that are driven by self-fulfilling default dynamics.[28]

2.7 Conclusion

This chapter provides an analysis of the evolution of the Italian debt market during the years of the crisis in Europe after 2009. The analysis is done using a calibrated model of sovereign default. While the model results match some of the observations of the data, there are substantial discrepancies to be mentioned. First, the model suggests that a default should have occurred in the early periods of the crisis. Second, the observed evolution of the interest rate spread on Italian debt in the later periods of the crisis (a steep increase in 2011 and the later decline) can not be fully explained by the fundamentals considered in the model. However, also the self-fulfilling default crisis present in the model do not deliver a good explanation, as their quantitative importance is decreased massively by the long maturity of the Italian debt in the data.

[27] Conesa and Kehoe (2015) use an extended version of the Cole and Kehoe (2000) model to analyze the incentives of the countries in Europe to adjust there debt levels in the face of the crisis.

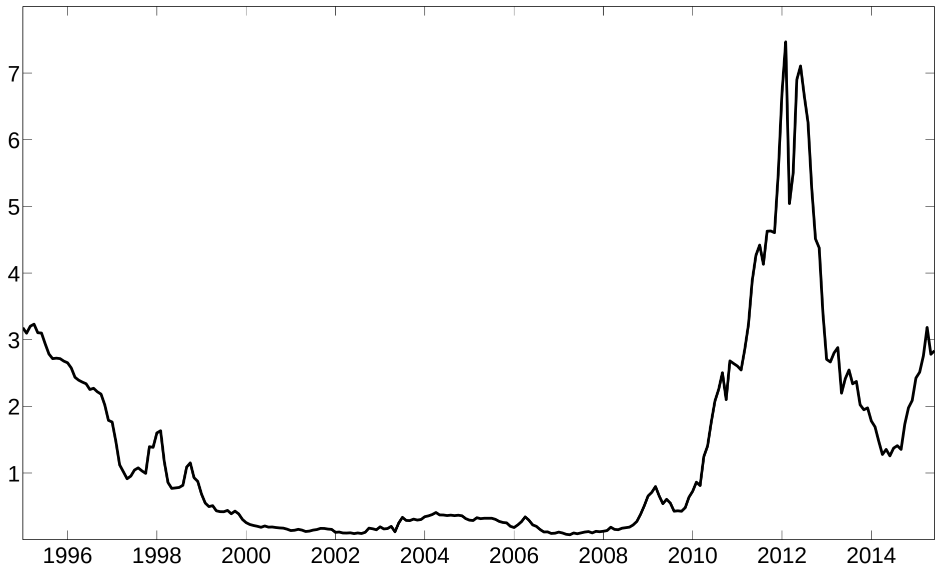
[28] Bacchetta et al. (2015) analyze to what extend monetary policy can help to avoid this type of crisis.

While the analysis of sovereign default with theoretical models shows that a steep increase of the spreads on government bond yields itself is not a proof of irrational behavior on financial markets, the comparison of the results from the model with the data indicates that there are other factors than only the basic fundamentals that played an important role over the sample period. One major issue absent in the model is the bailout policy of the European governments and the policy announcements and bond buying programs of the European Central Bank. The presence of third-party credit and guarantees affects the prices on bond markets and, as the policy in Europe evolved over time, might explain part of the variance of the spread over the sample period. Summing up, the analysis in this chapter underlines the (rather obvious) fact that there are many aspects to be taken into account when the debt crisis in Europe is analyzed. At the same time it warns of the potentially premature conclusion to take dramatic movements in the bond market as unambiguous evidence for irrational and unfounded behavior of "the markets".

Appendix to Chapter 2

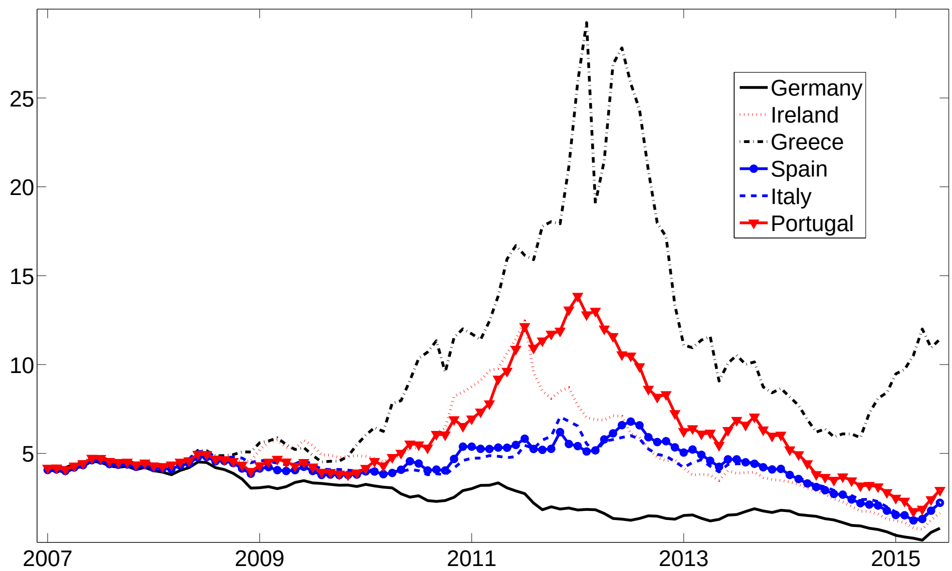
2.A Additional Figures

Figure 2.9: (Cross-sectional) Standard deviation of long-term interest rates (EMU12)



Notes: Graph shows the cross-sectional standard deviation of the EMU convergence criterion bond yields for the EMU12 countries. EMU12: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Spain. Data: Eurostat.

Figure 2.10: Long term interest rates for selected European countries



Notes: Graph shows EMU convergence criterion bond yields for selected European countries. Data: Eurostat.

Chapter 3

House Prices, Credit and Monetary Policy in the U.S. and the U.K.[1]

3.1 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 output 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 market.

The combination of the recent experience of the crisis and 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

[1]This chapter is based on joint work with Anna Grodecka.

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 exogenous 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. and 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., a country where there is an ongoing debate about macroprudential measures and the Financial Policy Committee dealing with regulation and macroprudential policy has been established as a part of the Bank of England. Having identified monetary and credit shocks in our model, we investigate the role of these shocks in the development of house prices and output. We find that in the U.S. 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 insignificant for U.S. data. For the U.K., we find a short-term decline of house prices after a negative credit shock, but no significant effect of a monetary shock on house prices.

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 3.2, briefly discusses the related literature. Section 3.3 outlines the employed estimation procedure and the data used in our analysis. Section 3.4 derives the sign restrictions used to generate our results, which in turn are presented in Section 3.5. Section 3.6 concludes.

3.2 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.

3.2.1 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.

3.2.2 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 center of the 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.

3.3 Estimation and Data

A VAR model is given by:

$$y_t = \mu + B_{(1)}y_{t-1} + B_{(2)}y_{t-2} + ... + B_{(p)}y_{t-p} + u_t, \qquad (3.3.1)$$

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

$$u_t = Av_t, \tag{3.3.2}$$

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

$$\left[a^{(1)}, a^{(2)}\right] = \tilde{A}\left[q^{(1)}, q^{(2)}\right]. \tag{3.3.3}$$

$a^{(1)}$ 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 (3.3.3) 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 (3.3.3). 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.[2]

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.[3] 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.[4] The sample includes the subprime mortgage crisis and ends with the fourth quarter of 2013.[5] 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 3.1 shows the time series of the six variables over the considered period.

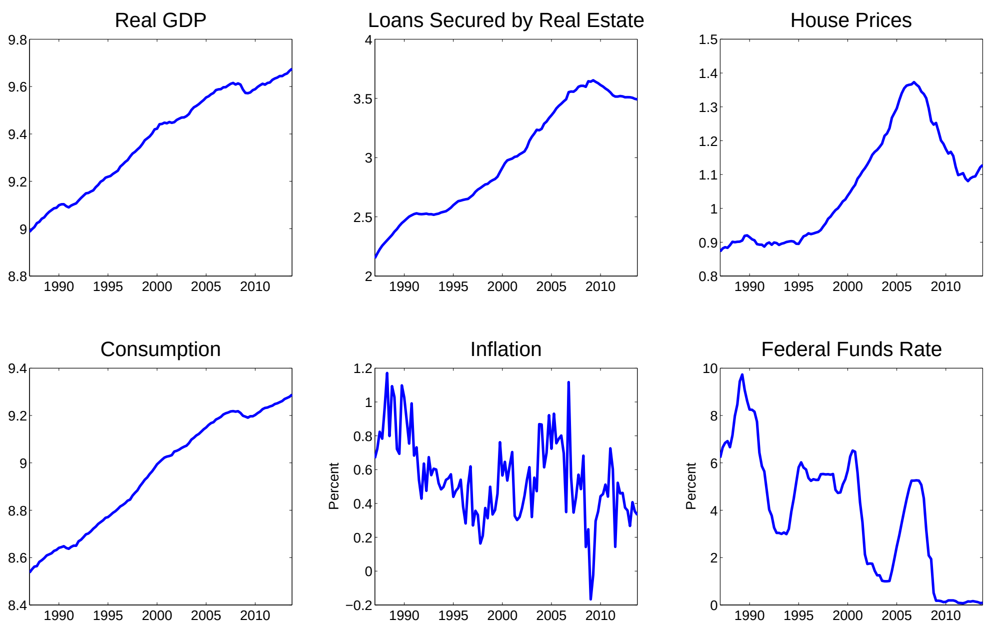
[2] Another possibility suggested by the information criteria would be to estimate a model with four lags. We did this excercise too and our conclusions do not change.

[3] 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.

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

[5] 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.

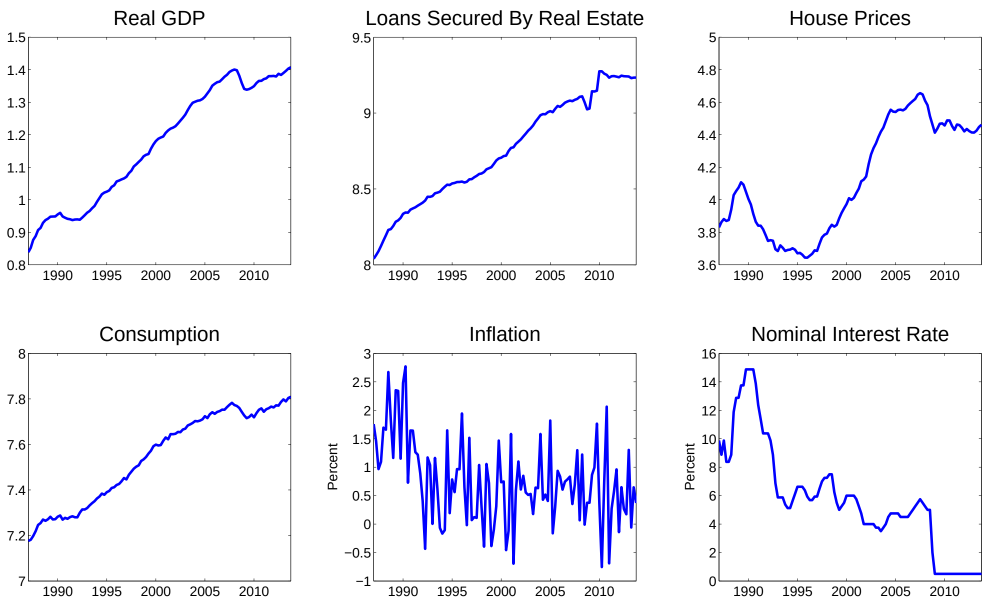
Figure 3.1: U.S. data series used in the analysis



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.

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 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 3.2 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.

Figure 3.2: U.K. data series used in the analysis



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.

3.4 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 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:

$$R_t b''_t = m'' E_t(q_{t+1} h''_t \pi_{t+1}), \tag{3.4.1}$$

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,[6] 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:

$$m''_t = \rho_{m''} m''_{t-1} - e_{m'',t}, \tag{3.4.2}$$

[6]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.

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

3.4.1 Model results 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.[7] Table 3.1 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).

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 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).

[7] 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.

Table 3.1: Admitted intervals for model parameters in the U.S. case

	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 (1990)
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.

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 (1990).

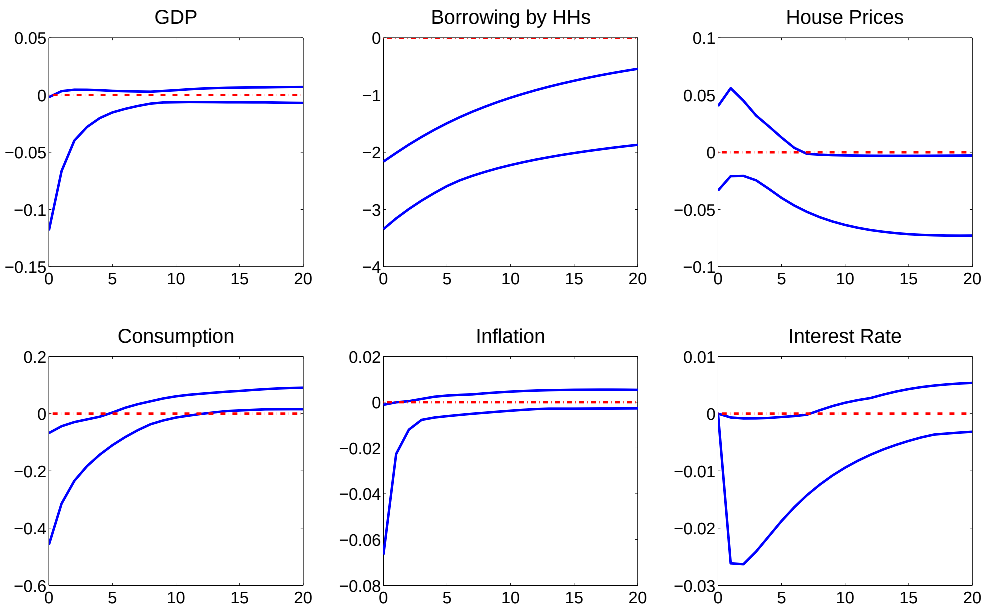
The Calvo parameter θ determining the probability of a fixed price in a given period is chosen to include values yielding an average price duration of 6.7 to 9 months, based on Enders et al. (2011) and Iacoviello (2005). The parameter defining capital adjustment costs in the economy, ψ, is somehow controversial 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 3.3 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.

Figure 3.3: Credit Shock - Impulse response functions of the DSGE model (U.S.)



Notes: Pointwise minima and maxima of the impulse response functions 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.

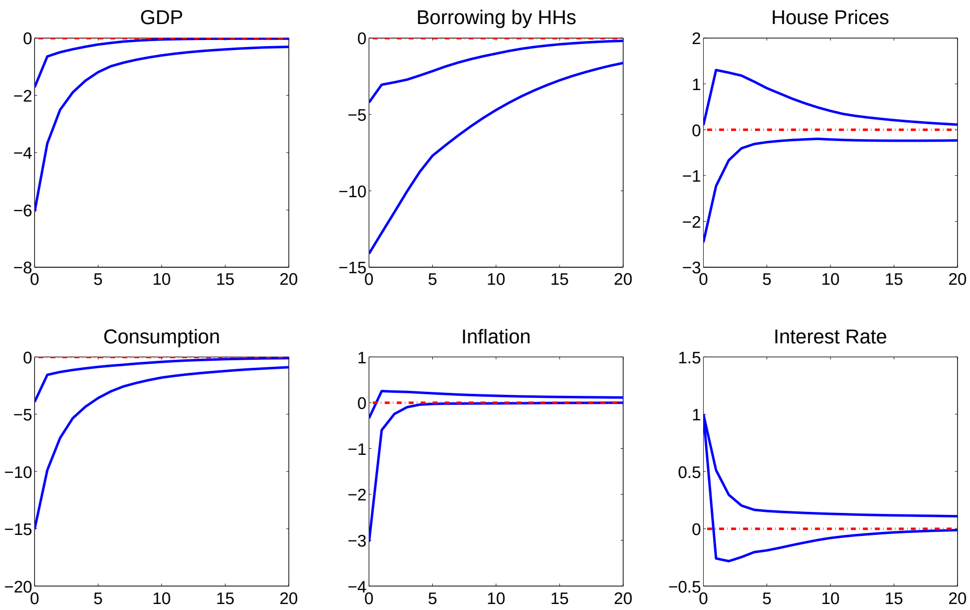
The shock generates a fall in the interest rate, inflation, GDP, borrowing by the households, and aggregate consumption. Whereas the contraction in borrowing is long-lasting, the decline of the other variables is observed only in the initial periods after the shock. With respect to house prices the response 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 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 ρ_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 ρ_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 3.4) 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 3.4 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.

We summarize the resulting sign restrictions in Table 3.2. In both cases we leave the response of house prices and output open, as this is our main point of interest. Table 3.2 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 parameter 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. The responses after both shocks distinguish them from the preference shock through the response of consumption - 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

Figure 3.4: Monetary Shock - Impulse response functions of the DSGE model (U.S.)



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

from the LTV shock, while the inflation response distinguishes it from the monetary shock.[8]

[8]Appendix 3.A contains the impulse response functions for the remaining three shocks of the model presented in Table 3.2.

Table 3.2: Sign restrictions for different shocks derived from the DSGE model (U.S.)

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.

3.4.2 Model results for the U.K.

We apply the same methodology as outlined above for the U.K. Table 3.3 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.

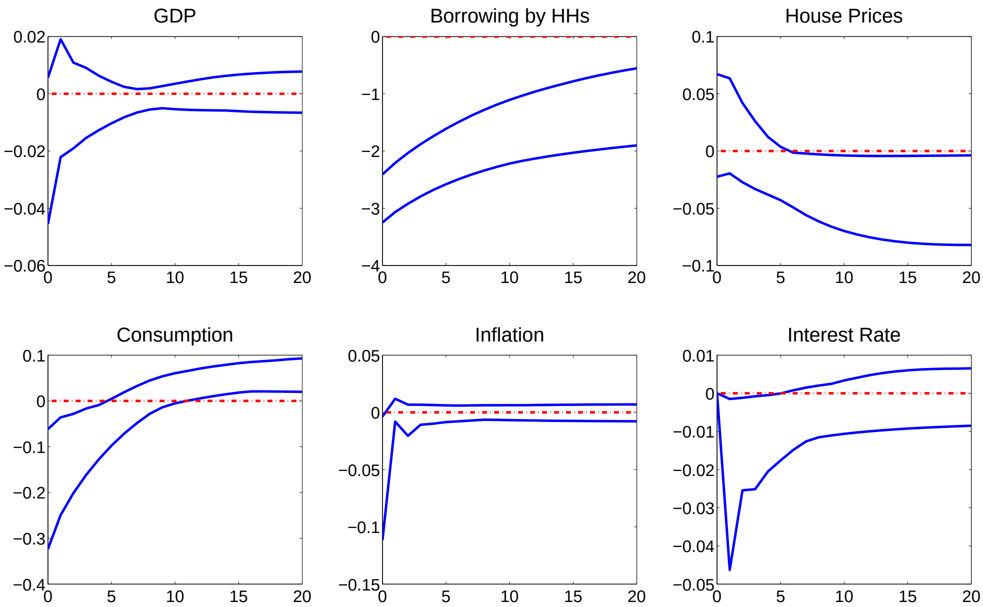
Table 3.3: Admitted intervals for model parameters for the U.K. case

	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 (1990)
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.

The resulting sign restrictions resulting for the U.K. case are summarized in Table 3.4 and are based on the results presented in Figure 3.5 and Figure 3.6. 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 3.A contains the impulse response functions for the remaining three shocks of the model presented in Table 3.4.

Figure 3.5: Credit Shock - Impulse response functions of the DSGE model (U.K.)



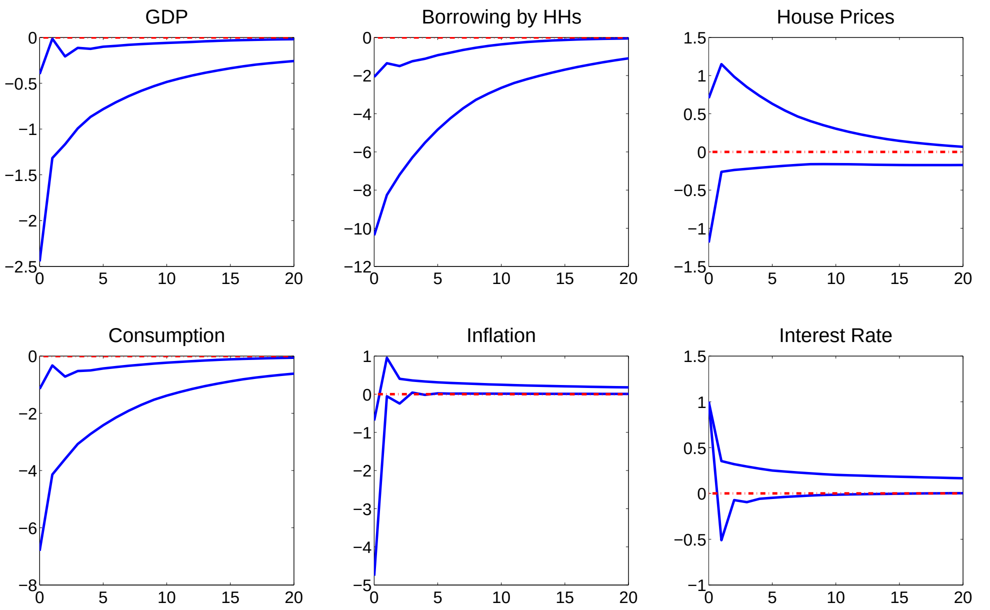
Notes: Pointwise minima and maxima of the impulse response functions of the chosen variables after an exogenous one-percentage fall in the LTV ratio. The impulse responses are measured in percentage deviations from steady state.

Table 3.4: Sign restrictions for different shocks derived from the DSGE model (U.K.)

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.

Figure 3.6: Monetary Shock - Impulse response functions of the DSGE model (U.K.)



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

Table 3.5: Sign restrictions imposed on the VAR model (U.K. and U.S.)

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)

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.

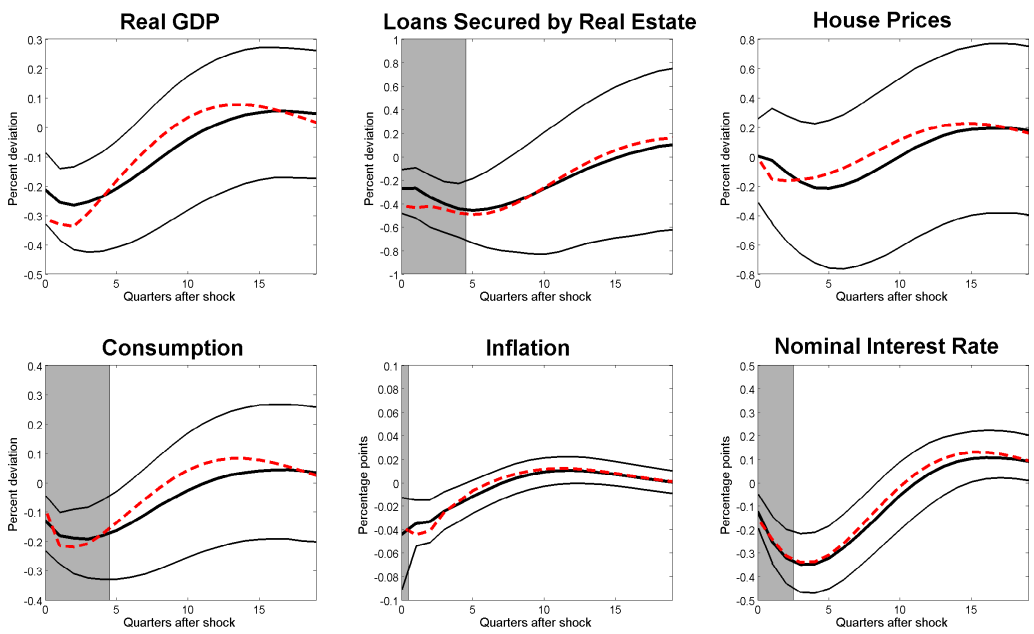
To sum up, despite the differences in calibration, the identifying restrictions for our VAR analysis derived from the DSGE simulation in the case of the monetary and the credit shock are the same for the U.S. and the U.K. and are summarized in Table 3.5.

3.5 Results

3.5.1 The VAR analysis for the U.S.

Using the sign restrictions outlined in the previous section, we employ the method explained in Section 3.3 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 3.7 shows the reaction of the six variables to a negative credit shock. In addition to the (pointwise) median of the impulse response functions (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 3.7 and Figure 3.8 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 3.7), we note that the response of house prices, which was left unrestricted, is not clear, although the median and the median model suggest a short-term contraction. The GDP exhibits a

Figure 3.7: Estimated impulse responses to a credit shock (U.S.)

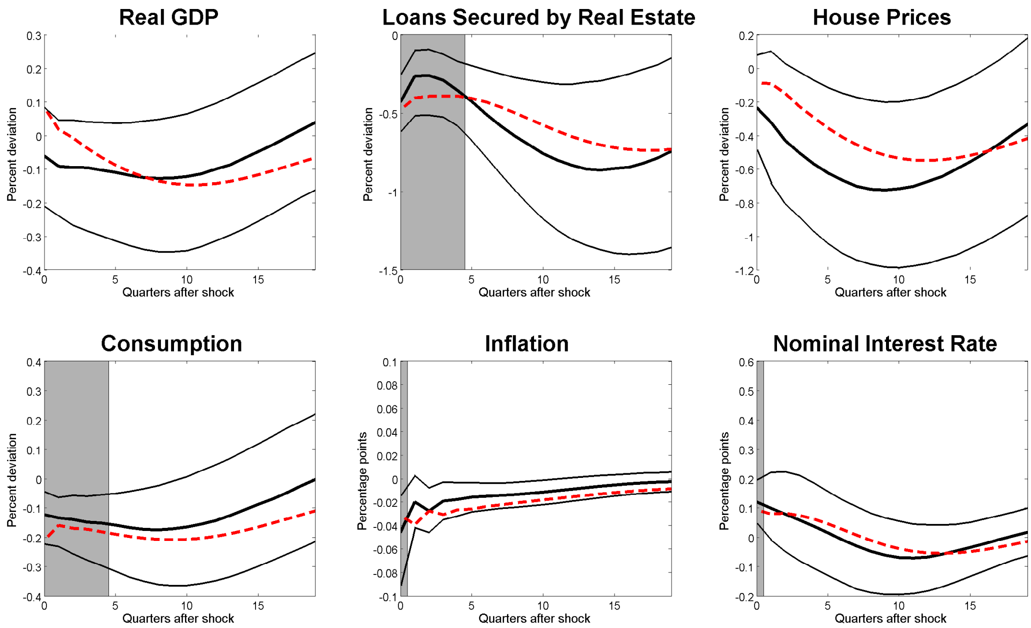


Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative credit shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

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 3.8 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 3.8: Estimated impulse responses to a monetary shock (U.S.)

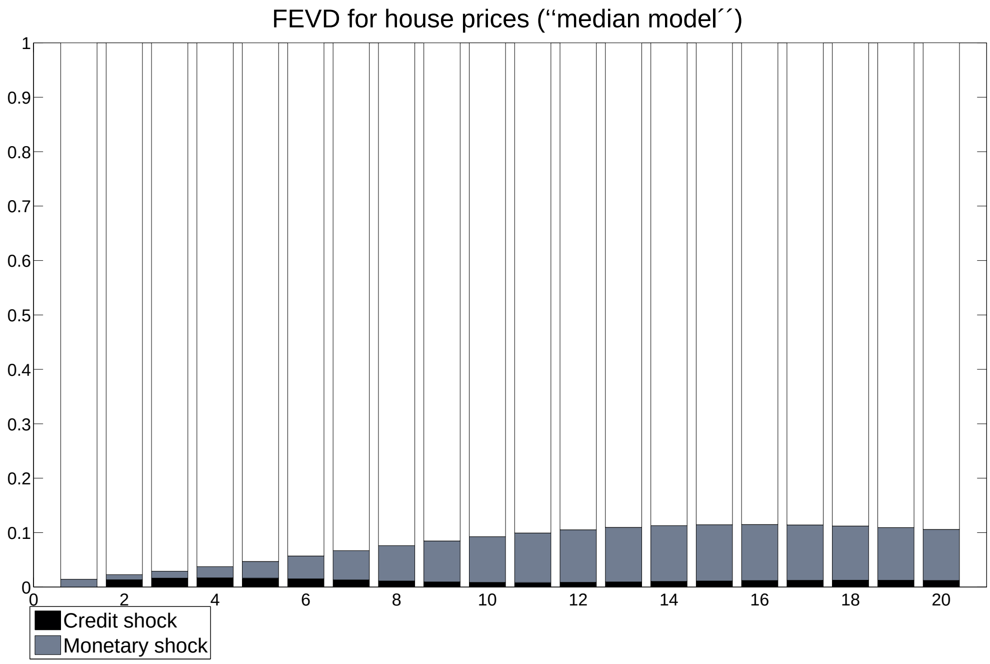


Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative monetary shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

Figure 3.9 shows the forecast error variance decomposition of the median model for the house prices up to a 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.[9]

[9] Figure 3.21 in the Appendix 3.A shows how the FEVD of the median model compares to the FEVD of the full set of admissible models.

Figure 3.9: Forecast error variance decomposition for house prices (U.S.)

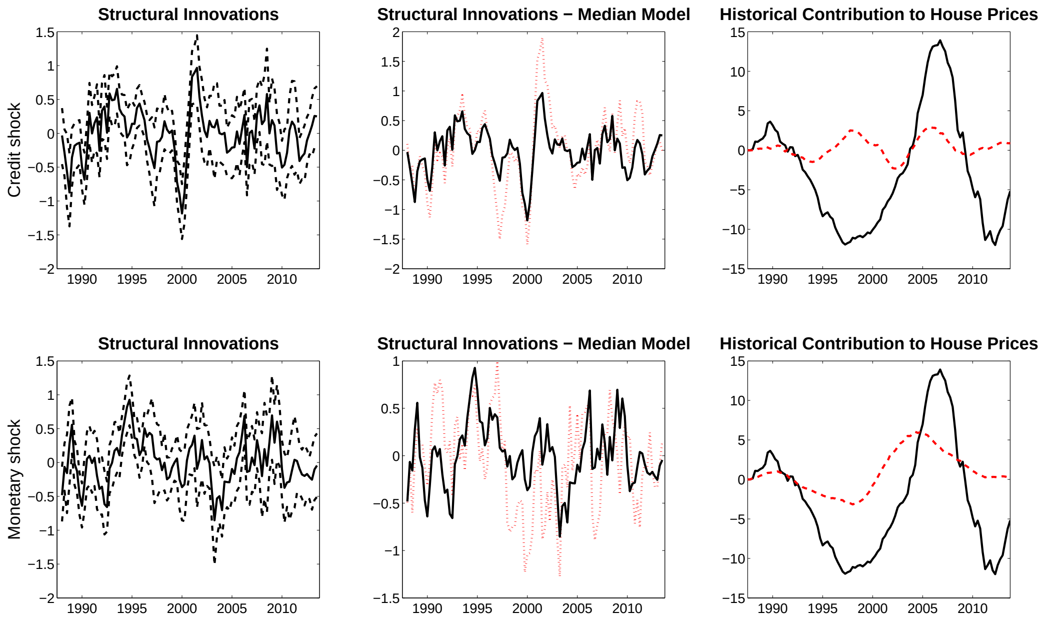


Notes: The graph shows the shares of the forecast error variance explained by the credit shock (black) and the monetary shock (gray). The remaining share is explained by the unidentified other shocks.

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 3.10 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 à 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 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 3.10 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 3.10 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 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 3.10 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.

Figure 3.10: Estimated innovations (U.S.)

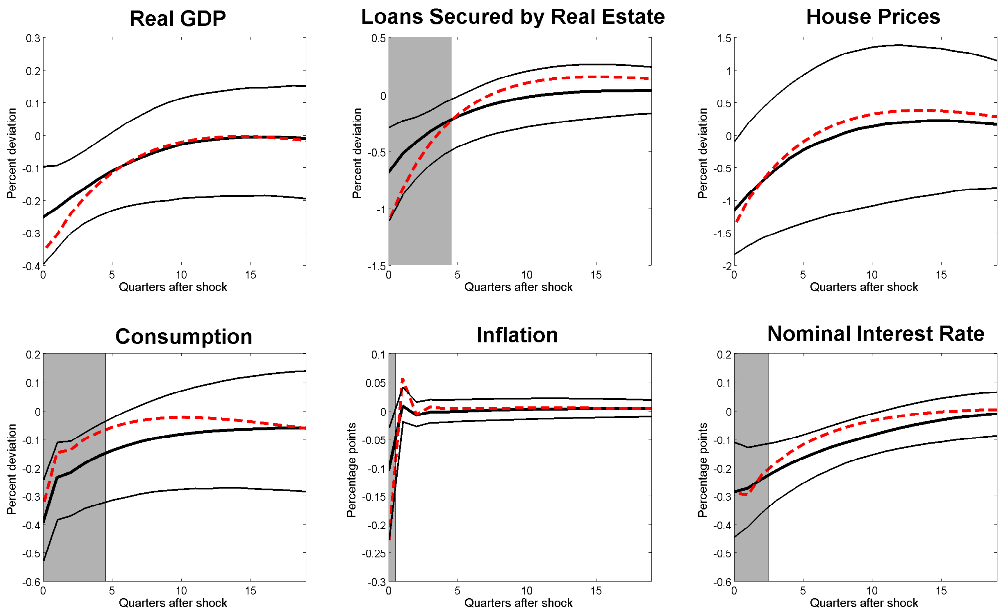


Notes: The figure shows the estimated innovations associated with the two identified shocks (four-quarter moving averages). The left panels show the median and the 16% and the 84% quantile of the different draws. The middle panels show again the median (continuous line) and the innovation implied by 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.

3.5.2 The VAR analysis for the U.K.

Turning to U.K. data, Figure 3.11 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 3.11 with the analogous figure for the U.S. (Figure 3.7), 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.

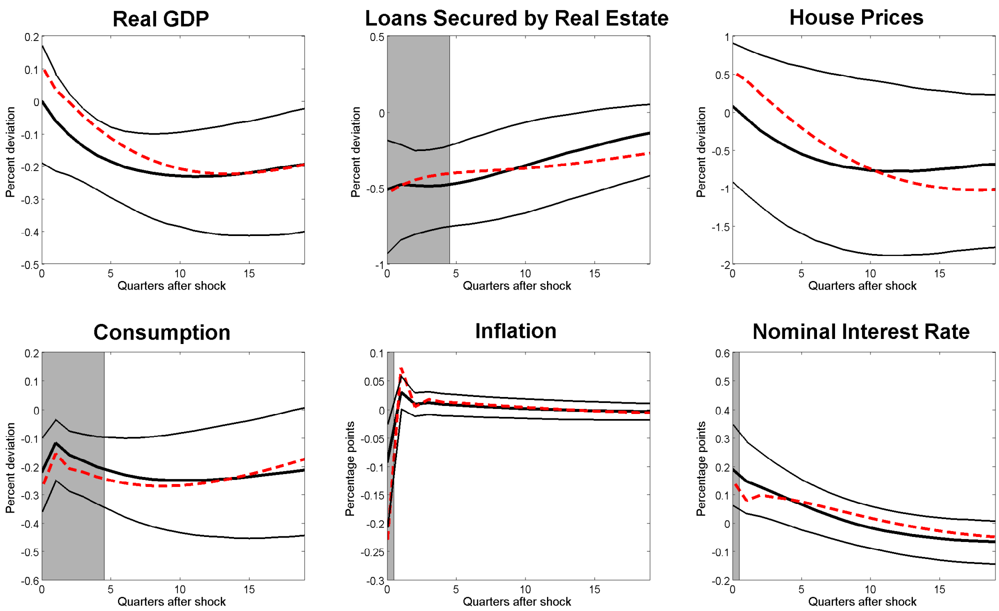
Figure 3.11: Estimated impulse responses to a credit shock (U.K.)



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

Looking at the impulse responses to a monetary shock, which are depicted in Figure 3.12, 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 3.12: Estimated impulse responses to a monetary shock (U.K.)



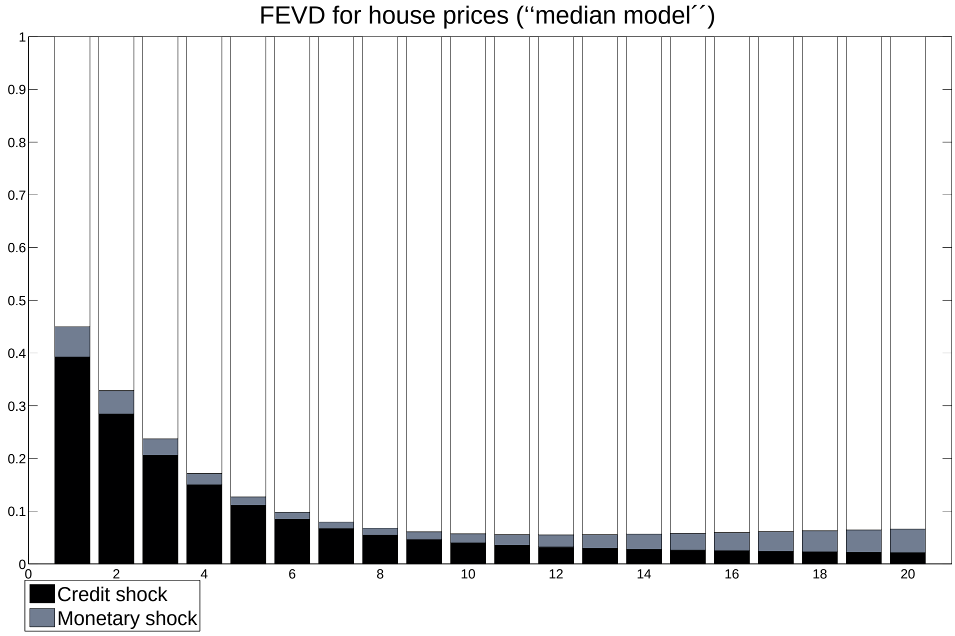
Notes: The graph shows the pointwise median and the 16 and 84 percentiles of the estimated impulse response functions to a negative monetary shock. The dashed line is the impulse response of the median model as suggested by Fry and Pagan (2007).

Figure 3.13 shows the forecast error variance decomposition of the median model for the house prices up to a 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%.[10]

Figure 3.14 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.

[10]Figure 3.22 in the Appendix 3.A shows how the FEVD of the median model compares to the FEVD of the full set of admissible models.

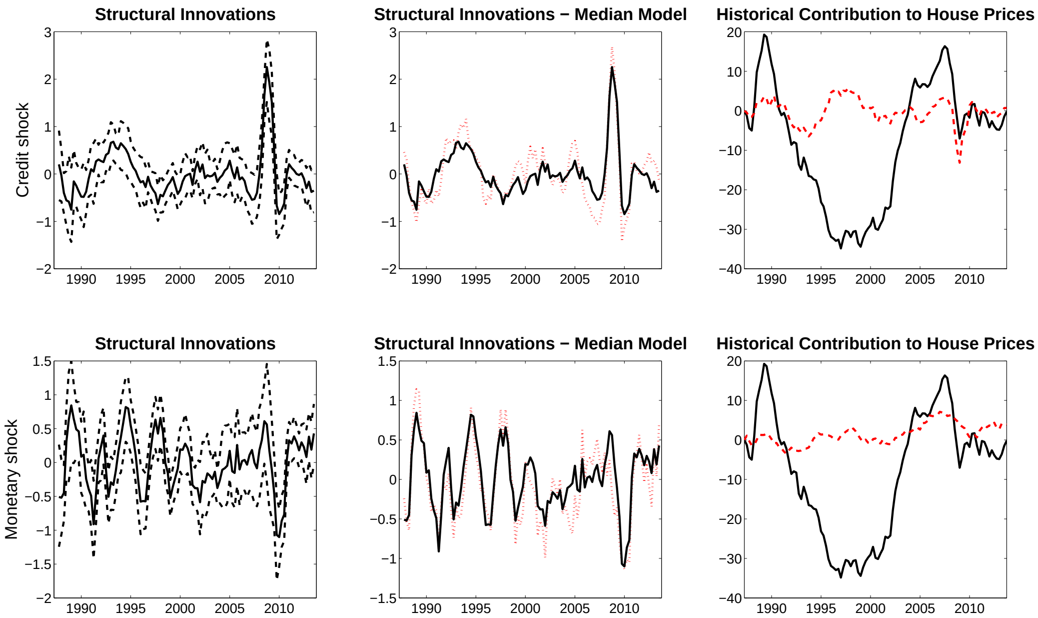
Figure 3.13: Forecast error variance decomposition for house prices (U.K.)



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

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 3.12 with the ones in Figure 3.8, 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

Figure 3.14: Estimated innovations (U.K.)



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.

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.[11] 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

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

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 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 HM Treasury, 2003).

3.5.3 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.

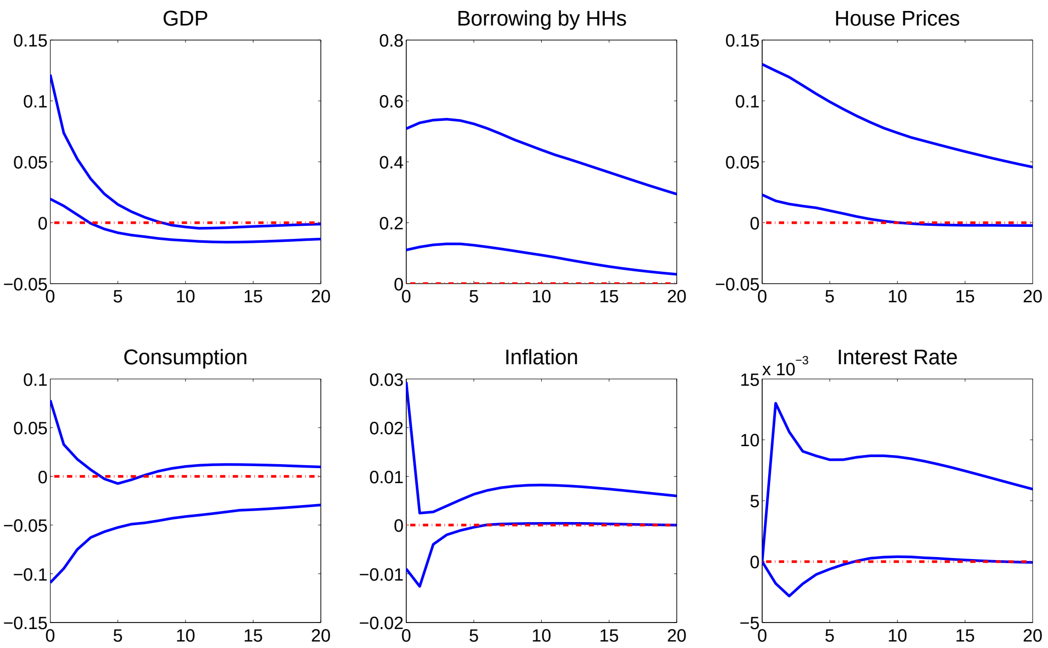
3.6 Conclusion

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. We find different results for the two countries. In the U.S., a negative monetary shock lowers house prices, while the impact of a negative credit shock on house prices is insignificant. For the U.K., we find a short-term decline of house prices after a negative credit shock, but no significant effect of a monetary shock on house prices. 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 the 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 3

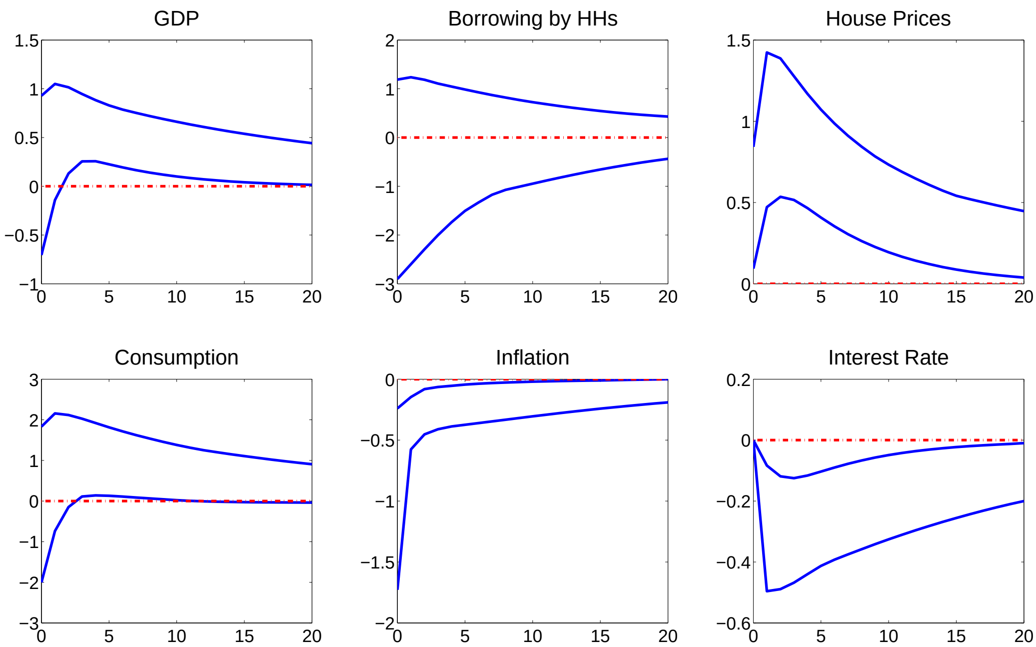
3.A Additional Figures

Figure 3.15: Housing Preference Shock - Impulse response functions of the DSGE model (U.S.)



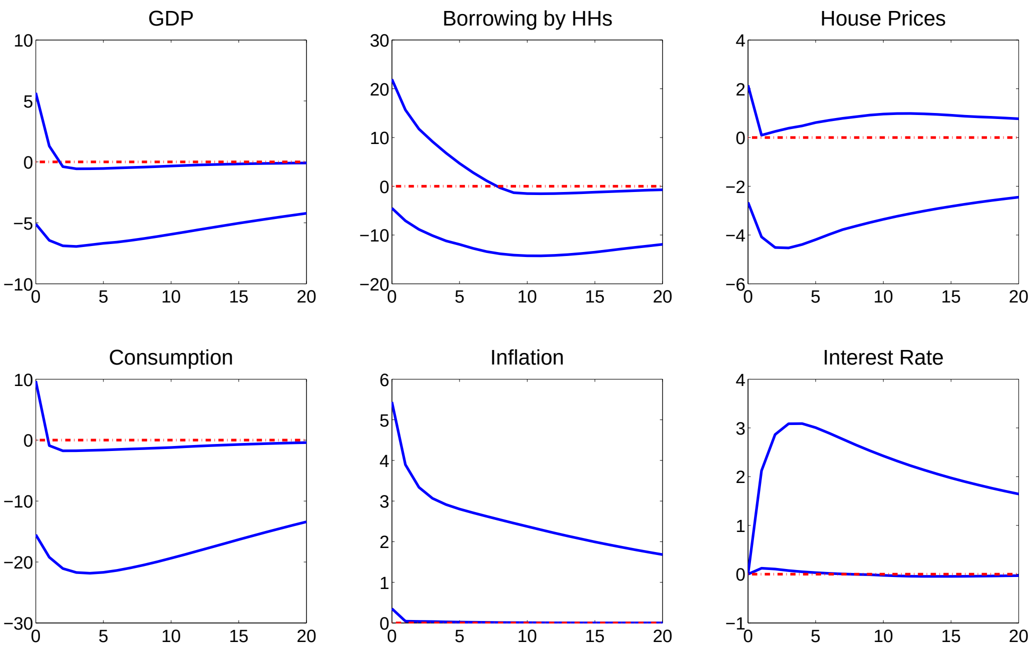
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in households' housing preference. The impulse responses are measured in percentage deviations from steady state.

Figure 3.16: TFP Shock - Impulse response functions of the DSGE model (U.S.)



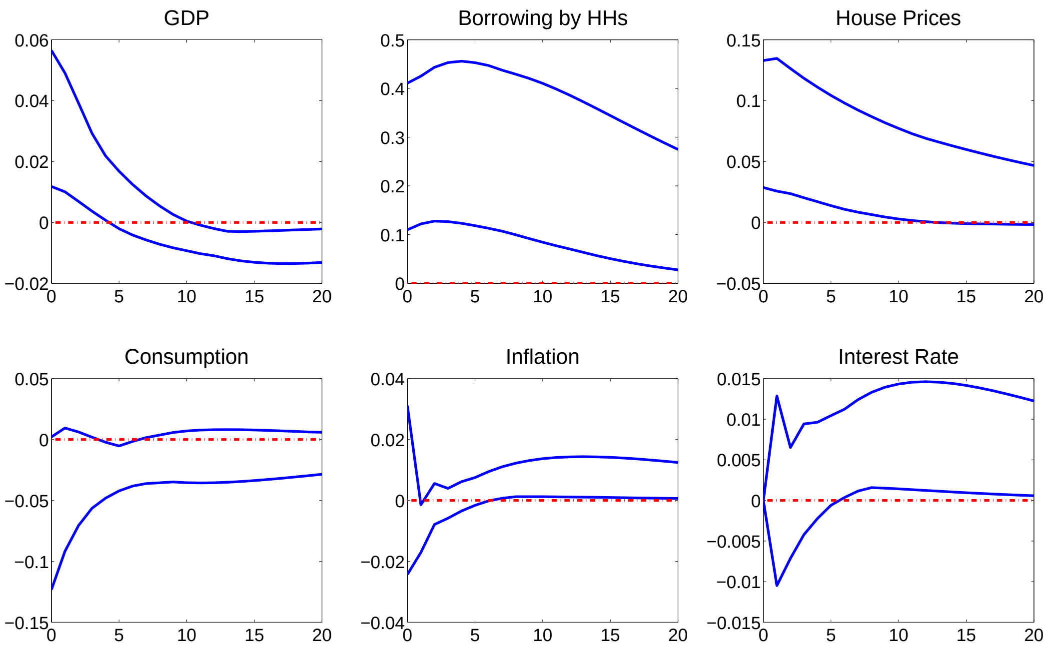
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the productivity. The impulse responses are measured in percentage deviations from steady state.

Figure 3.17: Inflation Shock - Impulse response functions of the DSGE model (U.S.)



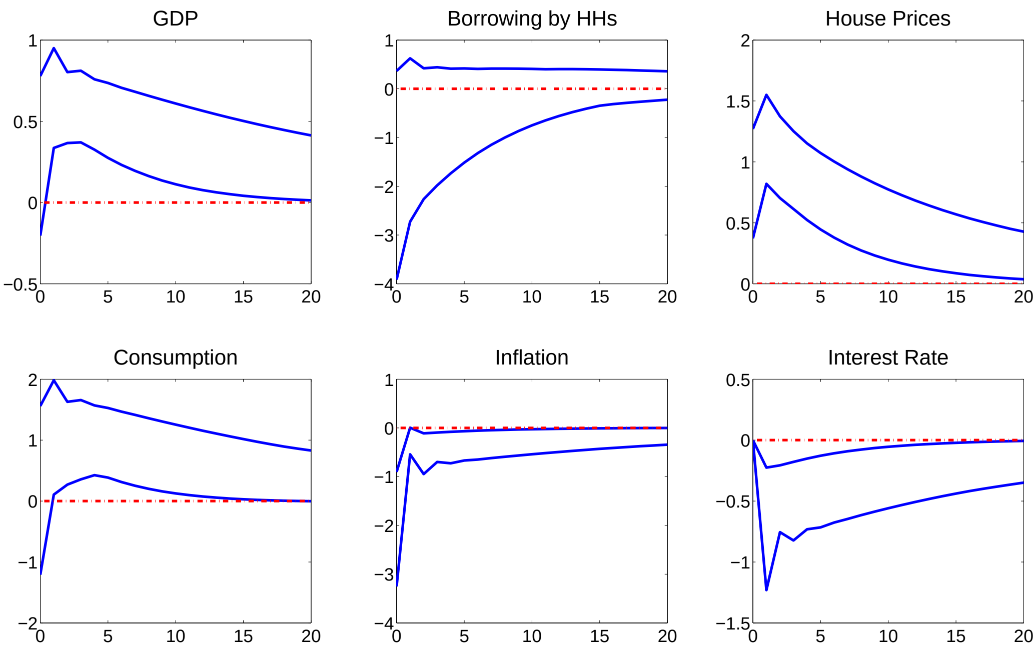
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the inflation. The impulse responses are measured in percentage deviations from steady state.

Figure 3.18: Housing Preference Shock - Impulse response functions of the DSGE model (U.K.)



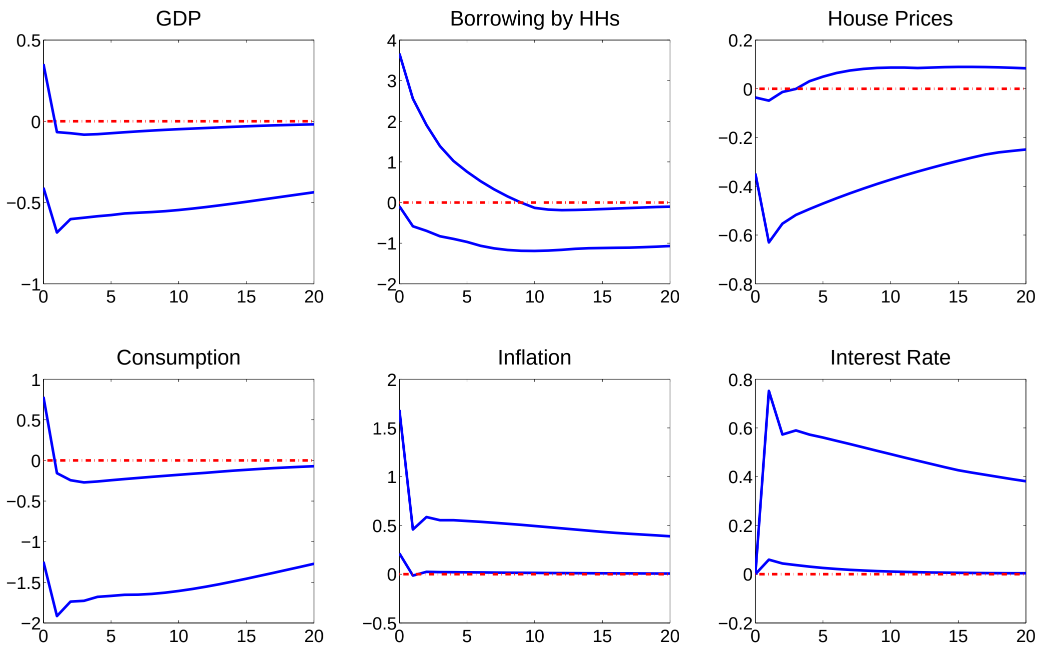
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage fall in households' housing preference. The impulse responses are measured in percentage deviations from steady state.

Figure 3.19: TFP Shock - Impulse response functions of the DSGE model (U.K.)



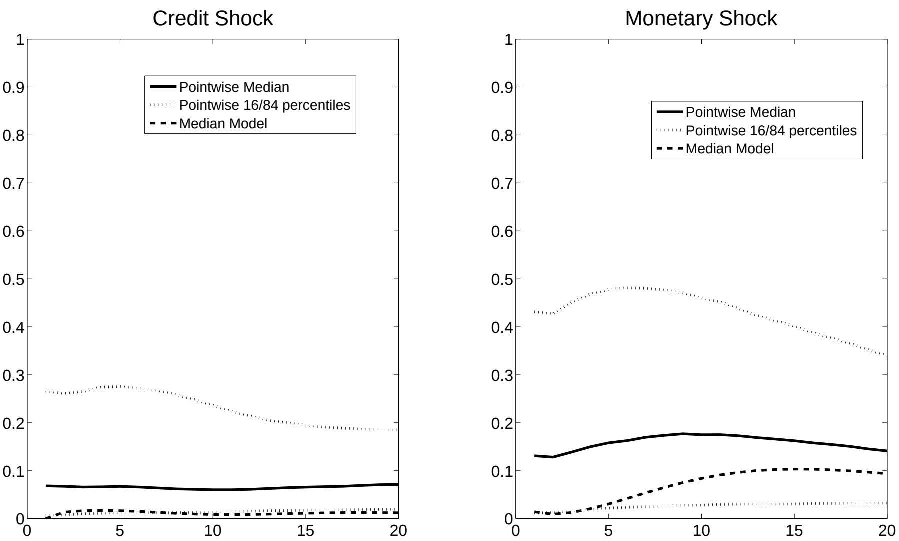
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the productivity. The impulse responses are measured in percentage deviations from steady state.

Figure 3.20: Inflation Shock - Impulse response functions of the DSGE model (U.K.)



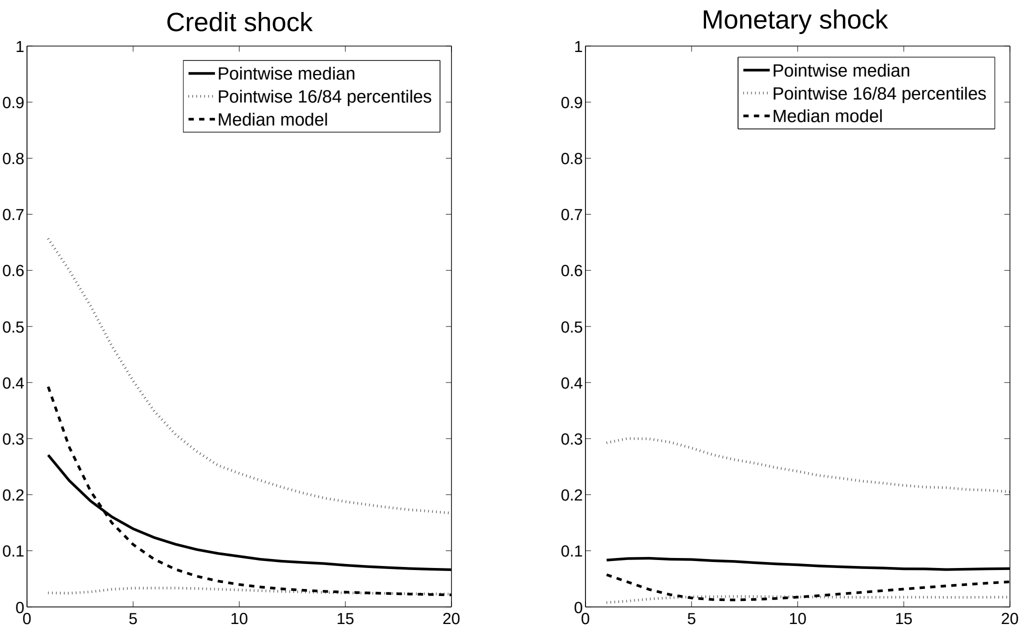
Notes: Pointwise minima and maxima of the chosen variables after an exogenous one-percentage increase in the inflation. The impulse responses are measured in percentage deviations from steady state.

Figure 3.21: 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 3.22: Forecast error variance decomposition of house prices (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.

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