Macroprudential Policy Interactions in a Sectoral DSGE Model with Staggered Interest Rates

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Abstract

We develop a two-sector DSGE model with a detailed banking sector along the lines of Clerc et. al. (2015) to assess the impact of macroprudential tools (minimum, countercyclical and sectoral capital requirements, as well as and LTV limit) on key macroeconomic and financial variables. The banking sector features residential mortgages and corporate lending subject to staggered interest rates à la Calvo (1983), which is motivated by the sluggish movement of lending rates due to fixed interest rate loan contracts. Other distortions in the model include limited liability, bankruptcy costs and penalty costs for deviations from regulatory capital. We estimate the model using Bayesian methods based on quarterly U.K. data over 1998Q1-2016Q4. Our contributions are threefold. We show that: (i) coordination of macroprudential tools may have a welfare-improving effect, (ii) macroprudential tools would have improved some macroeconomic indicators but not have prevented the Global Financial Crisis altogether, (iii) staggered interest rates may weaken the transmission of macroprudential tools that work through interest rates.

Keywords: Sectoral DSGE model; macroprudential policy; interest rate stickiness.
JEL codes:

1 Introduction (Old Version)

The Financial crisis of 2008 brought to forefront the risks inherent in the financial system and the possible role of macro prudential tools to maintain financial and macroeconomic stability. BIS (2018) suggests that the micro prudential regulation is necessary but not sufficient to maintain financial stability. Regulatory tools which directly track and respond to macro economic developments could enable regulators to deal with boom bust cycles and the resulting threat to the banking system in an effective and timely manner.

As a result, a number of new measures have been added to the regulatory toolkit in different countries eg. Countercyclical capital buffers, Loan to Value (LTV) limit, Loan to Income limit

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etc in the aftermath of the financial crisis, although the capital adequacy ratio is still the main focus of prudential policy and Basel norms. Capital Adequacy ratio is the minimum capital banks are required to hold as a proportion of their risk weighted assets.Counter cyclical capital buffer(CCB) is the additional capital banks are required to hold in response to expansionary credit boom, so as to mitigate the credit growth and stability the financial cycle. The objective of the CCB tool is to enable banks to build up capital in times of a financial boom so as to increase resilience at the time when the boom turns into bust.LTV limit is the maximum amount that a borrower can borrow as a proportion of the value of the underlying asset. The capital requirement is related to the bank's equity whereas the LTV limit is related to the borrower's equity.

There is growing empirical and theoretical literature on the effect of macro prudential policy tools on the macro economy.This paper aims at two objectives. The first is to explore the role of interest rate stickiness on the transmission of macro prudential policy tools such as the capital adequacy ratio, LTV limit, and countercyclical capital and countercyclical LTV limit.

The second objective of the paper is to study how these policies interact with each other.There are very few papers which have more than one such macro prudential tools in the same model.As a result, the literature has not given much attention on the possible interaction between the tools.In this paper, we look at two key policy tools, Capital adequacy ratio and loan to value limit.

Although the literature on interest rate stickiness has existed since the 90s, there has been no attention towards this aspect in the literature on either monetary policy or macro prudential policy. Whereas the idea of price stickiness in the goods market is a key aspect of new Keynesian models, the same has not been discussed in the context of interest rate stickiness in the loan markets except for Gerali et al (2010).

As per Kobayashi (2007), interest-rate stickiness could arise both from (a) the existence of adjustment costs of changing loan rates. This may be due to customer's costs of changing banks (switching costs), menu costs of changing interest costs, highly regulated banking sector or less competitive banking sector (b) the presence of overlapping multi-period contracts.The presence of multi period loan rate contracts, for example a fixed interest mortgage contract would make the adjustment of interest rates sluggish in response to policy actions.

This sluggish adjustment of interest rate could have macro economic implications as interest rate is a key element in the transmission of monetary as well as macro prudential policy.

One of the important channels through which capital regulation affects the economy is through it's impact on the interest rates. As the bank's cost of equity is higher than cost of deposits, an increase in the capital requirement would increase the weighted average cost of capital for the bank and hence would also cause an increase in the lending rate charged by the banks. This could have further macro economic implications as higher interest rate would have a negative impact on credit growth, investment etc. This is also the rationale for using counter cyclical buffers to "lean against the wind" so as to dampen excess fluctuations in the economy. Thus, flexibility or stickiness of the lending rates could have potential impact on the transmission of the macro prudential policy tools

To understand the macroeconomic implications of interest rate stickiness, we build a dynamic stochastic general equilibrium model based on Clerc et al (2015) with a detailed banking sector,financial frictions and macro prudential policy rules. As far as we know, this is the first paper which models interest rate stickiness as in Calvo (1983) in a DSGE framework.

We find that interest rate stickiness dampens the effect of change in capital requirement on the credit growth and investment.On the other hand, interest rate stickiness increases the effectiveness of change in LTV limit. The counter cyclical capital buffer is also less effective in smoothing the credit cycle if the interest rates adjust sluggishly. However, it is still better than a counter cyclical LTV limit for leaning against the wind. Further, we find that the volatility in the macro economic variables in response to key shocks also increases due to interest rate stickiness.

As regards interaction between the two tools, we find that the impact of the change in capital requirement is higher when the LTV limit is higher i.e.for a higher level of LTV limit, the increase in capital requirement causes a higher proportional fall in lending and investment.However, the the change in LTV limit has a higher impact when the capital requirement is lower.

The the paper is organized as follows. Section 2 reviews the existing literature in the area. Section 3 provides empirical evidence for interest rate stickiness for the UK and major economies of the Euro zone. Section 4 describes the model and section 5 summarizes the key results of the model. Section 6 concludes.

2 Literature review (Kunal Version)

new stuff that needs to be added–> see the references section at the end

Literature on financial frictions and role of banks in DSGE models has been growing since the financial crisis of 2008. Our model attempts to bring together two streams of literature. One is based on the celebrated Bernanke, Gilchrist and Gertler (1999) where some fraction of borrowers default in equilibrium. Borrowers default due to limited liability and shocks (both aggregate and idiosyncratic) which cause the value of the asset to go below the loan amount. The other stream of literature is based on borrowing constraints as in Kiyotaki and Moore (1997).

Several papers have built upon BGG framework to include the role for the banking sector. As in BGG, most papers assume that return on debt is state contingent, implying that banks or financial intermediaries make a risk free return. Thus, in these models, there is no role for bank capital. Clerc et al (2015) depart from this assumption, and develop a model where banks are exposed to risk and can default in equilibrium. Banks are also prone to taking higher risk due to limited liability and deposit insurance. The model features a meaning trade-off between costs of banking sector defaults on the one hand and higher cost of capital on the other. This is used to perform normative as well as positive analysis of bank capital requirement. Our paper is closely related to Clerc et al (2015). We build upon this model to include interest rate stickiness and Loan to Value limits.This allows us to analyze the interaction between the two tools.However,we would focus on positive aspect of the model.

The model developed by Benes and Kumhof (2014) also features both borrower and bank level default. They study the role of a countercyclical capital in a monetary economy and find significant welfare gains.

Hodbod et al (2016) develop a similar model and show how a countercyclical risk weight can be used as a macro prudential tool to attenuate a financial cycle. Lorez et al (2018) evaluate different rules for setting countercyclical buffers in a small open economy model for the Irish economy.

The other stream of literature on financial friction pertains to models with borrowing constraints in the form of a collateral constraint as in Kiyotaki and Moore (1997). Iacoviello (2005) builds a DSGE model with housing sector and collateral constraint to analyse monetary policy transmission. Mendoza and Bianchi (2008) and Jeanne and Korinek (2008) provide rationale for macro prudential policies due to a pecuniary externality associated with collateral constraints. Gerali et al (2010) explore the role of banking sector related shocks in a model with binding collateral constraint.

Both these strands of literature are mutually exclusive in that they either have a default in equilibrium or an exogenous collateral constraint. In this paper, we bring together both these elements, where borrowers (and banks) can strategically default and borrowers are subject to collateral constraint on the new loans (which appears in the model as LTV limit) .Another paper which attempts to do so is Nukhwoon & Tsomocos (2017).The advantage of this approach is that the collateral constraint can be looked upon as a LTV limit imposed by the bank as well as a policy instrument of the regulator.

Other important papers with a key role for banking sector within a DSGE framework include Goodfriend & McCallum (2007), Curdia and Woodford (2008), Meh and Moran (2010), Cristiano, Motto and Rostagno (2014) Empirical papers.

Gerali et al (2010) is an example of DSGE model which incorporates interest rate stickiness. They do it by introducing quadratic adjustment costs in the profit function of the banks.In this paper, we introduce price stickiness as in Calvo (1983).

Nukhwoon & Tsomocos (2017) attempt to explain the financial crisis with default risk shock and a risk premium shock in a DSGE model, similar to Clerc et al (2015). They analyze the role of macro prudential policy tools such as countercyclical capital buffers, LTV limit and state contingent LTV limit.

There are very few papers which look at different prudential policies in the same model.For example, Boissay & Collard (2016) study the transmission mechanism of liquidity and capital regulations in a DSGE model.They find that both policies reinforce each other and support the Basel III's "multiple metrics" approach.

Goodhart et al (2013) study multiple financial regulation in an integrated framework using a simplified model.They analyze combinations of capital regulations, margin requirements, liquidity regulation, and dynamic provisioning to achieve financial stability and maximizing welfare.Popoyan et al(2017) develop an agent-based model to study the macroeconomic impact of alternative macro-prudential regulations and their possible interactions with different monetary policy rules.

We would like to clarify that the interest rate sluggishness that we discuss in this paper is about lending rates and not the sluggishness in the policy rates or Taylor rule inertia as in Rudebusch (2000,2006). As regards interest rate stickiness, there is literature from the 90s, which tries to explain the rationale for interest rate stickiness. For example the presence of a highly regulated or less-competitive financial sector (Hannan and Berger, 1991, Neumark and Sharpe, 1992),administrative/menu costs in changing loan rates (Mester and Saunders, 1991), customer's costs of changing banks (Neumark and Sharpe, 1992),etc.

Lowe & Rohling (1992) provide theory and evidence on interest rate stickiness.They consider theories are based on equilibrium credit rationing, switching costs, implicit risk sharing and consumer irrationality. Their empirical evidence provides support for the switching cost explanation.

In recent times,Driscoll and Judson (2013) examine the dynamics of eleven different deposit rates for a panel of over 2,500 branches of about 900 depository institutions observed weekly over ten years. They find that rates are downwards-flexible and upwards-sticky, and show that a simple menu cost model can generate this behavior. Bernstein & Fuentes(2004) provide evidence that the lending rates in Chile are flexible as compared to most other countries.

Moazzami (2010) finds that lending rates in the US have been stickier than those in Canada. However, the US lending rate rigidity, has decreased in recent years.

Sorenson & Werner (2006) investigate the pass-through between market interest rates and bank interest rates in the euro area.They find heterogeneity in interest pass through across loan products and that the speed of adjustment of interest rates is slow.

Nakajima & Teranishi (2009) show that the loan rates are sticky to a policy interest rate in all Eurozone countries for all loan maturities, the degree of stickiness differs across the countries, and the degree of difference is more prominent for longer loan maturities.Andries and Billon (2014) provide a survey of the empirical literature on interest rate pass through.The results show that although there is complete long run pass through of interest rates, there is an incomplete short-run pass-through and a heterogeneous adjustment of bank interest rates across bank products and euro zone countries.

In the empirical section of this paper, we explore one of the sources of interest stickiness related to the nature of loan contract i.e.fixed interest loans. Macro economic models with banking sector generally assume a one period loans and thereby all loans to have a variable interest rate. In reality, there are both fixed interest and variable interest loans for different maturities. The existence of fixed rate contracts and longer term loan contracts has been neglected by the literature except for Bluwstein et al (2018), Greenwald (2017) etc. With fixed interest contracts, change in policy (whether monetary or macro prudential) would impact variable interest loans and new fixed interest loans but not the existing stock of outstanding fixed interest loans.

3 Interest rate stickiness in the U.K. (Kunal version)

(-Kunal version, I only updated the last figure (based on new lending rates))
-Check if the data is on new lending or existing lending
-We should maybe replace Figure 1 with a matlab figure to be consistent across the paper?
-Important points to stress: –> Pass-through on impact is very low for all rates
–> Pass-through typically takes at least several months in all contract types (except for floating rate)
–> Pass-through not complete in longer-term contracts (But this is not something we capture with the Calvo mechanism?)
-We mention the cross-country evidence but the results go into Appendix

Although interest rate stickiness could arise due to number of reasons highlighted by the literature such as market power, level of competition, regulation, switching/menu costs etc, we highlight the importance of interest rate stickiness emanating from the nature of loan contract i.e. existence of long term loans and fixed interest loans.

In this section, we compare the response of (effective)lending rates for different terms of interest rate fixation to change in policy rates. The following graph depicts the movement of mortgage rates (for different maturities) over the period of last 20 years in the UK:

We use the monthly data on effective interest rates (between January 2004 to January 2016) for mortgage loans in the United Kingdom (for different terms of interest rate fixation) from Bank of England database. As can be seen in figure below, the response of effective variable

Figure 1: Mortgage lending rates in the UK

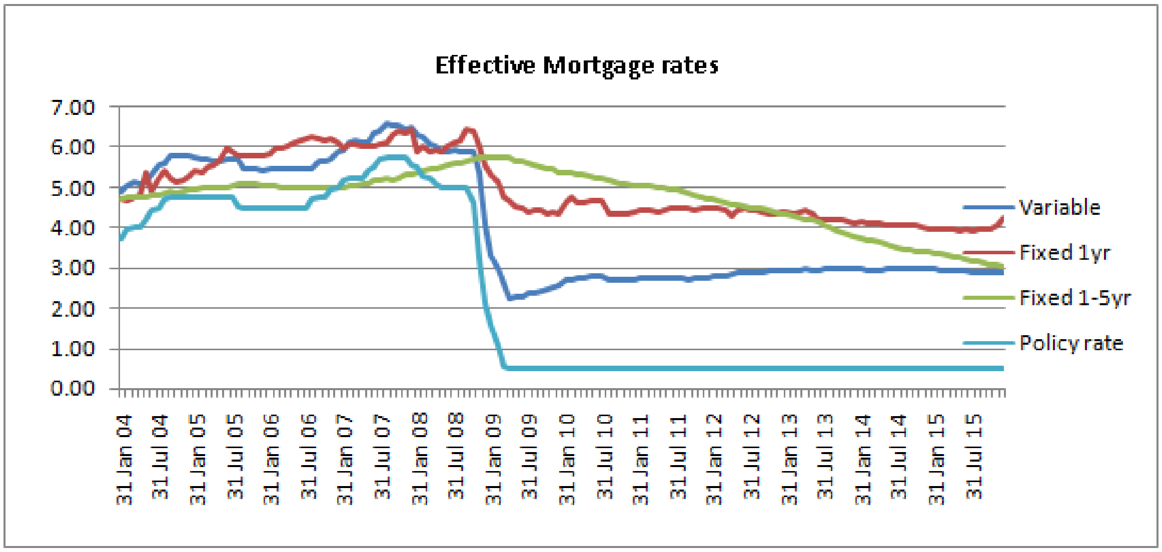
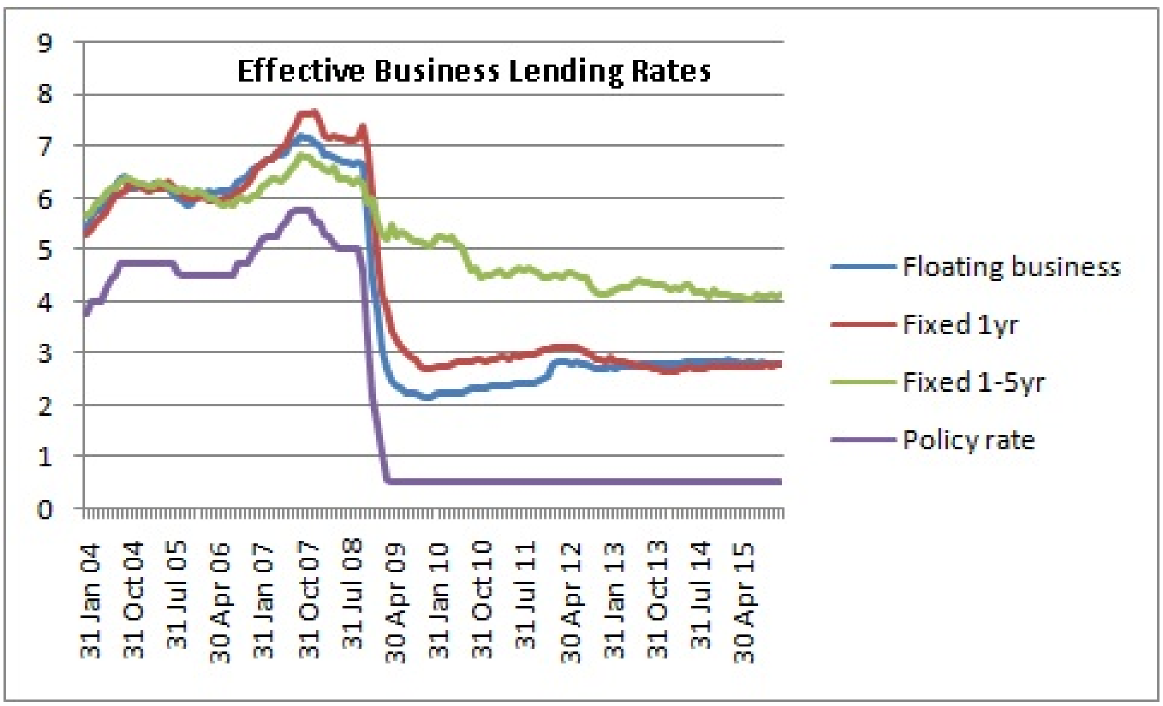


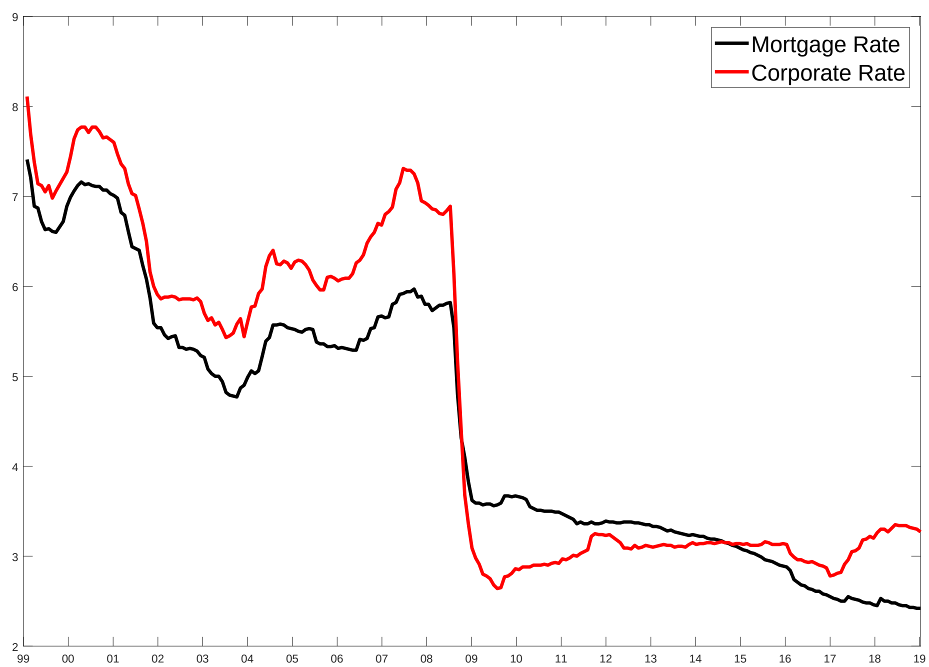
Figure 2: Business lending rates in the UK



interest rate mortgages (to changes in the policy rate) is faster than the effective fixed interest mortgages (as expected).So also the response of the fixed interest mortgages decreases with the increase in the initial term of interest rate fixation. The effective interest rates for longer term of initial interest rate fixation, change slowly as compared to the shorter term of initial interest rate fixation because of the fixed nature of the interest rate for the respective term. The effective interest rate implies that a given portfolio of loans has a mix of older loans (which are being repaid over a period of time) which pay interest rate at the interest rates fixed in the past whereas the fresh loans pay interest at the current market rates (depending upon the interest rate pass through). As a result, even if the market interest rates change, the effective interest rates would not change immediately. They change slowly as the older loans are repaid and fresh loans are added to the loan portfolio over a period of time. The same can be observed in the graph for business interest rates

Interest rate stickiness arising due to fixed term loan contracts can vary across different sectors, depending upon the proportion of long term contracts in the portfolio. The following figure presents the effective lending rate for the overall portfolio of all fixed interest loans (i.e.this includes different fixed term contracts) in case of business loans and mortgage loans. We find that the interest rate pass through is slower for the mortgage loan portfolio as compared to the business loan portfolio due to higher proportion of longer term fixed interest loan contracts.

Figure 3: Mortgage lending rates v/s Business lending rates in the UK



3.1 Econometric Methodology

Is the data used in this section on **new lending** or the average of **all existing lending**? We need to make the former is used (that is also what we use in the model estimation section)

As a first step to investigate the extent of sluggishness in the movement of interest rates, we attempt to find out how lending rates change in response to change in central bank policy rate.Following the empirical literature on interest rate pass-through models (some citations here would be nice) , we run a vector error correction model, where policy interest rates are considered to be the most direct determinants of retail bank lending rates. We run the following vector error correction model based on Johansen (1991):

$$\Delta R_t = \sum_{k=1}^{K} \delta_k \Delta R^m_{t-k} + \sum_{q=1}^{Q} \gamma_q \Delta i_{t-q} + \alpha(\mu + R^m_t - \beta i_t) + u_t \tag{3.1}$$

Where R_t is the effective lending rate (mortgage loans), i_t is the Bank of England policy interest rate,coefficient β is the long run equilibrium relationship between bank lending rate and policy rate and the coefficient α is the speed of adjustment of the lending rate to the long run equilibrium. The coefficients of the lags of the first difference of policy rate capture the short-run response of mortgage lending rates to the policy rate. We conduct this exercise for three different lending rates, variable interest rate, fixed interest for a term of up to 1 year and fixed interest rate for a term of 1 to 5 years. Results are summarized in the following table.

Table 1: Regression of UK Bank lending rate on BOE policy rate

Regressor	Floating rate	Fixed < 1 year	Fixed 1 to 5 year
ß$_t$	0.016***	0.0057	0.0025
Δ ß$_{t-1}$	0.896***	0.435***	0.018
Δ ß$_{t-2}$	0.016	-0.293***	-0.0158
Δ ß$_{t-3}$	-0.008	0.242***	0.0097
Δ ß$_{t-4}$	-0.196***	-0.037	0.0054
constant	0.1366***	-	-

In case of floating interest rate loans, the response on impact is very low. However,around 90 percent of the pass through takes place in the following month.

The above table highlights that the response of floating interest rate (as depicted by coefficient γ_q (what is the corresponding γ_q in the table? Is the constant equivalent to $\alpha * \mu$? Notation on deltas should be also be consistent in the table and regression model maybe?)) on the central bank policy rate is higher than the response of 1 year fixed rate loans, which in turn is higher than the response of the 1 to 5 year fixed rate loans.

In case of fixed term of up to 1 year, the response on impact is very low (less than 0.01 percentage point) and around 45 per cent of the pass through takes place in the following month.

The pass through for the 1 to 5 year fixed term loans is very low. However,there exists a long term co-integration relationship between the two interest rates. do we interpret the table as follows: there is no significant pass-through in the following 4 months on 1-5 year fixed-term loans because none of the coefficients are significant? relatedly: does the negative term on β_{t-2} on fixed<1year loans mean the pass-through works in the opposite direction in that month? Summing up all the coefficients, can we claim the pass-through in the following 4 months in only 45 %?

For the fixed rate loans, the sum of short run coefficients is less than 1 suggesting an incomplete pass through of policy interest rate.

Thus, the pass through to the fixed interest loans is not only sluggish but also incomplete, whereas the pass through to variable interest loans is faster and almost complete.However, in

[0]*** is 1 per cent, ** is 5 per cent and * is 10 per cent level of significance

all the cases including floating interest rate, the response of lending rate on impact is very low (less than 2 percent) what is "all cases" referring to here? Isn't there only regression here with the floating rate?.

The fact that floating interest rates adjust faster than the fixed term interest rates,implies that the existence of fixed rate contract is an important source of interest rate sluggishness. So also,the pass through of interest rate changes on impact (i.e. the speed of adjustment) is very small implies that other sources of stickiness such as switching costs, menu costs, market structure/competition, regulation could also be relevant.

4 Model Overview

Our model closely follows Clerc et. al. (2015), which augments the baseline model of Bernarke, Gilchrist and Gertler (1999) with a detailed banking sector and different types of default on households, corporates and banks to determine the optimal capital adequecy ratio (CAR) for the banking sector, as well as to analyze the macroeconomic implications of bank capital structure under different shocks.

The BGG framework assumes that interest rates charged by the banks are state contingent. This implies that higher interest rates charged on non-defaulters are sufficient to meet the losses arising from defaulters. This means that banks always make a risk-free return on their investments, which makes the capital structure of the bank irrelevant in the original BGG framework.

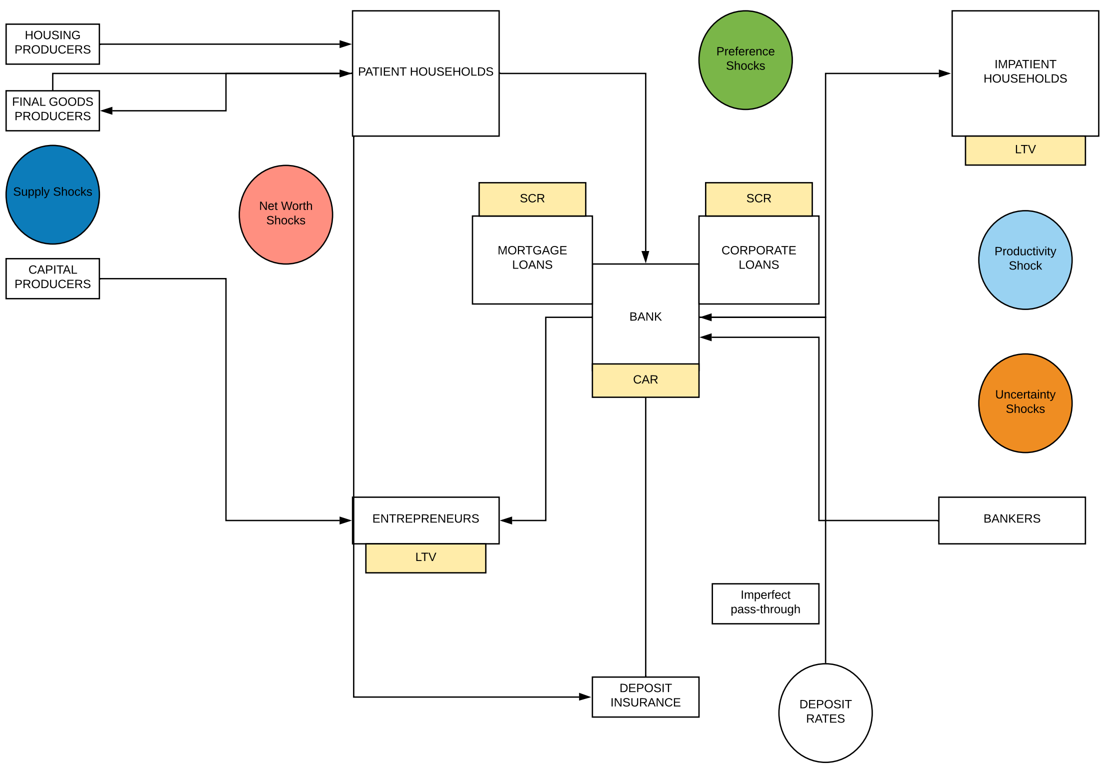
Clerc et. al. (2015) departs from the BGG framework by assuming a non-contingent lending rate, which implies that in the event of defaults by borrowers, banks may also suffer losses. Therefore, with costly state verification of borrowers, defaults are costly and entail a dead-weight loss for the economy, which necessitates a role for bank capital. They further assume that investor wealth is scarce and hence cost of equity capital is higher than debt funding. This implies that although bank capital is necessary to avoid higher default rates, it is also expensive at the same time, thus creating a trade-off for holding capital.

Our model deviates from Clerc et. al. (2015) in several important ways. On the banking side, we introduce staggered interest rates à la Calvo (1983) to capture the sluggishness of mortgage and corporate lending rates, which is motivated by the empirical evidence shown in Section 3. Further, we endogenize the bank's capital level by allowing it to be determined in equilibrium through the bank's decision problem. Accordingly, the bank maximizes over its lending rates to households and businesses subject to interest rate sluggishness. The minimum and sectoral capital requirements are introduced as penalty costs on the bank's decision problem, which creates a precautionary motive for the bank to hold a capital level higher than the minimum required. This is a realistic setup since banks typically maintain capital buffers to ensure they do not breach the regulatory minimum. This differs from Clerc et. al. (2015), which assumes that banks always hold the minimum capital requirement.

On the household side, we introduce a Loan to Value (LTV) limit, which is a key feature of the mortgage lending market. The LTV limit is qualitatively similar to an exogenous collateral constraint as in Iacoviello. We further introduce a similar LTV limit on businesses, although we do not evaluate the impact of this since the Financial Policy Committee (FPC) in the U.K. does not have such a regulatory tool.

Other key distortions and frictions in the model follow Clerc et. al. (2015). Accordingly, both the bank and borrowers in the model are subject to limited liability. The limited liability of banks, along with the presence of deposit insurance implies that banks have an incentive to over-borrow and thereby over-lend, since they do not fully internatilize the costs of default suffered by the deposit insurance agency and the economy as a whole. As such, regulatory capital is a means to restrict the use of excessive bank leverage. The model further features costly state verification, which implies that the use of leverage is more expensive and that defaults are costly.

Key agents in the economy are patient and impatient households, entrepreneurs, banks, a deposit insurance agency, housing, & capital and final goods producers. Figure ?? provides an overview of all economic agents. Below we provide the maximization problem for each agent type. The associated first-order conditions can be found in the Appendix.



Households: there are two types of households, patient and impatient, with patient households having a higher discount factor as in Iacoviello (2015). Both patient and impatient households have concave utility functions and derive utility from consumption goods, housing and leisure. The individual households are a part of a representative dynasty, which provides perfect risk sharing within the group. Thus, all individual households within the type are (ex-post or ex-ante? identical. While the individuals face idiosyncratic shocks, they are perfectly insured within their dynasty and hence consume and save/borrow identically.Both households supply labour in a competitive labour market.

Patient households are savers who supply deposits to the bank in equilibrium, and buy houses with their own funds. Both households types derive utility from consumption as well as housing goods, and dis-utility from labour. As such, the patient household's maximization problem is given as:

$$\max_{c_t^s, L_t^s, D_t, H_t^s} E_t \sum_{t=0}^{\infty} \beta_s^t [log(c_t^s) + vlog(H_t^s) - \frac{(L_t^s)^{1+\eta}}{1+\eta}] \tag{4.1}$$

subject to the following budget constraint:

$$c_t^s + q_t^H H_t^s + D_t = w_t L_t^s + q_t^H H_{t-1}^s (1-\delta) + D_{t-1} R_t^D + \pi_t \tag{4.2}$$

where π_t includes profits of final goods producing firms and investment & housing production firms (which are owned by patient households), dividends from entrepreneurs and lump-sum transfers from deposit insurance agency.

Impatient households borrow from banks using their houses as collateral as in Bernanke, Gertler & Gilchrist (1999). Mortgage loans are made on a limited-liability basis, which implies that individual households can default whenever the value of their house is lower than the outstanding mortgage loans. The value of the house depends both on aggregate shocks, which affect the value of their house, as well as idiosyncratic shocks which affect the default decision of individual borrowers. In equilibrium, borrowers with an idiosyncratic shock below a certain threshold default, in which case the bank takes possession of the house subject to a state verification cost.

We introduce a loan-to-value (LTV) limit set by the macroprudential regulator on the flow of new lending, which is similar to a collateral constraint as in Kiyotaki & Moore (1997). With the exception of having a different discount factor, the impatient household has the same objective function as the patient household, which is given as follow:

$$\max_{c_t^m, B_t^m, L_t, H_t^m} E_t \sum_{t=0}^{\infty} \beta_m^t [log(c_t^m) + vlog(H_t^m) - \frac{(L_t^m)^{1+\eta}}{1+\eta}] \tag{4.3}$$

subject to the following budget constraint, which reflects their borrowings under limited liability:

$$c_t^m + q_t^H H_t^m - B_t^m = w_t L_t^m + \int_{\bar{\omega_t^m}}^{\infty} \left(\omega_t^m q_t^H H_{t-1}^m (1-\delta) B_{t-1}^m R_{t-1} \right) dF \omega_t^m + P_t \tag{4.4}$$

The term under the integral reflects the limited liability of the borrowers as they default on their loans when the idiosyncratic shock ω_t^m is below the threshold level of $\bar{\omega^m}_t$. The default threshold of the borrowers is determined by:

$$\bar{\omega^m}_t q_t^H H_{t-1}^m (1-\delta) = B_{t-1}^m R_{t-1}^m \tag{4.5}$$

Finally, the LTV limit (or the borrowing constraint) is given by:

$$[B_t^m - (1-rp) B_{t-1}^m] R_t <= \epsilon_t E_t [q_{t+1}^H [H_t^m - H_{t-1}^m (1-\delta)]] \tag{4.6}$$

where rp denotes the loan repayment rate and ϵ_t is the LTV limit. We assume that the LTV limit always binds in the steady state and it's neighbourhood.

Entrepreneurs are risk neutral agents who own and maintain the stock of physical capital. They rent capital to the final goods producing firms. Entrepreneurs derive utility from transferring part of their wealth to the saving dynasty by paying out dividends and retaining the rest for the next period as retained earnings. Entrepreneurs invest in capital goods and finance their investment by means of their own funds, i.e. net worth, and borrowings from banks. Similar to mortgage loans, these are limited liability loans and hence subject to default by individual entrepreneurs in the event of value of assets falling below the value of outstanding loans. The value of the capital depends both on aggregate shocks as well as idiosyncratic shocks which affect the default decision. In equilibrium, entrepreneurs with an idiosyncratic shock below a certain threshold default. As in the case of households, assets are seized by banks and subject to costly state verification costs. The entrepreneurs' decision rule is given as follows:

$$\max_{K_t, B_t^e} E_t(W_{t+1}^e) \tag{4.7}$$

with

$$W_{t+1}^e = max[\omega_{t+1}^e(r_{t+1}^k + (1-\delta)q_{t+1}^K K_t) - R_t^F b_t^e, 0] \tag{4.8}$$

The default decision of the entrepreneurs is determined by:

$$\bar{\omega^e}_t q_t^K K_{t-1}^m (1-\delta) = B_{t-1}^e R_{t-1}^f \tag{4.9}$$

Similar to the impatient households, entrepreneurs are subject to the following LTV limit on the flow of new borrowing:

$$[B_t^e - B_{t-1}^e(1-rp)]R_t^f = \epsilon_t E_t[q_{t+1}^F[K_t - K_{t-1}(1-\delta)]] \tag{4.10}$$

A fixed proportion of wealth χ^e is paid out as dividends. This simple dividend paying rule for the entrepreneurs is given by:

$$c_t^e = \chi^e W_t^e \tag{4.11}$$

As a result, the retained earnings by the entrepreneurs is given by:

$$n_t^e = (1-\chi^e)W_t^e \tag{4.12}$$

The balance sheet identity of the entrepreneurs follows as:

$$n_t^e + B_t^e = q_t^K K_t \tag{4.13}$$

Banks are financial intermediaries who channel savings from the savers to the borrowers. On the asset side of the banks, there are loans to households (mortgage lending) and entrepreneurs (business lending) respectively. As described earlier, these loans may default depending on aggregate state shocks and idiosyncratic borrower shocks in which case the banks seize the assets subject to state verification costs, which can also be viewed as bankruptcy costs.

On the liability side of the banks, there are deposits held by the patient households and equity capital held by the bankers. Deposits are insured by the Deposit Insurance Agency (DIA). There is a capital adequacy requirement set by the regulator which, along with a penalty cost function, which determines the amount of equity capital held by the bankers.

One of the key features of the model is that banks may also default depending on the performance of their loan portfolios, which is driven by aggregate shock, and idiosyncratic shocks similar to the impatient households and entrepreneurs. The banks face an idiosyncratic shock to their returns on loans and therefore, in equilibrium, a fraction of banks below a certain threshold of the idiosyncratic shock level default. In case of default, the bank loan assets are possessed by the DIA, subject to costly state verification.

The banks' balance sheet identity is as follows:

$$n_t^b + D_t = B_t^m + B_t^e \tag{4.14}$$

we dont have this following part in the code. This seems to be the old version replaced by 4.22-4.24? Otherwise I don't understand what's going on here.

$$\max_{R_t^{mi}, R_t^{fi}} E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t [\{(1 - G_{t+1}^H)(\widetilde{R_t^{mi}})(B_t^{mi}) + (1 - G_{t+1}^F)\widetilde{R_t^{fi}} B_t^{ei}\} - (1 - F^) R_t^D D_t + Penaltycost] \tag{4.15}$$

$$\widetilde{R_t^{mi}} = (1 - E_t F_{t+1}^m) R_t^{mi} + E_t G_{t+1}^m (1 - \mu^m)(R_t^{mi} / E_t \bar{\omega}_{t+1}^m) \tag{4.16}$$

$$\widetilde{R_t^{fi}} = (1 - E_t F_{t+1}^e) R_t^{fi} + E_t G_{t+1}^e (1 - \mu^e)(R_t^{fi} / E_t \bar{\omega}_{t+1}^e) \tag{4.17}$$

The demand for Loans is given by:

$$B_t^{mi} = (\frac{R_t^{mi}}{R_t^m})^{-\tau} B_t^m \tag{4.18}$$

$$B_t^{ei} = (\frac{R_t^{fi}}{R_t^f})^{-\tau} B_t^e \tag{4.19}$$

R^{mi} and R^{fi} are the rates of interest that the bank would charge in the absence of interest rate sluggishness. τ is the elasticity of substitution and determines the market power of the bank, while μ represent the bankruptcy cost of households and firms respectively. is this paragraph correct?

Penalty costs for violating the regulatory requirements are modeled as a non-pecuniary? gain in utility if the capital adequacy ratio is higher than the minimum capital requirement and a non-pecuniary cost if the capital adequacy ratio is lower than the minimum capital requirement with the following functional form:

$$PC_t = \nu^b \frac{[\frac{\phi_t^b}{\bar{\varphi}_t}]^{1-\sigma} - 1}{1 - \sigma} \tag{4.20}$$

which is based on Nukhwoon & Tsomocos (2018). The marginal gains of having excess capital are decreasing, whereas the marginal costs of having a shortfall in capital are increasing, whenever σ is greater than 1. This creates an incentive for banks to maintain capital at a higher level than the minimum regulatory requirement. In reality, we find that banks do maintain capital buffer over what is the minimum required this needs a reference. The parameter ν^b determines the weight attached to this penalty costs.

Staggered interest rates: while we find that one of the main sources of interest rate stickiness is the existence of fixed-interest rate loans as shown by our empirical exercise in Section 3, interest rate stickiness can be attributed to various reasons such as switching or menu costs, market structure, regulation and so on. Therefore we introduce interest rate stickiness in a broader sense by modeling it as in Calvo (1983). This approach has the benefit of including all possible sources of interest rate stickiness in a reduced form. As such, we assume that only a proportion of 1-ξ of banks are able to change their lending rates in a given period, whereas the remaining proportion ξ are unable to change their lending rate, which remains fixed at previous period's value. Accordingly, the composite interest rate in the economy is a weighted average of the current interest rate charged by the banks that can change their interest rate, and the previous period's interest rate used by the banks that cannot change their interest rate.

In order to micro-found the staggered interest rate setting, we assume that there is imperfect competition in the banking sector, where banks offer differentiated loan products as in Gerali et. al. (2010) and are able to set their interest rate in the monopolistically competitive loan market. The borrowers then take a composite loan product consisting of these differentiated banking services. The first-order conditions of the bank for interest rates resemble the first-order conditions for prices in a standard New Keynesian setting with price stickiness, and they are given as:

$$R_t^{mi} = \frac{\tau}{\tau - 1} \frac{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t MC_t}{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t rm_t} \tag{4.21}$$

$$R_t^{fi} = \frac{\tau}{\tau - 1} \frac{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t MC_t}{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t rf_t} \tag{4.22}$$

$$MC_t = \lambda_{st+1}[(1 - F_t^B) R_{Dt} + \frac{\nu^b (\phi_t^b / \bar{\varphi}_t)^{(1-\sigma)}}{(B_t^{mi} + B_t^{ei})}](R_t^m)^\tau B_t^m \tag{4.23}$$

where the interest rate charged by banks is a function of present discounted value of present and future "marginal cost" (MC) times the mark-up, where the MC includes the interest rate paid on deposits in a competitive deposit market, and the penalty cost associated with deviating from regulatory capital requirements. **Deposit Insurance Agency** insures the deposits, where the assets of the defaulting banks are taken over by the agency and are subject to bankruptcy costs. The difference between the amount of deposits and the value of realized assets is recovered by imposing a lump-sum tax on households.

Final goods producing firms are modeled as a unit mass of perfectly competitive firms, which combine capital and labor to produce the consumption good. The firms rent capital from entrepreneurs, and they are owned by patient households. They produce the final goods using a standard Cobb-Douglas technology:

$$Y_t = E_{A_t} K_{t-1}^{\alpha} L_t^{1-\alpha} \tag{4.24}$$

Capital goods and housing production comes from competitive firms, owned by patient households, that buy finished goods and produce capital goods and housing subject to quadratic adjustment costs. These firms produce new units of capital and housing using consumption goods, which are then sold to entrepreneurs and households. As such, they represent the supply side of capital goods and housing, and they pin down the equilibrium asset prices.

Exogenous Processes

The model is equipped with 12 exogenous AR(1) processes across different sectors. On the housing side, we have two preference shocks on housing and consumption $E_{J,t}$ and E_{C_t}, which affect the taste of both patient and impatient households for consumption and housing goods respectively. These shocks can be equivalently interpreted as the degree of risk aversion to purchasing consumption and housing goods. We further have a housing price shocks $E_{H,t}$, which is an external shock that directly affects the housing price index[1]. In the absence of a monetary policy shock, the external housing shock is intended to capture the effects of a looser monetary policy on house prices, which is discussed in further detail in the estimation section. Finally, we have a shock on the LTV limit of the households, $E_{LTVH,t}$ which is introduced to relax the restrictiveness of an always binding collatoral constraint.

On the corporate side, we have a net worth shock $E_{We,t}$, which is a transfer from the housing sector to the businesses, which we use as a proxy for an exogenous government spending shock in our model. We also introduce a risk shock $E_{Se,t}$ into the corporate sector, which affects businesses' likelihood of default. Finally, we have an expected capital price shock $E_{EbF,t}$, which drives the stock market sentiment in the model.

On the banking side, we have bank risk shock $E_{Sb,t}$ that has a similar meaning as tis counterpart in the corporate sector. The bank is further subject to a bank capital shock $E_{CAB,t}$, affect its capital ratio, and two mark-up shocks on its interest rate setting $E_{markup^m,t}$ and $E_{markup^F,t}$, which affect the cost of mortgage and corporate lending respectively for the bank. These mark-up or cost-push shocks help introduce a wedge between the realized interest rates and the rates that the bank would use in the absence of interest rate stickiness.

Finally, the Cobb-Douglas production function of final goods producing firms is subject to a productivity shock $E_{A,t}$[2].

Estimation

Measurement equations

We use quarterly data from U.K. over the period $1998Q1 - 2016Q4$ for key macroeconomic and financial variables[3]:

- Output growth:
  $\Delta Y_t^{obs} = \gamma_Y + Y_t - Y_{t-1}$,
- Wage growth:
  $\Delta W_t^{obs} = \gamma_W + W_t - W_{t-1}$,
- Investment growth:
  $\Delta I_t^{obs} = \gamma_I + I_t - I_{t-1}$,
- Consumption growth:
  $\Delta C_t^{obs} = \gamma_C + C_t - C_{t-1}$,

[1]This shock can also be thought of as a measurement error, i.e. the component of the housing prices that is not explained internally by the model.

[2]We also experimented with different combinations of shocks across different sectors, e.g. a risk shock on the housing sector, an LTV limit shock on the corporate sector, housing and capital depreciation shocks and a net worth shock in the banking sector. The particular set of shocks reported in the paper emerges as the best combination of shocks in terms of model likelihood and providing a reasonable historical variance decomposition for key variables.

[3]Further details on the construction of the observable variables can be found in the appendix.

- Mortgage lending rate:
  $R^{H,t^{obs}} = 100(\bar{R^H} - 1) + R^m_t$,

- Business lending rate:
  $R^{m,t^{obs}} = 100(\bar{R^m} - 1) + R^m_t$,

- Deposit rate:
  $R^{D,t^{obs}} = 100(\bar{R^D} - 1) + R^D_t$,

- House price growth rate:
  $\Delta q^{H,t^{obs}} = \gamma_{\Delta q^H} + q^H_t - q^H_{t-1}$,

- Business lending growth rate:
  $\Delta b_{e,t}{}^{obs} = \gamma_{\Delta b_e} + b^e_t - b^e_{t-1}$,

- Mortgage lending growth rate:
  $\Delta b_{m,t}{}^{obs} = \gamma_{\Delta b_m} + b^m_t - b^m_{t-1}$,

$\gamma_Y, \gamma_W, \gamma_I, \gamma_C, \gamma_{\Delta q^H}$ and $\gamma_{\Delta b}$ are obtained by demeaning the series prior to estimation, since our model does not feature steady-state growth. $\bar{R^H}$, $\bar{R^m}$ and $\bar{R^D}$[4] denote the gross lending and deposit rates at the steady-state of the model.

Calibrated parameters and Prior Distributions

Prior to estimation, we fix a number of parameters by either following conventional values used in the literature or to generate steady-state values consistent with U.K. data. Parameters relating to default costs are based on Mendicino et. al. (2015): the depositor cost of bank default γ is fixed at 0.1. The bankruptcy cost of households, businesses and banks μ_m, μ_e and μ_B are set to a common value of 0.3. The discount factor for patient households is 0.995.

For some parameters, we use standard values following convention in the literature. Accordingly, capital share in production is set to 0.3, while the Frisch elasticity of labor η is 1. The labor preference parameters for both types of households φ_s and φ_m are normalized to 1 since they mainly scale the size of the economy. The parameters a_s and a_b are set to 0.5, which determine the share of total default costs paid by saving and borrowing households respectively.

Some parameters are closely linked with the steady-state of the economy. We use these parameters to generate plausible ratios for some of the key variables. The housing preference parameters for both types of households, v_s and v_m, as well as business and bank dividend payout parameters, χ_e and χ_b, are used to generate plausible business and mortgage lending to aggregate output ratios. Accordingly, we set $v_s = 0.25$ and $v_m = 0.5$, while the divident payouts are set to $\chi_e = 0.1$ and $\chi_b = 0.15$. These generate lending ratios of 133% and 86% for corporate and mortgage lending to output respectively, which are reasonably close to the historical means of the corresponding U.K. ratios over the estimation period, which are 118% and 81% respectively. At the given values, mortgage lending constitutes 38% of total lending

[4] We assume that the deposit rates are equivalent to the official Bank Rate in our estimation exercise since there is no monetary policy in our model. In the presence of monetary policy, an alternative would be to introduce another layer of sluggishness from the Bank Rate to deposit rates. However, Pariès et. al. (2010) find little evidence for the importance of this channel based on EU data.

in steady-state. Similarly, we set the housing and capital depreciation rates to $\delta_H = 0.01$ and $\delta_K = 0.04$, which yields an investment to output ratio of 0.12%, which is close to the historical mean of 0.17% for the U.K. economy over this period where did I take these ratios from?.

The parameters determining market power of the bank, τ_m and τ_F are both set to 40, whereas the hyperparameters in the cost function are set to $\psi_b = 5$ and $\nu = 0.5$.

Parameters relating to macroprudential regulation are fixed in our benchmark estimations. Accordingly, for minumum capital requirements, we use a benchmark value of $\phi_H = \phi_F = 0.11$ for both sectors, which is close to the historical minimum capital requirements for U.K. over this period. We further assume there is no CCyB in place in our benchmark estimations. Similarly, the LTV limit for both households and businesses is assumed to be fixed in our benchmark estimation, which is set to 0.86, close to the historical average over this period for the U.K. economy. specify which periods and which values these historical averages correspond to.

The remaining 35 parameters are estimated using Bayesian likelihood methods to match the data. For the AR(1) coefficients of all exogenous shocks, we use a standard Beta distribution with mean 0.5 and standard deviation 0.2 following Smets-Wouters (2007) add to citations. The standard deviations of all exogenous shocks are assigned a diffuse uniform prior over the interval $[0, 10]$. The volatility of i.i.d. shocks on households, businesses and banks follow a common Inverted Gamma distribution with mean 0.1 and standard deviation 2: we choose to use more informative priors for these parameters since both aggregate and i.i.d shocks mainly relate to the level of default rates in a first-order approximation, hence estimating both sets of parameters with uninformative priors may lead to identification issues. For the cost adjustment parameters ψ_i and ψ_h, we assume a conventional normal distribution with a mean of 5 and standard deviation 2, which is a wider and less informative prior than previous literature (see e.g. Smets-Wouters which assumes N(4,1.5), check also what is assumed in Compass).Finally, for the Calvo parameters on interest rates, we follow Pariès et. al. (2010) and assume a Beta distribution with mean 0.5 and standard deviation 0.2. This is similar to previously assumed priors for Calvo price setting on prices and wages, which typically follows similar Beta distributions.

We notice that the steady state is very sensitive to the remaining 4 parameters: habit formation λ, repayment rates for households rp and businesses rpe, and the discount factor of impatient households β_m. For these parameters, the likelihood function is also very irregular and we observe large jumps in the objective function for small parameter changes, which makes the computation of standard errors and posterior distributions around these variables very hard with conventional methods. For these parameters, we therefore use the following approach: we compute the point estimates for the candidate density (i.e. posterior mode) without computing the standard errors. These 4 parameters are then fixed at their point estimates and are exluded in the posterior MCMC draws, i.e. we compute the posterior distributions of the remaining 31 parameters conditional on the point estimates of these 4 parameters.

The posterior distribution of the remaining 31 parameters are computed using 4 parallel MCMCs, each with 200000 draws where the first half of each chain is discarded as the burn-in sample. The scaling coefficient of the parameter covariance matrix is adjusted to obtain an acceptance ratio of around 35% in each case.

Table 2: Prior Distributions

Parameter	Prior		
	Dist	Mean	Variance
ϵ_{Hd}	Uniform	10	5.77
ϵ_{Hk}	Uniform	10	5.77
ϵ_{A}	Uniform	10	5.77
ϵ_{J}	Uniform	10	5.77
ϵ_{Se}	Uniform	10	5.77
ϵ_{Sm}	Uniform	10	5.77
ϵ_{SB}	Uniform	10	5.77
ϵ_{We}	Uniform	10	5.77
ϵ_{markup_m}	Uniform	10	5.77
ϵ_{markup_e}	Uniform	10	5.77
ϵ_{EC}	Uniform	10	5.77
ϵ_{ECAB}	Uniform	10	5.77
σ_e	Inv. Gamma	2	0.1
σ_m	Inv. Gamma	2	0.1
σ_B	Inv. Gamma	2	0.1
ψ_i	Normal	5	2
ψ_h	Normal	5	2
ζ_m	Beta	0.5	0.2
ζ_e	Beta	0.5	0.2
ρ_{Hd}	Beta	0.5	0.2
ρ_{Hk}	Beta	0.5	0.2
ρ_{A}	Beta	0.5	0.2
ρ_{J}	Beta	0.5	0.2
ρ_{Se}	Beta	0.5	0.2
ρ_{Sm}	Beta	0.5	0.2
ρ_{SB}	Beta	0.5	0.2
ρ_{We}	Beta	0.5	0.2
ρ_{markup_m}	Beta	0.5	0.2
ρ_{markup_e}	Beta	0.5	0.2
ρ_{EC}	Beta	0.5	0.2
ρ_{ECAB}	Beta	0.5	0.2
β_m	Beta	0.98	0.01
ϕ_i	Normal	4	1.5
ϕ_h	Normal	4	1.5

Posterior Estimates & Distributions

Table 3 reports the point estimates as well as the 95% HPD intervals of all estimated parameters.

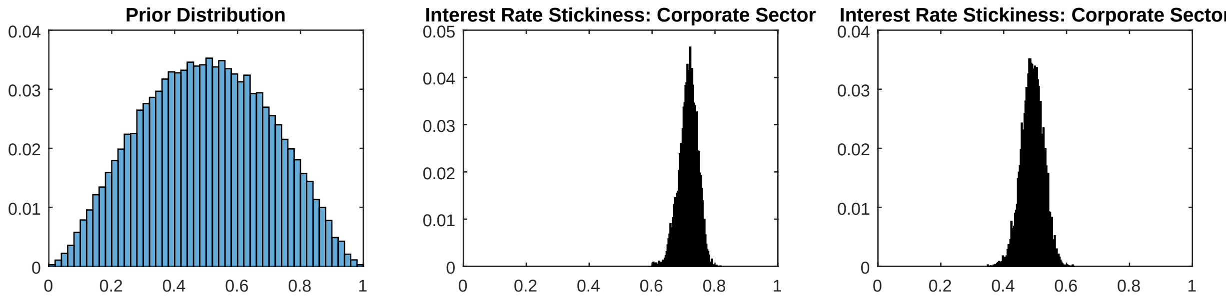
Of particular interest are Calvo parameters, for which the posterior distributions are along with the posterior mean and mode are shown in Figure ??. We find a Calvo probability of 44.7 % for corporate rates, whereas the probability for mortgage rates is 69.1 %. This means banks are able to reset the interest rates on corporate loans once every 1.81 quarters or 5.42 months, while it takes much longer to reset the interest rates on mortgage loans with an average of 3.24 quarters or 9.71 months. The 95 % confidence intervals are $[4.73, 5.93]$ months for corporate rates and $[8.21, 11.1]$ months for mortgage rates.

The shocks are typically estimated with high autocorrelation coefficients, with the exception of household and entrepreneur uncertainty shocks, as well as the bank capital shock. In particular the productivity, housing preference and bank uncertainty shocks have autocorrelation coefficients near unity, implying very high persistence. Regarding the capital and housing invesment adjustment cost parameters, we find values of 10.08 and 13.38 respectively, implying that housing investment is more sluggish compared to capital invesment.

Table 3: Posterior Estimates

Parameter	Posterior Mode	Mean	HPD % 5	HPD % 95
ϵ_A	0.0078	0.0079	0.0068	0.0092
ϵ_J	0.0971	0.1019	0.0841	0.1234
ϵ_H	0.0396	0.0499	0.0323	0.0739
ϵ_{Se}	0.0462	0.0728	0.0317	0.1483
ϵ_{SB}	0.0308	0.0317	0.0244	0.0398
ϵ_{We}	0.0053	0.0055	0.0047	0.0064
ϵ_{markup_m}	0.0005	0.0005	0.0004	0.0006
ϵ_{markup_e}	0.0004	0.0004	0.0003	0.0004
ϵ_{EC}	0.0288	0.0295	0.0253	0.0341
ϵ_{ECAB}	0.0379	0.038	0.029	0.0486
ϵ_{LTVH}	0.1353	0.1563	0.1105	0.208
ϵ_{EbF}	0.0423	0.0435	0.0369	0.0516
ρ_A	0.9956	0.9905	0.9786	0.9978
ρ_J	0.9849	0.9836	0.9733	0.9919
ρ_H	0.9572	0.9416	0.9051	0.9723
ρ_{Se}	0.499	0.4983	0.1723	0.8312
ρ_{SB}	0.0328	0.0498	0.0143	0.0984
ρ_{We}	0.8434	0.835	0.7663	0.8981
ρ_{markup_m}	0.8717	0.8685	0.7839	0.9447
ρ_{markup_e}	0.9347	0.9304	0.8851	0.969
ρ_{EC}	0.8424	0.8433	0.8012	0.8787
ρ_{ECAB}	0.5007	0.5002	0.1778	0.8234
ρ_{EbF}	0.9268	0.9194	0.8675	0.9678
ρ_{LTVH}	0.9292	0.9082	0.8207	0.971
ρ_{Wb}	0.9733	0.9587	0.9008	0.9907
ρ_{markup_m}	0.9532	0.9267	0.8536	0.9775
ρ_{markup_e}	0.8962	0.7038	0.2734	0.948
ρ_{EC}	0.8506	0.8567	0.8234	0.888
ρ_{ECAB}	0.2898	0.5034	0.176	0.8295
ψ_i	7.9159	8.0655	5.7808	10.5123
ψ_h	4.8532	5.821	3.5007	8.4709
ζ_m	0.7179	0.7155	0.6629	0.7607
ζ_e	0.4967	0.4914	0.4333	0.5468

Figure 4: Posterior distributions of estimated Calvo parameters on interest rate setting.



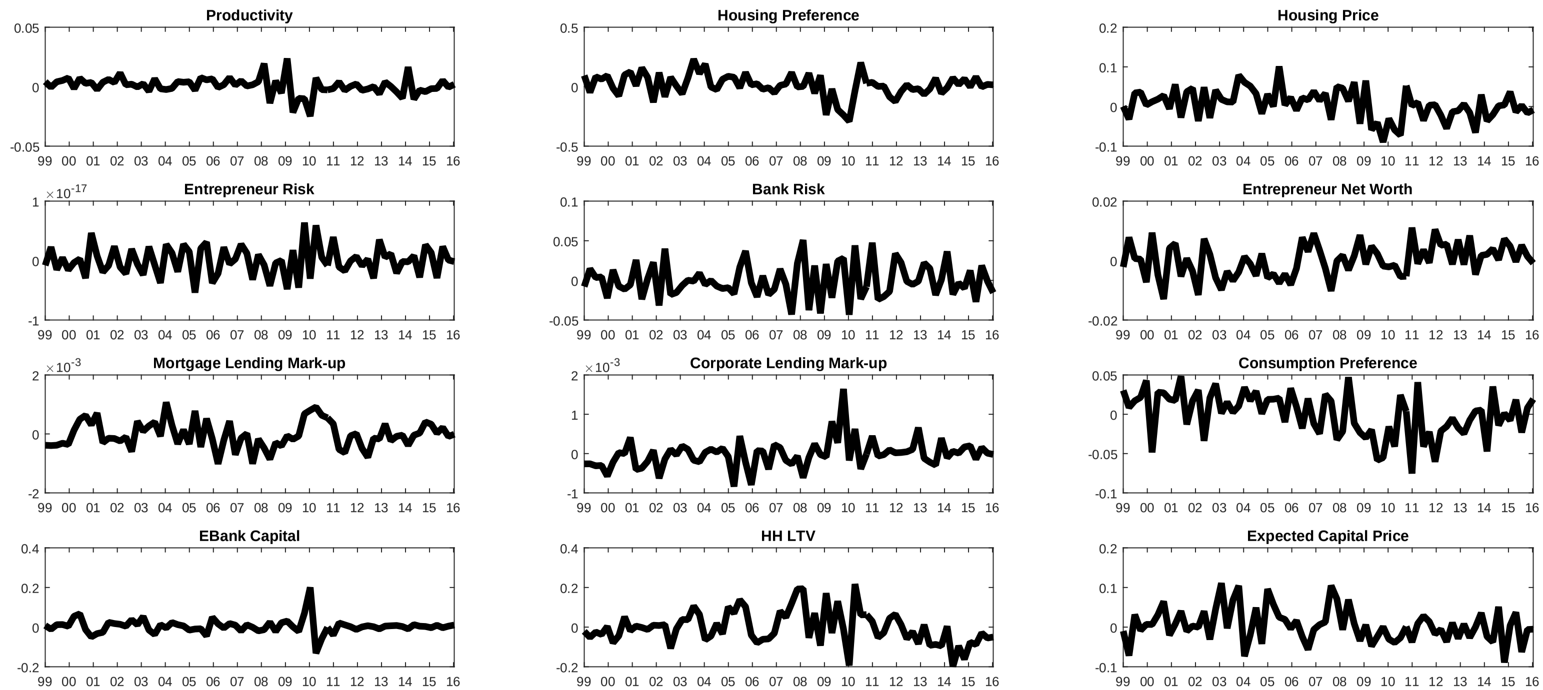
Estimated Shocks

Figure 5 shows some of estimated shocks over estimated period, particularly those that play a dominant role over the Global Financial Crisis period. Accordingly, the drops in the macroeconomic variables come out as a combination of several adverse shocks in the model. On the housing side, there is an increase in the housing depreciation shock, which means there is suddenly an increase in the supply of houses available on the market[5]. This is accompanied by a negative housing preference shock. This shift in the housing preference, ceteris paribus, would mean that households will shift their spending towards consumption rather than housing. Therefore the model generates a negative consumption preference shock to offset the impact of the housing preference shock on consumption. Together, these preference shocks can be interpreted as an increase in households' overall risk aversion that makes them less likely to purchase housing or spend on consumption as their income goes down. These shocks are accompanied by an increase in households' uncertainty (or risk) shock, which makes households more likely default other things being equal. Together, these shocks lead to an increase of around 5 % in the default rate of households over the crisis period. A similar story emerges on the banking side, where we observe an increase in the bank uncertainty shock and a negative bank net worth shock. Together, these shocks lead to a gradual and moderate increase in the bank default rates from 0.1 % to 0.2 %. As such, the primary source of contraction in the model emerges as the adverse shocks on the household side that drive down the house prices and household income, leading to an increase in the household default rate and a reduction in the mortgage lending growth.

On the corporate side, we do not observe a discernible difference in business default rates. In order to match the observed drop in business lending rates, the model generates an increase in the capital depreciation shock. Because this creates a larger than observed impact on the real side of the economy in output, investment and consumption, there is a positive increase in the productivity shock to offset some of the impact of the capital depreciation shock.

[5]We estimated an alternative version of the model where the housing depreciation shock is replaced with a house price expectation shock, in which case a negative expectation shock replaces the role of the positive supply shock as depicted here.

Figure 5: Estimated Shocks



Variance Decompositions

To illustrate which side of they economy, Figures ?? and ?? show the historical variance decompositions of household lending and output growth. The growth rate of household lending is mainly driven by housing depreciation and preference shocks, as well as uncertainty and bank capital shocks to a smaller extent, where the housing depreciation shock plays the most dominant role with a positive feedback before the crisis, and a negative impact after the crisis. As such, this shock emerges as the main driver of mortgage lending in our model. The consumption and housing preference shocks have two opposing effects on mortgage lending: on the one hand, a negative housing preference shock puts downward pressure on mortgage lending since households are less willing to spend their money on housing. On the other hand, a negative consumption preference shocks puts upward pressure on mortgage lending since it leads households to spend less on consumption and more on housing. For mortgage lending, the latter shock dominates in particular after the crisis, which leads to a positive contribution from preference shocks. Therefore the household depreciation shock is large enough to offset this positive feedback from preference shocks.

Corporate lending has a decomposition similar to mortgage lending, where the capital depreciation replaces the housing depreciation as the main driver of the lending rate. The negative spillover from this shock on output turns out to be larger than warranted by the data. Therefore the model generates a positive productivity shock after the crisis in order to mitigate some of the effects of this shock on output. In addition to these two, net worth and uncertainty shocks, as well as bank capital shocks to a smaller extent emerge as the main drivers of output growth in our model. Overall, the crisis period emerges as a combination of several adverse shocks in our framework.

Figure 6: Growth of Mortgage Lending

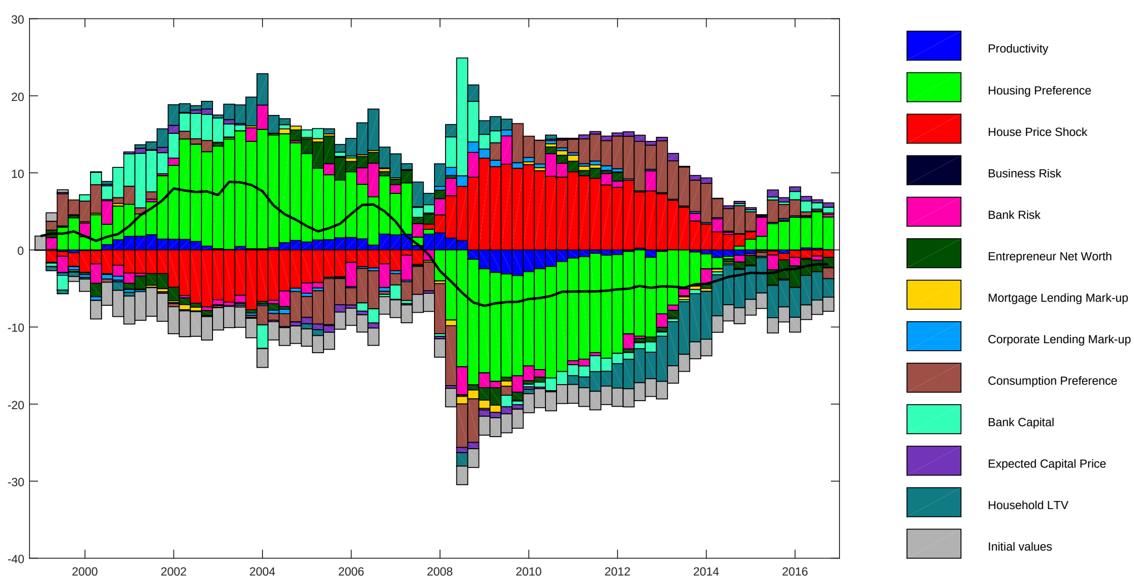
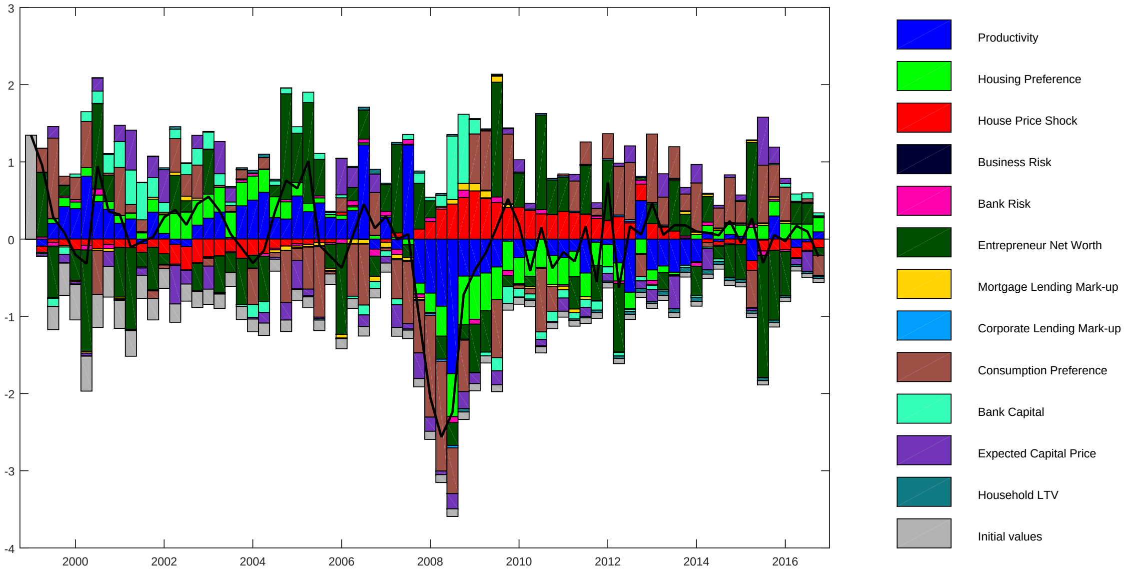


Figure 7: Output Growth



Impulse Responses & Interest Rate Stickiness

Before analyzing the effects of macroprudential tools on the economy, we first investigate the impact of staggered interest rates on shock propagation. Figures ?? through ?? report the impulse responses of several variables to three shocks originating in different sectors of the economy: a negative housing preference shock in the mortgage sector and a capital depreciation shock in the corporate sector, both of which play important roles in driving the business cycle as we saw previously; and a negative bank capital shock in the banking sector which may be interpreted as a proxy for monetary policy shocks.

Starting with the negative preference shock on Figure ??, this implies that households have a weaker preference for housing purchases, i.e. more risk aversion to housing. Therefore this has a direct impact on household borrowing, which is only marginally affected by the degree of interest rate stickiness: household borrowing drops more when mortgage rates are stickier, since the bank is unable to cut the interest rates as much in those cases to mitigate the negative impact of the shock. The impact on house prices is similarly negative and is not affected by the degree of stickiness

preference shock: households have a weaker preference for purchasing housing (or more adverse to purchasing housing) everything else equal. Therefore household borrowing decreases. Due to decreased housing demand, house prices go down. Interest rate stickiness has little effect on these two. The bank's response to decreased demand is to cut the interest rates, and the magnitude of this depends crucially on the degree of stickiness: the smallest change is clearly in the case where the Calvo probabilities are largest. The response of business borrowing also crucially depends on the stickiness: with small stickiness, the bank is able to shift its bundle towards corporate lending by cutting the interest rates, in which case there is a very little overall impact on business lending. When interest rates are sticky, the bank cannot adjust its rate as much as it would like, and as a result corporate lending goes down. As a result of this amplified impact on business lending, aggregate output experiences larger drops as interest rate stickiness increases. –>shock originating in the household sector, the biggest difference in IRFs in business borrowing since it takes longer to transmit through interest rates due to Calvo setting. (??? why is business borrowing going down in this case ???)

capital depreciation shock: business borrowing goes down since the return on equity on corporate investment is now smaller. Similar to above, the bank responds by cutting the interest rates, which crucially depends on the the degree of stickiness to boost demand. The response of mortgage rates depends on the degree of stickiness, but the overall impact is a reduction either initially or in the medium run (and the cumulative impact is a reduction in all cases). The largest impact on aggregate consumption and house prices is observed when interest rate stickiness is shut off in both sectors as one might expect. The spillover on aggregate output is rather small though, and it is similar in all cases. –> shock originating in the corporate sector, the biggest difference in IRFs in household borrowing and house prices since the transmission from one sector to the other affected by interest rates. The real effects (on output and consumption) are much smaller in this case compared to the housing preference shock. This might be due to the corporate interest rates already being small in the baseline case, so shutting it off does not have as large an effect. –> shock originating in the corporate sector, the biggest difference in IRFs in household borrowing and house prices, since it takes longer for the shock to transmit to the other sector, same as the above argument.

negative bank capital shock: the bank would like to reduce its lending since it has less capital now, so its response is to increase the lending rates. When interest rates are stickier, it is not able to increase its interest rates as much. Therefore the impact on household and corporate borrowing, and therefore on aggregate output, is smaller with stickier interest rates. –> shock originating in the banking sector, both housing and corporate related IRFs reflect this since the shock now needs to transmit into both sectors through interest rates. Therefore we get the larger differences across the board in IRFs as opposed to the previous two shocks.

Figure 8: Negative Housing Preference Shock

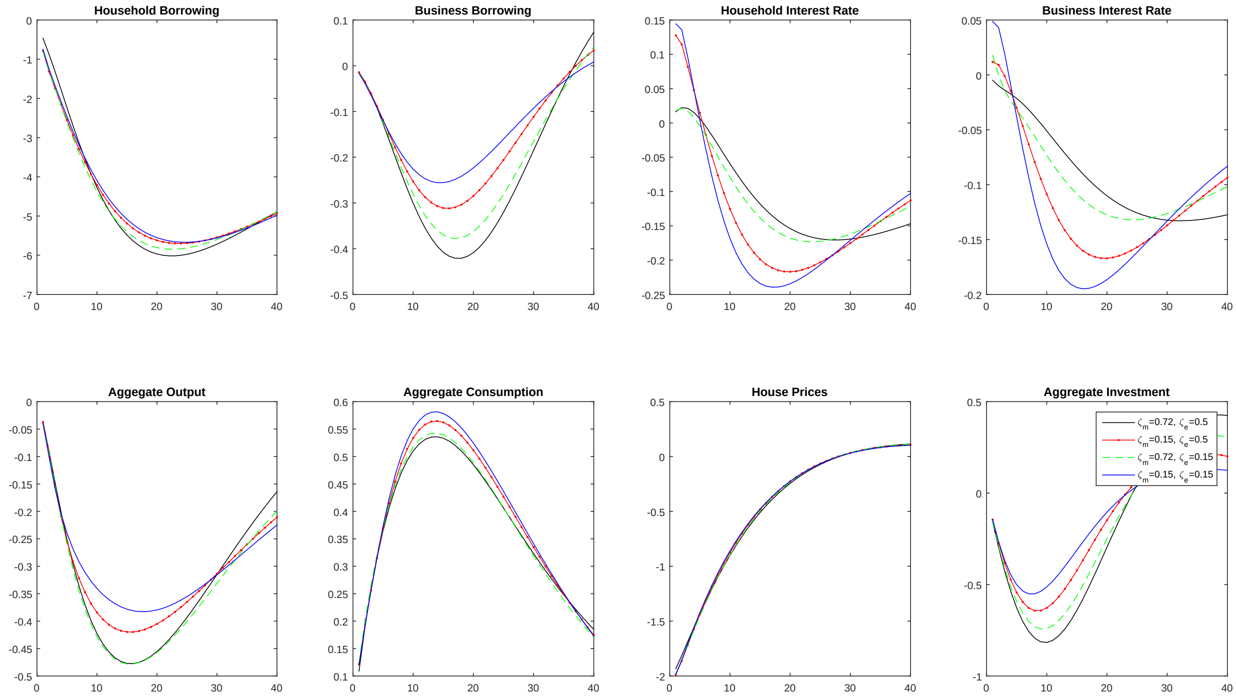


Figure 9: Negative Capital Price Expectation Shock

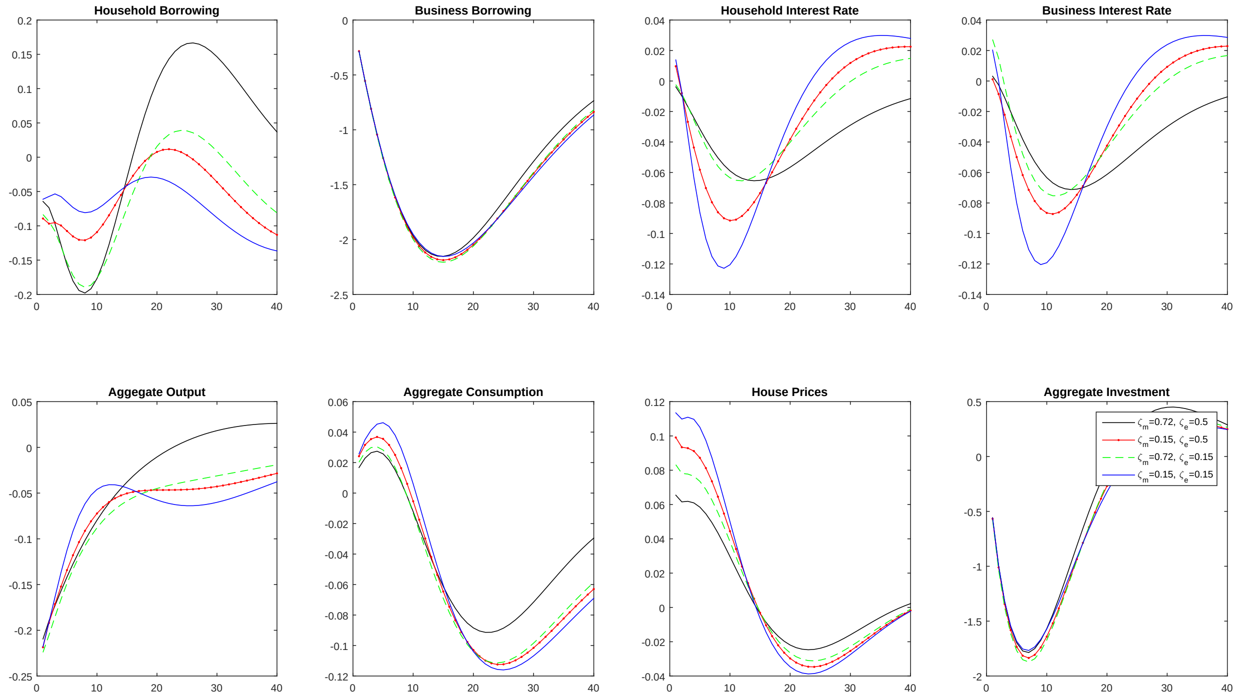


Figure 10: Negative Bank Capital Shock

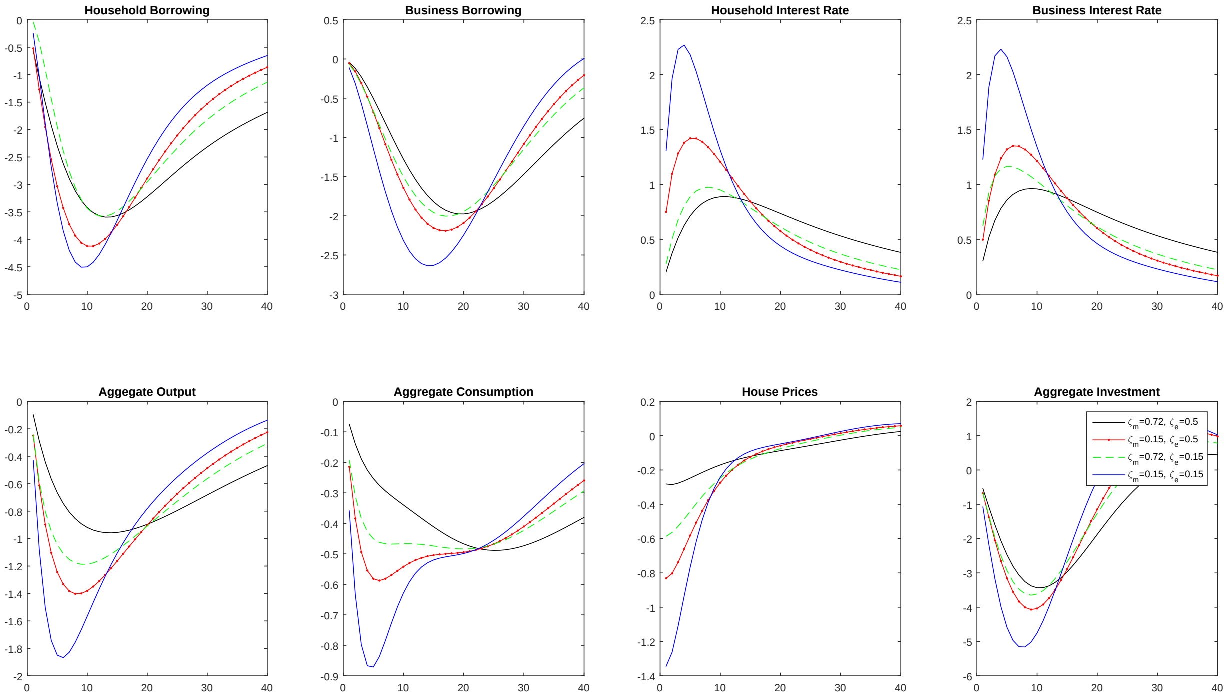


Figure 11: Negative Housing LTV Shock

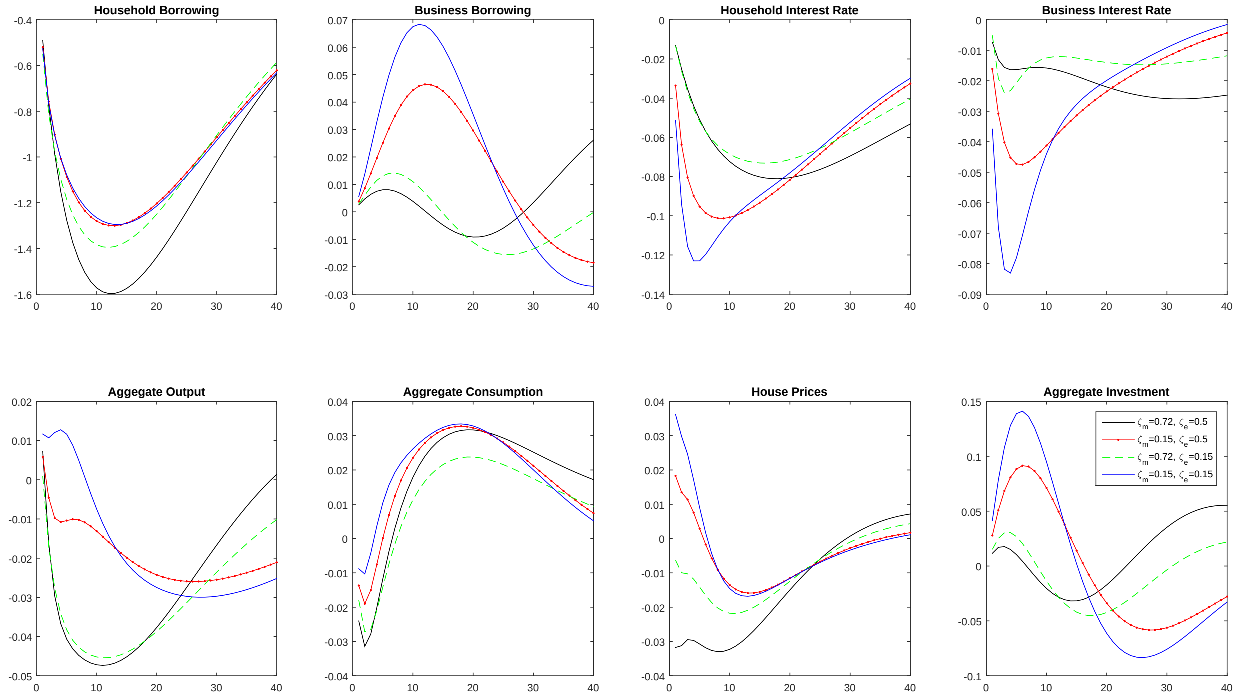
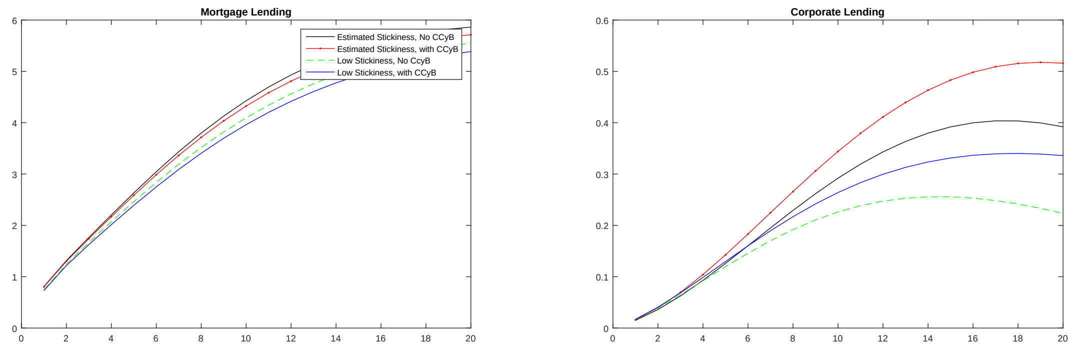
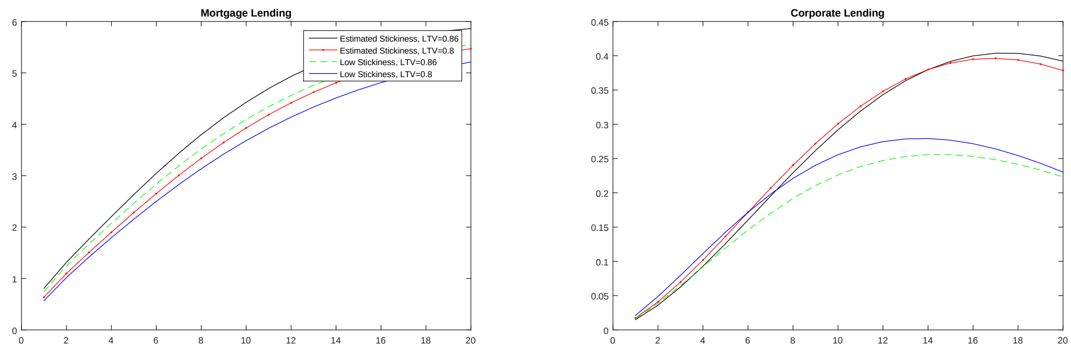


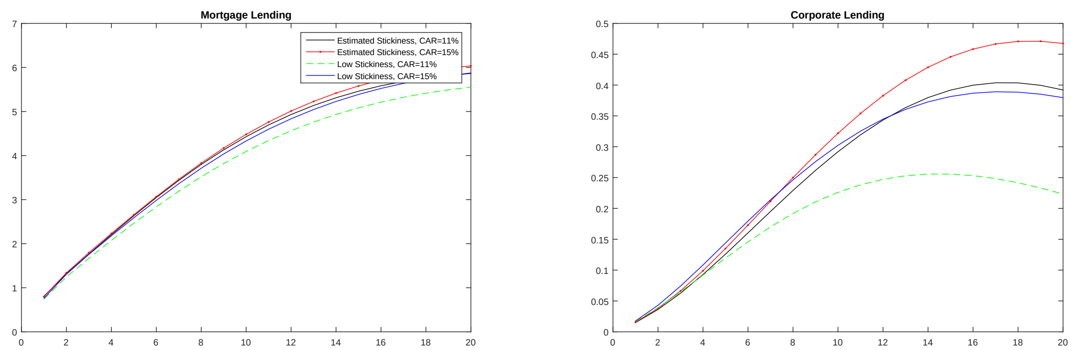
Figure 12: Positive housing depreciation shock. Cumulative difference calculated as the



(a) Cumulative differences: 0.45 % and -0.21 %.

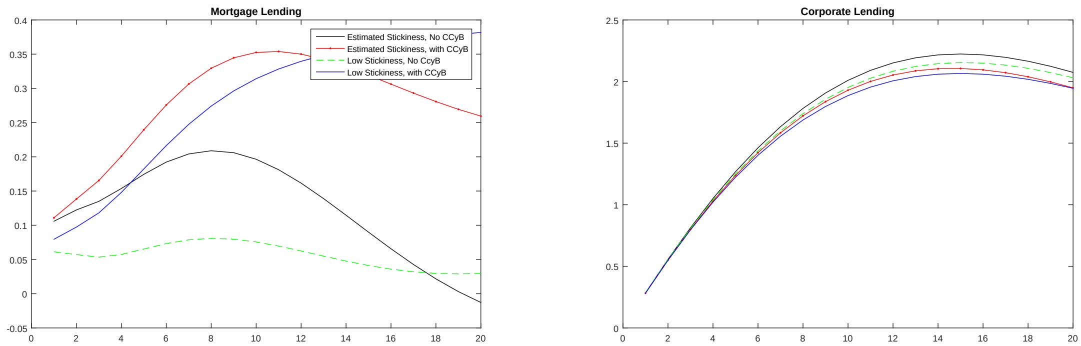


(b) Cumulative differences: -1.18 % and 0.25 %.

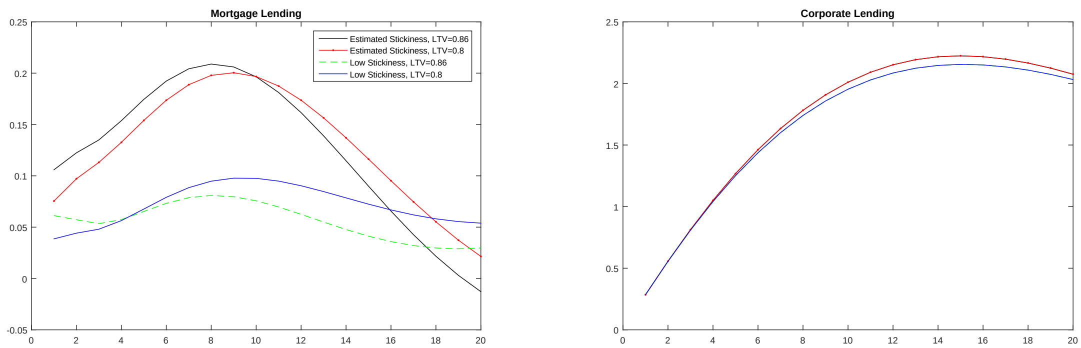


(c) Cumulative differences: 2.85 % and 0.91 %.

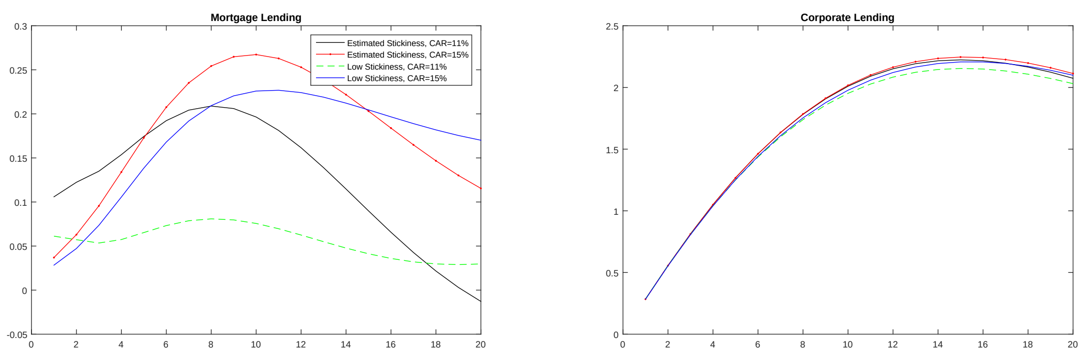
Figure 13: Positive capital depreciation shock. Cumulative difference calculated as the



(a) Cumulative differences: 1.4 % and -0.34 %.

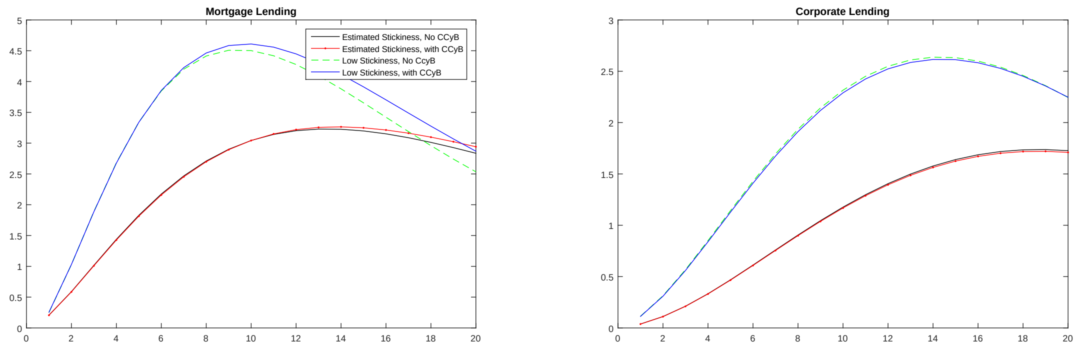


(b) Cumulative differences: -0.02 % and 0.003 %.

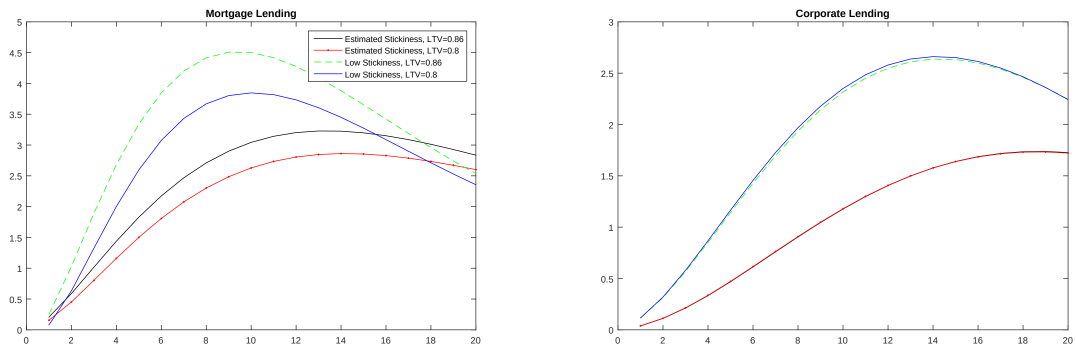


(c) Cumulative differences: 0.85 % and 0.34 %.

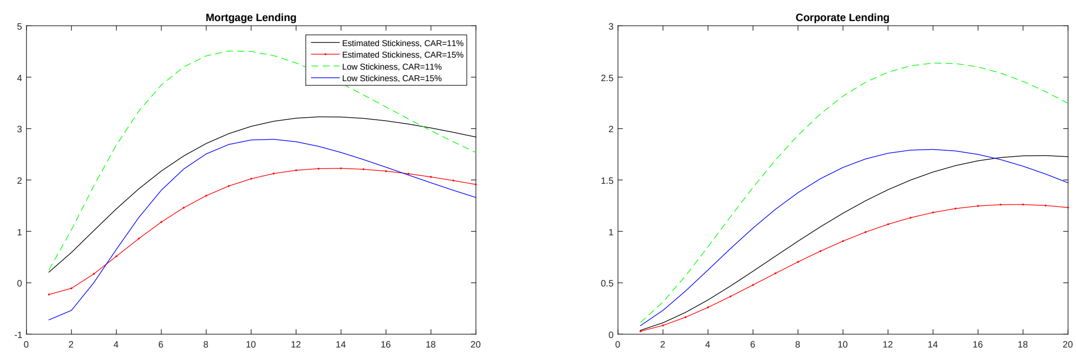
Figure 14: Negative bank capital shock.



(a) Cumulative differences: 2.2 % and 0.128 %.



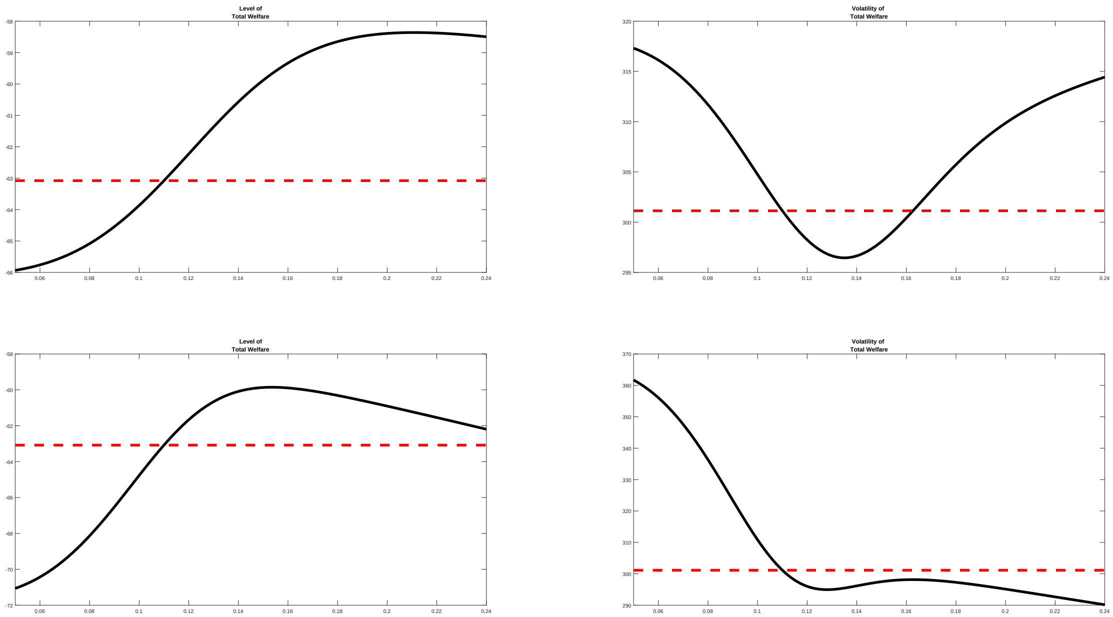
(b) Cumulative differences: 3.62 % and 0.33 %.



(c) Cumulative differences: 11.59 % and 6.25 %.

Macroprudential Policy & Steady State

Figure 15: Sectoral capital requirements on mortgage lending with a baseline of 11 %. Welfare maximizing value is 20.7 % with a weight of 0 on volatility. It decreases to 17.6 % with a weight of 0.1 on the volatility. **Welfare improvement: 7.47 % and 4.26 % respectively.**



Optimal Minimum & Sectoral Capital Requirements and LTV limit

Objective function:

$$E[W_t] - \omega\sqrt{Var[W_t]}$$

where welfare W_t is defined as a weighted average of patient and impatient households:

$$W_t = \frac{W_t^s C_t^s + W_t^m C_t^m}{C_t^s + C_t^m}$$

Table 4: Maximizing over prudential policy parameters, one at a time.

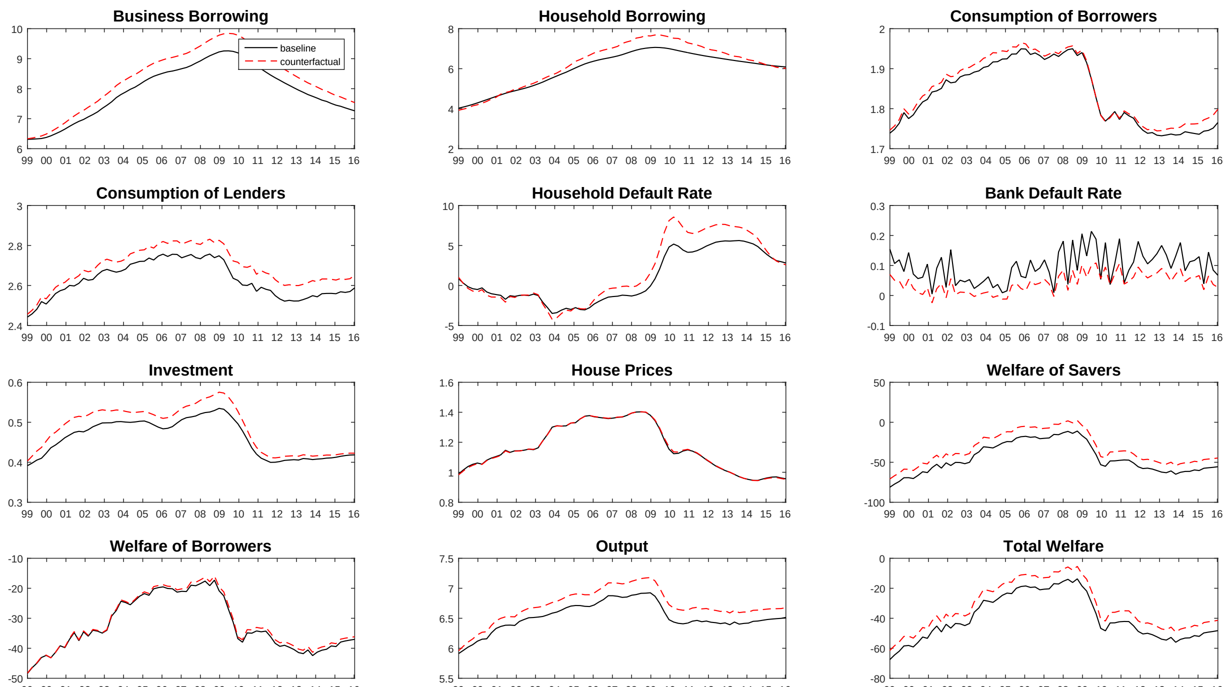
	ω	0	0.1
Parameter			
LTV		89.4 % (0.014 %)	86.6 % (0.001 %)
SCR-Mortgage		20.7 % (7.47 %)	17.6 % (4.26 %)
SCR-Corporate		15.5 % (3.33 %)	16.7 % (3.22 %)
CAR		15.5 % (5.11 %)	14.5 % (3.82 %)
CCyB		0 % (0 %)	Max. attainable

Table 5: Maximizing over SCRs and LTV at the same time

	ω	0	0.1
Parameter			
LTV		91.25 %	94.06 %
SCR-Mortgage		21.25 %	15.88 %
SCR-Corporate		5(Min. attainable) %	12.50 %
Welfare Improvement		8.01 %	4.8 %

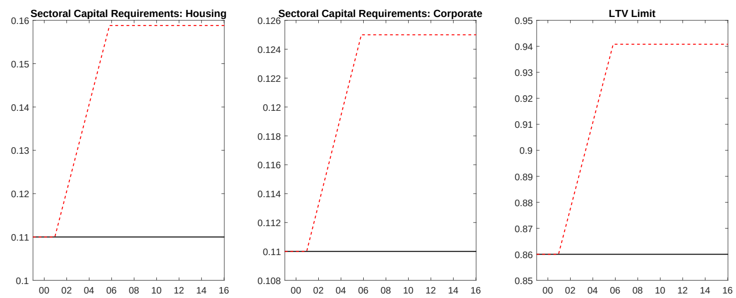
Counterfactuals

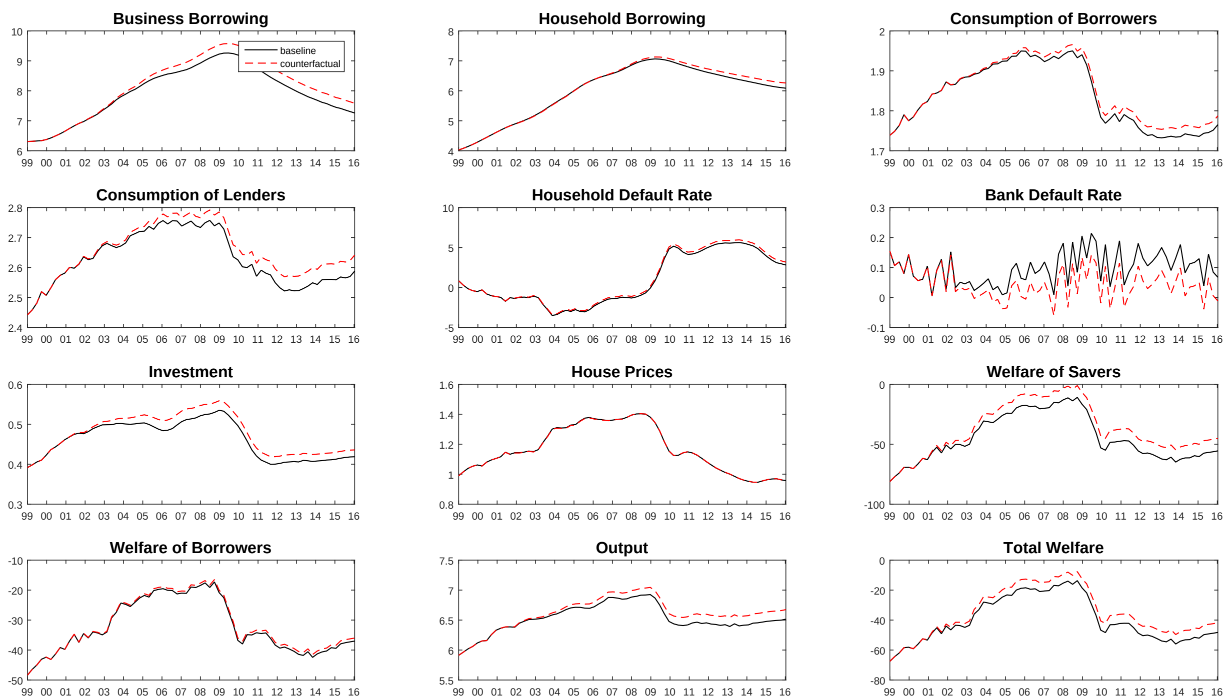
Figure 16: Counterfactual I: using optimized values with 0.1 weight on volatility. $\phi_H = 15.8\%, \phi_F = 12.5\%, \epsilon_H = 94\%$.



Variable	% Change in Level	% Change in Volatility
Corporate Credit	0.049	0.15
Mortgage Credit	0.042	0.23
Output	0.028	0.157
Household Welfare	0.176	0.035

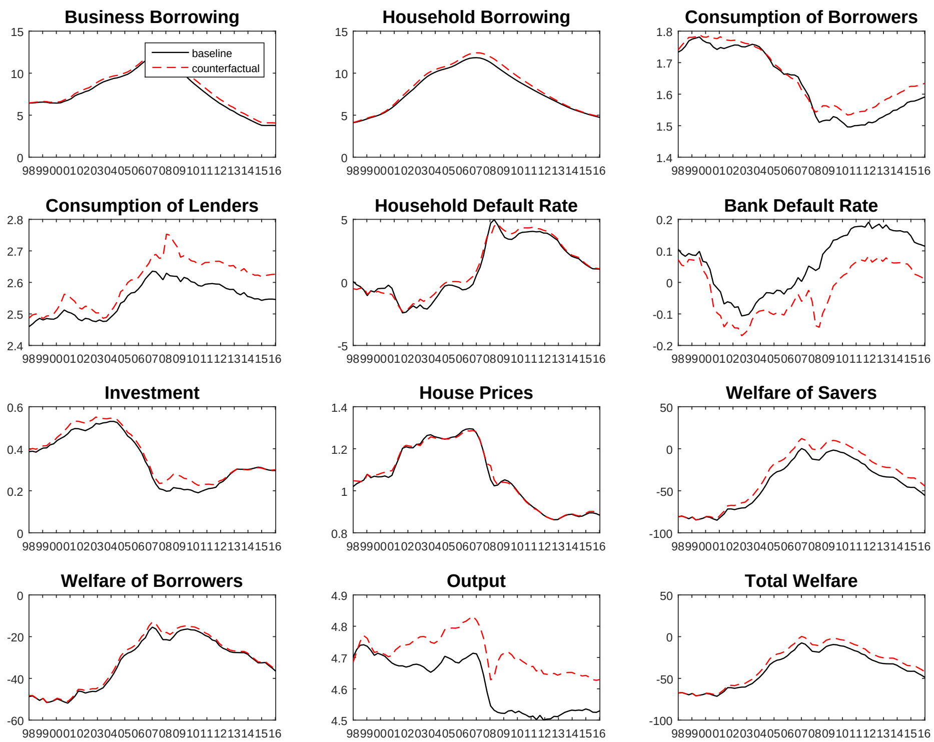
Figure 17: Same counterfactual phased-in over a 5-year period over 2001-2006 in equal increments.





Variable	% Change in Level	% Change in Volatility
Corporate Credit	0.024	0.11
Mortgage Credit	0.008	0.04
Output	0.013	0.107
Household Welfare	0.114	0.073

Figure 18: Same counterfactual as above, without interest rate stickiness.



Variable	% Change in Level	% Change in Volatility
Corporate Credit	0.041	0.003
Mortgage Credit	0.029	0.066
Output	0.02	-0.29
Household Welfare	0.12	0.1

Table 6: Does CCyB improve things when optimal SCRs are in place?

Variable	% Change in Level	% Change in Volatility
Baseline optimal SCR+LTV		
Corporate Credit	0.024	0.11
Mortgage Credit	0.008	0.04
Output	0.013	0.107
Household Welfare	0.114	0.073
CCyB 2.5 %, both sectors		
Corporate Credit	0.073	0.273
Mortgage Credit	0.005	0.097
Output	0.039	0.275
Household Welfare	0.194	0.059
CCyB 2.5 %, mortgages		
Corporate Credit	0.032	0.045
Mortgage Credit	0.081	0.397
Output	0.027	0.134
Household Welfare	0.191	0.047
CCyB 2.5 %, corporate		
Corporate Credit	0.058	0.17
Mortgage Credit	0.044	0.26
Output	0.041	0.266
Household Welfare	0.21	0.075

Table 7: Does CcyB improve things when SCRs are at their baseline value?

Variable	% Change in Level	% Change in Volatility
Baseline SCR+LTV		
Corporate Credit	0.024	0.11
Mortgage Credit	0.008	0.04
Output	0.013	0.107
Household Welfare	0.114	0.073
No Interest Stickiness		
Corporate Credit	0.019	0.059
Mortgage Credit	0.047	0.188
Output	0.015	0.10
Household Welfare	0.071	0.059

5 Conclusion (old version)

In this paper, we provide cross country evidence of interest rate sluggishness due to fixed interest rate loan contract. The response of fixed term interest rates is lower as compared to the floating interest rate term. Moreover,the immediate impact on lending rates is small even for floating interest loans. The interest rate pass through is complete for the floating rate loans and incomplete for fixed term interest loans, both for the UK as well as the four Euro zone economies.

We use a two sector DSGE model with a crucial role for the banking sector, to 1)evaluate the role of interest rate stickiness in the transmission of macro prudential policy and 2) study the interaction between capital requirement and the LTV limit. We find that sluggishness in the adjustment of interest rates lowers the impact of the capital regulation on the economy.At the same, interest rate stickiness makes the a change in LTV policy more effective. It also increases the volatility of macro economic variables to various shocks. We find that interest rate stickiness dampens the effectiveness of the countercyclical capital policy under different shocks. However countercyclical capital rule is still more effective than the LTV rule.As regards the interaction between the policy tools, we find that the impact of a change in capital requirement is higher when the LTV limit in the economy is high. On the other hand, the change in LTV limit has a higher impact when the capital requirement is lower.

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Cross country evidence on interest rate stickiness

We do a similar econometric exercise for France, Germany, Italy and Spain. We regress the monthly lending rate with 1 to 5 years of initial rate fixation on ECB policy rate and compare this with the regression of interest floating rate loans on ECB policy rate. We use the data from ECB Statistical Data warehouse.For the fixed rate loans, we use effective interest rate data for loans to corporations with an initial rate fixation period of over one to five years. For the floating rate loans, we use effective interest rate data for loans to corporations of (over EUR 1M) and an initial rate fixation period of up to one year.

We find similar results for the Eurozone countries. The response of the lending rate on impact (i.e. during the same month) is very small. In case of variable interest rate loans,the bulk of adjustment takes place in the following period, whereas the adjustment in fixed rate loans is reflected over a longer period.

Table 8: Regression of 1 to 5 year lending rate on ECB policy rate

Regressor	France	Germany	Italy	Spain
ß$_t$	0.054***	0.015***	0.014**	0.0027
Δ ß$_{t-1}$	0.257***	0.246***	0.258***	0.151**
Δ ß$_{t-2}$	0.316***	-0.009	0.124***	0.215**
Δ ß$_{t-3}$	0.294***	0.134***	0.17***	0.203**
Δ ß$_{t-4}$	-0.249*	-0.04	-0.119**	-0.049
Δ ß$_{t-5}$	0.366***	0.033	-0.09	-0.047**
constant	0.105***	0.035***	0.046**	0.014

Table 9: Regression of floating year lending rate on ECB policy rate

Regressor	France	Germany	Italy	Spain
$ß_t$	0.0729***	0.137***	0.034**	0.045**
Δ $ß_{t-1}$	0.766***	0.481***	0.597***	0.670**
Δ $ß_{t-2}$	- 0.009	0.389***	0.251***	0.203
Δ $ß_{t-3}$	0.577***	0.1915	0.284***	0.466**
Δ $ß_{t-4}$	-0.07	-0.157	0.049	-0.333*
Δ $ß_{t-5}$	0.09	0.017	0.0165	-0.0165
constant	0.139***	0.158***	0.08**	0.153**

The above table shows that the interest rate pass through in France.In response to 1 percentage point change in policy rate, there is less than 0.05 percentage point change in the fixed term lending rate on impact. Around 0.25 percentage point change in interest rate is passed through during the following month and around 0.3 percentage point change is passed through during the third and fourth months after the policy rate change.

For the floating interest rate loans, the response on impact is also low. However,around 76 percent of the pass through takes place in the following month and there is a complete pass through by the end of four months.

The above table shows that the interest rate pass through in Germany.In response to 1 percentage point change in policy rate, there is less than 0.015 percentage point change in the fixed term lending rate on impact. Around 0.25 percentage point change in interest rate is passed through during the following month and around 0.13 percentage point change is passed through during the fourth month after the policy rate change.

For the floating interest rate loans, the response on impact is also low. However,around 48 percent of the pass through takes place in the following month and there is a complete pass through by the end of four months.

The above table shows that the interest rate pass through in Italy.In response to 1 percentage point change in policy rate, there is less than 0.015 percentage point change in the fixed term lending rate on impact. Around around 0.26 percentage point change in interest rate is passed through during the following month and around 0.12 and 0.17 percentage point change is passed through during the third month and fourth months after the policy rate change.

For the floating interest rate loans, the response on impact is also low. However,around 60 percent of the pass through takes place in the following month and there is a complete pass through by the end of four months.

The above table shows that the interest rate pass through in Spain.In response to 1 percentage point change in policy rate, there is less than 0.01 percentage point change in the fixed term lending rate on impact. Only around 0.15 percentage point change in interest rate is passed through during the following month and around 0.2 change is passed through during the third month and fourth months after the policy rate change

For the floating interest rate loans, the response on impact is also low. However,around 67 percent of the pass through takes place in the following month and there is a complete pass through by the end of four months.

To sum up,there is a clear pattern which emerges for all the four Eurozone economies.The response of fixed term lending rates on impact is very low.Around 25 per cent of the pass through takes place in the following period and around 20 to 30 per cent of the pass through takes place in the third and fourth months. Overall, the pass through of interest rate for fixed term loans is incomplete as observed in the UK data.

For the floating interest rate loans, the on impact is also low. However,around 50 to 70 percent of the pass through takes place in the following month and there is a complete pass through by the end of four months.

On the whole, we find that interest rate pass through is fastest in France as compared to Germany where it is the slowest among the four Eurozone economies.

Posterior distributions of all estimated parameters

Figure 19: Posterior Parameter Distributions

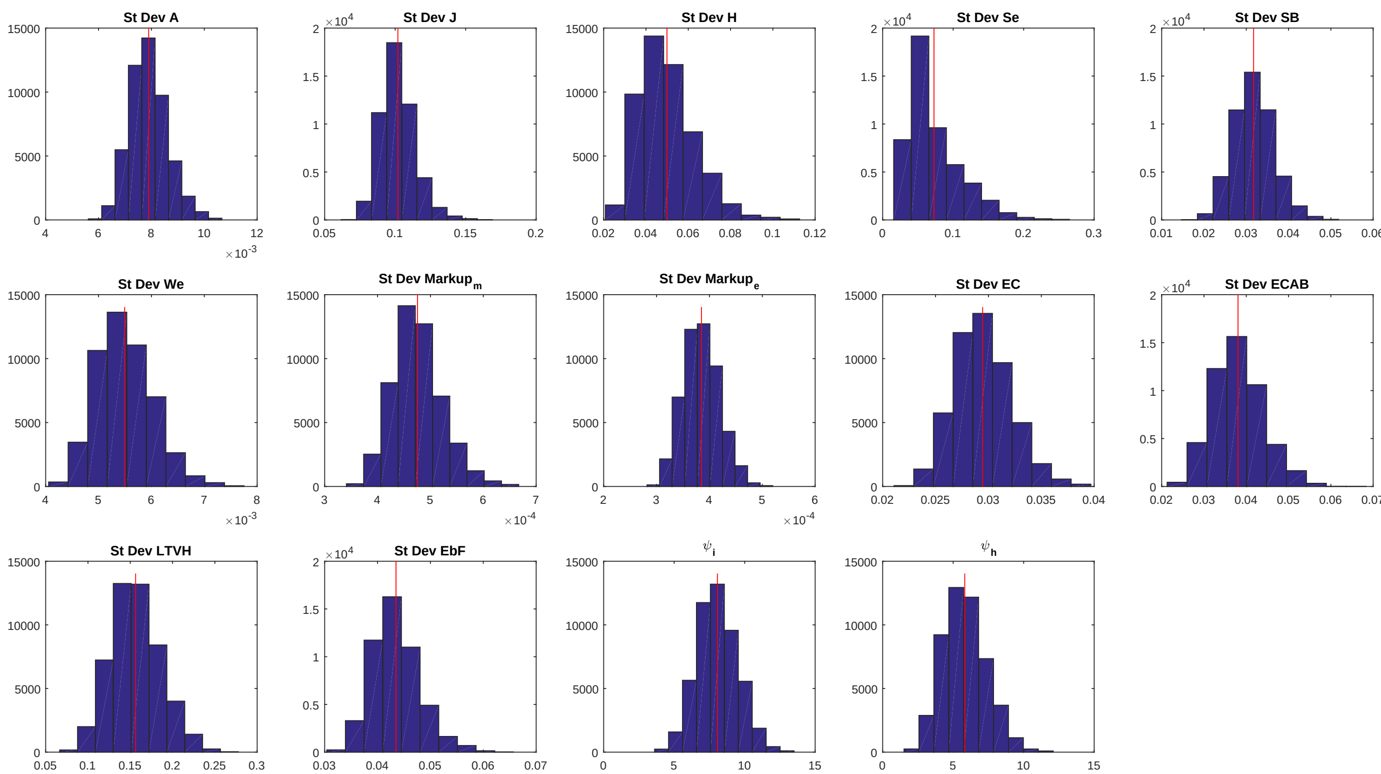
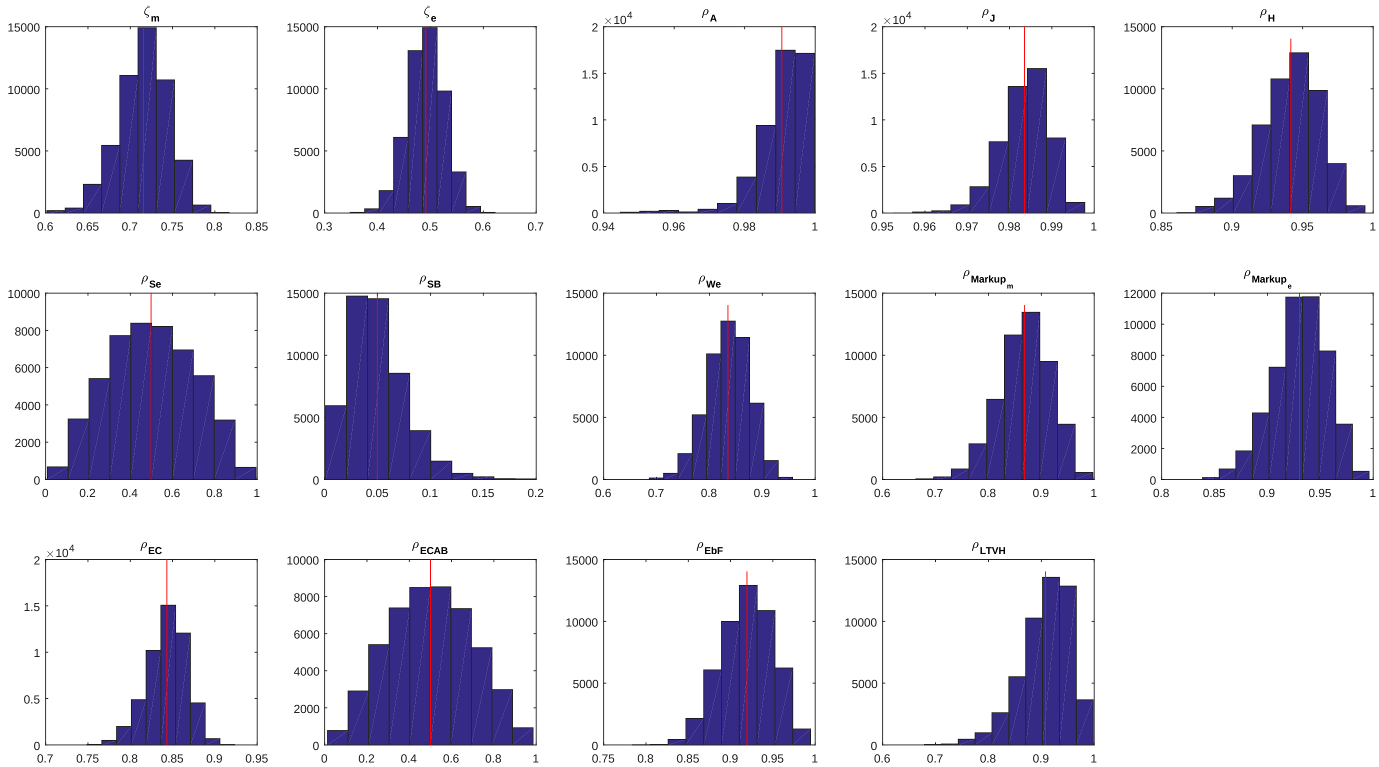


Figure 20: Posterior Parameter Distributions



Model overview

This is a infinite time horizon model with patient and impatient households.The other key agents in the model are entrepreneurs, banks,deposit insurance agency, final/investment/housing goods producers.

Households

There are two types of households, patient and impatient, with patient households having a higher discount factor as in Iacoviello (2015).Both patient and impatient households have concave utility functions and derive utility from consuming goods, housing and leisure. The individual households are a part of a representative dynasty,which provides perfect risk sharing within the group. Thus, all individual households within the type are identical.Even if the individuals face idiosyncratic shocks, they are perfectly insured within their dynasty and hence consume and save/borrow identically.Both households supply labour in a competitive labour market.

Patient households

In equilibrium, patient households are savers who hold deposit with banks and buy houses with their own funds.

The objective function of the patient households (as is the case with impatient households) includes utility from consumption goods and housing and dis utility from labour.

$$\max_{c_t^s, L_t^s, D_t, H_t^s} E_t \sum_{t=0}^{\infty} \beta_s^t [log(c_t^s) + vlog(H_t^s) - \frac{(L_t^s)^{1+\eta}}{1+\eta}] \tag{.1}$$

This is subject to the following budget constraint:

$$c_t^s + q_t^H H_t^s + D_t = w_t L_t^s + q_t^H H_{t-1}^s (1-\delta) + D_{t-1} R_t^D + \pi_t \tag{.2}$$

The term π_t includes profits of final goods producing firms and investment/housing production firms (which are owned by patient households), dividends from entrepreneurs and lumpsum transfers from deposit insurance agency.

The FOCs for deposit and Housing stock is given by:

$$U'(c_t^s) = \beta_s E_t[U'(c_{t+1}^s) R_{Dt}] \tag{.3}$$

$$U'(c_t^s) q^H = E_t[\beta_s U'(H_{t+1}^s) + \beta_s U'(c_{t+1}^s)(1-\delta) q_{t+1}^H]; \tag{.4}$$

Impatient households

Impatient households borrow from banks using their houses as collateral as in Bernanke, Gertler & Gilchrist (1999) . These mortgage loans are made on a limited liability non-recourse basis, implying that individual households default whenever the value of the house is lower than the outstanding mortgage loans.The value of the house depends both on aggregate shocks (which affect house prices) as well as an idiosyncratic shock which determines whether an individual borrower defaults. In equilibrium, borrowers with an idiosyncratic shock below a certain threshold default.In the case of default, the bank takes possession of the houses in which case it is subject to state verification costs.

The borrowing is subject to LTV (Loan to value) limit set by the regulator. It is similar to a borrowing/collateral constraint as in Kiyotaki & Moore (1997).

The objective function of the impatient households is the same as that of the patient households except for the discounting factor:

$$\max_{c_t^m, B_t^m, L_t, H_t^m} E_t \sum_{t=0}^{\infty} \beta_m^t [log(c_t^m) + vlog(H_t^m) - \frac{(L_t^m)^{1+\eta}}{1+\eta}] \tag{.5}$$

The budget constraint of impatient households reflects their borrowings under limited liability:

$$c_t^m + q_t^H H_t^m - B_t^m = w_t L_t^m + \int_{\bar{\omega_t^m}}^{\infty} \left(\omega_t^m q_t^H H_{t-1}^m (1-\delta) B_{t-1}^m R_{t-1}\right) \, dF\omega_t^m + P_t \tag{.6}$$

The term under the integral reflects the limited liability of the borrowers as they default on their loans when the idiosyncratic shock ω_t^m is below the threshold level of $\bar{\omega^m}_t$.

The default decision by the borrowers is given by:

$$\omega_t^m q_t^H H_{t-1}^m (1-\delta) <= B_{t-1}^m R_{t-1}^m \tag{.7}$$

The threshold level of $\bar{\omega^m}_t$ satisfies:

$$\bar{\omega^m}_t q_t^H H_{t-1}^m (1-\delta) = B_{t-1}^m R_{t-1}^m \tag{.8}$$

The LTV limit (or the borrowing constraint) is given by:

$$[B_t^m - (1-rp)B_{t-1}^m]R_t <= \epsilon_t E_t[q_{t+1}^H [H_t^m - H_{t-1}^m (1-\delta)]] \tag{.9}$$

where rp is the loan repayment rate and ϵ_t is the LTV limit.

The limit always binds in the steady state and it's neighborhood.

The FOCs for Mortgage loans and Housing stock is given by:

$$E_t U'(c_t^s) - \beta_m U'(c_{t+1}^s)(R_t^m(1-def_{t+1})) - \lambda_t R_t^m + \lambda_{t+1}(1-rp)(1-def_{t+1})R_{t+1}^m = 0 \tag{.10}$$

$$E_t U'(c_t^s) q^H = \beta_m U'(H_{t+1}^s) + \beta_s U'(c_{t+1}^s)(1-Gm_{t+1})(1-\delta)q_{t+1}^H + \lambda_t(\epsilon_t q_{t+1}^H) - \lambda_{t+1}(\epsilon_{t+1} q_{t+2}^H)(1-\delta) \tag{.11}$$

where def is the probability of default and the function Gm() represents the proportion of housing stock taken over by the bank for defaulted loans.λ_t is the lagrange multiplier on the LTV constraint.

Entrepreneurs

Entrepreneurs are risk neutral agents who own and maintain the stock of physical capital. They rent capital to the final goods producing firms. Entrepreneurs derive utility from transferring part of their wealth to the saving dynasty (paying dividends) and retaining the rest for the next period (retained earnings). Entrepreneurs invest in capital goods and finance their investment by means of their own funds (net worth) and borrowings from banks. Similar to mortgage loans, these are limited liability non-recourse loans and hence subject to default by individual entrepreneurs in the event of value of assets falling below the outstanding loans.The value of the capital depends both on aggregate shocks (which affect house prices) as well as an idiosyncratic shock which determines whether an individual entrepreneur defaults. In equilibrium, borrowers with an idiosyncratic shock below a certain threshold default. As in the case of households, assets are seized by banks and subject to costly state verification costs.

$$\max_{K_t, B_t^e} E_t(W_{t+1}^e) \tag{.12}$$

$$W_{t+1}^e = max[\omega_{t+1}^e (r_{t+1}^k + (1-\delta)q_{t+1}^K K_t) - R_t^F b_t^e, 0] \tag{.13}$$

The default decision of the entrepreneurs is given by:

$$\omega_t^e q_t^H K_{t-1}(1-\delta) <= K_{t-1} R_{t-1}^f \tag{.14}$$

The threshold level of $\bar{\omega^m}_t$ satisfies:

$$\bar{\omega^e}_t q_t^K K_{t-1}^m (1-\delta) = B_{t-1}^e R_{t-1}^f \tag{.15}$$

As borrowing is subject to LTV limit as follows:

$$[B_t^e - B_{t-1}^e(1-rp)]R_t^f = \epsilon_t E_t[q_{t+1}^F[K_t - K_{t-1}(1-\delta)]] \tag{.16}$$

Dividend rule:

A fixed proportion of wealth χ^e is paid out as dividends. This simple dividend paying rule for the entrepreneurs is given by:

$$c_t^e = \chi^e W_t^e \tag{.17}$$

As a result the retained earnings by the entrepreneurs is given by:

$$n_t^e = (1-\chi^e)W_t^e \tag{.18}$$

The balance sheet identity of the entrepreneurs is :

$$n_t^e + B_t^e = q_t^K K_t \tag{.19}$$

Banks

Banks are financial intermediaries who channel savings from the savers to the borrowers.On the asset side of the banks, there are loans to households (mortgage lending) and entrepreneurs (business lending) respectively. As described earlier, these loans may default depending on aggregate state shocks and idiosyncratic borrower shocks in which case the banks seize the assets subject to state verification costs (these can also be viewed as bankruptcy costs).

On the liability side, there are deposits held by the patient households and equity capital held by the bankers. Deposits are insured by the Deposit Insurance agency. There is a capital adequacy requirement set by the regulator which along with a penalty cost function, which determines the amount of equity capital held by the bankers.

The key feature of the model is that banks may also default depending upon the performance of their loan portfolios (aggregate shocks) and idiosyncratic shocks (on similar lines as the borrowers). The banks face an idiosyncratic shock to their returns on loans.Thus, in equilibrium, a fraction of banks below a certain threshold of the idiosyncratic shock level default. In case of default, the bank loan assets are also subject to possession by the deposit insurance agency and costly state verification.

The banks' balance sheet identity is as follows:

$$n_t^b + D_t = B_t^m + B_t^e \tag{.20}$$

The maximization problem of the bank is given by:

$$\max_{R_t^{mi}, R_t^{fi}} E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t [\{(1-G_{t+1}^H)(\widetilde{R_t^{mi}})(B_t^{mi}) + (1-G_{t+1}^F)\widetilde{R_t^{fi}} B_t^{ei}\} - (1-bankdef.prob)R_t^D D_t + Penaltycost] \tag{.21}$$

$$\widetilde{R_t^{mi}} = (1-def.prob^m)R_t^{mi} + G_{t+1}^m(1-\mu^m)(R_t^{mi}/\bar{\omega}_{t+1}^m) \tag{.22}$$

$$\widetilde{R_t^{fi}} = (1 - def.prob^e)R_t^{fi} + G_{t+1}^e(1-\mu^e)(R_t^{fi}/\bar{\omega}_{t+1}^e) \qquad (.23)$$

The demand for Loans is given by:

$$B_t^{mi} = (\frac{R_t^{mi}}{R_t^m})^{-\tau} B_t^m \qquad (.24)$$

$$B_t^{ei} = (\frac{R_t^{fi}}{R_t^f})^{-\tau} B_t^e \qquad (.25)$$

Rmi/Rfi is the rate if interest charged by individual bank,τ is the elasticity of substitution between banks and determines their market power. μ is the proportion of state verification/bankruptcy costs.

Penalty cost function

Penalty costs are modeled as a non pecuniary gain in utility if the capital adequacy ratio is higher than the minimum capital requirement and a non pecuniary cost if the capital adequacy ratio is lower than the minimum capital requirement.

$$Penaltycost_t = \nu^b \frac{[\frac{\phi_t^b}{\bar{\varphi}_t}]^{1-\sigma} - 1}{1-\sigma} \qquad (.26)$$

The above functional form,based on Nukhwoon & Tsomocos (2018) builds in a non-linearity in the penalty costs.The marginal gains of having excess capital are decreasing whereas the marginal costs of having a shortfall in capital are increasing, whenever σ is greater than 1. This creates an incentive for banks to maintain capital at a higher level as compared to the minimum regulatory requirement. In reality, we find that banks do maintain capital buffer over what is the minimum required.The parameter ν^b determines the weight attached to this penalty costs.

Interest rate stickiness

Although, interest rate stickiness can be attributed to various reasons such as switching costs,menu costs, market structure, regulation etc.,we find the one of the main sources of interest rate sluggishness is the existence of fixed interest loans.

We introduce interest rate stickiness in a broader sense by modeling it as in Calvo (1983). This approach also has the benefit that it includes all possible sources of interest rate sluggishness in a reduced form (including the effect of long term fixed interest loans).It is assumed that only a ξ proportion of banks are able to change their interest rates in a given period, whereas the remaining 1-ξ proportion of banks are not able to change their interest rate. This staggered interest rate setting implies that the composite interest rate in the economy is an average of the current interest rate charged by the fraction of banks who can change the interest rate and the previous period interest rate. To micro-found the staggered interest rate setting, we assume that there is imperfect competition in the banking sector. Banks offer differentiated loan products as in Gerali et al (2010) and are able to set their interest rate in the monopolistically competitive loan market.The borrowers takes a composite loan product comprising of all the aforesaid differentiated banking services.The composite interest rate paid by the borrowers is thus staggered on account of the Calco friction.In short,we extend the New Keynesian approach to goods market to the loan markets so as to generate interest rate stickiness.

The FOCs for the interest rates are as follows.The FOC is similar to the FOC for price in a standard New Keynesian model with goods price stickiness:

$$R_t^{mi} = \frac{\tau}{\tau - 1} \frac{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t MC_t}{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t rm_t} \tag{.27}$$

$$R_t^{fi} = \frac{\tau}{\tau - 1} \frac{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t MC_t}{E_t \sum_{t=0}^{\infty} \xi^t \beta_s^t rf_t} \tag{.28}$$

$$MC_t = \lambda_{st+1}[(1 - bankdef.prob)((1 - \phi_t))R_{Dt} + \frac{\nu^b(\phi_t/\varphi_t)^{(1-\sigma)}}{(B_t^{mi} + B_t^{ei})}](R_t^m)^\tau B_t^m \tag{.29}$$

As in the New Keynesian model with price stickiness, the interest rate charged by banks is a function of present discounted value (with the stickiness parameter) of present and future marginal cost times the mark up. The marginal cost includes the interest rate paid on deposits (in a competitive deposit market) and the penalty cost associated with the deviation from the regulatory capital requirement. The only difference from the standard New Keynesian version is the presence of borrower and bank defaults in the interest FOC for interest rate equation

Deposit Insurance Agency

The deposit insurance agency insures the deposits. The assets of the defaulting banks are taken over by the agency and is subject to bankruptcy costs.The difference between the amount of deposits and the value of assets realized assets is recovered by the charging a lumpsum tax on households.

Final goods producing Firms

There is a unit mass of perfectly competitive firms which combine capital and labour to produce the consumption good which is the numeraire.The firms rent capital from entrepreneurs. The firms are owned by patient households. They produce the final goods using a standard Cobb Douglas technology.

$$Y_t = A_t K_{t-1}^{\alpha} L_t^{1-\alpha} \tag{.30}$$

Capital goods and Housing production

These are competitive firms which buy finished goods and produce capital goods /housing subject to quadratic adjustment costs.These firms produce new units of capital and housing using consumption goods which are then sold to entrepreneurs and households,respectively, at prices qK and qH. They represent the supply side of the capital goods/housing and pin down the equilibrium asset prices.These firms are also owned by the patient households.

They maximize their profits as follows:

$$\max_{I_t} E_t \sum_{i=0}^{\infty} \beta_s^t \{\frac{c_t^s}{c_{t+1}^s}\}[q_{t+i}^K I_{t+i} - \{1 + g[\frac{I_{t+i}}{I_{t+i-1}}]\}] \tag{.31}$$

$$\max_{I_t^H} E_t \sum_{i=0}^{\infty} \beta_s^t \{\frac{c_t^s}{c_{t+1}^s}\}[q_{t+i}^H I_{t+i} - \{1 + g[\frac{I_{t+i}^H}{I_{t+i-1}^H}]\}] \qquad (.32)$$

Macro Prudential Policy

The Macro Prudential policy pursued by the regulator includes a minimum capital requirement (also known as capital adequacy ratio) for the banks and a maximum loan to value ratio (LTV) for the borrowers. The regulator also sets a countercyclical capital rule which responds to the credit growth in the economy.

$$CR_t = \bar{CR} + \psi^{cr} log(B_t/\bar{B}) \qquad (.33)$$

The first part of the rule is the static minimum capital requirement which the banks are supposed to hold at any point of time. The second part is the counter cyclical component,which tracks the credit growth in the economy.

On similar lines,following is the rule for the LTV limit:

$$LTV_t = L\bar{T}V - \psi^{LTV} log(B_t/\bar{B}) \qquad (.34)$$