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Asymmetric Macro-Financial Spillovers

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Abstract

The 2008 financial crisis has shown that financial busts can influence the real economy. However, there is less evidence to suggest that the same holds for financial booms. Using a Markov-Switching vector autoregressive model and euro area data, I show that financial booms tend to be less procyclical than financial busts. To identify the sources of asymmetry, I estimate a non-linear DSGE model with a heterogeneous banking sector and an occasionally binding borrowing constraint. The model matches the key features of the data and shows that the borrowers' balance sheet channel accounts for the asymmetry in the macro-financial linkages. The muted macro-financial transmission during financial booms can be exploited for macroprudential policies. By comparing capital buffer rules with monetary policy 'leaning-against-the-wind' rules, I find that countercyclical capital buffers improve welfare.

JEL Code: E44, E58, E52

Keywords: Macro-financial linkages, non-linearities, Markov-Switching VAR, credit channel, occasionally binding constraints, DSGE, macroprudential policy, leaning-against-the-wind policy

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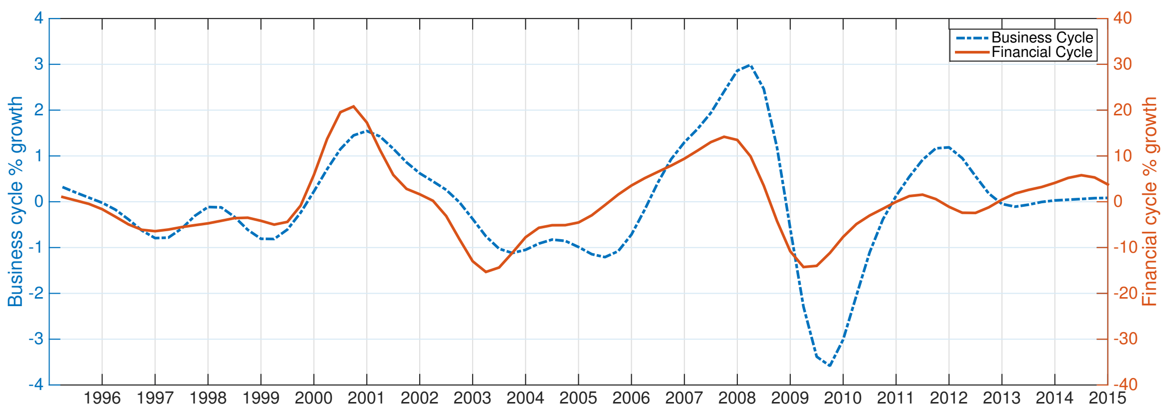
1 Introduction

It is commonly assumed that financial cycles are procyclical and accelerate business cycle fluctuations (see e.g. Borio, 2014). It is more disputed whether the relationship between financial and real cycles is symmetric. Symmetry would imply that financial booms strengthen business cycle booms to the same extent as financial busts intensify recessions. While the financial crisis in 2008 has shown that a downturn in the financial sector can cause a long and deep recession, there is growing evidence to suggest that financial sector upturns do not reinforce business cycle booms in the same way (see e.g. Del Negro and Schorfheide, 2013 and Lindé et al., 2016).

The nature of the procyclicality is particularly interesting for the euro area, as the financial sector plays a special role for the real economy. Unlike the US, the European financial sector consists mostly of banks, and corporate debt financing is largely conducted via bank loans rather than debt securities. This creates a strong feedback loop between the banking sector and the real economy.[1] The financial sector adds on average only 5% of gross value added to the GDP of the euro area. Despite this seemingly small contribution, the dynamics of both the business and financial cycles are very similar. As shown in Figure 1, which displays cyclical and financial indicators that are constructed from GDP and asset price data[2], the turning points in the business and financial cycles are strongly correlated. Furthermore, in agreement with Jordà (2014); Borio (2014), financial cycles tend to lead business cycles and are more volatile. Also note that while the overall correlation between the two cycles is positive and large with a correlation coefficient of 0.77, the positive correlation for booms disappears after 2010 indicating that the procyclicality might indeed be asymmetric.

Figure 1: The financial and business cycle in the euro area



Note: The blue, dashed line indicates the business cycle, and the red, solid line shows the financial cycle. I follow Drehmann et al. (2012) and characterise the business and financial cycles using the Band-Pass Filter. The business cycle is constructed on real GDP data, while I use a composite asset price indicator with house prices and equity prices as measures of private financial wealth. Note the different scales on the axes for the business and financial cycle indicators.

In this paper, I explore whether macro-financial linkages are asymmetric and, if so, what generates these asymmetries.

[1]The share of corporate financing in the US is 80% via debt securities and 20% via bank loans, while in the euro area the share is 16% debt securities and 84% bank loans (based on the ECB flow of funds and the FED financial account data).

[2]The financial indicator is similar to Borio et al. (1994). It includes both private property and equity prices for private sector wealth. I use the private property index provided by the ECB, and the Euro Stoxx 50 as a measure for equity. The weights of the two factors are given in the ESA 2010 survey by Table 26 and Table 7, respectively. As in Borio et al. (1994), I assume that the building to land ratio is roughly 2:1.

I contribute to the existing literature in three ways. Firstly, I provide evidence suggesting that financial shocks have an asymmetric effect on real variables. I construct a Bayesian Markov-Switching VAR (MS-VAR) and compare the effects of a positive financial shock in normal times to a negative shock during credit constrained periods using euro area data. Secondly, using a structural model, I explore the reasons behind the asymmetric macro-financial transmission. The model features a heterogeneous banking sector as in Gerali et al. (2010) and an occasionally binding borrowing constraint as in Guerrieri and Iacoviello (2015a). By including a banking sector and occasionally binding borrowing constraints on the side of entrepreneurs, I match the empirical characteristics of the euro area financial sector more closely. Importantly, it also allows me to distinguish between the borrowers' balance sheet channel and the bank balance sheet channel. I use the method of Guerrieri and Iacoviello (2015a) to solve and estimate the non-linear model. Finally, I study whether countercyclical monetary and macroprudential policies could be welfare improving, once the observed non-linearities are accounted for. While studies have shown that these policies can be costly in boom times (see e.g. Adrian and Liang, 2014 and Svensson, 2014), this might not necessarily hold true in a non-linear framework.

I find that the output response to a positive shock in unconstrained times is three times smaller than a negative shock during constrained episodes. The MS-VAR also shows that loans fall significantly during constrained periods, but respond little to a positive shock in normal times. Inflation is mostly unaffected by financial shocks and is independent of the state of the economy. The structural model closely matches the stylised facts, which were detected by the MS-VAR and indicates that the asymmetric transmission of financial shocks is mainly due to the borrowers' balance sheet channel. In addition, I find that countercyclical capital buffers can be welfare improving and more effective in increasing the consumption welfare of households than comparable 'leaning-against-the-wind'-type Taylor rules (LATW).

While the links between the financial sector and the real economy have been closely scrutinised in recent years, there are only a few studies that have looked at non-linearities in the macro-financial relationship.

The first part of this paper is closely related to work by Hubrich et al. (2013) and Hartmann et al. (2015). Both papers explore the relationship between financial shocks and the macroeconomy in the euro area, and find evidence in favour of non-linearities in a regime-switching VAR with a financial stress indicator. In addition to using a larger sample period, my paper differs by allowing the switching to take place based upon the different states of the credit cycle, rather than upon the financial stress regimes. Credit conditions were also used in Calza and Sousa (2006) to determine regimes in a threshold VAR. Using a sample that ends in 2002, they find stronger financial spillover effects for credit cycle downturns than upturns. These effects are shown to be more pronounced in the US than in the euro area.

The structural model is closely linked to Guerrieri and Iacoviello (2015a), which however focuses on housing shocks and household borrowing in the US. In my model, the presence of an explicit banking sector, credit supply friction, and capital creates additional feedback loops between the real economy and the financial sector.[3] The asymmetric role of financial frictions are also investigated in Del Negro and Schorfheide (2013) and Lindé et al. (2016). Whereas the former paper evaluates the individual forecast performance of the basic Smets-Wouters model versus the same model augmented with financial frictions, the latter paper estimates a non-linear, regime-switching DSGE model. Both papers find that financial frictions become more important, once the economy has entered a stress state. Relative to the latter paper, I introduce an occasionally binding constraint, which allows me to endogenise the switch between normal and credit constrained times.

This paper is organised as follows. Section 2 empirically analyses whether the macro-financial relationship

[3] For an extensive review of the literature on macro-financial linkages in DSGE models, see Gerke et al. (2013).

is asymmetric using a MS-VAR. Section 3 briefly describes a structural model with financial frictions and occasionally binding constraints, the solution and estimation methods, and studie the fit of the model to the euro area data. Section 4 uses the estimated structural model to examine asymmetries in the macro-financial linkages. Section 5 studies the welfare properties of countercyclical macroprudential and monetary policy rules. Section 6 concludes.

2 Empirical Model

In this section, I use a Markov-Switching SVAR to investigate whether the transmission of financial shocks is asymmetric. For simplicity, I assume that there are two states of the world: (i) a normal state where households and firms are able to freely borrow and (ii) a credit constrained state in which credit to households and firms is limited, possibly because of binding borrowing constraints.

The VAR includes five variables: output growth, y_t, inflation, π_t, interest rate, i_t, loans to private sector growth, b_t, and asset price growth, q_t. Loans to the private sector capture the credit channel.

All data is monthly and collected from the ECB Statistical Warehouse for the euro area. Industrial production and the Harmonised Index of Consumer Prices (HICP) measure output and inflation, respectively. I use the EONIA (Euro OverNight Index Average) rate as a proxy for interest rates. The EONIA rate is the rate at which banks provide loans to each other for the duration of one day. It is a more useful measure of the interest rate than the main refinancing rate, as it moves closely with the main refinancing rate in normal times, but has the added benefit of also responding to changes in liquidity moves, when unconventional monetary policy measures are implemented. In addition, unlike the main refinancing rate, the EONIA can enter into negative territory, which it does at the end of the sample. The loan growth rate to euro area non-monetary financial institutions measures credit growth in the private sector. The Euro Stoxx 50 represents asset prices. Output, the HICP, loans, and asset prices are reported in annual growth rates and the interest rate in first differences. The sample spans the period from September 1999 until April 2016.

2.1 Model Specification and Estimation

The model is estimated using Bayesian methods (see Krolzig, 1997). All coefficients are assumed to be regime-variant. Regime-dependent intercepts, A_{0s}, are important to inspect the average differences depending on the state of the credit cycle, while regime-variant autoregressive coefficients, $A_{i,s}$, can track differences in the transmission channels. I also allow for Markov-Switching in the variance, ε_t, to account for the likely increase in variance of financial variables during the credit constrained state, which could otherwise bias my coefficient estimates. The states are $s_t = \{N, C\}$, where N is a normal state, and C a credit constrained state. To identify the states, I restrict the level of credit growth to be larger in the normal state than in the credit constrained state, i.e. $\frac{A_{o,N}}{1-\sum_{i=1}^{p} A_{i,N}} > \frac{A_{o,C}}{1-\sum_{i=1}^{p} A_{i,C}}$ for the credit growth variable, where p is the number of lags. The transition probabilities between the states are assumed to be constant, so that the model is represented by

$$y_t = \begin{cases} A_{0N} + \sum_{i=1}^{p} A_{i,N} y_{t-i} + \sum_N^{\frac{1}{2}} \varepsilon_t \\ A_{0C} + \sum_{i=1}^{p} A_{i,C} y_{t-i} + \sum_C^{\frac{1}{2}} \varepsilon_t \end{cases} . \tag{1}$$

To keep the model parsimonious, I use $p = 1$ for the autoregressive annual rates, and a constant in terms of deterministic variables. I estimate the model by employing a 4-step Gibbs sampler procedure, in which

I first compute the states and then draw for the transition probabilities, the coefficients, and the variance. The algorithm I use is the following:

1. Use a filter-smoothing algorithm to determine the states $s^l|y, A^{l-1}$ (Frühwirth-Schnatter, 2006).

2. Draw transition probabilities $p^l|s^l$ from a Dirichlet distribution.

3. Draw regime dependent intercepts and constant coefficients $A_s^l|y, s^l, p^l, \sum_s^{l-1}$ from a Normal distribution.

4. Draw regime dependent covariance matrices $\sum_s^l |y, s^l, p^l, A_s^l$ from an Inverse Wishart distribution.

l is the number of sample draws, and y the data. The priors for the parameters are stated in each step of the algorithm. The initial 1000 draws are discarded as burn-in and the remaining chain is thinned by recording only every 25th draw to avoid excessive autocorrelation between the draws, which would otherwise slow down the convergence to the posterior distribution.

I initialise the algorithm by assuming that credit growth is positive in the normal state $a_{0,4}^N > 0$, and the initial transition probability of remaining and switching states is given by 0.9 and 0.1, respectively. This makes the states themselves persistent, and comparable with the results of the structural model. I report the identified states and the first two moments of the variables in the two states in Figure A.1 and Table A.1. The credit constrained state is identified around the year 2000 to 2004, after the dot-com collapse, and then again from 2008 to 2014 during the financial and sovereign debt crises. As expected, the mean of each variable during the constrained state is significantly lower than during the normal state, and the variance for each variable is more than twice as large.

My main interest is to examine whether the credit channel (proxied by loans to the private sector) is weaker and the real economy less affected, when financial markets are booming and credit is expanding, than it would be the case when financial conditions are deteriorating. In other words, I want to examine how the financial sector passes-through positive financial shocks to the real economy in normal times relative to negative financial shocks in credit constrained times.

I identify financial shocks by applying a recursive identification scheme on the contemporaneous coefficient matrix. I divide variables into fast and slow moving, in which asset prices belong to the first group and the macroeconomic variables belong to the second group. The interest rate, as a monetary policy proxy, reacts both to output and inflation contemporaneously. Loans are assumed to be slower than asset prices, since banks' credit conditions need time to adjust. Hence, the order of the variables follows: output, inflation, interest rate, loans, and asset prices. The shock of interest is an unexpected, exogenous shock to asset price growth. The exogeneity assumption holds well, as many of the financial shocks in this sample originated from the outside the euro area (e.g. the dot-com bubble, Financial Crisis in 2008 emerged from the US).

2.2 The results

To examine the dynamics across states, I report the impulse responses and the contribution of asset price growth shocks to the forecast error variance of output. I compare the responses of a positive shock in a normal state to a negative shock in a constrained state. The reason for looking at these specific shocks is that financial booms usually occur, when credit is easily available and the financial sector is hit by positive surprises, while financial busts coincide with a tightening of credit supply and negative, unexpected shocks to financial markets.

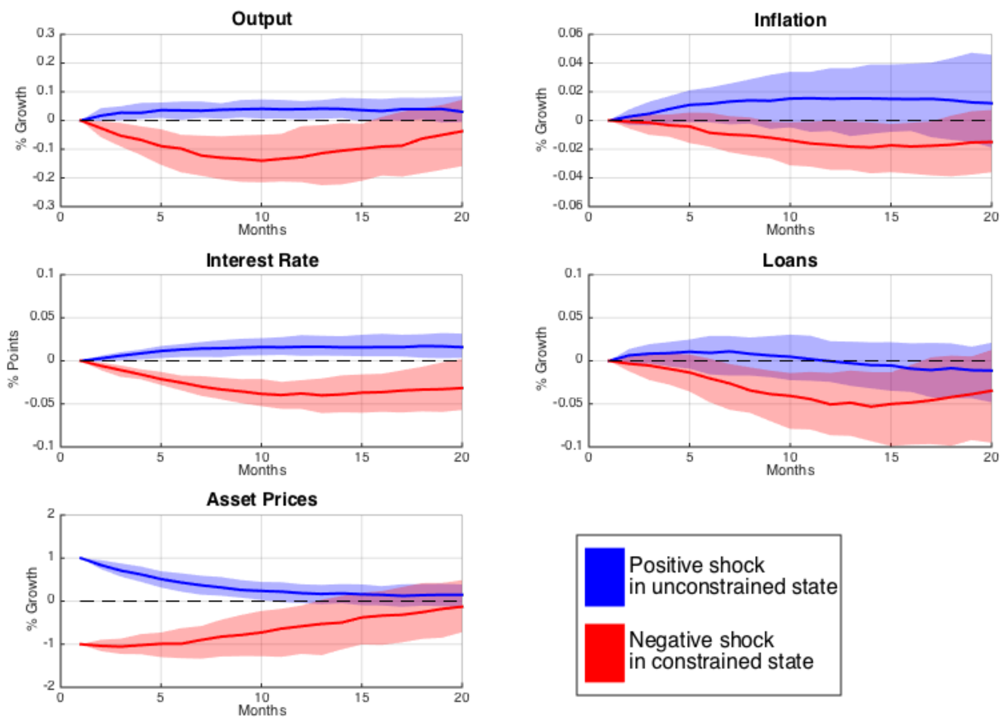
Because the model is non-linear, impulse responses are constructed using conditional forecasts. I apply the methodology of Koop et al. (1996) in which the responses are computed by subtracting the forecast that is conditional only on the history of the model, $\mathcal{F}_{t-1}$, from the forecast which is also conditional on the sign of the shock, ϵ_t, and the state of the model,

$$\begin{aligned}
\Phi_y^+(\mathcal{F}_{t-1}, \epsilon_t, s_t, \tau) &= E(y_{t+\tau}|\mathcal{F}_{t-1}, \epsilon_t > 0, s_t = N) - E(y_{t+\tau}|\mathcal{F}_{t-1}), \\
\Phi_y^-(\mathcal{F}_{t-1}, \epsilon_t, s_t, \tau) &= E(y_{t+\tau}|\mathcal{F}_{t-1}, \epsilon_t < 0, s_t = C) - E(y_{t+\tau}|\mathcal{F}_{t-1}).
\end{aligned}$$

This methodology is particularly suited to compute impulse responses in my case, as they allow for non-linear effects due to the sign or the magnitude of the shock. I calculate conditional forecasts 50 times per draw and then average the impulse response, Φ, over the repetitions and compute the credible set using the 16th and 84th percentile of the Monte Carlo draws. Figure 2 shows the results for a normalised financial shock that lasts for one period.

Most variables move as expected. Output, inflation, the interest rate, loans and asset prices all rise following a positive financial shock (in blue), and fall following a negative financial shock (in red).

Figure 2: Impulse responses to a financial shock



Note: The shaded regions report point-wise 68% credible sets. The financial shock is normalised to 1% of asset price growth and imposed for one period.

The figure shows clear asymmetry both in the financial market and in the macroeconomic responses. For example, the negative shock on asset prices in credit constrained times persists more than the equivalent positive shock during normal times. This asymmetry is also evident in the responses of loans. When credit conditions are slack, a positive shock does little to increase loan growth. However, when credit is already restricted, a negative shock causes loans to fall significantly and persistently. Thus, it seems that the credit channel, represented here by the dynamics of loans, only operates significantly in the credit constrained scenario for the negative shock.

The macroeconomic responses show a similar pattern. Output falls more than three times as much as it rises, indicating a very strong and significant asymmetric behaviour of the macro-financial linkages. Inflation dynamics do not seem to differ significantly in the two scenarios, and are affected by a large degree of uncertainty in the responses. The effect on the interest rate is significantly negative and persistent in the negative scenario. In the normal state, the interest rate rises, although by a smaller amount.

To sum up, there seems to be evidence of asymmetries in the responses of financial markets to positive and negative shocks, and in the transmission to the real economy, making financial booms smaller than financial busts.

The weaker role of the financial sector during normal times is confirmed by looking at the forecast error variance decomposition. Table 1 reports the variance decomposition in the normal state and the constrained state (in italics) for output growth. The most striking difference is between the medium-term effects of financial shocks on output. In the normal state, financial shocks only explain roughly 10% of output growth over the 1-5 year horizon. However, in the credit constrained state, financial shocks explain almost one third of output growth variation highlighting again the asymmetry of macro-financial linkages.

Table 1: Forecast Error Variance Decomposition in normal (left) and constrained (right) state for output growth

Periods	y_t (Demand)		π_t (Supply)		i_t (Monetary)		b_t (Loans)		q_t (Financial)	
1 month	100	*100*	0	*0*	0	*0*	0	*0*	0	*0*
2 months	96.69	*99.05*	0.80	*0.04*	1.41	*0.06*	0.23	*0.07*	0.60	*0.70*
1 year	52.84	*61.50*	21.15	*1.35*	7.35	*2.27*	2.92	*1.95*	11.05	*30.62*
2 years	28.63	*51.17*	42.52	*3.04*	6.33	*2.38*	3.88	*5.89*	11.77	*32.13*
5 years	15.53	*49.32*	48.83	*4.72*	6.92	*3.34*	5.56	*7.18*	10.34	*31.92*

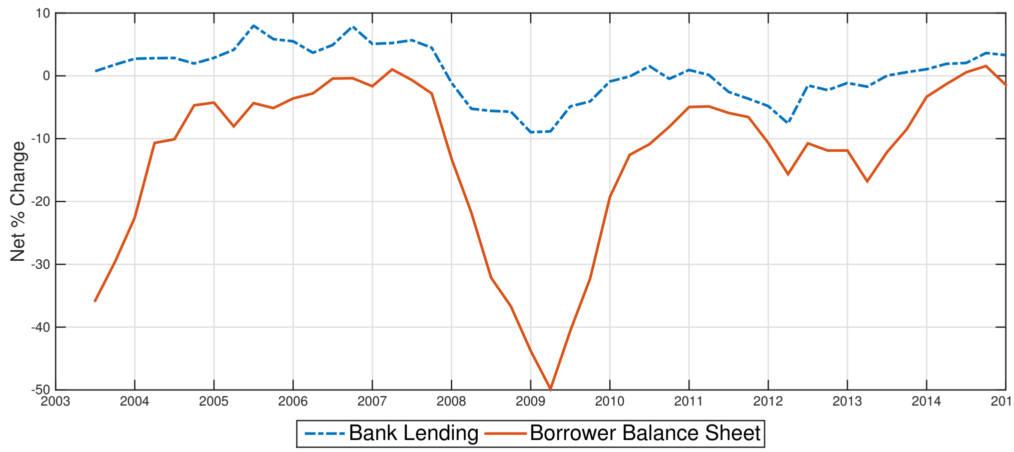
Note: The left hand side number of the column represents the variance decomposition in the normal state, the right hand side number in italics displays the results for the constrained state. The values are in percentages and represent the median draw of the Gibbs sampler.

Limitations: Disentangling the Credit Channel As the VAR only includes loans and thus only allows us to look at the aggregate movement of credit, it is difficult to understand the exact transmission mechanism in the data. The credit channel can be disentangled into two components (a) the borrowers' balance sheet channel, and (b) the bank balance sheet channel. The borrowers' balance sheet channel typically arises due to the asymmetric information problem and the unenforceability of contracts between lenders and borrowers which gives rise to an external finance premium (Bernanke et al., 1999) and collateral requirements (Kiyotaki and Moore, 1997). In contrast, the bank balance sheet channel is related to banks' inability to buffer their loan supply in times of adverse shocks and dependence of borrowers on these loans.

For policy purposes, it is useful to understand which of these channels plays a greater role in the transmission of financial shocks to the real economy. Survey data can provide an initial clue about the relative importance of the two channels over time. I use the quarterly Bank Lending Survey of the ECB to split the qualitative responses of financial institutions to changes in their loan supply into answers regarding bank lending versus balance sheet conditions. I then construct two indicators by measuring the difference between the net percentage of forecasters that have responded that conditions regarding lending supply (bank lending) and borrowers' quality (borrowers' balance sheet) have tightened versus eased as in Ciccarelli et al. (2014).

Figure 3 shows the two indicators. While both indicators run relatively in parallel during normal times, the borrowers' balance sheet indicator falls faster and is clearly more negative during more credit constrained episodes than the bank lending indicator. As this corresponds to the asymmetric response of loans in Figure 2, presumably, the borrowers' balance sheet seems to play a greater role for the observed asymmetry in the macro-financial transmission. However, it should be noted that due to the self-reporting by banks, banks are more likely to over-emphasise the borrower channel and potentially skew the survey results in their favour. The structural model I use in the next section provides firmer evidence that it is indeed the borrowers' balance sheet channel which is more important.

Figure 3: Credit Indicator



Source: Ciccarelli et al. (2014) and author's own calculations based on the ECB's quarterly Bank Lending Survey of Professional Forecasters. The y-axis represents the difference between the net percentage of forecasters responding that conditions with regard to supply lending (bank lending) and borrower's quality (balance sheet) have tightened to the ones who respond that credit conditions have eased. The blue, dotted line represents the bank lending indicator, and the red, solid line indicates the balance sheet indicator.

3 DSGE Model

To understand the asymmetric transmission of financial shocks in financial markets and the real economy, I use a structural model. The model has two main features: (i) an occasionally binding borrowing constraint to allow for different states of the world, and (ii) a detailed financial sector that allows me to distinguish between the borrower and the bank balance sheet channel. The model is an extension of the work by Gambacorta and Signoretti (2014), which in turn builds upon the banking model of Gerali et al. (2010). The financial sector in the model has two main characteristics: (i) a target leverage ratio and quadratic adjustment costs for banks, which gives rise to credit supply frictions, and (ii) a borrowing constraint for entrepreneurs which requires them to provide capital as a collateral, and thus creates credit demand frictions. The borrowing constraint is the crucial link between the financial sector and the real economy, as it introduces the 'financial accelerator' mechanism into the model: when a negative financial shock occurs, capital income falls, so that capital is less worth as a collateral. As a consequence, borrowers have to reduce their borrowing which causes investment and output to fall.

The model I use is to a large extent similar to Gambacorta and Signoretti (2014) except for two key changes. Firstly, I allow for the borrowing constraint of the entrepreneurs to be occasionally binding. As in the empirical model, there are two states of the world: one state in which the borrowing constraint is binding and credit conditions are tight, and another state in which the constraint is slack and agents can borrow unlimitedly.

Secondly, I consider a larger number of shocks to analyse the effects of disturbances in the financial sector and estimate the model. In addition to a standard technology and a cost-push shock, I introduce a monetary policy shock and two financial shocks: (i) a shock to the loan-to-value (LTV) ratio of entrepreneurs, and (ii) a net worth (default) shock. A shock to the LTV ratio is often described as a credit squeeze or risk perception shock. A positive shock (an increase in the loan-to-value ratio) allows entrepreneurs to borrow more for the same amount of collateral and vice versa. A net worth shock instead redistributes wealth between borrowers and lenders. The shock enters the budget constraint of both entrepreneurs and banks. Both of these shocks are modelled to be exogenous from conditions in the Euro Area to capture the idea that they represent global shocks (originating e.g. from the US) which however still affect the balance sheet and risk perceptions of European firms and banks.

3.1 Description of the Model

The model contains several agents: patient households, impatient entrepreneurs, retailers, wholesale and retail banks, capital goods producers, and a central bank. There is one type of households, which are patient and provide labour to impatient entrepreneurs. The entrepreneurs produce intermediate goods that are sold to retailers competitively. These retailers differentiate the intermediate goods and sell them with a mark-up to households, who also own the retailers and keep their profits. Banks have two branches: a wholesale and a retail branch. Wholesale banks take deposits from households and operate under perfect competition. Retail banks are monopolistic and give out loans to entrepreneurs for a mark-up. In addition, they take and monitor collateral from the entrepreneurs given an LTV ratio. There is also a central bank that sets the policy rate and determines the capital-asset ratio for banks, which is fixed. Finally, in order to derive a price for capital, there are capital producers who buy undepreciated capital from entrepreneurs and re-sell it for a new price back to entrepreneurs taking into account quadratic adjustment costs. The borrowers' balance sheet channel is captured by the borrowing constraint of the entrepreneurs and affects credit conditions via the net worth of the borrower. The bank balance sheet channel describes credit supply on the lenders' side via the leverage ratio that accounts for both bank lending, as well as bank capital.

Households

Households maximise

$$\max_{c_t^P, l_t, d_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_P \left[\log(c_t^P) - \frac{l_t^{1+\phi}}{1+\phi} \right], \tag{2}$$

where c_t^P is consumption, l_t is labour supply, β_P is the patient discount factor. They deposit savings at wholesale banks, for which they receive a risk-free return. They also own retail firms, which are monopolistic and generate a profit, so that they are subject to the budget constraint

$$c_t^P + d_t \leq w_t l_t + (1 + r_{t-1}^{ib}) d_{t-1} + J_t^R, \tag{3}$$

where d_t are bank deposits, w_t is the real wage, and r_t^{ib} is the short term policy rate. J_t^R are the profits of the retail sector and ϕ is the elasticity of labour. The first-order condition yields the standard consumption Euler equation

$$\frac{1}{c_t^P} = \mathbb{E}_t \frac{\beta_P(1+r_t^{ib})}{c_{t+1}^P}. \tag{4}$$

Households also provide labour to the entrepreneurs for the production of intermediate goods, which follows the usual labour supply schedule

$$l_t^{\phi} = \frac{w_t}{c_t^P}. \tag{5}$$

Entrepreneurs

Entrepreneurs need to borrow from banks and hold capital, but also produce goods, employ households and consume. They form the link between the real economy and the banking sector and are thus important for generating a feedback loop between the financial and macroeconomic side of the model. The entrepreneurs maximise

$$\max_{c_t^E, l_t^d, b_t^E} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_E \log(c_t^E). \tag{6}$$

with respect to their consumption, c_t^E, labour demand, l_t^d, and bank loans, b_t^E. The optimisation problem is subject to a budget constraint, which is

$$c_t^E + (1+r_{t-1}^b)b_{t-1}^E + w_t l_t^d + q_t^k k_t^E \leq \frac{y_t^E}{x_t} + b_t^E + q_t^k(1-\delta^k)k_{t-1}^E + \epsilon_t^b, \tag{7}$$

where r_t^b is the interest rate on bank loans, k_t^E is the entrepreneurs stock of capital, q_t^k is the price of capital, and y_t^E is the intermediate output produced by entrepreneurs. $\frac{1}{x_t} = \frac{P_t^W}{P_t}$ is the relative competitive price of the intermediate good produced by the entrepreneur, and δ^k is the depreciation rate of capital. The net worth shock, ϵ_t^B, enters the budget constraint of the entrepreneurs by altering their income. It follows an AR(1) process with an i.i.d shock ε_t^b and a variance σ^b. The entrepreneurs are also subject to an occasionally binding borrowing constraint

$$b_t^E \leq \frac{m_t^E q_{t+1}^k k_t^E(1-\delta^k)}{1+r_t^b}, \tag{8}$$

where m_t^E is the stochastic LTV ratio which follows an AR(1) process with an i.i.d shock ε_t^{me} and variance σ^{me}. A high LTV ratio implies that banks can lend more for the same amount of collateral and vice versa.

The borrowing constraint determines how much entrepreneurs can borrow from banks. For small enough shocks, $\beta_P > \beta_E$ ensures that the borrowing constraint is binding and credit is constrained in the economy. However, with larger shocks the constraint becomes slack.

Entrepreneurs do not work but use capital and labour in the production of intermediate goods. As in Kiyotaki and Moore (1997), capital has many functions in this model and thus establishes another important feedback mechanism between the real economy and the financial sector. Capital is used (i) in the production of intermediate goods, (ii) as a collateral for the entrepreneurs, and (iii) as a source of funds for investment. The production function for intermediate goods follows a standard Cobb-Douglas form

$$y_t^E = A_t^e (k_t^E)^{\alpha} (l_t^d)^{(\alpha-1)}, \tag{9}$$

where α denotes the capital share, and A_t^e technology. A_t^e is stochastic and follows an AR(1) process with an i.i.d. technology shock ε_t^a with variance σ^a. Entrepreneurs operate under perfect competition. Their optimal consumption Euler equation is

$$\frac{1}{c_t^E} - \lambda_t^E = \mathbb{E}_t \frac{\beta_E (1 + r_t^b)}{c_{t+1}^E}. \tag{10}$$

This is similar to the households' Euler equation but differs by the Lagrange multiplier on the borrowing constraint, λ_t^E, which represents the marginal value of one unit of additional borrowing. Another difference is that entrepreneurs, unlike households, discount at a higher rate and face the higher bank loan rate, r_t^b, rather than the risk-free rate, r_t^{ib}. The labour demand schedule is

$$\frac{(1-\alpha) y_t^E}{l_t^d x_t} = w_t. \tag{11}$$

The investment Euler equation equalises the marginal benefit with the marginal cost of saving capital. As capital also serves as collateral, the equation also depends on the Lagrange multiplier of the borrowing constraint and the LTV ratio. It follows

$$\frac{\lambda_t^E m_t^E q_{t+1}^k (1-\delta^k)}{1 + r_t^b} + \frac{\beta_E}{c_{t+1}^E} \left[q_{t+1}^k (1-\delta^k) + r_{t+1}^k \right] = \frac{q_t^k}{c_t^E}, \tag{12}$$

where r_t^k is the return to capital which is defined by the marginal product of capital as

$$r_t^k \equiv \alpha \frac{A_t^E (k_t^E)^{(\alpha-1)} (l_t^d)^{(1-\alpha)}}{x_t}. \tag{13}$$

Banks

The banking sector is divided into a perfectly competitive wholesale and a monopolistic retail sector. The wholesale sector maximises bank profits by optimising the net interest margin between the loan and deposit rate subject to the quadratic adjustment costs of deviating from a target leverage ratio ν

$$\max_{b_t,d_t} R_t^b b_t - r_t^{ib} d_t - \varepsilon_t^b - \frac{\theta}{2}\left(\frac{K_t^b}{b_t} - \nu\right)^2 K_t^b. \tag{14}$$

To simplify, I set the deposit rate equal to the risk-free rate set by the central bank. Wholesale banks are subject to a balance sheet constraint that can also be interpreted as a capital adequacy constraint. Loans have to be backed up by sufficient bank capital and deposits at the beginning of the period before any losses from the net worth shock have been realised

$$b_t - \mathbb{E}_t[\epsilon_{t+1}^b] = d_t + K_t^b. \tag{15}$$

Leverage generates a feedback between the interest rate spread and the real economy. ε_t^b is the same net worth shock as in (7) that transfers wealth between entrepreneurs and banks. It is modelled as in Iacoviello (2015).

K_t^b is the banks' capital and θ is the parameter for capital adjustment cost for banks. Combining (14) and (15), the first-order condition of the wholesale bank is

$$R_t^b = r_t^{ib} - \theta\left(\frac{K_t^b}{b_t} - \nu\right)\left[\frac{(b_t - d_t)^2 - b_t\mathbb{E}_t[\epsilon_{t+1}^b] + \mathbb{E}_t[\epsilon_{t+1}^b]^2}{b_t^2}\right]. \tag{16}$$

The retail bank on the other hand, repackages the wholesale loans and charges a mark-up, $\overline{\mu}^b$, on the wholesale loan rate, so that the retail loan rate becomes

$$r_t^b = R_t^b + \overline{\mu}^b. \tag{17}$$

The retail banks have market power, which helps them to adjust their lending in response to shocks or cycles. Another crucial determinant for the feedback loop between the banking sector and the real economy is bank capital. Bank capital accrues from past capital and retained earnings, J_t^B,

$$K_t^b = K_{t-1}^b(1 - \delta^b) + J_{t-1}^B. \tag{18}$$

Since it is procyclical, bank capital worsens, when output declines due to decreasing banks' profits. The latter is defined as the sum of both the retail and wholesale sector profits on loans and deposits, respectively, and depends on the condition of the macroeconomy

$$J_t^B = r_t^b B_t - r_t^{ib} D_t - \frac{\theta}{2}\left(\frac{K_t^b}{b_t} - \nu\right)^2 K_t^b. \tag{19}$$

Retailers and Capital Good Producers

The monopolistic retailers are differentiating the intermediate goods produced by the entrepreneurs at no cost and sell them with a mark-up, x_t. However, retailers face quadratic price adjustment cost, which causes prices to be sticky. The parameter κ_P represents the parameter for price stickiness.

The first order condition of the retailers generates the classic New Keynesian Philip's curve

$$1 = \frac{mk^y}{mk^y - 1} + \frac{mk^y}{mk^y - 1} mc_t^E - \kappa_P(\pi_t - 1)\pi_t + \beta_P \mathbb{E}_t \left[\frac{c_t^P}{c_{t+1}^P} \kappa_P(\pi_{t+1} - 1)\pi_{t+1} \frac{Y_{t+1}}{Y_t}\right], \tag{20}$$

where the marginal cost are, $mc_t^E \equiv \frac{1}{x_t}$. The firm's mark-up, mk^y, is stochastic and follows an AR(1) process with the autocorrelation coefficient ρ_{mk} and an i.i.d. mark-up shock, ε_t^{mk}, with variance σ_{mk} .

Capital good producers are perfectly competitive and their main task is to transform the old, undepreciated capital from entrepreneurs to new capital without any additional costs. They then resell the new capital to the entrepreneurs in the next period at price P_t^k, so that the real price of capital is $q_t^k \equiv \frac{P_t^k}{P_t}$. In addition, capital producers 'invest' in the final goods bought from retailers, which are not consumed by household, and also transform these into new capital.

The final goods to capital transformation is subject to quadratic adjustment costs that are parameterised by κ_i, the investment adjustment cost parameter. The first-order condition of capital good producers is

$$1 = q_t^k \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa_i \left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + \beta_E \mathbb{E}_t \left[\frac{c_t^E}{c_{t+1}^E} q_{t+1}^k \kappa_i \left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right], \tag{21}$$

with capital evolving according to

$$K_t = (1 - \delta^k)K_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t. \tag{22}$$

Monetary Policy

Monetary policy follows a standard Taylor rule, so that the policy rate is set according to

$$1 + r_t^{ib} = (1 + r^{ib})^{(1-\rho_{ib})}(1 + r_{t-1}^{ib})^{\rho_{ib}} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\rho_{ib})} \left(\frac{y_t}{y}\right)^{\phi_y(1-\rho_{ib})} (1 + \varepsilon_t^r). \tag{23}$$

where ρ_{ib} is the autoregressive coefficient, and ϕ_π and ϕ_y are the monetary policy parameter. ε_t^r is an i.i.d monetary policy shock with variance σ^r. The monetary policy authority is also responsible for setting a target leverage ratio for banks to avoid an over-leveraging of the economy similar to the real world Basel capital ratios.

Market Clearing and Aggregation

Goods and labour markets clear. The resource constraint of the economy is

$$Y_t = C_t + I_t, \tag{24}$$

as it is a closed economy with no government intervention.

3.2 Solving and Estimating the Model

Because the entrepreneurs' borrowing constraint is occasionally binding, I need to apply non-standard solution and estimation methods. Disregarding non-linearities in the borrowing constraint, as is often done in the literature, would lead to a symmetric transmission mechanism and symmetric feedback from financial variables over the credit cycle. If we were to assume that borrowing constraints were always binding, we would also need to believe that the discount factor of impatient agents is higher than the discount factor of patient agents, and that shocks are so small, that the economy does not move too far from its steady state level. This assumption is often violated in practise, since financial shocks can wipe out a large percentage of asset prices in a very short time.

Solution Method

I use the method of Guerrieri and Iacoviello (2015b) which uses a piece-wise linear approach to approximate the global solution. The idea behind the method is to treat the binding and non-binding scenario as two separate regimes for which a first-order approximation can be used. One of the requirements for this method to work accurately is that the system is always expected to return to the initial regime in finite time. As we have seen with in Section 2, this requirement is not particularly restrictive, as state switching between the constrained and unconstrained credit regimes is relatively common in the data. Also, it is consistent with the notion that credit constrained periods are expected to proceed times of credit expansions. While the method is unable to capture any anticipatory effects, it has some key advantages over fully fledged global methods: It is computationally fast and can be applied to non-linear models with a large number of state variables, for which global methods would otherwise be infeasible. Moreover, Guerrieri and Iacoviello (2015b) show that the difference between the piecewise-linear solution method and a global solution method is quantitatively small in selected examples and that the solutions are very accurate for models with occasionally binding constraints.

Data

To estimate the model, I use five observable variables, which are related to $[y_t^{obs}, \pi_t^{obs}, r_t^{ib,obs}, b_t^{obs}, q_t^{obs}]$ of the model. The data is reported quarterly from 1999Q1 until 2016Q2. I use euro area GDP for Y_t, inflation based on the HICP for π_t, the EONIA rate for r_t^{ib}, an index for the notional stock of loans to the private sector for b_t, and the EURO STOXX 50 equity price index for asset prices, q_t. The data is detrended using a one-sided Hedrick-Prescott filter, except for the interest rate and inflation, which are demeaned and divided by 400% to express quarterly rates.[4] The smoothing parameter is set to $\lambda = 1600$ to compute the quarterly

[4] The one-sided filter has the advantage that it is strictly backward-looking, so that only past information is used to separate the trend and cyclical component without changing the timing of information and of the shock.

business cycle component.

Calibration and Priors

Not all parameters of the model are estimated. Those that are calibrated are reported in Table A.2. It is important to properly calibrate the two discount factors, as they are crucial for the dynamics of the model with an occasionally binding borrowing constraint. The more impatient the entrepreneurs are relative to the patient households (the smaller β_E), the more they discount future consumption and value an additional unit of borrowing, thus the larger the Lagrange multiplier on borrowing ${\lambda_t}^E$. The increase in the Lagrange multiplier in turn causes the borrowing constraint to become more binding and makes it less likely for it to become slack unless very large shocks occur. For the impatient discount factor, I use a value of $\beta_E = 0.975$ based on Iacoviello (2005) and a slightly higher patient discount factor of $\beta_p = 0.9943$ based on Gerali et al. (2010). The latter is computed by matching the mean, monthly deposit rate on M2 in the euro area.

I calibrate the target capital-to-loans ratio, $\nu = 0.09$ in line with the Basel Accords. I follow Gerali et al. (2010) for the entrepreneur's steady state LTV ratio, $m^E_{ss} = 0.35$ which is in line with the values for non-financial corporations in the euro area (firms' LTV ratio is significantly lower than households), and use their estimated value for the bank capital adjustment cost of $\theta = 11$. The other calibrated parameters for labour elasticity, the steady state values for marginal costs and mark-up, the capital share, and the deprecation rate of capital are set to standard values in the literature for the euro area (see e.g. Gambacorta and Signoretti, 2014). To model the macro-financial transmission channels as close as possible to the data, I estimate the parameters for price stickiness, the investment adjustment cost, the monetary policy parameters, and the shock parameters.

Estimation

For the estimation, I use relatively non-informative prior values for the chosen parameters as reported in Table 2. To construct the likelihood I follow Guerrieri and Iacoviello (2015a) and use the piecewise-linear solution from the previous step. The Bayesian estimation follows a random walk Metropolis-Hastings algorithm in which the likelihood is computed by solving for the errors recursively. The main advantage of this method is that it is computationally faster and more feasible for a larger state space than (i) the Kalman filter approach or (ii) particle filter methods.

The first step is to recursively solve for the errors, $\varepsilon_t = \{\varepsilon^a_t, \varepsilon^{mk}_t, \varepsilon^r_t, \varepsilon^{me}_t, \varepsilon^b_t\}$, which are drawn drawn from a multivariate Normal distribution, given the past unobserved components, X_{t-1} and the current realisation of Y_t. Due to the unobserved components, the filter requires initial values for X_0 that represent the steady state values of the model. For that purpose, I use the first ten observations. Once the filtered errors are computed, the next step is to evaluate the log-likelihood

$$\log(f(Y^T)) = -\frac{T}{2}\log(\det(\Sigma)) - \frac{1}{2}\sum_{t=1}^{T}\varepsilon'_t(\Sigma^{-1})\varepsilon_t - \sum_{t=1}^{T}\log(|\det\frac{\partial\varepsilon_t}{\partial Y_t}|). \tag{25}$$

I can use a short-cut in the computation of the Jacobian matrix, $\frac{\partial\varepsilon_t}{\partial Y_t}$. From the piecewise-linear solution, we implicitly get $\frac{\partial\varepsilon_t}{\partial Y_t} = (\mathbf{H}_t\mathbf{Q}(X_{t-1,}\varepsilon_t))^{-1}$ and the local linearity of the solution guarantees the invertibility of the Jacobian matrix during the implicit differentiation step. By combining prior information with the likelihood and maximising it using a random walk Metropolis-Hastings algorithm, I get the posterior parameter estimates.

The advantages of this method are two-fold: On the one hand, the method only requires an initial guess whether the constraint in the model is binding or not, so that convergence is easier achieved than having to guess the path of all endogenous variables. On the other hand, the algorithm is comparatively fast, since the Jacobian matrix that is needed to compute the likelihood is already provided as a by-product of the solution method.

I restrict the choice of parameters for estimation to the parameter for price stickiness, κ_P, investment adjustment cost, κ_i, the monetary policy parameters, ϕ_π, ϕ_y, the autoregressive coefficients, $\rho_A, \rho_{ib,}\rho_{mk}, \rho_{me}, \rho_B$, and the five standard errors of the shocks, $\sigma_A, \sigma_{r,}\sigma_{mk}, \sigma_{me}, \sigma_B$. In particular κ_i is important to estimate rather than calibrate, as it determines the feedback loop between asset prices and output. As can be seen from Eq. (21), the smaller κ_i is, the more responsive are capital good producers to changes in asset prices. Previous calibration values of this parameter are very imprecise and diverge by a factor of 100 (Gambacorta and Signoretti, 2014), so that estimation can provide valuable information. To improve the efficiency of the algorithm, I estimate the model with a strictly binding borrowing constraint using standard Bayesian methods first and use these values as starting values for the algorithm. The results are reported in Table 2.

The parameters seem reasonably well identified and mostly driven by the likelihood component of the posterior distribution. The parameter for investment adjustment cost is similar to what has been found in Gerali et al. (2010) ($\kappa_i = 10.26$). However, the price stickiness parameter is notably larger than in the previous literature. One explanation for the high κ_p is the lack of wage stickiness in the model, so that κ_p is soaking up the additional stickiness that is present in the data. Since I use the EONIA rate as the observable interest rate, the Taylor parameter on inflation, ϕ_π, reacts more strongly to movement in prices. Overall, the estimates of the standard parameter are in line with what is known in the literature. In addition, I can now also provide a more precise value of the investment adjustment cost parameter that is crucial in determining macro-financial spillovers.

Table 2: Estimated Parameters

Parameters	Description	Prior Mean	Posterior Mean	Posterior std	Prior shape	Prior std
κ_p	Price stickiness	20.00	85.9940	0.0056	Gamma	10.00
κ_i	Investment adj. cost	5.00	11.2019	0.0039	Gamma	2.50
ϕ_π	Taylor rule on π	2.00	6.0229	0.0004	Gamma	1.00
ϕ_y	Taylor rule on y	0.10	0.1905	0.0018	Normal	0.15
AR Coefficients						
ρ_A	Technology	0.80	0.9896	0.0006	Beta	0.10
ρ_{mk}	Mark-up	0.80	0.8359	0.0007	Beta	0.10
ρ_{ib}	Taylor rule	0.75	0.6082	0.0008	Beta	0.10
ρ_{me}	LTV ratio	0.80	0.8164	0.0009	Beta	0.10
ρ_B	Net worth	0.80	0.9167	0.0005	Beta	0.10
Standard Errors						
σ_A	Technology	0.01	0.0157	0.0003	Inv.Gamma	0.50
σ_{mk}	Mark-up	0.01	0.0646	0.0005	Inv.Gamma	0.50
σ_r	Taylor rule	0.01	0.0248	0.0010	Inv.Gamma	0.50
σ_{me}	LTV ratio	0.01	0.0225	0.0007	Inv.Gamma	0.50
σ_B	Net worth	0.01	0.0198	0.0001	Inv.Gamma	0.50

Note: The posterior statistics are based on 50 000 draws from the random walk Metropolis-Hastings algorithm. Starting values were chosen based on the estimated parameters of the model with a permanently binding borrowing constraint. The first 50% of draws are discarded as burn-in.

3.3 Validation

To assess the theoretical model, I evaluate its ability to (i) capture asymmetries, and (ii) reproduce the macro-financial transmission described in Section 2.

For the asymmetries, I compare how well the DSGE model manages to identify the credit constrained and unconstrained state. Figure A.1 reports the probability of being in the credit constrained state both in the MS-VAR and in the DSGE model. The identified states in both models are almost identical. Both models identify an unconstrained state approximately between 2004 and 2008 and then again for a period starting in 2014. A credit constrained episode is identified from 2000 to 2004, from 2008 to 2014 in the period of the financial and sovereign debt crises, and in the last few periods of the sample. It appears that the regimes identified by the MS-VAR proceeds the states identified in the model by one or two months and are marginally more persistent for the unconstrained state. Overall, the model performs well along this dimension.

For the macro-financial transmission, I compare the monthly VAR impulse responses with the VAR impulse responses based on simulated data from my model. As the model is estimated using quarterly data, I need to re-calibrate the time-varying parameters to a monthly frequency before simulating the data.[5] I draw errors for the five shocks from a normal distribution with zero mean and the estimated standard deviation of the shocks. I then simulate the observable variables of the model, $[y_t^{obs}, \pi_t^{obs}, r_t^{ib,obs}, b_t^{obs}, q_t^{obs}]$, 100 times

[5] The time-varying parameters in the model are the discount factors, the AR coefficients of the error processes, the depreciation rate, and the price and investment adjustment costs. To convert these parameters to a monthly frequency, I take the discount rates and AR coefficients to the power of one third, divide the deprecation rate by three and multiply the adjustment costs times three (Pfeifer, 2013).

and feed the averaged data into the same MS-VAR algorithm as in Section 2. Figure A.2 reports the results. The model performs well in matching the response of output, asset prices, and loans. The credible sets of the responses with the simulated data fully include the responses of the model with the real data. The only dimension for which the model seems to be unsuccessful is in replicating the response of inflation and as a consequence interest rates: both are insignificant with the simulated data. Note however that this was also the case for the empirical responses of the annual inflation and given how quantitatively small the responses are, this failure is of little consequence for the macro-financial transmission.

Overall, the results of the DSGE model are largely consistent with the empirical results of the MS-VAR, and both asymmetries, as well as macro-financial transmission are well accounted for.

4 The Transmission of Financial Shocks

Using the estimated model, I study the transmission properties of two financial shocks: an LTV ratio shock, ε_t^{me} and a net worth shock, ε_t^b. Both shocks affect the entrepreneurs' ability to borrow. However, they differ significantly in the way they impact loans. The LTV shock affects the supply of loans that banks can give to entrepreneurs via the LTV ratio, m_t^E, as seen in (8). Instead, the net worth shock affects the demand and supply of loans via the budget constraints of both entrepreneurs and banks.

The advantage of using the model is in the ability to dissect the credit channel into its two components: the borrower and the bank balance sheet channels. The bank balance sheet channel works through the leverage ratio of banks, $lev_t = \frac{K_t^b}{b_t}$. The balance sheet channel functions through the net worth of entrepreneurs,

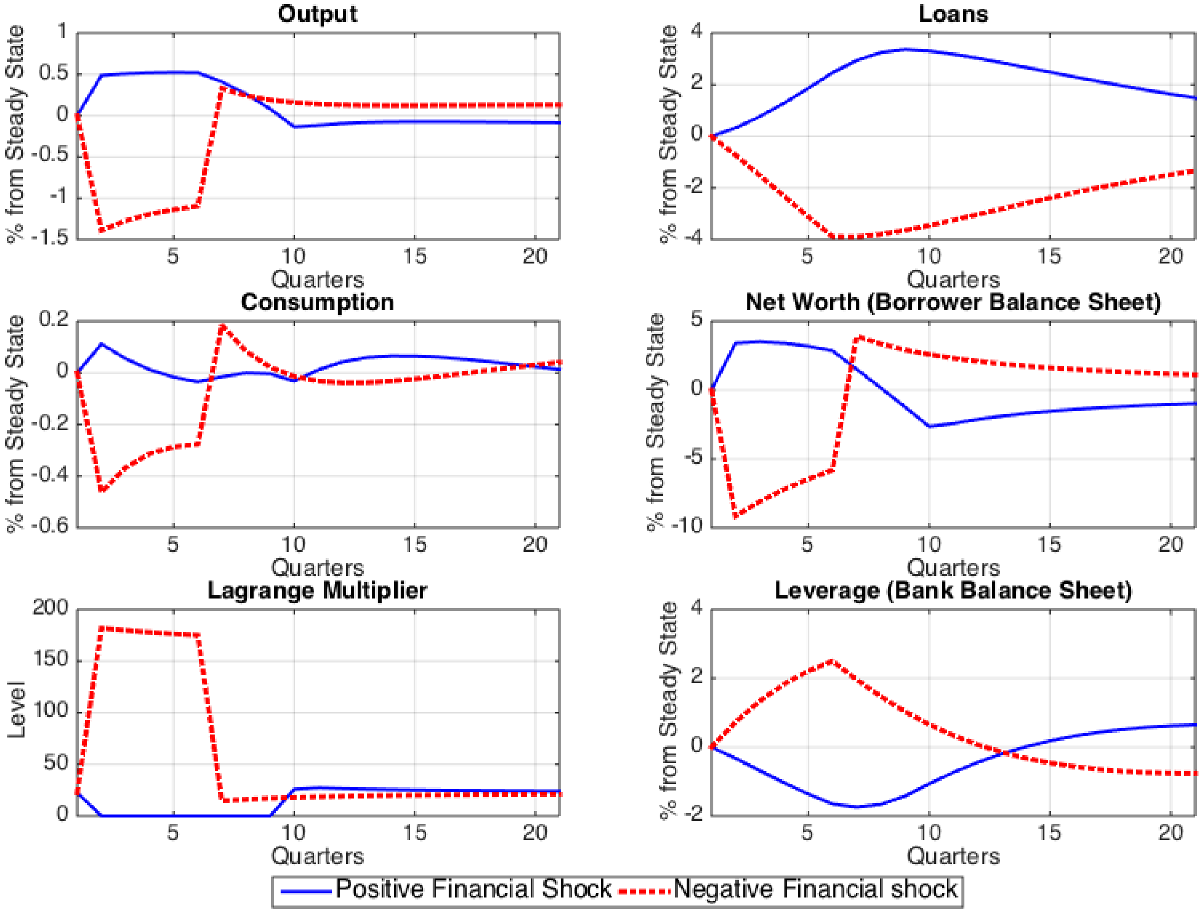
$$NW_t = q_t^k(1-\delta^k)K_{t-1} - (1+r_{t-1}^b)B_{t-1} + \alpha\frac{Y_t}{x_t}. \tag{26}$$

The question is which of these channels is dominant in producing asymmetries between the financial system and the real economy in different states.

4.1 LTV ratio shock

Figure 4 shows the response of the model to a one standard deviation shock to the entrepreneurs' LTV ratio. A positive shock (with a slack borrowing constraint) is in blue, and a negative shock (with a binding borrowing constraint) is the dotted, red line. The left column reports the responses of the macroeconomic variables, output, Y_t, consumption, C_t, and the Lagrange multiplier on the borrowing constraint, λ_t^E, while the right column represents the responses of the financial sector. In particular, the general response of loans, b_t, is further broken up into (i) the response of the leverage ratio of banks, lev_t, and (ii) the response of the net worth of entrepreneurs, NW_t.

Figure 4: Responses to an LTV financial shock



Note: The blue line indicates a positive shock, while the red dotted line represents a negative shock. The financial shock is a one standard deviation shock to the LTV ratio, which raises the LTV ratio by 2.2 percentage points. The parameters and standard error are set to the posterior mean. The shock is induced for 5 periods, after which the series reverts back to its steady state.

A positive shock to the LTV ratio causes the borrowing constraint in (8) to become slack, as entrepreneurs can borrow more for less collateral. As banks can now supply more loans, total loans increase. The ability to borrow more for less capital leads to an increase in the entrepreneurs' net worth. Also, since banks do not back up the additional loans with an equivalent amount of bank capital, their leverage ratio decreases. On the macroeconomic side, current consumption and production increase. Entrepreneurs are able to consume more, and have more capital to invest. The additional consumption drives up the production of intermediate goods, the demand for labour, and, in turn, consumption and employment of households increase. Overall, total consumption and output in the economy rise.

The opposite holds true for a negative LTV shock: with entrepreneurs having to provide more collateral for the same amount of loans, an additional unit of borrowing becomes more expansive and loans decrease, leading to the opposite reaction and a fall in the macroeconomic variables.

As is apparent from Figure 4, the responses of the variables following a positive and negative shock are clearly asymmetric due to the occasionally binding borrowing constraint. When the constraint is binding, one additional unit of borrowing is associated with positive marginal utility, $\lambda_t^E > 0$. In contrast, a slack constraint that follows from a positive financial shock causes households to consume more today without the need to borrow, so that the marginal utility of borrowing, λ_t^E, is zero. The agents are allowed to borrow more, but there is no additional utility from borrowing. This is why loans increase by less for the positive scenario than they fall for the negative case. With less demand for loans, the leverage ratio of banks also decreases slightly less relative to the decrease from a negative shock, as banks are deleveraging faster in a credit constrained scenario. Note also that the asymmetry in the net worth of entrepreneurs (representing the borrowers' balance sheet channel) is very large with a negative shock causing net worth to fall three times more than it rises for a positive shock. The magnitude of the difference is similar to what we have seen in Figure 3.

This asymmetry is reflected in the size and shape of the responses of macroeconomic variables. In terms of size, the responses between a positive and a negative shock differ depending on the state of the world. A slack borrowing constraint following a positive shock causes entrepreneurs to consume more. However, as the marginal utility of borrowing is zero and because of diminishing marginal returns to consumption, their marginal utility of consumption decreases, so that consumption spending increases only by a small amount. As in Section 2, output increases only incrementally following a positive shock and three times less so than for a negative shock. When the constraint is binding, the results differ. Consumption becomes more sensitive to changes in the credit market, as the net worth of entrepreneurs falls more strongly. A negative financial shock increases the marginal utility of borrowing, so that agents adjust their consumption more.

In terms of shape asymmetries, we can observe that the output, consumption, and the net worth of entrepreneurs are less persistent and revert back quicker to the steady state after a negative shock. The quicker response occurs because the multiplier on the borrowing constraint, λ_t^E, reverts back to its steady state value quicker for a negative shock than for a positive shock that causes the constraint to become slack.

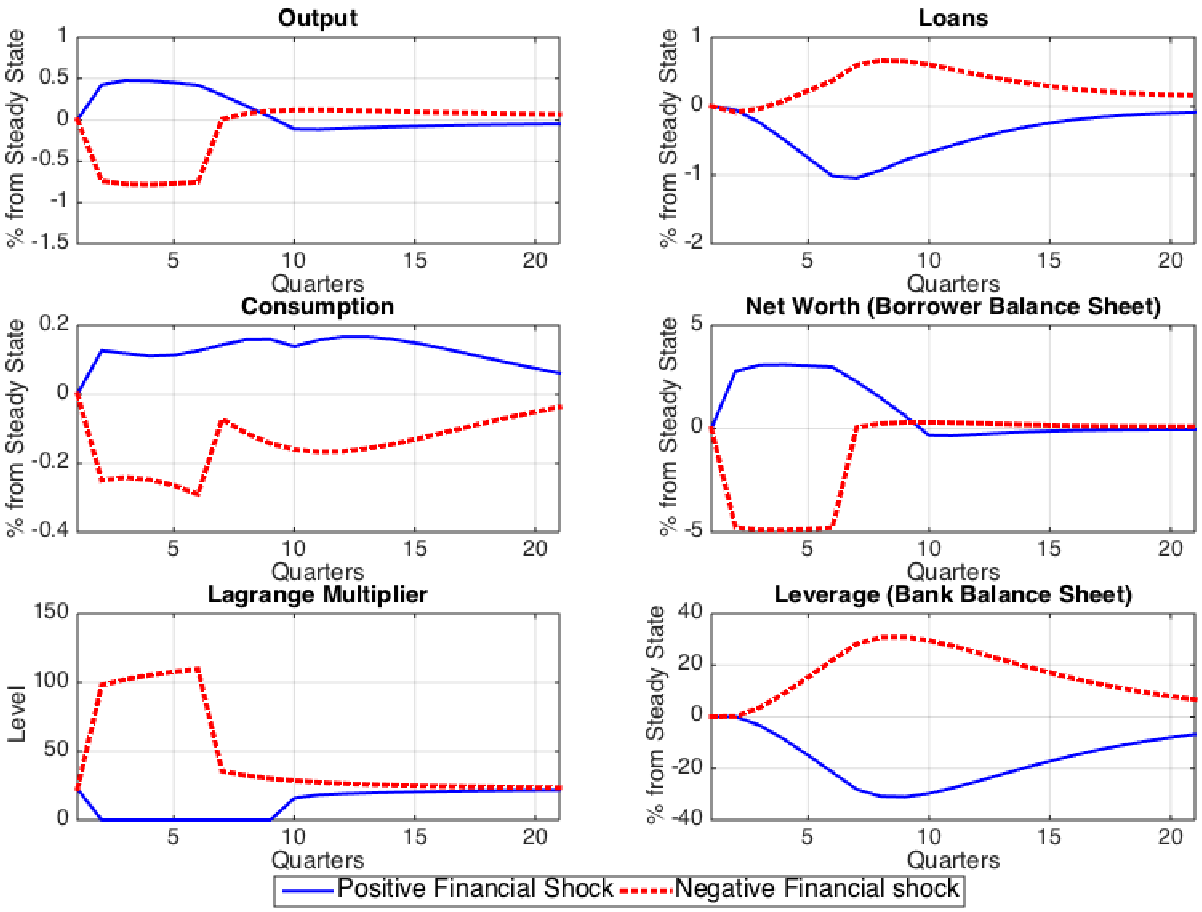
In terms of the relative importance of the two transmission channels, even though both credit channels show some asymmetry, it is the borrowers' balance sheet channel that reacts stronger during a credit constrained regime and is responsible for the asymmetric pass-through to the real economy. To provide further evidence for this claim, I run a simulation in which banks cannot adjust their leverage ratio, therefore effectively switching the bank balance sheet off. Figure A.3 shows the responses, when transmission is taking place exclusively via the borrowers' balance channel. The only noticeable difference is that the response of leverage is zero. For all other variables, the effect of turning the channel off is barely visible. Hence, we can conclude that it is indeed the borrowers' balance sheet channel that is driving the asymmetric macro-financial transmission.

4.2 Net worth shock

Figure 5 shows the response of the model to a one standard deviation shock to the entrepreneur's net worth, ε_t^b. While this type of shock also affects the entrepreneurs' borrowing constraint, it goes through the system differently than the LTV shock.

While the left-hand side of the figure looks similar to the one reported following an LTV shock, the right-hand side and, particularly, the reaction of loans is different. The LTV shock increases the LTV ratio and leads to an increase in loans. The net worth shock on the other hand acts more like a shock to the demand of loans. When the borrowing constraint is binding and a negative net worth shock hits he economy, entrepreneurs want to borrow more given their increased marginal utility of borrowing, but can only borrow up to when the borrowing constraint becomes binding.

Figure 5: Responses to a net worth financial shock



Note: The blue line indicates a positive shock, while the red dotted line represents a negative shock. The financial shock is a one standard deviation shock to the entrepreneurs' budget constraint. The parameters and standard error are set to the posterior mean. The shock is induced for 5 periods, after which the series reverts back to its steady state.

In contrast, a positive net worth shock increases the wealth of entrepreneurs, so that even when the constraint is slack, they do not need to borrow more to satisfy their current consumption, as is shown in (7), and start to deleverage. Banks' leverage ratio increases strongly, as banks need to smooth out the losses caused by ε_t^b with bank capital, as can be seen in the capital adequacy constraint in (15). For the net worth shock, the bank balance sheet channel is reacting very strongly, albeit symmetrically.

While there are sizeable differences between the responses of loans from the LTV and the net worth shock, the responses of the macroeconomic variables and net worth are very similar even in terms of magnitude. With a positive financial shock, entrepreneurs are richer, which increases total consumption, and output. The net worth of entrepreneurs still responds very asymmetrically, but the drop for a negative net worth shock is less dramatic than for a negative LTV shock. Consumption is more persistent and the asymmetries are not as strong as with the LTV shock, but they still follow a similar pattern. As the response of leverage is ten times larger for a net worth shock, the bank balance sheet channel is quantitatively more important for macro-financial transmission than under an LTV shock.

Figure A.4 shows the responses, when the bank balance sheet channel is switched off and only the borrowers' balance sheet channel is responsible for the transmission of the financial shock. The effects are more visible than under an LTV shock. It is apparent that the bank channel has a mitigating yet symmetric role on output volatility.

To sum up, the main driver for the asymmetry in macro-financial spillovers in response to both shocks is the borrowers' balance sheet channel.

5 Monetary and Macroprudential Policies: A Welfare Analysis

In this section, I analyse the effects of two countercyclical policy measures: leaning-against-the-wind (LATW) and countercyclical macroprudential capital buffers (CCB). The advantages of these policies are thought to be a reduction in (i) the probability and costs of financial crises, and (ii) the volatility of the credit cycle (and therefore also the volatility of business cycles). However, countercyclical policies have often been found to be too costly to implement, as they can reduce the level of bank lending and output (see e.g. Svensson, 2014 for LATW or Van den Heuvel, 2008, and BIS (2010) for CCB). In this section, I study whether this conclusion still holds, when there are asymmetries in the transmission of financial shocks.

The idea of LATW-type monetary policy is that central banks smooth financial cycles and stabilise asset prices by allowing the interest rate to vary with asset prices. To model it, I extend the monetary policy rule in (23) by including an additional term for asset prices, $\left(\frac{q_t}{q}\right)^{\phi_q(1-\rho_{ib})}$, so that the new monetary policy rule follows

$$1 + r_t^{ib} = (1 + r^{ib})^{(1-\rho_{ib})}(1 + r_t^{ib})^{\rho_{ib}} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\rho_{ib})} \left(\frac{y_t}{y}\right)^{\phi_y(1-\rho_{ib})} \left(\frac{q_t}{q}\right)^{\phi_q(1-\rho_{ib})} (1 + \varepsilon_t^r). \tag{27}$$

The concept behind a CCB is that the capital adequacy ratio is adjusted for a measure of the financial cycle, which affects the lending behaviour of banks throughout the credit cycle and thus also dampens output volatility (Angelini et al., 2015). I follow the Basel III regulation and set the target leverage ratio, ν_t, in (14) to be time-varying and follow a countercyclical rule that depends on the credit-to-GDP ratio

$$\nu_t = (1 - \rho_v)\nu + (1 - \rho_v)\chi_v \left(\frac{B_t}{Y_t}\right) + \rho_v \nu_{t-1}. \tag{28}$$

For the calibration, of these two rules, I set the value of the autoregressive parameter in (28) to be $\rho_v = 0.9$, to make the policy very persistent, once the target leverage for banks is changed. The sensitivity of the capital ratio to the financial cycle is calibrated to $\chi_v = 0.0129$ to match an average deviation of 0-2.5% from the steady state value, as is foreseen by Basel III. To provide a fair comparison between the two policies, I calibrate the parameter of asset-leaning in (27), ϕ_q, to match the policy impact effect of the CCB rule on a negative shock on asset prices. This yields $\phi_q = 0.00375$ for the Taylor rule parameter.

To evaluate the welfare effects over the financial cycle, I calibrate the positive shock in an unconstrained state and the negative shock in a constrained credit state to correspond to the magnitude and duration of an average euro area credit cycle. Based on the asset price indicator in Section 1, the average magnitude is 8.3% and -7.3% for a boom and bust, respectively, lasting for roughly 4 years each. I follow Adam and Billi (2008) and Ascari and Ropele (2012) and compute the consumption welfare gain of households, μ^*, as the percentage value that would make the utility without countercyclical policies equivalent to the utility under the alternative policy (indicated by *), i.e.

$$\sum_{t=0}^{T} \beta^t u(c_t(1+\mu^*), l_t) = \sum_{t=0}^{T} \beta^t u(c_t^*, l_t^*), \tag{29}$$

where $\mu^* \geq 0$. Using the utility function from (2), and solving for the welfare gain, μ^*, yields

$$\mu^* = \exp[\sum_{t=0}^{T} \beta^t u(c_t^*, l_t^*) - \sum_{t=0}^{T} \beta^t u(c_t, l_t)] - 1. \tag{30}$$

The consumption welfare gain, μ, then represents the percentage of consumption households are gaining over one financial cycle in the euro area by adopting the alternative policy. The welfare gain in household consumption from the monetary policy rule is -0.24%, while the welfare gain from the macroprudential rule is positive, 2.14%.[6] The fact that countercyclical macroprudential policies can be welfare improving even without accounting for the reduction in the probability and costs of potentially prevented financial crises, is crucial for policy making, as the 2.14% can be considered as a lower bound for the actual welfare gain.

The difference in the welfare effects of the two policies is not surprising. Introducing an additional asset-price component into the standard Taylor rule only dampens the response of asset prices and does not affect the shape of the response. The response of the remaining variables in the financial sector is largely unaffected by the modified monetary policy rule and only changes the magnitude of the output and inflation responses. In contrast, adding macroprudential policy alters the steady state of the model and affects the responses of the financial sector as a whole. As banks need to adjust their leverage ratio to meet the time-varying target, the variability of leverage becomes much smaller and the variability of loans and the retail rate increase. This means that the target leverage ratio increases during a downturn, which causes banks to increase their lending rate and pass-on the higher costs to the consumers. By increasing lending spreads, borrowers reduce their demand for loans, which translates into less real activity. The opposite holds true for an upswing. Quantitatively, the reduction in the lending rate does not spur the same response in real activity.

While both these policies are specifically calibrated to match real life situations and thus not generalisable, the current analysis already provides a valuable insight into how asymmetric macro-financial linkages can be exploited. Policy makers can design countercyclical policy measures to reduce the volatility caused by the financial cycle without risking a substantial reduction in output during boom times. Macroprudential policies are particularly more powerful, as they affect the financial transmission channels directly. This result is consistent with Bruneau et al. (2016) who also find that macroprudential rules are preferred to a Taylor rule augmented for housing.

6 Conclusion

I conclude that the macro-financial transmission of financial shocks is asymmetric. The pass-through of a positive shock to the real economy is smaller during normal times than the pass-through of a negative shock during constrained times. This result is obtained both empirically in a MS-VAR, as well as in a structural, estimated DSGE model. In addition, the structural model allows me to distinguish between the two different

[6] Note that in a linear model, the welfare effects over the cycle would roughly be zero, as the welfare gains in bust times would cancel out the symmetric welfare losses in boom times. The steady state of the baseline model is the same under the new monetary policy rule, while introducing the macroprudential rule alters the steady state level of consumption and labour. Using (30), the steady state welfare from CCB is 0.08% smaller than under the baseline model. However, this implies that the transient welfare gain of introducing CCB is 2.14%-0.08% = 2.06%, and still positive.

macro-financial channels, the bank and borrowers' balance sheet channels. I find that in particular the borrower balance sheet channel plays a more dominant role in the asymmetry of the transmission, which is consistent with survey data.

In terms of policy, my analysis shows that the asymmetry in macro-financial linkages can be exploited by using countercyclical policies. Time-varying macroprudential capital buffer rules, as suggested by Basel III, seem more consumption welfare improving than an equivalent LATW policy, and actually constitute a welfare gain for households over the duration of the euro area financial cycle. Given that the model is not even taking into account the added benefits of a reduction in the probability and costs of financial crises, the welfare effects are likely to be larger.

An interesting extension of this paper would be the inclusion of risk and the precautionary savings motive. The risk channel affects the decision of households and firms to delay their consumption and investment. By extending the model with risk, it would be possible to analyse the effects of financial shocks on financial stability and give a more complete picture of macro-financial linkages. It would make it possible to inspect the build-up of risky asset bubbles during financial booms and the benefits of countercyclical policies for the reduction of crisis probability. Another interesting avenue would be to look at international macro-financial spillovers and the role of domestic macroprudential policies. As financial markets operate globally, imposing regulations can often have spillover effects on other countries.

To sum up, this paper has provided strong evidence that there are asymmetries in the transmission of shocks from the financial sector to the real economy. Neglecting these non-linearities could have sizeable and distortionary effects on policy recommendations, and should therefore be taken into account, when designing monetary and macroprudential policy.

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Appendix

Table A.1: Mean and standard deviation conditional on states

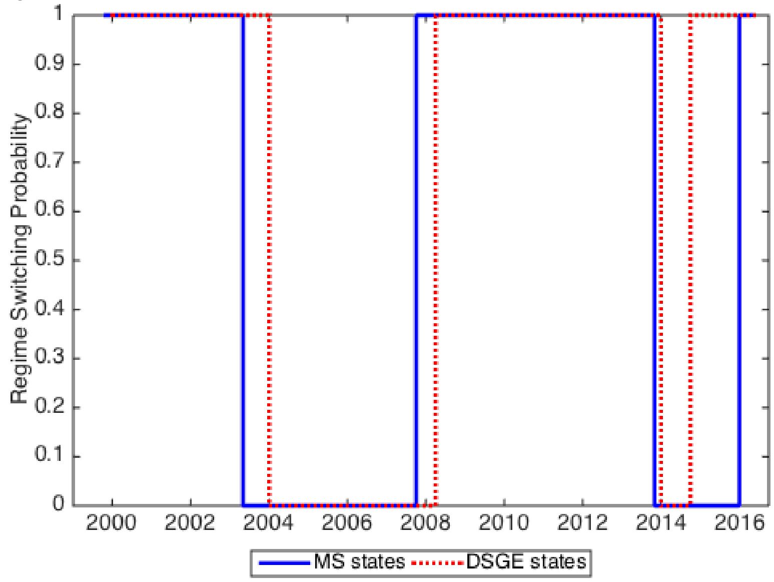
	Normal State	Constrained State
y	1.8591 (1.6745)	-0.9308 (6.0830)
π	1.4149 (0.9194)	2.0690 (0.8645)
i	0.0491 (0.6443)	-0.3660 (1.3072)
b	1.0345 (1.3501)	-1.8018 (2.594)
q	9.4368 (13.1354)	-7.9783 (26.3424)

Note: The values report the mean value of the variables conditional on the state with the standard deviation reported in brackets.

Table A.2: Calibrated Parameters

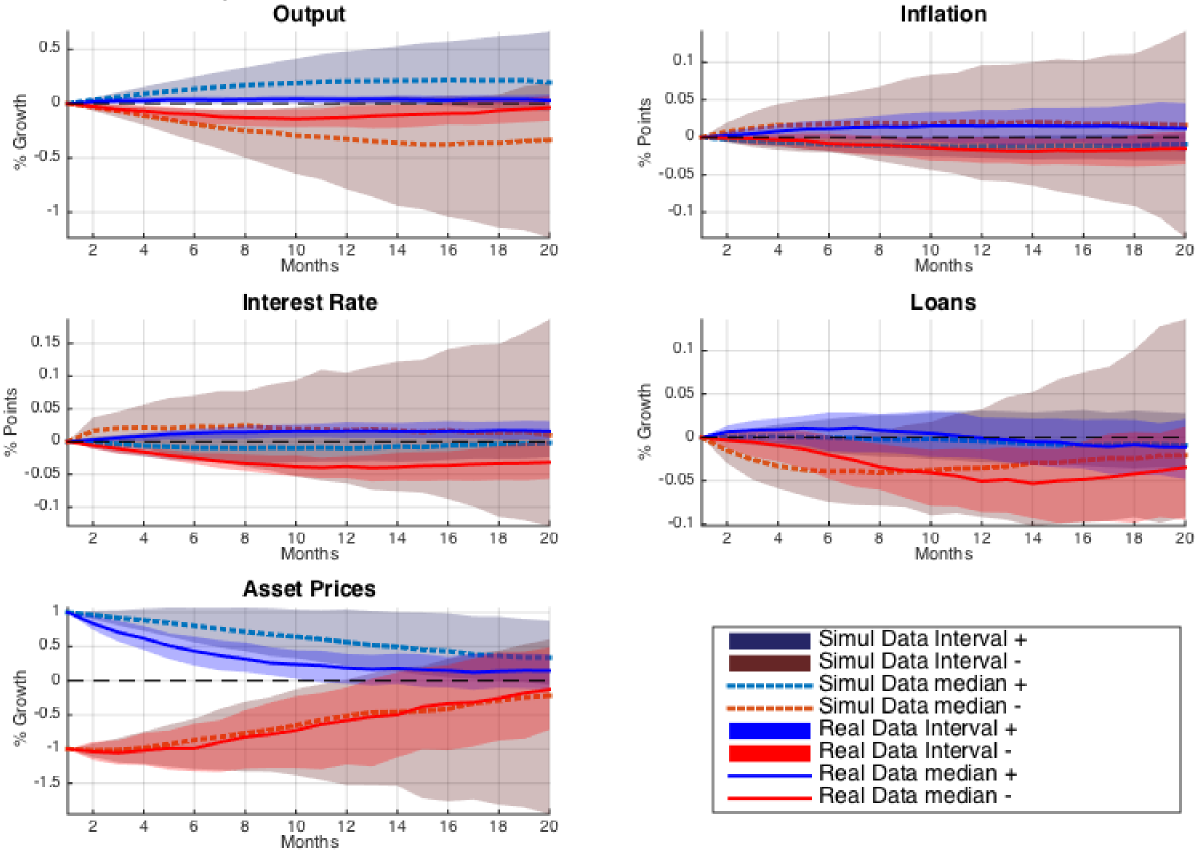
Parameters	Description	Value
β_P	Discount factor patient households	0.9943
β_E	Discount factor impatient entrepreneurs	0.975
ϕ	Elasticity of labour	1
mk^{ySS}	Steady state mark up	1.2
α	Capital share in production	0.25
δ_k	Depreciation Rate of Capital	0.050
$mcspread$	Marginal cost spread	0.0050
π^{ss}	Steady state of inflation	1
m_e^{ss}	Steady state Loan-To-Value ratio	0.35
θ	Bank capital adjustment cost	11
ν	Target capital-to-asset ratio	0.09

Figure A.1: State identification based on MS-VAR and DSGE model



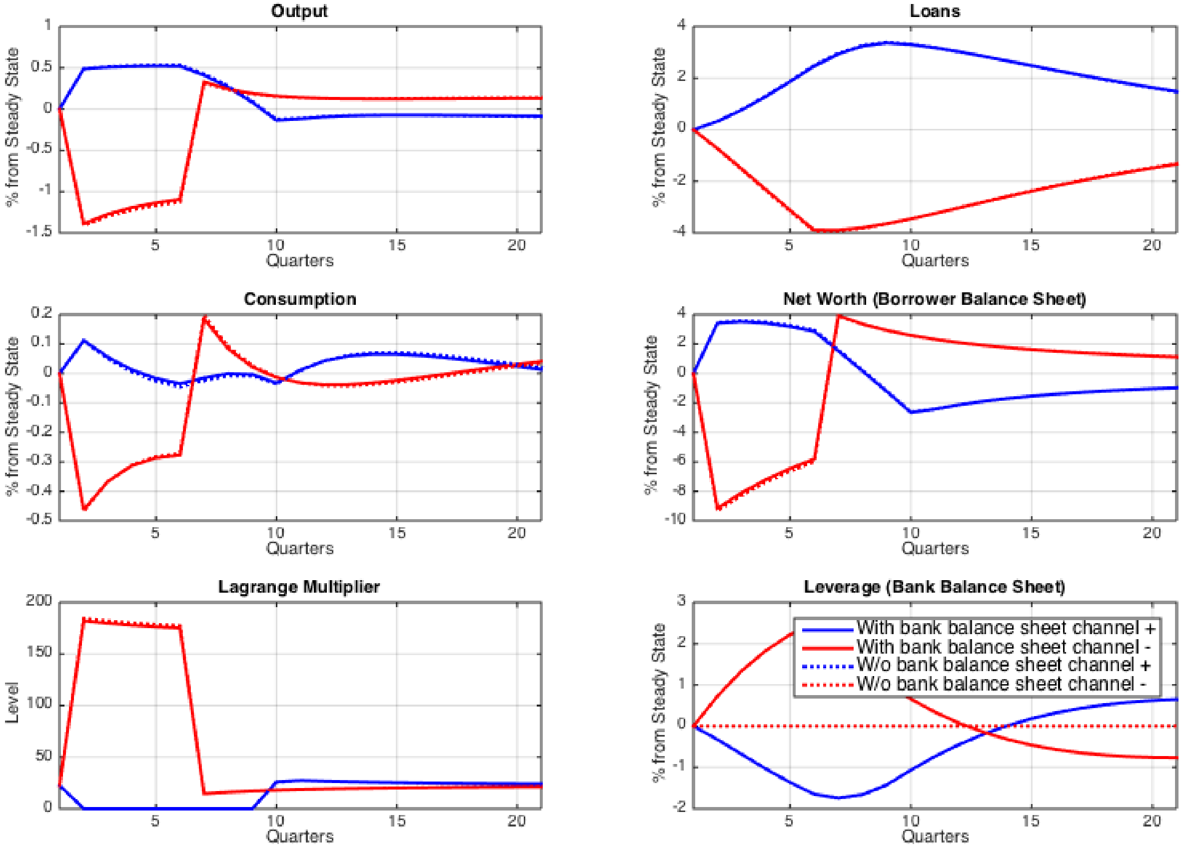
Note: The blue, solid line represents the states identified by the MS-VAR, while the red dotted line indicates the states identified by the non-linear, estimated DSGE model. The y-axis shows the probability of being in a credit constrained state.

Figure A.2: MS-VAR Impulse response comparison real vs. simulated data



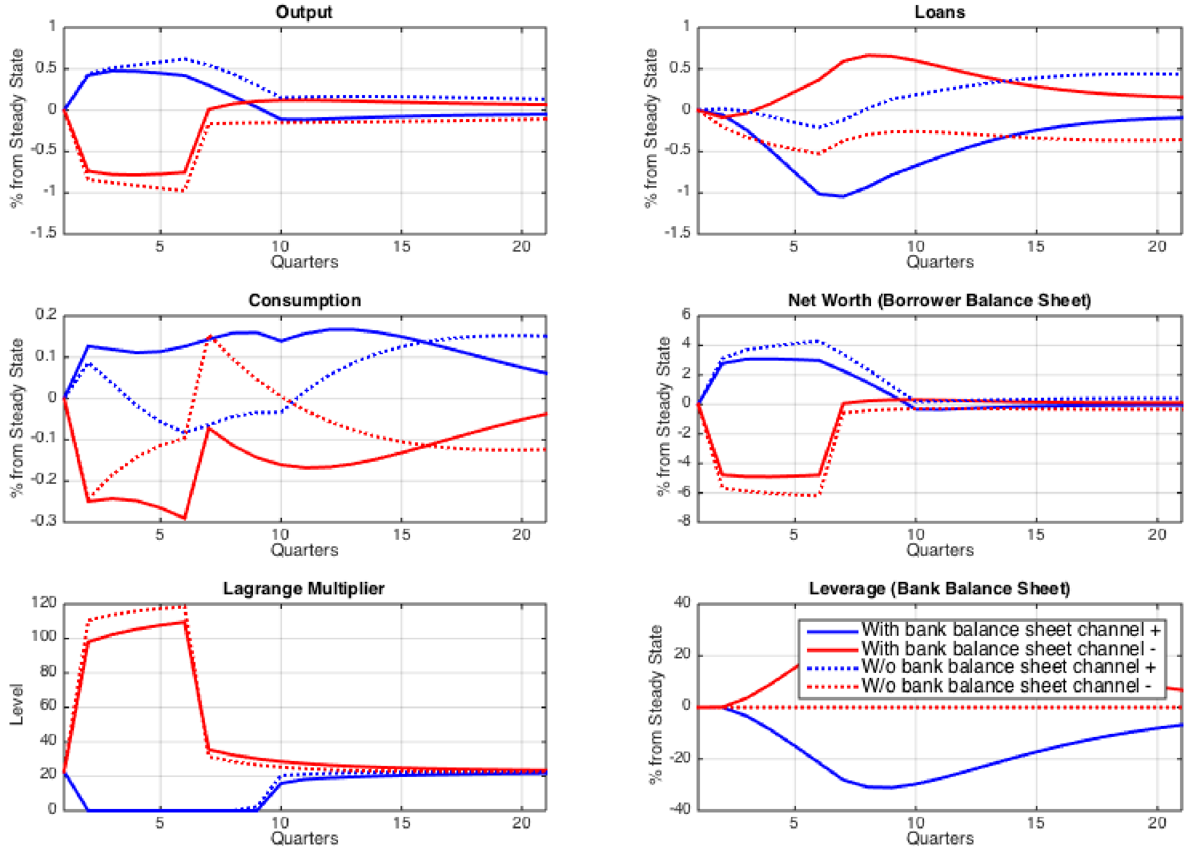
Note: The shaded regions report point-wise 68% credible sets. The coloured regions report the credible sets for the real data, while the grey, transparent interval represents the credible set based on the model with simulated data. The solid lines show the median response for the model with the real data, and the dashed lines report the median for the simulated data.

Figure A.3: LTV shock without bank balance sheet channel



Note: The blue line indicates a positive shock, while the red line represents a negative shock. The solid line is the baseline model, while the dotted line is the model without a bank balance sheet channel. The parameters and standard error are set to the posterior mean. The shock is induced for 5 periods, after which the series is left to revert back to its steady state.

Figure A.4: Net worth shock without bank balance sheet channel



Note: The blue line indicates a positive shock, while the red line represents a negative shock. The solid line is the baseline model, while the dotted line is the model without a bank balance sheet channel. The parameters and standard error are set to the posterior mean. The shock is induced for 5 periods, after which the series is left to revert back to its steady state.

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