Working Paper Series

No 41 / April 2017

Financial frictions and the real economy

by
Mario Pietrunti

ESRB
European Systemic Risk Board
European System of Financial Supervision

Abstract

This paper investigates in a non-linear setting the impact on the real economy of frictions stemming from the financial sector. We develop a medium scale DSGE model with a banking sector where an occasionally binding constraint on banks' capital induces a relevant non-linearity. The model - estimated on Italian data from 1999 to 2015 via a likelihood-free method - is able to generate business cycle asymmetries as in actual data that cannot replicated by linear models. Lastly, the role of macro-prudential policies in smoothing the cycle is discussed.
Keywords: Financial frictions, non-linear DSGE Models, likelihood-free estimation.
JEL Class.: C15, E32, E44, G01.

1 Introduction

After the Great Financial Crisis of 2008, the relevance of financial frictions in business cycle dynamics has been the subject of a vast research activity, with the development of new strands of literature highlighting the role of the financial sector as a source of business cycle fluctuations and as a shock propagator (Brunnermeier et al., 2013). From a normative viewpoint, the role of financial frictions has also spurred a debate on how to ensure stability in the financial system; this has led to the development of a new set of so called "macroprudential" policy tools.[1]

This widespread debate notwithstanding, surprisingly little quantitative research has been performed so far on the relevance of non-linear dynamics within the financial sector for the real economy. Indeed, a major shortcoming of most quantitative models with a financial sector lies in the fact that they are usually solved via a linear approximation around the steady state of the system. This in turn implies that the impact of the financial sector on the economy is symmetric both in boom and in bust periods.

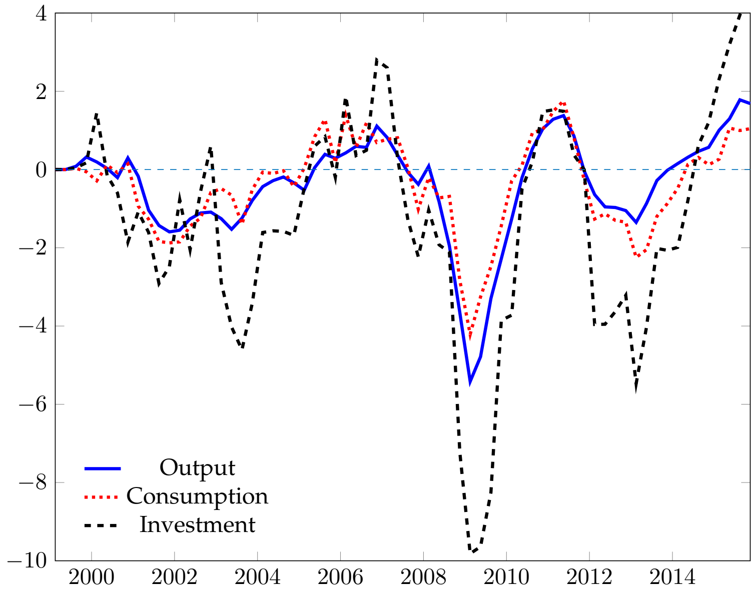
In this paper we attempt at quantitatively gauging the asymmetric impact on the real economy of financial frictions by estimating a DSGE model on a crisis hit economy, such as the Italian one. We choose Italy for two main reasons. First, the financial frictions we want to investigate arise from within the banking sector and influence quantities and prices of bank loans. In this respect, the Italian financial system is an fitting example, as financial intermediation is mainly performed by traditional banks.[2] Secondly, in the last decade Italy experienced a double dip recession that can be used as a laboratory to test the relevance of the non-linear dynamics of the financial accelerator model (see Figure 1).

The key research questions of the paper are then related to identify the impact on real variables of tensions arising in the banking sector.

[1]This label covers a variety of policies sharing the common objective of reducing systemic risk in the economy and of mitigating the financial cycle (Claessens, 2014). Some of these tools are already part of the standard toolkit of financial regulators: as a way of example, at the end of 2015 in Europe the national measures in the EU/EEA notified to the European Systemic Risk Board (ESRB), or of which the ESRB was aware, of macroprudential interest were 213.

[2]In 2013, banks accounted for almost 85 percent of total financial sector assets. The vast majority of Italian banks runs a traditional business model where the prevailing items on the asset side of the balance sheet are loans to the economy. The prevailing source of funding is deposits and customers loans (IMF, 2013).

Figure 1: Business cycle dynamics for output, consumption and investment in Italy (1999-2015)



Note: This figure displays the dynamics of output, consumption and investment in Italy from 1999q1 to 2015q4. Series are detrended with a one-sided HP filter with smoothing parameter equal to 1600. Data are at a quarterly frequency and are reported in per cent.

We try and answer the above questions by making use of a DSGE model with a banking sector where financial frictions can bite only occasionally. This non-linearity should help in principle in identifying asymmetries in the cycle: it has indeed been shown in the literature that occasionally binding credit constraints may give rise to asymmetric business cycles (Li and Dressler, 2011).

A further contribution of the paper is related to the estimation of large non-linear DSGE models. The model we are dealing with has indeed an occasionally binding constraint that gives rise to financial frictions in the economy; this implies that the model operates under two regimes: one in which financial frictions are in place and the other in which the allocation of resources is not affected by financial constraints. Keeping the model in its non-linear form should in principle help in better capturing the interaction between the financial system and the real economy compared to its linearized version.

However, so far one of the main hurdles for investigating large non-linear models has been their computational complexity. Here we rely on a method recently brought forward in Guerrieri and Iacoviello (2015b) for solving this class of models. One of the advantages of this method lies in its computational simplicity, which drastically reduces computational time and thus makes it possible to bring the model to the data. We therefore make use of an estimation technique that has been rarely employed so far for DSGE models which does not require computing the likelihood function. This method, that is gaining popularity in other disciplines, is known as Approximate Bayesian Computation (ABC, see Beaumont et al. 2002). We show that ABC can be easily implemented for estimating non-linear DSGE models and that it provides several advantages compared to other methods currently used in the estimation of non-linear DSGE models, such as the Simulated Method of Moments (Fernández-Villaverde and Rubio-Ramírez 2007 and Ruge-Murcia 2012). We show that the non-linear version of the model is better able than its linearized counterpart to approximate the asymmetries in real variables that can be observed in the data. More precisely, the estimated non-linear model better matches higher order moments (such as skewness and kurtosis) of output, consumption and investment.

Further, we show that keeping the non-linearity in the model is also of consequence for policy interventions aimed at smoothing out the real effects of the financial cycle. Hence, in the last section of the paper the impact of two macroprudential policy interventions is discussed: a counter-cyclical capital buffer in the banking sector and a pro-active monetary policy that reacts to the credit cycle. These policies are effective in reducing the impact of financial crises and in smoothing out the cycle, although with different degrees.

The current paper is related to two main strands of literature. First, it is related to papers embedding financial frictions, introducing them via an agency problem in the financial intermediation activity (see *ex multis* Gertler et al. 2010 and Gertler and Karadi 2011). Most of these papers are however solved via a first order approximation of the system around the steady state, thus assuming that financial constraints are binding at any point in time. Some recent papers have instead investigated the properties of models à la Gertler and Karadi (2011) assuming that financial frictions are only occasionally binding: Bocola (2014) is a paper very close to ours in terms of modelling, although its focus is on the effects of sovereign default risk on lending behavior. Prestipino (2014), Akinci and Queralto (2014) and Swarbrick et al. (2016) also rely on a similar non-linear set up, although the former has a policy focus on *ex-post* bail-outs. In all of these models however the estimation of a rich set of parameters is not viable since they are solved via global methods. Hence, a possible gain in solution accuracy comes at the cost of a significantly lower computational tractability.

The second strand of literature is related to solving and estimating non-linear DSGE models with financial frictions. In this respect the paper most close in spirit is Guerrieri and Iacoviello (2015a). In that paper, the authors use the solution method discussed above for estimating a DSGE with an occasionally binding collateral constraint on housing and a zero lower bound for the policy rate. They however estimate the model via maximum likelihood, whereas this paper relies on a method of moments estimation approach, that can be easily applied to any non-linear model.[3]

The rest of the paper is organized as follows. In Section 2 the key ingredients of the model are introduced. In Section 3 the solution of the model is presented along with the estimation strategy. In Section 4 the model is actually brought to the data and the results discussed. In Section 5 the role of macroprudential policies in the current framework is discussed. Section 6 concludes.

2 The Model

The model relies on a standard New Keynesian DSGE framework, enrichred with a financial sector à la Gertler and Karadi (2011). In this model, households provide labor services to the production sector but do not directly hold physical capital. Instead, the financing of production is intermediated by banks, which get funded by a combination of households' bank loans and internal equity and invest in both loans to firms and in government bonds. The production sector is made of intermediate good producers, capital producers and retailers. The distinction between intermediate good producers and capital producers is introduced in order to have a real friction in investment, which is subject to adjustment costs. As the household and production sides of the economy are relatively standard, a more accurate description of these sectors is relegated to Appendix A. In what follows, we will mainly focus on the banking sector and on government policies.

2.1 The banking sector

We assume that the representative household is made of a fraction of workers while the remaining part is made of bankers. Each banker runs a bank. In each period a fraction

[3] Also Bluwstein (2016) employs a maximum likelihood approach to estimate a model with financial frictions à la Gerali et al. (2010) and an occasionally binding constraint.

$(1-\sigma)$ of bankers becomes workers within the family and is replaced by an equal fraction of workers that become bankers. The new bankers are endowed with funds provided by the household.

In each period t, the funds available to a banker are bank loans d_t, bought by workers, and real net worth n_t, which arises from past earnings (for surviving bankers) and from endowments provided by the household (for new bankers). A banker uses these resources to buy private assets (loans) k_t at price $p_{k,t}$,[4] and long-term government bonds b_t at price $p_{b,t}$. The balance sheet of a banker then writes

$$p_{k,t}k_t + p_{b,t}b_t = n_t + d_t. \tag{1}$$

At the end of period t returns from the two assets are accrued and are used to repay the bank loans. The leftover is the net worth of the banker which accumulates according to the following law of motion:

$$n_t = (1 + r_{k,t})\, p_{k,t-1}k_{t-1} + (1 + r_{b,t})p_{b,t-1}b_{t-1} - (1 + r_{d,t-1})\, d_{t-1} \tag{2}$$

where $r_{k,t}$, $r_{b,t}$ and $r_{d,t}$ are respectively the returns on firms' loans, on government bonds and on bank loans.

The banker's objective is to maximize the discounted value of its net worth:

$$v_t = E_t \left\{ \sum_{s=1}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} (1-\sigma)\sigma^{s-1} n_{t+s} \right\}, \tag{3}$$

where λ_t is the Lagrange multiplier on the household's budget constraint. Up to this point, the introduction of a banking sector does not give rise to financial frictions per se and does not alter the dynamics of this economy. The financial friction is therefore introduced in the form of a minimum regulatory capital requirement. More precisely, it is assumed that the banking regulator requires that the discounted value of the bankers' net worth should be greater or equal than the current value of assets, weighted by their relative risk. Hence, denoting with $\alpha \in (0, 1]$ the risk weight on loans to the real economy and with $\alpha\alpha_b \in (0, 1]$ the risk weight for government bonds, the regulatory constraint

[4] The loans to the real economy are in fact a financial instrument that resembles more an equity contract (Gertler and Karadi, 2011).

writes:

$$v_t \geq \alpha(p_{k,t}k_t + \alpha_b p_{b,t}b_t). \tag{4}$$

To solve the banker's problem we adopt a guess and verify approach. We guess that the value function is a linear object of the form $v_t = \gamma_t n_t$, where γ_t can be interpreted as the marginal value of an extra unit of net worth. Then we can rewrite the value function as

$$v_t = \max_{k_t,b_t} E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} n_{t+1} \right\} \tag{5}$$

subject to constraint (4), with $\Omega_t \equiv 1 - \sigma + \sigma\gamma_t$. Hence the first order conditions for k_t and b_t and the complementary slackness condition read:

$$\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(r_{k,t+1} - r_{d,t} \right) \right\} = \alpha\mu_t \tag{6}$$

$$\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(r_{b,t+1} - r_{d,t} \right) \right\} = \alpha\alpha_b\mu_t \tag{7}$$

$$\mu_t \left[\gamma_t n_t - \alpha \left(p_{k,t}k_t + \alpha_b p_{b,t}b_t \right) \right] = 0 \tag{8}$$

where μ_t is the multiplier for constraint (4). The multiplier can be interpreted as the shadow value of relaxing the credit constraint. Therefore, it is also a measure of the severity of the financial friction. Indeed, note that when the constraint is not binding (i.e. $\mu_t = 0$), we get that $E_t \left\{ r_{k,t+1} \right\} = E_t \left\{ r_{b,t+1} \right\} = r_{d,t}$, so that the financial friction is shut down and the frictionless economy allocation is recovered. An alternative interpretation of the constraint being not binding is that when $\mu_t = 0$ the economy is in a Modigliani-Miller setup: it is indeed indifferent for the bank to hold equity and debt, as their rate of return is equivalent.

Another useful remark is the following. In the light of our guess of the value function, we can rewrite (4) as follows:

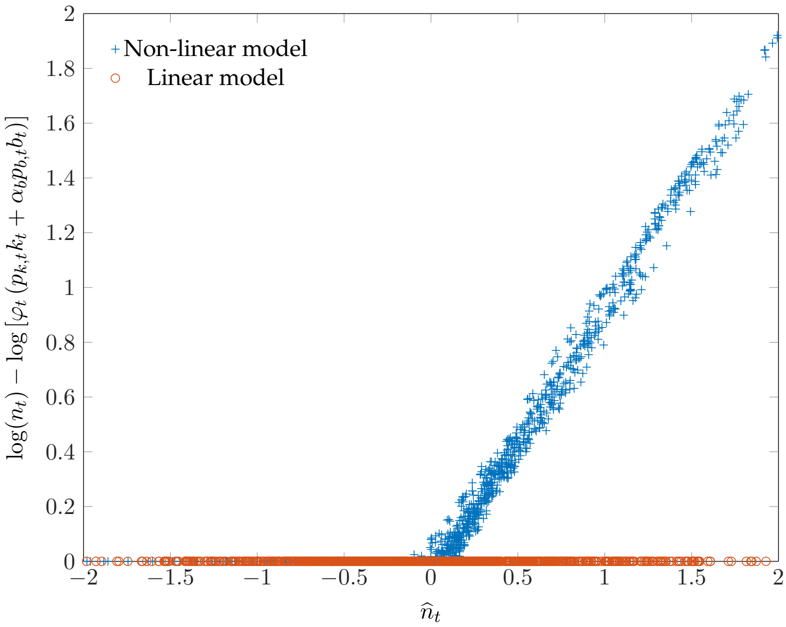
$$n_t \geq \varphi_t \left(p_{k,t}k_t + \alpha_b p_{b,t}b_t \right) \tag{9}$$

where $\varphi_t = \frac{\alpha}{\gamma_t}$ has a straightforward interpretation as a capital ratio. In other words, in order to comply with regulatory requests - assumed to be perfectly enforceable -, the bank needs to keep this ratio at a level at least equal to φ_t.

As in Bocola (2014) and in Prestipino (2014), but in contrast with the original contribution by Gertler and Karadi (2011), we do not impose that the constraint is binding all the time. We instead treat it as an occasionally binding constraint, thus introducing a relevant non-linearity in the model.

To see the relevance of such assumption, in Figure 2 the amount of bankers' net worth along with the difference (in logs) between the left and the right-hand sides of inequality (9) is plotted. More precisely, Figure (2) draws from a simulation of the model, with parameters values equal to the ones resulting from the calibration and estimation exercises conducted in the following sections. On the horizontal axis we plot bankers' net worth in log-deviation from the steady state. On the vertical axis we plot the difference between the left- and the right-hand sides of (9) in logs.

Figure 2: Occasionally binding credit constraint



Note: This figure plots data from a simulation of the model for 1000 p eriods. It displays on the horizontal axis the value of n_t in long-deviation from the steady state, while on the horizontal axis the log of both sides of the inequality (9). The values of the parameters are the ones derived from the results of the calibration and estimation exercise discussed in the following sections.

If the constraint was always binding, the difference between the left and the right hand sides of inequality (9) would be zero as the net worth of bankers would always equate the right hand side of the equation. This is indeed what actually happens when the model is linearized around the steady state (linear model).

If the model is solved assuming that the constraint is binding only occasionally, instead, there are times in which the net value of bankers exceeds the minimum level required by the regulator. An interesting feature of the non linearity is that when the constraint is not binding the relationship between the net worth of banks and the amount of assets held (ie. the amount of loans to the economy and of government bonds) is less stringent. This occurs more often when banks are well capitalized. In other words, the probability of the constraint being slack is higher with high values of $\widehat{n}_t$.

Turning to the solution of the bankers' problem, if we substitute equation (2) and the FOCs into the value function we get

$$v_t = \alpha\mu_t \left(p_{k,t}k_t + \alpha_b p_{b,t} b_t\right) + \beta \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(1 + r_{d,t}\right) n_t \tag{10}$$

then using FOCs and the guess for the value function we can recover the value of γ_t:

$$\gamma_t n_t = \gamma_t \mu_t n_t + \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(1 + r_{d,t}\right) n_t \right\} \tag{11}$$

$$\gamma_t = \frac{1}{1-\mu_t} \left[\beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(1 + r_{d,t}\right) \right\} \right]. \tag{12}$$

In the first expression it can be seen that the marginal value of an extra unit of net worth can be decomposed into two terms: the return on equity when the constraint is not binding and the gain that comes from relaxing the regulatory capital constraint.

The description of the banking sector is concluded by constructing the aggregate law of motion for the net worth of the banking sector as a whole. Aggregate net worth is made of the sum of the net worth of old and new bankers, weighted by their number. The old bankers' net worth is given by combining (1) and (2). As for new bankers, their net worth is given by their endowment. We assume that the transfer to new bankers is proportional to the beginning of period net worth n_{t-1}, with proportionality coefficient

ω. On aggregate, the law of motion of real net worth n_t is thus

$$\begin{aligned} n_t = \;& \sigma\left[(r_{k,t} - r_{d,t-1})p_{k,t-1}k_{t-1} + (r_{b,t} - r_{d,t-1})p_{b,t-1}b_{t-1}\right] \\ & + \left[\sigma(1 + r_{d,t-1}) + \omega\right] n_{t-1}. \end{aligned} \tag{13}$$

2.2 Government

The government finances its public expenditure by raising taxes and issuing long term bonds. Long-term bonds are modeled assuming that in each period only a fraction δ_π of them comes to maturity. On the remaining fraction of bonds the government pays a coupon ρ. In order to introduce sovereign credit risk in the model in a parsimonious way, we assume that the fraction of short-term bonds may be subject to the reprofiling shock $\varphi_{b,t}$. Such a shock implies a reprofiling of debt maturity: in case of a negative shock, the government is unexpectedly lengthening the maturity structure of its bond stock and partly postponing the reimbursements of short term bonds, thus implying a partial default. The shock does not aims at introducing actual default of the government, but it is rather meant to capture a confidence shock in government bonds, leading investors to charge a higher return on this asset class.

Then, denoting $\tilde{\delta}_\pi = \delta_\pi e^{\varphi_{b,t}}$, the government budget constraint writes

$$p_{b,t}\left[b_t - (1 - \tilde{\delta}_\pi)b_{t-1}\right] = b_{t-1}\left[\tilde{\delta}_\pi + (1 - \tilde{\delta}_\pi)\rho\right] + g_t - Tax_t, \tag{14}$$

where the return on bonds will be equal to

$$1 + r_{b,t} = \frac{\tilde{\delta}_\pi + (1 - \tilde{\delta}_\pi)(\rho + p_{b,t})}{p_{b,t-1}}. \tag{15}$$

It can be noticed that as long as $1 - \rho - p_b, t > 0$, a condition easily satisfied for a reasonable calibration of parameters, a positive confidence shock leads to a sudden and unexpected increase in the interest rate on long-term government bonds.

Lastly, total taxes are equal to

$$Tax_t = T_t + \tau_c c_t + \tau_w w_t h_t \tag{16}$$

where T is a lump sum tax, τ_c is a consumption tax and τ_w is a tax on labor. We assume that government spending obeys the fiscal rule[5]

$$\widehat{g}_t = \gamma_g \widehat{g}_{t-1} + \lambda_g \widehat{b}_t + \varphi_{g,t} \tag{17}$$

where $\widehat{g}_t$ and $\widehat{b}_t$ denote log-deviations from the steady state and $\varepsilon_{g,t}$ is a disturbance to government spending.

To close the model, we introduce monetary policy in the form of a simple Taylor rule

$$i_t = \rho_{mp} i_{t-1} + (1-\rho_{mp}) \left[\frac{\kappa_\pi}{4} \hat{\pi}_t^a + \frac{\kappa_y}{4} (\log y_t - \log y_{t-4}) \right] + \varphi_{R,t} \tag{18}$$

where $1 + \pi_t^a = \prod_{p=0}^{3} (1 + \pi_{t-p})$ and

$$1 + i_t = (1 + r_{d,t})\, E_t(1 + \pi_{t+1}). \tag{19}$$

3 Model solution and empirical strategy

3.1 Solution of the model

The key challenge in solving the model is related to the non-linearity of the system and, accordingly, to its intractability for estimation purposes. Indeed, dealing with a large non-linear model is still considered a daunting task for practitioners: accurate methods such as those grouped under the label of ”global methods” are usually computationally intensive and can only deal with rather few state variables.[6]

For models with occasionally binding constraints, an interesting alternative has been recently put forward by Guerrieri and Iacoviello (2015b). The basic intuition behind the suggested method is to approximate the policy functions via a first-order piecewise linear approximation around the steady state of the model. The method builds on the fact that models with an occasionally binding constraint can be summarized by two regimes: one

[5]To ensure the stationarity of bond dynamics, an endogenous fiscal rule is needed as shown in Bohn (1995).

[6]As already acknowledged, this is one of the main differences of this paper with Bocola (2014), where global methods are used in the solution of the model. This implies that in that paper estimation has to be performed in two steps, given the high computational burden.

in which the constraint is binding and the other in which the constraint is not binding.[7] The linearization of each regime is performed around the (unique) steady state of the model and then a guess-and-verify approach is employed to identify the transition path from one regime to the other. The interested reader can find an accurate description of the algorithm along with the minimal properties of the model required for applying the method in the original paper by Guerrieri and Iacoviello (2015b).

An important assumption for the solution method to work is that in the long run, in absence of shocks, the model has to return to its unique non-stochastic steady state. In the present paper, we assume that the steady state exists and is located in the regime where the financial constraint is binding. When we will discuss the actual calibration and estimation of the model, we will check that the value of the multiplier at steady state is effectively greater than zero (ie. the constraint is binding).[8]

The solution of the current model, under the proposed method, can be written in its canonical form as

$$X_t = P_t X_{t-1} + Q_t \varepsilon_t \tag{20}$$

where X_t is the vector of endogenous variables - both jump and predetermined -, P_t and Q_t are time-varying transition matrices which depend on X_{t-1} and ε_t (ie. $P_t \equiv P\left(X_{t-1}, \varepsilon_t\right)$ and $Q_t \equiv Q\left(X_{t-1}, \varepsilon_t\right)$) and ε_t is the vector of the structural shocks.

3.2 Estimation strategy

The solution technique discussed above poses a challenge in terms of estimation, since the likelihood of the system - although observable - is computationally hard to recover. In principle one could still make use of maximum likelihood methods to estimate the system of equations (20). Indeed, this is what Guerrieri and Iacoviello (2015a) do when they bring their model to the data. However, in what follows we explore a more general estimation procedure that can be applied to any non-linear DSGE model. The method employed belongs to the class of likelihood-free methods and is called Adaptive Bayesian Computation (ABC, see Beaumont et al. 2002). In essence, the ABC method builds on

[7] The argument can be made more general in case of more than one occasionally binding constraint.

[8] Note however that this is an unrequired step in the procedure, as the linearization under the two regimes could be performed around any other point.

an MCMC sampler, whose acceptance/rejection criterion is given by the distance of a given set of simulated moments from their empirical counterparts. To the best of our knowledge, this is one of the first papers where this method is employed for estimating a DSGE.[9] For the model at hand, the estimation procedure we propose is equivalent in terms of computational time to estimating the model via maximum likelihood.

The likelihood-free algorithm is described in Table 3.2.

---

1. Initialize θ_1, $x_1(\theta_1)$
2. For steps $t = 1, ..., T$
   (a) Generate θ' from the proposal distribution $q(\cdot, \theta_t)$
   (b) Compute $x' \sim \pi\left(x|\theta'\right)$
   (c) Calculate $r = \min\left\{1, \frac{\pi_\varepsilon(y|x',\theta')\pi(\theta')q(\theta',\theta_t)}{\pi_\varepsilon(y|x_t,\theta_t)\pi(\theta_t)q(\theta_t,\theta')}\right\}$
   (d) Draw $u \sim U[0,1]$
      i. if $u \leq r$ then $(x_{t+1}, \theta_{t+1}) = (x', \theta')$
      ii. else $(x_{t+1}, \theta_{t+1}) = (x_t, \theta_t)$
   (e) Go back to step (a).

Table 1: Estimation algorithm

Some ingredients of the algorithm need further clarification. First, the proposal distribution $q(\cdot, \theta_t)$ is a standard random walk proposal: $q(\cdot, \theta_t) \sim \mathbf{N}(\theta_t, c)$, where the variance-covariance matrix c is obtained as the inverse of the hessian of log-likelihood of linear model, appropriately scaled to obtain a satisfactory acceptance rate. Secondly, as for the weighting function $\pi_\varepsilon\left(y|x', \theta'\right)$ we make use of a Gaussian kernel density:

$$\pi_\varepsilon\left(y|x, \theta\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\rho(T(x),T(y))} \tag{21}$$

[9] A New Keynesian model in continuous time is estimated with this technique in Hayo and Niehof (2014), while a more general discussion of the application of this method to DSGE models is in Scalone (2015).

where $T(x)$ and $T(y)$ are respectively simulated and empirical moments. The function $\rho\,(T(x), T(y))$ is instead the Mahalanobis distance between empirical and simulated moments:

$$\rho\,(T(x), T(y)) = \left\{ [T(x) - T(y)]^{\top}\, W^{-1}\, [T(x) - T(y)] \right\}^{\frac{1}{2}} \tag{22}$$

where the weighting matrix W is a diagonal matrix whose elements are given by the absolute deviation (in percent) between the empirical moments and the moments generated by a 1,000 periods simulation of the linear version of model.

Making use of the Gaussian kernel density has a practical advantage compared to other kernel density functions in that it does not require to impose an arbitrary bound for the maximum distance acceptable between $T(x)$ and $T(y)$ (see Sisson and Fan 2011).

Overall, the ABC method has two main advantages compared to other methods. First, alike to the Simulated Method of Moments it implies that one does not need to compute the likelihood of the system. This is particularly useful when the likelihood is not available or hard to compute. Secondly, the Bayesian nature of ABC gives this method a huge practical advantage compared to the Simulated Method of Moments, since one can make use of priors to inform the exploration of the space of parameters.

4 Implementation and data

Turning to actual implementation, the total number of parameters in the model is 42. We split the set of parameters into two subsets. A first subset of 19 parameters is recovered via calibration of steady state values. A discussion of the calibration of these parameters is reported in the next section. The remaining 23 parameters are instead estimated.

The data used in the estimation are 7 Italian macroeconomic series taken at quarterly frequency in the period 1999q1 to 2015q4. The variables include real per-capita consumption, GDP and investment. For inflation we take the Harmonised Index of Consumer Prices. We then take three series for interest rates: the bank bonds rate R_d is the average rate on bank bonds, the return on physical capital R_k is represented by the interest rate on loans to non-financial corporations, while the interest rate on government bonds R_b is an index produced by the Bank of Italy known as ”Rendistato”. This index is the average yield on a basket of government securities weighted by their outstanding amount. The series for consumption, GDP and investment are detrended with a one-sided HP-filter with smoothing parameter set at 1600.

As for priors, for most of the parameters (with the exception of values for the variance of the shocks) we use values reported in Cahn et al. (2017) (CMS from now on), where a fairly similar model on euro area data is estimated. The set of moments we use for estimation is made of the variance of the above seven series and their correlation. On top of these moments we also target first order autocovariance, skewness and kurtosis of output, consumption and investment. We therefore end up with 37 moments to be matched (see Table 3).

4.1 Calibration

A subset of 19 parameters is calibrated in such a way that the steady-state value of some variables matches the average in the period 1999-2015 of their empirical counterparts.[10] The parameter values are reported in Table 1.

[10] Detailed computations of the steady state of the model are reported in a Technical Appendix, available upon request.

Parameter	Value	Description
β	0.991	discount factor
ζ	2	inverse of Frisch elasticity of labor supply
a_0	.034	utilization cost parameter
χ	22.59	labor supply scale parameter
δ	.025	depreciation rate
θ	.3	capital share
Nominal rigidity parameters		
θ_p	6	product elasticity of substitution
ξ_p	.66	price reoptimization probability
ι_p	.17	degree of inflation indexation
Banking sector parameters		
α	0.1535	risk weight on loans
α_b	0.8890	relative risk weight on bonds
$\hat{\omega}$	0.0024	new bankers' endowments
Fiscal parameters		
τ_c	.061	consumption tax
τ_w	.082	labor tax
δ_π	.0388	share of short-term government bonds
ρ	0.007	coupon on long-term bonds
Steady state values		
b/y	4.4	steady state debt-to-gdp ratio
g/y	0.19	steady state share of government consumption
π	0	steady state inflation

Table 2: Calibration values

The discount factor β is set to 0.991 in order to match the annual Italian banking sector average yield on bonds of 3,65% between 1999 and 2015.[11] The inverse of the Frisch

[11]Indeed, at the steady state the following relationship holds: $1 = (1 + R_d)\beta$.

elasticity of labor supply is fixed at 2, a value that is standard in a vast macro literature (eg. see Smets and Wouters 2007). The degree of habit formation and the parameter for adjustment costs in investment are taken from the estimation performed by CMS.

Then, we set a_0 in the adjustment cost function reported in equation (30) in such a way to obtain a normalized steady state capital utilization of 1. The scale parameter for labor supply, χ, is chosen to match a steady state value for labor equal to .33, as is standard in the literature. The depreciation rate δ and the capital share in the production function, θ, are also assigned standard values.

The values for parameters related to the nominal rigidity block are taken from CMS. Among those, the product elasticity of substitution is set at a level that implies a price markup of 20 per cent, while firms are assumed to be able to reoptimize their prices once every three quarters.

Turning to parameters related to the banking sector, the risk weight parameter α is instead chosen to match the annual Italian banking sector average yield on loans to the non-financial sector. Such a yield was equal to 3,83 per cent on an annual basis between 1999 and 2015. The parameter governing the relative risk of government bonds as compared to the loans to firms, α_b, is also taken to match the average interest rate on Italian government bonds from 1999 to 2015. Such a rate is the Rendistato yield, which on average was equal to 3,81 per cent in the reference period. Lastly, the parameter related to the endowment of new bankers, $\hat{\omega}$, targets the average capital ratio for Italian banks from 1999 to 2015, equal to 11.7 per cent.[12] Note in passing, that such calibration of banking sector parameters implies that the multiplier at steady state is positive ($\mu = 0.004$), thus implying that the reference regime is the one in which the financial constraint is binding.

Moving to fiscal parameters, the value for τ_c corresponds to the average amount of VAT as a percentage of GDP (6.1 per cent). The value of the labor tax parameter τ_w corresponds to the revenue of labor taxation (for employed paid by employees) as a percentage of GDP (8.2 per cent). The source for these values is Eurostat (2014). As for parameters related to government bonds, the share of short-term government bonds, δ_π, is chosen to match the average residual life (6,44 years) of Italian government bonds (source: Ital-

[12] The capital ratio series is available from the IMF and is given by the ratio of total regulatory capital over risk-weighted assets.

ian Treasury). The coupon paid on long term issuances, ρ, is instead set to a value that matches the average coupon on BTPs issued from 1999 to 2015 (2,98% a year, source: Italian Treasury).

Two steady state relationships are also imposed: the debt-to-GDP ratio is set at 4.4, which is the equivalent at a quarterly frequency of the average debt-to-GDP per year in Italy from 1999 to 2015 (109 per cent). The ratio of government spending over GDP is instead set at the value of 19 per cent, as in the data.[13] Lastly, inflation at the steady state is set for simplicity (and in line with the literature) at zero per cent.

4.2 Estimation Results

The estimation chain is made of 100,000 draws with an acceptance rate equal to 32%. The results of the estimation are reported in Table 2.

[13]These two ratios are computed based on data from the Italian quarterly national accounts, provided by Istat. The amount of government debt is computed as the outstanding amount of general government debt net of deposits held by the Bank of Italy.

Parameter	Prior			Posterior		Linear model	
	shape	mean	s.d.	mean	s.d.	mean	s.d.
κ_π	gamma	1.67	2	1.49	0.342	1.41	0.081
κ_y	gamma	0.73	2	0.64	0.122	0.09	0.057
λ_g	beta	-0.3	1	-0.46	0.318	-0.93	0.033
η	inv. gamma	0.55	0.1	0.52	0.104	0.53	0.001
ν_i	inv. gamma	4	1	10.64	3.130	3.26	0.024
a_1	inv. gamma	0.4	0.1	0.40	0.100	0.43	0.004
σ	inv. gamma	0.985	0.1	0.806	0.258	0.996	0.002
ρ_c	beta	0.5	0.1	0.50	0.095	0.50	0.001
ρ_k	beta	0.7	0.1	0.72	0.095	0.63	0.001
ρ_i	beta	0.9	0.1	0.91	0.089	0.92	0.002
ρ_z	beta	0.7	0.1	0.71	0.101	0.81	0.002
ρ_b	beta	0.8	0.1	0.79	0.099	0.88	0.005
ρ_g	beta	0.9	0.1	0.90	0.056	0.85	0.002
ρ_r	beta	0.5	0.1	0.49	0.099	0.45	0.002
γ_g	beta	0.5	0.1	0.51	0.114	0.40	0.002
ρ_{mp}	beta	0.5	0.1	0.51	0.095	0.45	0.002
σ_c	inv. gamma	0.01	2	0.010	0.010	0.014	0.001
σ_k	inv. gamma	0.01	2	0.008	0.007	0.003	0.000
σ_i	inv. gamma	0.01	2	0.011	0.015	0.019	0.002
σ_z	inv. gamma	0.01	2	0.029	0.057	0.006	0.001
σ_b	inv. gamma	0.01	2	0.007	0.006	0.433	0.041
σ_g	inv. gamma	0.01	2	0.008	0.007	0.027	0.002
σ_r	inv. gamma	0.01	2	0.011	0.013	0.001	0.000

Note: This table reports the estimated values of parameters under an Adaptive Bayesian Computation algorithm based on 100,000 draws from prior distributions. The posteriors of the linear model are recovered via a standard MCMC estimation based on 100,000 draws from the same prior distributions.

Table 3: Estimation Results

For comparison, we also report the posterior mean and standard deviations derived from the linearized version of the model (with financial frictions always binding) estimated with standard Bayesian techniques, using the same priors. Estimated parameters can be grouped in two subgroups: the first is made of various parameters related both to policy and to frictions in the economy. The second subgroup is made of parameters related to the autoregressive component and to the variance of the shocks. First, it is interesting to note that the inflation coefficient of the Taylor rule is fairly similarly estimated in both the linear and non-linear models and its value is close to the reference value of 1.5. On the other hand, the output gap parameter is fairly high compared to the literature, but in line with the finding of CMS. This is one of the most relevant differences in estimation with respect to the linear model, which in turn displays a much lower value for such parameter.[14] In this subset of parameters, it is also worth highlighting that the parameter ν_i, related to investment adjustment costs, takes a relatively high value (three times higher than CMS and than the value obtained in the linear estimation). Also, the survival probability of bankers $(1 - \sigma)$ implies an average life of a banker of about one year and three months.

The remaining parameters are the autoregressive parameters and the standard deviations of the shocks. Concerning the former, it is interesting to note that the autoregressive parameters are basically confirmed in the posterior, whereas the variances of these shocks tend to differ in the linear and non-linear models. More precisely, we find that the values of most of the variances turn out to be lower in the non-linear version of the model (with the exception of the variances of capital quality, productivity and interest rate shocks). This suggests that part of the exogenous variation in the linear model is endogenized in the non-linear version. In other words, the non-linear model is better able to endogenously generate business cycle fluctuations, whereas the linearized model needs to rely more on external disturbances to match the big swings observed in the data.

4.3 Matching moments

Turning to moments matching, in Table 3 we plot the values of the moments used in the estimation exercise both in the data and in the linear model.

[14] It is worth to note here that since we are estimating the monetary policy rule on data of a country which belongs to a monetary union, one has to interpret the Taylor rule as an equation that merely closes the model.

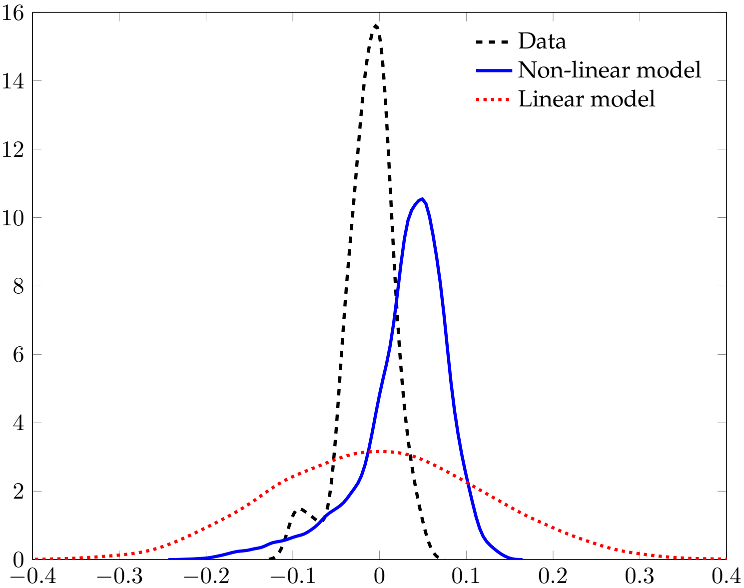
Moment	Data	Non-linear model	Linear model	Moment	Data	Non-linear model	Linear model
Standard deviation				i, R_b	0.3	-0.13	-0.1
y	0.13	0.15	0.19	i, R_k	0.41	-0.09	-0.13
c	0.12	0.21	0.26	i, π	0.38	0.05	0.46
i	0.28	0.52	1.21	R_d, R_b	0.53	0.04	0.42
R_d	0.01	0.07	0.05	R_d, R_k	0.91	0.02	0.43
R_b	0.01	0.23	0.11	R_d, π	0.42	-0.4	-0.03
R_k	0.01	0.3	0.12	R_b, R_k	0.65	0.93	0.77
Correlation				R_b, π	0.68	-0.3	-0.5
π	0.02	0.07	0.06	R_k, π	0.53	-0.23	-0.49
y, c	0.9	0.53	-0.04	First order autocorr.			
y, i	0.91	0.77	0.64	y	0.91	0.86	0.87
y, R_d	0.38	-0.73	-0.03	c	0.84	0.96	0.97
y, R_b	0.3	-0.22	-0.34	i	0.84	0.99	0.98
y, R_k	0.54	-0.16	-0.32	Skewness			
y, π	0.36	0.27	0.68	y	-1.44	-0.33	0.03
c, i	0.87	0.36	-0.25	c	-0.7	0.06	0
c, R_d	0.27	-0.36	-0.09	i	-0.82	-1.28	0.06
c, R_b	0.41	0.01	0.08	Kurtosis			
c, R_k	0.44	0.03	0.11	y	6.15	3.33	2.96
c, π	0.42	-0.28	-0.35	c	3.61	2.88	2.86
i, R_d	0.31	-0.22	0.04	i	4.27	5.34	2.81

This table reports the value of the moments used in the estimation of the model. The estimated moments for the linear and non-linear versions of the model are computed via a simulation for 10,000 periods of the two models, with parameters values taken from the estimation above described. Standard deviation for each series is multiplied by 10.

Table 4: Empirical and Simulated Moments

The non-linear model represents a significant improvement in terms of variance matching compared to its linear counterpart. This comes at the expense of matching correlations among the selected variables, where the performance of the non-linear model compared to the linear one is mixed. Also the performance in terms of matching auto-correlations (with one or two lags) is relatively similar in the linear and non-linear models. However, the importance of solving the model non-linearly can be gauged when one moves to higher order moments. What the non-linear version of the model adds is indeed an asymmetric behavior of variables in boom and bust periods. This can be observed in Figure 3 where we plot the density of investment both in the data and in a 10,000 period simulation of the two models.

Figure 3: Investment density



Note: In this figure the density of investment both in the data and in the models is reported. Density is computed through a normal kernel smoothing estimate over 100 equally spaced points. The density for the linear and non-linear model is computed via a 10,000 periods simulation of the models, with parameters values taken from the estimation and calibration exercises above described.

It can be noted that the distribution of investment in the data displays a fat left tail, which is mainly associated with the slump in 2008-2009. The linear version of the model approximates the density poorly, due to the fact that linear models are by definition symmetric.

In Table 4 we report skewness and kurtosis of output, consumption and investment in the two versions of the model and in the VAR(1), with parameters values as in the previous section and simulating the model for 10,000 periods.

	Output	Consumption	Investment
	Skewness		
Non-linear model	-0.33	0.06	-1.28
p-value	*< 0.1%*	*2.44%*	*< 0.1%*
Linear model	0.03	0	0.06
p-value	*18.59%*	*> 95%*	*1.35%*
VAR(1)	0	-0.03	-0.03
p-value	*99.38%*	*26.91%*	*25.44%*
Data	**-1.44**	**-0.70**	**-0.82**
p-value	***< 0.1%***	***1.74%***	***0.65%***
	Kurtosis		
Non-linear model	3.33	2.88	5.34
p-value	*< 0.1%*	*0.85%*	*< 0.1%*
Linear model	2.96	2.86	2.81
p-value	*46.13%*	*0.36%*	*< 0.1%*
VAR(1)	3.02	2.98	3.05
p-value	*60.73%*	*75.38%*	*26.44%*
Data	**6.15**	**3.61**	**4.27**
p-value	***0.01%***	***19.42%***	***4.57%***

Note: This table reports skewness a kurtosis tests for output, consumption and investment computed from a simulation for 10,000 periods of the models, with parameters values taken from the estimation described in the text, and from the data. The numbers in italic are the p-values for the D'Agostino (1970) test (for skewness) and of the Anscombe and Glynn (1983) test (for kurtosis). The null hypotesis for the D'Agostino test is that skewness is not significantly different from zero (see . The null hypothesis for the Anscombe test is that kurtosis is not significantly different from 3 (as in the normal distribution).

Table 5: Asymmetry of real variables

It can be noticed that with respect to output and investment, the non-linear model is the only one that is able to match the negative skewness of the two distributions, thus confirming the quantitative relevance of the occasionally binding constraint, that induces asymmetric cycles, with crisis episodes being deeper than booms. Consumption is instead found not to be significantly skewed in the three models, while in the data it displays a moderate skew to the left mainly related to the 2009 crisis episode.

Turning to kurtosis, the data reveal that output and investment - although less markedly - display a leptokurtic distribution, thus implying a higher peak and fatter tails compared to the normal distribution. These features of the data are confirmed in the non-linear model, whereas they are rejected - again by definition - in the two linear models.

5 Counterfactuals with macroprudential policies

In this section we build on the estimation results to perform policy counterfactuals and to quantitatively assess the impact of macroprudential policies on the real economy. Here macroprudential policies are introduced as two different tools. First of all, we introduce a Countercyclical Capital Buffer (CCyB) in the banking sector. The CCyB can be viewed as the main macroprudential tool of the Basel III regulatory framework and it is aimed at ensuring ”that banking sector capital requirements take account of the macro-financial environment in which banks operate” (BCBS, 2011). In practical terms, it implies that the regulatory capital ratio should increase during the positive phase of the financial cycle, in order to make the banking sector more resilient.

A direct regulatory intervention in the banking system, however, is not the only macroprudential policy option available. Indeed, after the Great Financial Crisis of 2008 new streams of literature have been explored (and old streams of literature revived) investigating the role of more standard tools, such as monetary policy, in stabilizing the financial cycle. The question of whether it is appropriate for monetary policy to include financial conditions in the Taylor rule is still open (see for example Gambacorta and Signoretti 2014). Therefore we introduce in the current setting, as a potential alternative to the countercyclical capital buffer, an enriched version of the Taylor rule that takes also into account the financial cycle.

Countercyclical capital buffer. We introduce the countercyclical capital buffer assuming that the banking regulator can make the capital requirement procyclical and dependent on the Credit-to-GDP gap. This policy tool has indeed a real-life counterpart in the Countercyclical Capital Buffer introduced in Basel III.[15] Specifically, we assume that under this policy the parameter α in equation (9) is not fixed anymore, but varies through the cycle according to the following formula:

$$\alpha_t = \alpha + \lambda_\alpha \widehat{CGG}_t \tag{23}$$

where $\widehat{CGG}_t$ is defined as in Basel III as current credit to the economy (k_{t-1}) divided by the average GDP in the last 4 quarters, net of the trend (ie. the Credit-to-GDP gap):

$$\widehat{CGG}_t = \frac{k_{t-1}}{0.25\sum_{i=1}^{4} y_{t-i}} - \frac{k}{y}. \tag{24}$$

In what follows λ_α is set at the value 0.2, which implies that the countercyclical add-on can reach a maximum value of about 2.5% in the simulation exercises. This is indeed the maximum value of the buffer envisaged in the Basel III accords.

Leaning-against-the-wind monetary policy. As an alternative option, the credit-to-GDP gap is introduced as an extra variable in the Taylor rule:

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\frac{\kappa_\pi}{4}\hat{\pi}^a_t + \frac{\kappa_y}{4}(\log y_t - \log y_{t-4}) + \lambda_i \widehat{CGG}_t\right] + \varphi_{R,t}. \tag{25}$$

Such an extended policy rule and its stabilization properties have been extensively studied both at the theoretical and quantitative level[16] and it has been adopted by various central banks to tackle bubbles in asset markets.[17] In the counterfactual scenario, the parameter λ_i is assigned the value of 0.05, which implies that the risk free rate is raised by up to 2% (at an annual frequency) in the boom phase of the credit cycle.

[15]See `http://www.bis.org/bcbs/basel3.htm`. The CCyB has been adopted in Italy for the first time in the first quarter of 2016 and was set to 0 %. See `http://www.bancaditalia.it/compiti/stabilita-finanziaria/politica-macroprudenziale/documenti/en_CCyB_2016Q1.pdf?language_id=1`.

[16]See *ex multis* Curdia and Woodford (2010), Cúrdia and Woodford (2015) and Gambacorta and Signoretti (2014).

[17]A case that has been intensely debated among academics and policymakers is the one of Sweden, where the Riksbank in recent years has pursued a relatively restrictive monetary policy in order to reduce risks stemming from the housing market (Svensson, 2016).

5.1 Counterfactuals

With these tools we investigate the features of our economy under the baseline case and in policy counterfactuals. In order to do so, we simulate the model for 10,000 periods with no macroprudential policies in place. Then we use the same shock sequence from the baseline case in three conterfactual scenarios where the following policy tools are active: a) countercyclical capital buffer; b) leaning-against-the-wind monetary policy; c) both instruments active at the same time. We then compute some features of interest of these economies, such as the variance and skewness of real variables (output, consumption and investment), the number of periods with binding financial frictions in place and the average length of an episode with financial frictions in place.[18] In Table 5 all these variables are reported along with their percentage deviation from the baseline scenario.

[18]Here we define a period in which financial frictions are binding as a period of financial stress. Therefore, for brevity, in Table 5 we will label such episodes as ”crisis” episodes.

Feature	Baseline (A)	CCyB (B)	Dev. % (B)-(A)	Monetary Policy (C)	Dev. % (C)-(A)	CCyB & Monetary Policy (D)	Dev. % (D)-(A)
Variance							
Output	2.29	2.26	**-1.1**	2.21	**-3.3**	2.21	**-3.4**
Consumption	4.28	4.29	**0.4**	3.62	**-15.5**	3.64	**-14.8**
Investment	26.54	25.37	**-4.4**	22.16	**-16.5**	21.56	**-18.8**
Skewness							
Output	-0.330	-0.326	**-1.2**	-0.186	**-43.7**	-0.179	**-45.9**
Consumption	0.055	0.061	**9.7**	0.046	**-16.8**	0.050	**-8.5**
Investment	-1.28	-1.30	**1.1**	-1.07	**-16.3**	-1.04	**-18.7**
Crisis times (%)	10.79	10.70	**-0.8**	10.51	**-2.6**	10.37	**-3.9**
Avg crisis length	3.26	3.26	**0.1**	3.32	**1.7**	3.28	**0.7**

Note: This table reports various features of the model under the three macroprudential policy scenarios. The features have been computed from a simulation of the model for 10000 periods under the same shocks. Variances are multiplied by 100. The length of a crisis period is in quarters. The columns Dev. % represent the percentage deviation of the outcome under each policy with respect to the outcome in the baseline (ie. without macroprudential policies) scenario.

Table 6: Counterfactuals

In the table it can be seen that output and investment volatility is reduced in all three cases. Monetary policy however seems the most effective policy in reducing volatility of real variables. As for the skewness of real variables, instead, the CCyB proves roughly ineffective, while monetary policy can significantly reduce the negative skewness of output and investment.

The economy has financial frictions in place for about 11 per cent of the time and no single macroprudential policy seems able to significantly reduce such n umber. On the other hand, monetary policy slightly increases the average length of the crisis (which in the baseline is about 3 quarters).[19]

[19] It has to be noted that the analysis carried so far is exclusively focussed on the transmission on the real economy of macroprudential policy stimulus. However, since no bank default will ever occur in equilibrium,

When the two policies are simultaneously active, the effect is roughly additive and no significant gain from complementarity seems to be obtained.

One may wonder whether such results are driven by the calibration of the policy tools or are instead inherent to their transmission mechanism. To answer such questions, in Appendix B, some sensitivity analysis is performed with respect to different values of the policy parameters λ_α and λ_i. The exercise shows that the gains from increasing the CCyB parameter are relatively modest, whereas the economy is far more sensitive to a change in the monetary policy parameter. Interestingly, raising the coefficients of both policy parameters implies that the economy stays in a financial crisis for longer. Also, with respect to monetary policy, a stronger reaction of the interest rate implies an increase in output volatility.[20]

Overall, two main takeaways should be taken from the counterfactual exercise. First, macroprudential policies seem indeed partly effective in smoothing business cycle dynamics. Second, monetary policy is the most effective policy, although both policies tackle different aspects of the dynamics induced by binding financial frictions. When simultaneously active, the policies induce a better smoothing of real variables.

6 Conclusion

In this paper we investigated the quantitative relevance of financial frictions in terms of inducing relevant non-linearities in the behavior of real economy variables. We made use of the method of Guerrieri and Iacoviello (2015b) for solving the model with a non-linearity arising from the presence of an occasionally binding credit constraint. We then showed how to estimate the model with likelihood-free methods. We further showed that the non-linear model is able to generate relevant asymmetries in the dynamics of output and investment that cannot be obtained with linear models. The results of the estimation were then used for performing counterfactual exercises with macroprudential policies in place. It is shown that the activation of these policy tools can indeed reduce business

the model is agnostic on whether the CCyB increases the resilience of the banking sector. For a model of macroprudential policies in which default in the banking sector is explicitely modelled, see Clerc et al. (2015).

[20] In principle, one would aim at performing a welfare analysis to investigate the optimal value of λ_i and λ_α, ie. the two macroprudential parameters. However, an analysis of this sort cannot be performed in this context, as the model is still solved via a first-order approximation in each regime.

cycle fluctuations and that monetary policy with a macroprudential term is indeed more effective than the CCyB in tackling the financial cycle.

Further research could be in the future devoted to welfare analysis in a non-linear environment, aimed at identifying the optimal instruments among the many available and their optimal parameterization.

References

AKINCI, O. AND A. QUERALTO (2014): "Banks, capital flows and financial crises," *FRB International Finance Discussion Paper*.

ANSCOMBE, F. J. AND W. J. GLYNN (1983): "Distribution of the kurtosis statistic b2 for normal samples," *Biometrika*, 70, 227–234.

BCBS (2011): "Basel III: A global regulatory framework for more resilient banks and banking systems," Tech. rep.

BEAUMONT, M. A., W. ZHANG, AND D. J. BALDING (2002): "Approximate Bayesian computation in population genetics," *Genetics*, 162, 2025–2035.

BLUWSTEIN, K. (2016): "Asymmetric Macro–Financial Linkages How useful is the financial sector for the economy?" Tech. rep.

BOCOLA, L. (2014): "The Pass-Through of Sovereign Risk," *Manuscript, University of Pennsilvania*.

BOHN, H. (1995): "The sustainability of budget deficits in a stochastic economy," *Journal of Money, Credit and Banking*, 257–271.

BRUNNERMEIER, M. K., T. M. EISENBACH, AND Y. SANNIKOV (2013): "Macroeconomics with financial frictions: A Survey," in *Advances in Economics and Econometrics: Volume 2, Applied Economics: Tenth World Congress*, Cambridge University Press, vol. 50, 3.

CAHN, C., J. MATHERON, AND J.-G. SAHUC (2017): "Assessing the Macroeconomic Effects of LTROs during the Great Recession," *Journal of Money, Credit and Banking*, forthcoming.

CLAESSENS, S. (2014): *An overview of macroprudential policy tools*, 14-214, International Monetary Fund.

CLERC, L., A. DERVIZ, C. MENDICINO, S. MOYEN, K. NIKOLOV, L. STRACCA, J. SUAREZ, AND A. P. VARDOULAKIS (2015): "Capital Regulation in a Macroeconomic Model with Three Layers of Default," *International Journal of Central Banking*, 11, 9–63.

CURDIA, V. AND M. WOODFORD (2010): "Credit spreads and monetary policy," *Journal of Money, Credit and Banking*, 42, 3–35.

CÚRDIA, V. AND M. WOODFORD (2015): "Credit frictions and optimal monetary policy," Tech. rep., National Bureau of Economic Research.

D'AGOSTINO, R. B. (1970): "Transformation to normality of the null distribution of g1," *Biometrika*, 679–681.

EUROSTAT (2014): "Taxation trends in the European Union: 2014 edition," Tech. rep.

FERNÁNDEZ-VILLAVERDE, J. AND J. F. RUBIO-RAMÍREZ (2007): "Estimating macroeconomic models: A likelihood approach," *The Review of Economic Studies*, 74, 1059–1087.

GAMBACORTA, L. AND F. M. SIGNORETTI (2014): "Should monetary policy lean against the wind?" *Journal of Economic Dynamics and Control*, 43, 146–174.

GERALI, A., S. NERI, L. SESSA, AND F. M. SIGNORETTI (2010): "Credit and Banking in a DSGE Model of the Euro Area," *Journal of Money, Credit and Banking*, 42, 107–141.

GERTLER, M. AND P. KARADI (2011): "A model of unconventional monetary policy," *Journal of monetary Economics*, 58, 17–34.

GERTLER, M., N. KIYOTAKI, ET AL. (2010): "Financial intermediation and credit policy in business cycle analysis," *Handbook of monetary economics*, 3, 547–599.

GUERRIERI, L. AND M. IACOVIELLO (2015a): "Collateral Constraints and Macroeconomic Asymmetries," .

——— (2015b): "OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily," *Journal of Monetary Economics*, 70, 22–38.

HAYO, B. AND B. NIEHOF (2014): "Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time New Keynesian Model," .

IMF (2013): "Italy: Financial System Stability Assessment," Tech. rep., iMF Country Report No. 13/300.

LI, S. M. AND S. DRESSLER (2011): "Business cycle asymmetry via occasionally binding international borrowing constraints," *Journal of Macroeconomics*, 33, 33–41.

PRESTIPINO, A. (2014): "Financial Crises and Policy," Tech. rep.

RUGE-MURCIA, F. (2012): "Estimating nonlinear DSGE models by the simulated method of moments: With an application to business cycles," *Journal of Economic Dynamics and Control*, 36, 914–938.

SCALONE, V. (2015): "Estimating Non-Linear Dsges with the Approximate Bayesian Computation: An Application to the Zero Lower Bound." Tech. rep.

SISSON, S. A. AND Y. FAN (2011): "Likelihood-free MCMC," *Handbook of Monte Carlo, ed. Brooks, A., Gelman, A., Jones, GL, Meng XL*, 313–335.

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

SVENSSON, L. E. (2016): "Cost-Benefit Analysis of Leaning Against the Wind: Are Costs Larger Also with Less Effective Macroprudential Policy?" Tech. rep., National Bureau of Economic Research.

SWARBRICK, J., T. HOLDEN, AND P. LEVINE (2016): "Endogenous financial crises in a model of occasionally binding constrained borrowing," .

A Rest of the model

A.1 Households

There is a continuum of measure one of identical households. In each household there is a fraction of bankers f, while the other members of the household are workers. There is perfect consumption insurance between workers and bankers. A typical household has the utility function

$$E_t \sum_{s=0}^{\infty} \beta^s e^{\varphi_{c,t+s}} \left\{ \log(c_{t+s} - \eta c_{t+s-1}) - \frac{\chi}{1+\zeta} \int_0^{1-f} h_{t+s}(i)^{1+\zeta} \mathrm{d}i \right\} \tag{26}$$

where c_t is private consumption. The flow of consumption services is subject to habit formation, with degree $\eta \in [0, 1)$, $h_t(i)$ is the supply of labor of each worker in the household, $\chi > 0$ is a scale parameter, and $\zeta \geq 0$ governs the elasticity of labor supply. Finally, $\varphi_{c,t}$ is a preference shock that follows a zero-mean AR(1) process of the form

$$\varphi_{c,t+1} = \rho_c \varphi_{c,t} + \sigma_c \epsilon_{c,t+1}, \quad \epsilon_{c,t} \sim N(0, 1). \tag{27}$$

The household maximizes (26) subject to the sequence of real budget constraints

$$(1 + \tau_c)c_t + d_t = (1 + r_{d,t-1})d_{t-1} + (1 - \tau_w)w_t h_t + Div_t + T_t \tag{28}$$

where w_t is the real wage rate paid to worker *i* and d_t denotes deposits paying the real interest rate $r_{d,t}$. Taxes are levied on the household in the form of a lump sum tax T_t and of taxes on consumption (τ_c) and on labor (τ_w). Finally Div_t denotes net aggregate profits redistributed by retailers, intermediate good firms, capital producers, and bankers to the households. Let λ_t denote the Lagrange multiplier on constraint (28).

A.2 Intermediate Good Production

At the end of period $t - 1$, a unit-mass continuum of intermediate good firms finances capital purchases to be used in the next period by issuing k_{t-1} which are bought by bankers at price $p_{k,t-1}$. At the beginning of period t the quality of capital is revealed to the firms through the realization of an AR(1) shock $\varphi_{k,t}$, so that efficient capital is

$\bar{k}_t = e^{\varphi_{k,t}} k_{t-1}$. In period t, these CRS firms have access to the technology

$$y_t = A(\upsilon_t \bar{k}_t)^{\theta} (e^{z_t} h_t)^{1-\theta}, \tag{29}$$

where A is a scale factor, h_t is the input of aggregate labor, $\bar{k}_t$ is the input of efficient capital (i.e. capital after the capital quality has been revealed), and υ_t is the capital utilization rate, entailing a cost $a(\upsilon_t)\bar{k}_t$ (measured in final good units). The utilization cost is such that in the deterministic steady state $a(\upsilon) = 0$. We therefore assume that

$$a(\nu_t) = a_0(\nu_t - 1) + \frac{a_1}{2} (\nu_t - 1)^2 , \tag{30}$$

Finally, z_t is a permanent productivity shock. Technical progress is assumed to evolve according to the process

$$z_t = z_{t-1} + \varphi_{z,t}, \tag{31}$$

$$\varphi_{z,t+1} = \rho_z \varphi_{z,t} + \sigma_z \epsilon_{z,t+1}, \quad \epsilon_{z,t} \sim N(0,1). \tag{32}$$

Let $P_{m,t}$ be the price of the intermediate goods. Hence, profits obey

$$P_{m,t} A(\upsilon_t \bar{k}_t)^{\theta} (e^{z_t} h_t)^{1-\theta} - W_t h_t - a(\upsilon_t) P_t \bar{k}_t \tag{33}$$

The FOC wrt h_t and υ_t are

$$w_t = (1-\theta) \frac{P_{m,t}}{P_t} \frac{y_t}{h_t}, \tag{34}$$

$$a'(\upsilon_t) = \theta \frac{P_{m,t}}{P_t} \frac{y_t}{\upsilon_t \bar{k}_t}. \tag{35}$$

Thus, the per-unit real cash flow accruing to effective capital $\bar{k}_t$ is

$$z_{k,t} = \theta \frac{P_{m,t}}{P_t} \frac{y_t}{\bar{k}_t} - a(\upsilon_t) \tag{36}$$

In equilibrium, the return on capital obeys

$$1 + r_{k,t} = \frac{z_{k,t} + (1 - \delta)\, p_{k,t}}{p_{k,t-1}} e^{\varphi_{k,t}}. \tag{37}$$

This return is entirely rebated to banks to pay for the date $t-1$ loan.

A.3 Capital Producers

Capital producers buy back $\tilde{k}_t$ units old efficient capital units, add to these new capital units using the input of final output (subject to adjustment costs) and sell the new capital to firms at the relative price $p_{k,t}$. Given that households own capital producers, the objective of a capital producer is to choose a contingent plan for i_t so as to maximize

$$E_t \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} \left\{ p_{k,t+s} \left[\tilde{k}_{t+s} + i_{t+s} \left(1 - S\left(\frac{i_{t+s}}{i_{t-1+s}} \right) \right) e^{\varphi_{i,t+s}} \right] - i_{t+s} - p_{k,t+s} \tilde{k}_{t+s} \right\}, \tag{38}$$

where $S(\cdot)$ is an adjustment cost function such that $S(1) = S'(1) = 0$. In the actual implementation of the model we will assume the following functional form for $S = \frac{\nu_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$. The associated FOC on i_t is

$$1 = p_{k,t} \left(1 - S\left(\frac{i_t}{i_{t-1}} \right) - S'\left(\frac{i_t}{i_{t-1}} \right) \frac{i_t}{i_{t-1}} \right) e^{\varphi_{i,t}} + E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} p_{k,t+1} S'\left(\frac{i_{t+1}}{i_t} \right) \left(\frac{i_{t+1}}{i_t} \right)^2 e^{\varphi_{i,t+1}} \right\}. \tag{39}$$

Notice that the FOC on $\tilde{k}_t$ implies that any value of $\tilde{k}_t$ is consistent with profit maximization. It follows that $\tilde{k}_t$ is pinned down by the equilibrium on the market for used capital, yielding $\tilde{k}_t = (1-\delta)\mathrm{e}^{\varphi_{k,t}} k_{t-1}$, so that

$$k_t = (1 - \delta)\, e^{\varphi_{k,t}} k_{t-1} + i_t \left(1 - S\left(\frac{i_t}{i_{t-1}} \right) \right) e^{\varphi_{i,t}}. \tag{40}$$

A.4 Retailers

Retailers simply repackage intermediate goods and sell it to the households. The final output composite writes

$$y_t = \left[\int_0^1 y_t(j)^{\frac{\theta_p - 1}{\theta_p}} \mathrm{d}j \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{41}$$

Retailers face nominal rigidities à la Calvo, thus assuming that only a fraction $1 - \xi_p$ of them is allowed to adjust its resale price. If retailers cannot reoptimize, they update their prices according to the rule

$$P_{t+1}(i) = (1+\pi)^{1-\iota_p}(1+\pi_t)^{\iota_p} P_t(i) \tag{42}$$

Each retailer who is allowed to reoptimize chooses the price that the maximises the discounted value of profits until the price will remain fixed, subject to the demand constraint.

$$\max_{P_t^*(j)} \quad E_t \sum_{s=0}^{\infty} (\beta\xi_p)^s \frac{\lambda_{t+s}}{\lambda_t} \left[P_t^*(j) \Pi_{k=1}^{s} (1+\pi)^{1-\iota_p}(1+\pi_{t+k-1})^{\iota_p} - P_{mt+s} \right] y_{t,t+s}^*(j) \tag{43}$$

$$\text{s.t.} \quad y_t^*(j) = \left(\frac{P_t^*(j)}{P_t} \right)^{-\theta_p} y_t \tag{44}$$

A.5 Resource Constraint and Equilibrium

The aggregate resource constraint is

$$c_t + g_t + i_t + a(\upsilon_t)e^{\varphi_{k,t}} k_{t-1} = y_t. \tag{45}$$

B Sensitivity Analysis

λ_a	0	1	1.5	2
Max CCyB	0	1.8%	2.6%	3.5%
Variance				
Output	2.29	2.27	2.26	2.25
Consumption	4.28	4.29	4.29	4.30
Investment	26.54	25.73	25.37	25.03
Skewness				
Output	-0.330	-0.327	-0.326	-0.325
Consumption	0.055	0.059	0.060	0.062
Investment	-1.28	-1.29	-1.30	-1.30
Crisis times (%)	10.79	10.73	10.70	10.66
Avg crisis length	3.26	3.26	3.26	3.31

Note: This table reports various features of the model under different values of λ_a. The features have been computed from a simulation of the model for 10000 periods under the same shocks. Variances are multiplied by 100. The length of a crisis period is in quarters. The row ″max CCyB″ reports the 99th quantile of the deviation between the capital ratio in the baseline scenario and in each scenario where the policy is active.

Table 7: Sensitivity of CCyB policy

λ_i	0	0.01	0.05	0.1
Max rate	0	0.4%	2.2%	4.4%
Variance				
Output	2.29	2.21	2.21	2.80
Consumption	4.28	4.12	3.62	3.20
Investment	26.54	25.28	22.16	22.25
Skewness				
Output	-0.33	-0.30	-0.19	-0.11
Consumption	0.06	0.06	0.05	-0.01
Investment	-1.28	-1.25	-1.07	-0.81
Crisis times (%)	10.79	10.77	10.51	9.92
Avg crisis length	3.26	3.34	3.32	3.34

Note: This table reports various features of the model under different values of λ_i. The features have been computed from a simulation of the model for 10000 periods under the same shocks. Variances are multiplied by 100. The length of a crisis period is in quarters. The raw ”max rate” reports the maximum deviation observed in the simulation in the risk free interest rate (R_d), in annual terms, from the baseline scenario (no policy).

Table 8: Sensitivity of monetary policy

C Data Sources

- real per capita gdp, y: Source: Istat, quarterly national accounts.
- real per capita consumption, c: final consumption expenditure of households and non-profit institutions serving households. Source: Istat, quarterly national accounts.
- real per capita investment, i: gross fixed capital formation. Source: Istat, quarterly national accounts.
- rate on deposits, R_d: Banks: average yield on bonds - outstanding amounts. Source: Bank of Italy, Money and banking.
- rate on loans to firms, R_k: Bank interest rates on euro loans to non-financial corporations: new business. Interest rate - loans other than bank overdrafts to non-financial corporations - new business. Source: Bank of Italy, Money and banking.
- rate on government debt, R_b: Average gross yield-to-maturity on bonds in the sample of pubblic-sector securities, subject to withholding tax listed on the Stock Exchange (Rendistato). Source: Bank of Italy, The financial market.
- inflation rate, π: Harmonised Index of Consumer Prices. Source: ECB.

Imprint and acknowlegements

The views expressed herein are those of the author and should under no circumstances be interpreted as reflecting those of Banca d'Italia or the Eurosystem. Part of this paper was written while visiting EIEF, whose hospitality is gratefully acknowledged. I thank Piergiorgio Alessandri, Francesco Bianchi, Fabrice Collard, Vincenzo Cuciniello, Davide Delle Monache, Martial Dupaigne, Patrick Fève, Christian Hellwig, Guido Lorenzoni, Julien Matheron, Stefano Neri, Roberto Pancrazi, Fabrizio Perri, Franck Portier, Giuseppe Ragusa, Juan Rubio-Ramirez, Jean-Guillaume Sahuc, Anatoli Segura, Federico Signoretti and Javier Suarez for useful suggestions and discussions.

Mario Pietrunti
Banca d'Italia, DG Economics, Statistics and Research; email: **mario.pietrunti@bancaditalia.it**

Postal address	60640 Frankfurt am Main, Germany
Telephone	+49 69 1344 0
Website	**www.esrb.europa.eu**

Note:
The views expressed in ESRB Working Papers are those of the authors and do not necessarily reflect the official stance of the ESRB, its member institutions, or the institutions to which the authors are affiliated.

ISSN	2467-0677 (online)
ISBN	978-92-95081-93-2 (online)
DOI	10.2849/50795 (online)
EU catalogue No	DT-AD-17-008-EN-N (online)