# Credit Cycles, Regime Switching and Monetary Policy*

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**Abstract**

Internationally synchronized credit cycles have become a major challenge for monetary policy. On the national level, monetary authorities moved to unconventional monetary policy to control the credit cycle on a national level. We include in an inflation targeting model of the type developed by Svensson (1997) a nonlinear Phillips curve – allowing for a state-dependent relation of the inflation rate and the output gap – and add nonlinear dynamics for credit flows and loan interest rate spreads. We solve such an extended monetary policy model and study the dynamic effects of price oriented as well as credit volume oriented monetary policy variants. We estimate our nonlinear simultaneous equation system based on data for the euro area, to thereby inform the model parameters and explore, via simulations, the stabilizing - destabilizing effects of price (credit cost) and non-price (credit volume) policies. On the basis of a proposed small scale nonlinear quadratic (NLQ) model with two regime switches –similar to more complex large scale models – we can explicitly study the effects of conventional and unconventional monetary policy for various economic scenarios with endogenous credit flows, variation of risk premia, and credit spread movements, first in the NLQ model and then through a regime switching VAR and corresponding impulse-responses.

Keywords: inflation targeting, credit cycles, credit spread, nonlinear Phillips curve, unconventional monetary policy, RS-VAR

JEL classification: E42, E52, E58.

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# 1 Introduction

Much recent research on inflation targeting has found that the dynamics of financial variables are of great relevance for the performance of monetary policy to stabilize the inflation rate and output. Research has found that in particular credit flows play an important role in driving real, nominal and financial variables.[1] Credit flows and credit cycles are viewed nowadays as quite internationalized and of significant relevance for the dynamics of the output gap – through the effect of credit spreads, credit volume and credit constraints on demand and output – but are also seen as important drivers of asset prices such as the value of stocks, bonds and real estate assets (see Schularick and Taylor (2012), Jordà et al. (2011) and Jorda et al. (2013)).

Motivated by this stream of literature, we propose a small scale macro model type that keeps features of more complex large scale models and aims to include price and volume of credit flows when modeling inflation targeting policies of central banks. It can be used to evaluate the effect of a change of the policy rate as well as a quantitative easing policy on macro variables. The latter policy affects credit flows and cost directly and has been activated when the interest rate reached the zero lower bound (ZLB). In the empirics we will mainly focus on the Euro area, and in this context we will allow for small negative rates, which were an empirical reality in the Euro area and albeit being still only slightly positive currently. The latter represents what has been referred to as an effective lower bound (ELB).

Many recent macroeconomic studies employ the output gap as an indicator for cyclical behavior on the real side and a forward-looking Phillips curve for the inflation dynamics. An inflation targeting policy is supposed to work through the labor and product market, represented by the output gap, and is likely to be impacted by interest rate variations through the Taylor rule. We add an important third component, credit flows and credit spreads, as variables dynamically interacting with the other macro variables in a nonlinear fashion.

In our context, however, monetary policy sets the short-term policy rate endogenously and may purchase financial market assets as unconventional monetary policy (UMP), thereby affecting term and risk premia. The non-linearities in our model pertain to regime changes in the output gap and how it impacts the inflation rate as well as to credit flows and credit conditions (loan interest rate spreads).[2] Given the nonlinearities in our model, in contrast to earlier LQ inflation targeting models we call our version a nonlinear quadratic (NLQ) model.

When we introduce a regime dependence of the variables on credit flows and credit spreads this resembles the work by Minsky (1986), and to some extent Kindleberger and Aliber (2011) but also relates to the recent empirical findings on credit cycles by Jorda et al. (2011, 2012). We introduce in expansions – when credit flows are extensive – a compression of credit spreads and in the regime of contraction rising credit spreads. Thus declining credit flows and rising credit spreads – usually associated with rising risk premia – are associated with contractions.[3] In this context we suggest

[1]The same is stressed from the perspective of the central banks, see Bernanke (2017) and Draghi (2017). Biggs et al. (2009) emphasize that changes in stocks of credit are not equivalent to pure new business flows, while the latter relate to short-term activity more strongly than stock-based growth. We reflect this aspect in our empirical model by employing new business flows of credit.

[2]It is worth noting that as (Borio 2012) states, credit cycles may evolve over a longer time horizon than the business cycle. We leave this an open question.

[3]As Draghi (2017) states for the euro area:.... by the start of 2014, the provision of bank credit to the real economy

that central banks focus, beside targeting inflation and output gap, also on the control of credit flows — rather than on asset price dynamics directly. [4]

After estimating the main parameters for the NLQ model with actual Euro area time series data, we can evaluate different scenarios where monetary policy faces different phases of the business cycles for example, regimes distinct inflation rates, output gaps and credit conditions. What we find is that monetary policy seems to face less challenges in a scenario of positive output gaps and positive inflation rates. In case the output gap is negative and the inflation rate is negative as well (deflation) there will be greater challenges while there is a double switching and the dynamics is contingent on credit flows and credit spread. The results of policies will significantly depend on credit flows and credit spreads impacted by monetary policy.

As to the empirical effectiveness of the UMP, we are able to empirically explore, using regime switching VAR (RS-VAR) methodology, to evaluate UMP more generally, by looking at the the dynamic effects of price (credit cost) oriented as well as credit volume oriented monetary policy variants. This allows us to study stabilizing/destabilizing effects of price (credit cost) and non-price (credit volume) drivers of output gap, inflation and credit flows and costs. Though we estimate our model primarily with EU data we will contrast also the Euro area with the US UMP.[5]

The macro time series data we are using for the estimation of the NLQ model as well as for the RS-VAR, are apart from standard macroeconomic variables, such as output gap, inflation, and credit flows, the the ECB policy rate, ECB balance sheet variables, bank loan rates and credit spreads, measures for output gap, inflation rate and credit flows. The central bank's balance sheet variables are meant to serve as a proxy for unconventional volume-based monetary policy. This set up allows us to put forward some new empirical results.

A state dependent impulse-response study is undertaken for credit regime dependent risk premia and credit spreads to explore empirically the monetary policy effects.[6] In particular, we show that the state-dependent UMP shocks as well as loan supply and loan demand shocks have differentiated effects on output, prices, credit flows and financial stability in recessions in contrast to expansions. Moreover, we demonstrate that the compression of risk premia and credit spreads by monetary policy tools is more easily achieved in expansions than in contractions. Thus a policy of leaning against the wind (against the credit expansion) too early, by tapering too early, letting credit spread rise again, might have strong contractionary effects due to the double switching effects.

The remainder of the paper is organized as follows. Section 2 discusses related literature. Section 3 presents the dynamic NLQ model. Section 4 discusses the empirical estimation method. Section 5 summarizes the results of the different policy scenarios. Section 6 studies impulse-responses using RS-VAR estimations. Section 7 concludes the paper. The Annex 1 to 3 establish some derivations,

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had dried up, shrinking at an annual pace of 1.7% in the first quarter. The euro area found itself in a vicious circle: as credit tightened, the economy worsened and risk perceptions rose, causing credit to tighten still more. The economic outlook at the time was marked by the risk of a further recession and potentially even deflation."

[4]As Jorda et al. (2011, 2012) have shown credit cycles are accompanied by financial market miss-pricing, for example in real estate and equity markets, but historically financial crises originated in a variety of sectors and it will be difficult for the central banks to target certain asset price driven sectors, wheres as targeting credit flows might be easier.

[5]Yet as regarding the latter we refer the reader to the early assessment paper by Mishkin (2011) and the comprehensive review paper by Bernanke (2017) who addresses many of the tools and criticisms of the UMP policy. A more skeptical view can be found in Greenlaw et al. (2018).

[6]A further detailed discussion of this is given in Gross and Semmler (2017).

present stylized facts underlying our model, and the solution method of our NLQ model.

## 2 Related Literature

Credit flows, credit fueled booms, and the instability of credit, appear to be at the root of the financial instability problem (Minsky (1986), Kindleberger and Aliber (2011), Schularick and Taylor (2012), Jordà et al. (2011) and Jorda et al. (2013)). As to the former, we follow up the Minsky hypothesis that "booms sow the seeds of the next crisis",[7] in the sense that in credit booms credit spreads are low and in contractions credit volume contracts and credit spreads are high.

Many relevant studies have been generated along those lines of research extending the inflation targeting model. Small scale macro models in this context that emphasize the role of credit flows and credit conditions are Woodford (2012), Ajello et al. (2016), Svensson (2014), Svensson (2016), Bonis et al. (2017), Bernanke (2017) and Wu and Zhang (2016) to which we aim to connect with our work. Those papers have put forward the position that financial instability can considerably derail inflation targeting monetary policy, implying significant non-zero crisis probabilities accompanied by large negative output and employment gaps.

In an early assessment of the Great Recession Mishkin (2011) views the missing financial - macro link in the inflation targeting models as the main cause why the coming of the Great Recession was not foreseen. The view of the instability of credit as cause for the fragile financial-macro dynamics is also shared by Mishkin (2011)[8] in his evaluation of the Great Recession where he argues this major nonlinearity was overlooked. To capture this fragility we propose a nonlinear quadratic (NLQ) model.[9] This is also reflected in the work of some authors, such as Svensson (2014) and Svensson (2016) who recently questions whether a too early exit from UMP by central banks might have higher cost than benefits in terms of output and employment losses.

As concerning the switching dynamics for a state dependence of credit flows and credit spreads the issue is discussed how credit flows are measured in the literature. A recent IMF (2017) paper examines the empirical relevance of credit growth versus the change of credit growth for business cycle contractions and expansions. There is an extensive debate in the literature[10] how to measure credit flows, as growth rate of credit, rate of change of growth rates (credit impulse), deviation from some estimated trend, or as credit gap. We will use a credit gap measure.

Likewise, much theoretical and empirical research has been done concerning a nonlinearity in the

[7] There are several aspects of the Minsky hypothesis, ranging from overoptimism at boom periods, with low risk perception, low risk premia and credit spreads, rising speculative and Ponzi financing, increased borrowing disconnected from collateral, over-leveveraging of agents, and then what has been called a "Minsky moment" — a rapid financial meltdown. The role of nonlinearities arsing from the financial markets is also stressed in Mishkin (2011) who points out that this was missing in the conventional inflation targeting model.

[8] The Minsky view, by referring to credit flows, is also vividly expressed in Kindleberger and Aliber (2005:10) when they state in their book: ".... the cycle of manias and panics results from the pro-cyclical changes in the supply of credit; the credit supply increases relatively rapidly in good times, and then when economic growth slackens, the rate of growth of credit has often declined sharply".

[9] The deficiency of a linear quadratic (LQ) model missing the role of the financial market in the inflation targeting model is strongly criticized by Mishkin (2011).

[10] See also Biggs et al. (2009).

Phillips curve.[11] Regime switching in the inflation dynamics has been assessed in both a theoretical setting as well as an empirical model in Gross and Semmler (2017) who have introduced a regime change in the output gap – in which it has a different impact on the inflation rate as a function of its own level (small/high impact at times of negative/positive output gaps). This feature has been referred to as a *convex* Phillips curve and is a topic that has been explored in the theoretical and empirical literature since long (see references in Gross and Semmler (2017)) Related evidence of different forms and sources of nonlinearities concerning inflation dynamics have been presented in the LIFT project of Cicarelli and  (Editors).

In those papers and reports the Phillips curve is shown to be nonlinear: flatter in the region of negative output gap in contrast to the region of a positive output gap. In Gross and Semmler (2017) this hypothesis is econometrically tested with six different measures of the output gap and quite robust results are obtained. The finding of a convex relation has important policy implications. A linear Phillips curves that often can be found in NK models will guide monetary policy to be too hesitant in a recession, as compared to expansions.

As to UMP policy, there is numerous work. According to UMP policy, an expansion of the central bank's balance sheets, through the purchase of assets (sovereign as well as corporate, i.e. in the Euro area) is supposed to stimulated increase in credit flows, and a reduction of credit risk, and credit spreads are supposed to stimulated expansions.[12] A careful and extensive review of what UMP has achieved, as opposed to conventional monetary policy, is undertaken in Bernanke (2017). An important issue is, as Bernanke (2017) states, the linkage of regime switching in the credit spread (and the change of the policy rate), asset price movements and financial intermediaries. Does UMP work through asset prices and can it generate a precarious asset price boom, that may burst? Indeed, UMP is supposed to work its way to the real side of the economy through the asset market, asset prices and portfolio holdings, as discussed in Bernanke (2017).

Central banks have claimed the de-risking of sovereign and private assets through central banks purchases of of those assets, implies reduced risk and term premia through UMP, and thus of credit spread. This will as the central banks' studies attempt to show, will not only affect the output gap and the credit flows, but also asset prices. Though the mechanism of how interest rate and credit spread affect asset prices and the reverse, is still somewhat controversial (see Hamilton et al.2018), one might need to keep this in mind, since it points to an uncertainty of what else might drive main results of UMP. [13]

To solve our model with double switching is challenging. In our dynamic decision model that we develop the short-term interest rate (the policy rate) is as a decision variable endogenous, which will interact with the three nonlinear state equations of the inflation rate, the output gap, credit flows and stage dependent credit spreads. Yet, the actual impact on the real side is not only through the

[11] For a survey see Gross and Semmler (2017).

[12] Again as Draghi (2017) states: "... We introduced a number of unconventional measures including negative deposit facility rates, targeted longer-term refinancing operations (TLTROs) and an expanded asset purchase program. These measures – known as our "credit easing" package – were aimed at combating the impairment of the transmission mechanism...."

[13] Bernanke (2017) addresses various kinds of criticism related to UMP, such as UMP: 1) produces precarious asset price bubbles, 2) leads to over-borrowing, sowing the seeds for the next cycle and bust, 3) creates wealth and income inequality due the capital gains affecting the top of the wealth pyramid, 4) does not leave any suitable instrument to manage the next crisis, and thus 5) points to the loss of potent monetary instruments for any subsequent recession. Bernanke (2017) responds to those criticism. Our paper focuses only on a limited set of issues.

policy rate, but through credit flows and credit spreads in our NLQ model.

As to the literature on the solution method we want to note that our finite horizon decision problem does not necessarily imply backward or myopic behavior,[14] but allows for short horizon – in contrast to infinite horizon – forward looking behavior.[15] We want to note that our method is more specifically discussed in Annex 3. It may suffice to note that our solution method used is a global solution algorithm, with no need to employ local linearization.[16] As to the decision horizon of models with financial variables, there are models such as Woodford (2012)'s infinite horizon and Ajello et al. (2016)'s two period model. Their state equations usually comprise a linear Phillips curve, the dynamics of the output gap and (possibly) credit aggregates, for example Ajello et al. (2016).[17]

The estimation of our dynamic system with two regime switches, including monetary policy responses, is not undertaken by single equation estimations but rather by a system estimation using the euro area data set using a full information maximum likelihood (FIML) estimator. There is also previous work on this estimation technique. We first need to approximate our continuous time version by a discrete time version and undertake then nonlinear (and linear) simultaneous equation system estimation following work such as Dagenais (1978), Belsley (1980) and Amemiya (1983). This data set is also used in sect. 6 to estimate the RS-VAR and to explore the state dependent impulse-responses, as in Mittnik and Semmler (2018), but in our context here undertaken in higher dimensional macro systems.

## 3 Monetary policy decisions in an NLQ model

As mentioned, we work with a finite-horizon decision model of the monetary authority when setting an approximately optimal policy rate. This allows for a shorter horizon and informationally constrained decision making in the sense of Sims' inattentiveness theory.[18] Given informational constraints we assume some rolling dynamic decision making with uncertainty reduced when moving forward and new information comes in. This also permits for adaptive behavior of economic

[14]Note that our model structure embodies foreword looking behavior since agents are predicting target variables over some future horizon.

[15]Policy makers do seem to make decisions with paying attention to some future horizon, but being inattentive (in the sense of Sims (2010)) to information of longer horizons. For a detailed study on the advantages of finite horizon models see Grüne et al. (2015). The difference of the procedure used here to NMPC is that instead of solving the model in a foreword moving fixed horizon window, here a sequence of monotone increasing horizons is solved.

[16]Which is often used in DSGE and NK models. As mentioned our global method is akin to the solution method proposed by NMPC (see Gruene and Pannek (2011), and Grüne et al. (2015)) which allows for finite time rolling decision making, decisions with receding horizon, informationally constrained agents in the sense of Sims (2010), and boundedly rational adaptive behavior.

[17]Draghi (2017) seems to confirm this mechanism of credit flows and credit spread as main drivers for recent expansions and contractions: "The unconventional monetary policy ...(allowed) to transmit the ECB's credit impulse to firms and households across the monetary union and to ensure sufficient financing to sustain the recovery – which is exactly what we have seen. In the first quarter of 2017, annual loan growth to euro area households stood at 2.6% and non-financial corporations at 1.6%, up from respective troughs of -0.6% in the second quarter of 2014 and -3.6% in the third quarter of 2013. Bank lending rates for both firms and households have dropped by around 110 basis points over the past three years and are now at historical lows."

[18]It can also be justified in terms of Gabaix's (2016) behavioral macro theory that allows for a different decision making for the shorter as compared to the longer horizon– for the former the discount rates are assumed to be higher.

agents when some fundamentals have changed.

Our model is nonlinear in the state variables but we want to take into account macroeconomic imbalances. This is done via an objective function quadratically penalizing deviations from four target variables. We thus call it a nonlinear quadratic (NLQ) model. We solve the arising dynamic decision problem (DDP) for the NLQ model numerically over a finite horizon.

### 3.1 Dynamics with two regime switches

We consider the following system of nonlinear differential equations with two regime switches:

$$\begin{bmatrix} \dot{\pi} \\ \dot{y} \\ \dot{l} \end{bmatrix} = \begin{bmatrix} \alpha_0 + \alpha_1 \pi + \alpha(y) \\ \beta_1 y - \beta_2(i + \delta(l) - \pi - r) + \beta_3(e^l - \hat{l})/\hat{l} \\ \gamma_1 l + \gamma_2 y + \gamma_3(i + \delta(l)) - \gamma_4 \pi \end{bmatrix} \tag{1}$$

Note that the first equation in the system (1) represents the Phillips curve, the second the IS-equation, and the third represent the driver of the credit gap and credit spread dynamics.

We do keep some parts of the dynamics linear,[19] some other parts are nonlinear. Our nonlinear parts affect the dynamics of the inflation rate, $\pi$, output gap, $y$, and the logarithm of credit flows, $l$.[20] Hereby the state variable $l$ is defined as the natural logarithm of credit flows (*credit flows* $= e^l$).

Note that the deviations of the standard inflation targeting model consist in the regime switching behavior of the inflation equation, $\alpha(y)$, the credit gap equation and $\delta(l)$, the credit spread dynamics. To represent our two regime changes, we use

$$\tilde{H}_c(x) = \frac{1}{1 + e^{-c_1 \cdot (x - c_2)}} \tag{2}$$

a kind of logistic function with smooth properties.

Using the approximation equ. (2), we can model a discontinuous functions as continuous such as $\delta$ and $\alpha$ :

$$\delta(l) = \mu_1 + \mu_3 \tilde{H}_c(e^l - \hat{l}) \tag{3}$$

$$\alpha(y) = \alpha_{21} + (\alpha_{22} - \alpha_{21}) \tilde{H}_c(y), \tag{4}$$

with parameters $c_1 = 10$, $c_2 = 0.01$. Using $\alpha_{21} = -0.05$, $\alpha_{22} = 0.15$.

[19] Which can be thought of being derived from some linearization of some NK model. as in Wu and Zhang (2016).
[20] Nonlinearities and regime switching have also been introduced in small and large scale DSGE models though using only moderate nonlinearities, see Herbst and Schorfheide (2016, sect. 7.2).

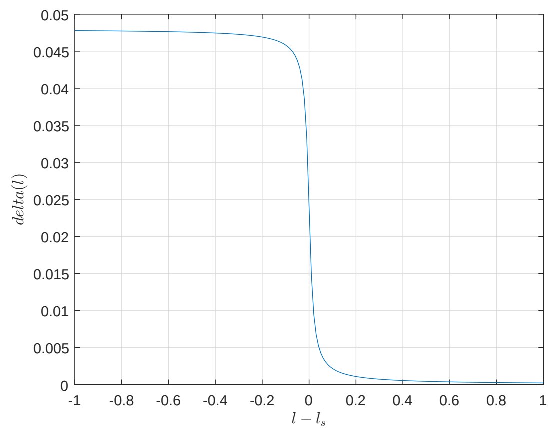


Figure 1: $\delta(l)$ function based on the function $\tilde{H}_c$; note that the credit spread quickly increases as the credit gap declines and in particular rises fast below a certain threshold

Figures 1 (and 2 below) visualizes our idea by using the equ. (2), as basis function for our nonlinear dynamics,[21] with the parameters parameters of table 1. Note that we here attempt to mimic the actual empirical behavior of switching functions. The actually used parameters with confidence bands estimated in section 4 where also the data sources and estimation procedures are discussed. For our stylized function for endogenous risk build up and credit spreads $\delta(l)$, using the parameters of table 1, we obtain an approximation as displayed in figures 1, representing $\delta(l)$ as in equ. (3).[22]

Our use of the credit spread is related to the use of the shadow interest rate which in recent work on the US and the Euro area can go negative (where risk premia can be driven down by QE type policies affecting the long rates), see Lemke et al. (2016) and Wu and Zhang (2016).[23] This means even if the policy rate moves to the ZLB the shadow rate can move further down. We will capture this possibility of a negative shadow rate by a ELB of the policy rate that can be negative too. Details on those issues and on the link between credit spread, shadow interest rate, credit flows and QE are discussed, using some stylized facts, in Annex 2.

The nonlinearity in Phillips-curve is represented by equ. (4) we obtain stylized and approximately a function such as $\alpha(y)$ depicted in figure 2.

[21]Note that the equ. (2) function resembles the regime switching functions used in the LSTAR and ESTAR models of Granger and Teraesvirta (1993), there usually used for one regime switch. Yet, in order to avoid the kink and non-differantiability at $x = 0$, which produces jumps in the control variables of the DDP, in our case the transition will be smoothed.

[22]We could as in Wu and Zhang (2016) use the shadow rate as the 3rd state variable instead of the credit flow equation. We would hereby then leave undetected the importance of credit cycles for macroeconomic dynamics.

[23]Both papers demonstrate by using a term structure model that the risk premia have been brought down in certain periods in the US, as well as in the euro area, due to QE policies. This causes the shadow interest rate to move below zero. In our case, though our credit spread is only moving to zero in figure 1, but of course, under the impact of QE policy it can also move below zero, as in Wu and Zhang (2016), for details see Annex 2.

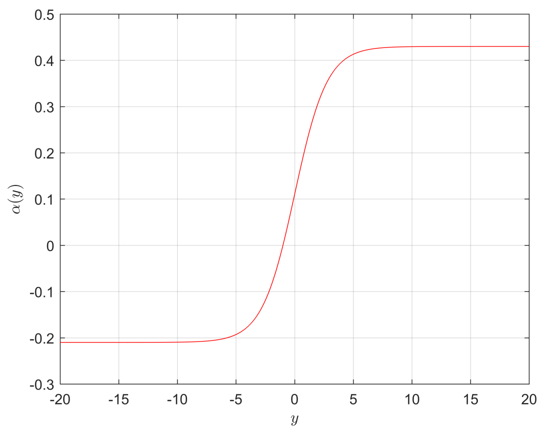


Figure 2: $\alpha(y)$ function based on function $\tilde{H}_c$; note that the value of $\alpha(y)$ moves up beyond a certain threshold of $y_t$.

The data sources and estimations of the parameters of such a nonlinear Phillips-curve $\alpha(y)$ are discussed in sect. 4.

Note that figure 2 visualizes the behavior of the third term of the Phillips curve equation which captures the nonlinear impact of the output gap on the change in the inflation rate. It reveals that the contribution from the output gap to the change in inflation is smaller (larger) at times of pronounced negative (positive) output gaps. The more extensive exploration of such a Phillips curve, and the nonlinear response of the inflation rate to the output gap, is undertaken in Gross and Semmler (2017b) where six alternative output gap measures are used as well as 28 European countries' data to establish the robustness of such a result. There it is also shown why a linear Phillips-curve, obtained through linearizations in New Keynesian models, maybe misleading in terms of monetary policy advise.

Note also that we have in the 2nd equ of equ (1) an additional term such as $\beta_3(e^l - \hat{l})/\hat{l}$. In Annex 1 we show that this term can be understood to measure the tightness of credit constraints, arising from collateral constrained borrowing, which can be relaxed or enforced through UMP in the form of macro prudential policies, for example allowing for higher or lower loan to value ratio and other credit guidance measures.[24]

Both the regime switching of the credit spread (and shadow rate), equ. (3), as well as the Phillips curve, equ. (4), are relevant for our study of the policy scenarios in sect. 5. As the shapes of our figures 1 and 2 suggest, the presumption is that the regime change in the asset markets occurs faster than for the inflation dynamics in the Phillips-curve. In those scenarios in sect. 5, in our designed dynamic version an estimated partially linear part of an IS-PC-credit gap model will interact with nonlinear dynamic forces resulting in quite complex outcomes.

[24] Wu and Zhang (2017) show also how such a term can be derived from a more specified general model.

### 3.2 The NLQ targets and two regime switches

In contrast to the LQ problem the central bank's NLQ problem has 4 targets and two regime switches. We solve the following discounted decision problem (DDP), with the nonlinearities in the state equation, as a finite horizon decision control problem::

$$\min_{i(\cdot)} V = \int_0^T e^{-\rho t}[(\lambda_{\pi(}\pi(\tau) - \pi_s)^2 - \lambda_y(y(\tau) - y_s))^2 - \lambda_l(l(\tau) - l_s)^2 - \lambda_i(i(\tau) - i_s))^2] \quad (5a)$$

$$\text{subject to}(1) - (4)$$

Setting up our NLQ problem as system dynamics in discrete form, given the estimated parameters of sect. 4, the problem reads as follows

$$\min_{i_k, x_k} \sum_{i=0}^{N-1} \rho_k \|x_k - x_s,\ i_k - i_s\|_\Lambda^2 \quad (6a)$$

$$\text{subject to, for all } k = 0, \ldots, N-1,$$

$$x_{k+1} = f_d(x_k, i_k), \quad (6b)$$

$$x_0 = x(0) \quad (6c)$$

$$x_k \in \mathcal{X}, i_k \in [-0.015, 3], \quad (6d)$$

where $x_k := (\pi(t_k), y(t_k), l(t_k))^\top$ are the discretized state variables, $i_k := i(t_k)$ is the discretized decision variable, $\rho_k := e^{-\rho t_k}$, and $f_d : \mathbb{R}^3 \times \mathbb{R} \to \mathbb{R}^3$ is the state transition map depending on the numerical solution method presented in Annex 3.

### 3.3 Model components and parameter uncertainties

Though the parameters of our discrete time system (6a)-(6d), as depicted there in a compact way, are estimated based on time series data for the Euro area that one may deem being of high quality, there is nonetheless some sizable uncertainty as to whether they are sufficiently accurately estimated, for details see Annex 3.

Our three-dimensional model and the parameter calibration and estimation resembles the work by Ajello et al. (2016). Yet, they undertake only single equation estimations, not system estimations. As to the entire set of parameters estimated in our model, for the linear and regime switching component, the greatest uncertainty pertains, as also Ajello et al. (2016) show, to the credit gap equation and the impact of credit flows and credit spread on aggregate output (IS equation), expressing how credit conditions are linked to the output gap (Ajello et al. (2016)).

In addition, the drivers of the credit flows are uncertain, specifically the set of parameters for the credit flows, the $\gamma_i'$s could be quite ambiguous. Ajello et al. (2016) present, using the data set on credit growth from Schularick and Taylor (2012) and Jorda et al. (2013) and an extensive analysis with some Bayesian restrictions of those parameters for the US economy.

For most of the study by Ajello et al. (2016) the parameter $\gamma_1$ is set to zero but they expect that it could be positive or negative. Also $\gamma_3$ is mostly set to zero as is $\beta_3$. When they explore the role of $\beta_3$ it is set to be positive, with some upper and lower bounds. The parameter $\gamma_4$ is in their study estimated about 0.5 being a significant estimation overall, which is insignificant according to our empirical model estimates.

Though we have done our own estimations of the parameters of the credit condition equation for the euro area in the context of a system estimation, we want to note that we also face a great uncertainty of the parameters of our dynamic credit equation. We follow the lead of Ajello et al. (2016) and undertake, in particular for critical parameters of the credit flow equation, some robustness tests using various parameter variations in our steady state estimations and dynamic simulations.

On the other hand one might think about other model components. Such monetary policy models with policy rate and UMP could be extended to include asset price movements and financial intermediaries. The argument is that asset price movements (fundamental or excess asset price movements, see Bernanke (2017)), are affecting credit flows through collateral value of assets. On the other hand credit expansions and contractions are the most important drivers of asset price booms and busts– and the reverse, see Schularick and Taylor (2012), Jorda et al. (2013).

Note that we take a short cut here and the credit flows in our model are directly the driver of the output gap, and indirectly also then of the inflation rate. The mediating mechanisms, asset price dynamics and bank lending, are not directly modeled here, yet one can expect a strong co-movement of those with the output gap and credit conditions and bank lending, see sect. 6. For further elaborations on the role of asset pricing and its interaction with bank lending and output dynamics, as measured in our IS equation, see Grauwe and Macchiarelli (2015), Schleer and Semmler (2015), and Blanchard and Summers (2017).

In fact, as Bernanke (2017) indicates, one could think of the regime switching in asset price movements as associated with the policy rate, credit flows and spreads. Since UMP is supposed to work its way to the real side of the economy through the asset market and portfolio holdings, as discussed in Bonis et al. (2017), there could be shifts in portfolio holdings as well, through reduced risk and term premia, and thus credit spreads.

Since such components are not modeled here, our regime switching mechanisms of how interest rate, credit spread and bank lending affect asset prices and the reverse,[25] could be more complex. We need to keep this in mind when we study tipping points stemming from the two switching functions, the dynamics of which indeed could be impacted by such other model components and mechanisms as well.

[25]A mechanism that is not without perils, at which also Draghi (2017) hints: "Of particular concern is the development of so-called credit-fuelled bubbles, which previous experience has shown to be particularly detrimental to financial stability."

# 4 Empirical model and estimations

Next we present the empirical system estimation procedure as well as the used data set of the Euro area used. For the purpose of empirical estimates of our nonlinear model we again approximate our above described continuous time dynamic model by a discrete time version and perform a system estimation.

## 4.1 Empirical system structure and data

Our empirical system is estimated based on a quarterly data sample covering the 2003Q1-2017Q2 period (58 quarters) for the Euro area (changing composition). In discrete time, the system has the following structure:

$$\begin{aligned} \Delta\pi_t &= -\alpha_1\pi_{t-1} + \alpha_2 + \frac{\alpha_{22}-\alpha_{21}}{1+\exp\left(-c_1\left(y_{t-1}-c_2\right)\right)} + \epsilon_t^{\Delta\pi} \\ \Delta y_t &= -\beta_1 y_{t-1} - \beta_2\left(i_{t-1}^{pol} + \delta_{t-1} - \pi_{t-1} - r\right) + \beta_3 l_{t-1}^{dev} + \epsilon_t^{\Delta y} \\ \Delta\ln\left(l_t\right) &= -\gamma_1\ln\left(l_{t-1}\right) + \gamma_2 y_{t-1} - \gamma_3\left(i_{t-1}^{pol} + \delta_{t-1}\right) - \gamma_4\pi_{t-1} + \epsilon_t^{\Delta l} \end{aligned} \tag{7}$$

We have replaced here the $\dot{x}$ notation and denote the incremental change from period to period by $\Delta$'s. The variable $\pi_t$ denotes the annualized quarter-on-quarter (QoQ) GDP deflator inflation rate, i.e. is defined as $\pi_t = 4\ln\left(p_t/p_{t-1}\right)$ where $p$ denotes the GDP deflator index. The variable $y_t$ denotes the real output gap, defined as $\ln\left(y_t^a/y_t^{trend}\right)$, where $y_t^{trend}$ was computed using the Hamilton filter (Hamilton, 2017). The variable $i_{t-1}^{pol}$ is the ECB main refinancing rate and $\delta_{t-1}$ denotes the Euro area aggregate private sector loan interest rate spread (spread to policy) pertaining to new loans to businesses and households within a quarter.

The sum of $i_{t-1}^{pol}$ and $\delta_{t-1}$ therefore yield the level loan interest rate to firms and households. Further, the term $r$ denotes the real interest rate that we set to 0.03.[26] The variable $l^{dev}$ is the real loan flow gap. It was computed by first deflating quarterly nominal private sector loan flows with the GDP deflator and then obtaining a real trend estimate $l^{trend}$ using the same Hamilton filter that we used for the output gap calculation. The real loan gap variable is defined as $l_t^{dev} = \left(l_t - l_t^{trend}\right)/l_t^{trend}$.

A next equation that we add to the system is for $\delta_t$ which is meant to capture the state-dependent nature of the loan interest rate spread $\delta_t$. It makes the loan interest rate spread a nonlinear function of the real credit flow, that is:

$$\delta_t = \mu_1 + \mu_2\left(\frac{1}{1+\exp\left(-c_3\left(\ln\left(l_t\right)-c_4\right)\right)}\right) + \epsilon_t^{\delta} \tag{8}$$

[26] It has been argued that in recent times, since 2008-9 the natural rate, $r$, has significantly fallen. Since we work with a shorter time series, we keep the natural rate at some text book level.

Note that figure 1 visualizes the state-dependent loan interest rate spread (to policy) as a function of the credit flow gap as it is estimated for equ. (8) which in principle is allowed to go negative similarly to the shadow rate in Annex 2.

## 4.2 Estimation method and results

We employ a full information maximum likelihood (FIML) estimator for our nonlinear system of equations. The FIML estimator maximizes the concentrated likelihood of the model with respect to the coefficient vector assuming that the error vectors of our system are i.i.d. multivariate normal. The coefficient covariance matrix is computed using the inverse of the outer-product of the gradient, the inverse of the negative of the observed Hessian of the concentrated likelihood.[27]

Specifically, we employ the Marquardt method, an iterative, first derivative method to obtain the parameter estimates. The coefficient $p$-values that we report are derived from coefficient standard errors that result from the Hessian approximation once convergence of the estimation was achieved.[28] Among the relevant entry points to the literature about FIML in nonlinear (and linear) simultaneous equation systems are Dagenais (1978), Belsley (1980) and Amemiya (1983).

Table 1 shows the empirical estimates of the nonlinear equation system. The $R$-squares of the Phillips curve, the IS equation, and the credit flow equation equal 33%, 22% and 31% respectively. The DW statistics (2.07, 1.6, 1.7) suggest that the equations' residuals are sufficiently free of remaining serial correlation.

All the estimated coefficients show the expected signs and are in general significant at conventional levels. Three exceptions that deserve some attention are $\gamma_1, \gamma_3$, and $\gamma_4$. For parameter $\gamma_1$ one might need to have a negative sign, or being zero, in order to obtain stability. $\gamma_3$ has the expected sign but the precision of the estimate ($p$-value at 0.41) suggests that it can not be distinguished from zero. Concerning $\gamma_4$ on the other hand, we would have expected the opposite sign, yet it is also insignificant. Text book presentations would suggest for $\gamma_4$ to obtain a positive sign, so we will also use this specification.

Overall, as also discussed in Ajello et al. (2016), the parameters of the drivers of credit flows are particularly difficult to estimate with precision, reflecting either some missing regime dependence that we have not yet considered in this respect or the actual absence of the relationship. With respect to these parameters, we will thus consider using alternative parameter settings to explore the robustness of our simulation results based on the double regime switching model.

In our numerical solution algorithm we adopt the estimated parameter set, including the two switching functions, as well as the formulated dynamics of our variables for the Phillips curve, the nonlinear equation for IS and credit flows by using the data on real GDP gap, QoQ inflation, loan

[27] The advantage of approximating the negative Hessian by the gradient's outer product is twofold: i) only first derivatives are used which is useful since the use of second derivative methods can be more computationally demanding and less easy to compute accurately; and ii) the outer product of the gradient is guaranteed to be positive semi-definite.

[28] Note that with respect to the parameter idendification there might be still the issue of a flat likelihood function and there might be multiple solutions, depending on initial conditions. Some experiments with the variation of starting values did not seem to indicate such problems, though there are some issues with the parameters of the credit flow equation, see below.

Table 1: Parameter estimates and their significance, based on euro area data, 2003Q1-2017Q2

| | Parameter | Estimate | p-value |
|---|---|---|---|
| PC | $-\alpha_1$ | -0.67 | 0% |
| | $\alpha_2$ | -0.21 | 0% |
| | $\alpha_{22}$ | 0.43 | 0% |
| | $\alpha_{21}$ | 0 | - |
| | $c_1$ | 0.72 | 11% |
| | $c_2$ | -0.001 | 0% |
| IS | $-\beta_1$ | -0.18 | 0% |
| | $-\beta_2$ | -0.45 | 0% |
| | $\beta_3$ | 0.03 | 3% |
| Credit | $-\gamma_1$ | 0 | 85% |
| | $\gamma_2$ | 0.81 | 0% |
| | $-\gamma_3$ | -0.48 | 41% |
| | $-\gamma_4$ | 0.61 | 52% |
| Credit spread | $\mu_1$ | 13.35 | 0% |
| | $\mu_3$ | -13.34 | 0% |
| | $c_3$ | 2.2 | 0% |
| | $c_4$ | 10.33 | 0% |

interest rate spread, nominal loan flow growth, real loan flow gap as the basis for our estimates. Our estimates confirm an important role of the nonlinearities in the interaction of our variables and are thus employed in our subsequent scenario analyses.

# 5 NLQ model and UMP

In each of the subsequent scenarios the full model is solved through the procedure as sketched in (5) of sect. 3, while using our estimated parameters and switching functions of sect. 4. In the model scenarios we consider conventional monetary policy as well as UMP, both recently well summarized and evaluated in Bernanke (2017) and Draghi (2017). We study a variety of scenarios and their challenges to both types of policies. Note that under UMP we understand here both the increase of balance sheets of the central bank (pure QE) as well as the working of it through the asset market affecting asset returns and credit spreads.

One could understand monetary policy shocks as follows: 1. interest rate policy shock (conventional policy rate change), 2. CB balance sheet shocks (pure QE, change of the CB's balance sheets), 3. credit supply shocks enacted by banks (loan rate change, price based) and 4. credit demand shocks (volume based). One could then evaluate the macro effects of those shocks. Since the policy rate is given endogenously in our model we by-pass shock type 1. Further, since, credit expansions are simultaneously connected to credit spreads in our model, we will also not consider shock 2. separately, but in rather in its link to 3. and 4.

Thus central bank's policy in the sense of UMP, comprises 2. - 4. which is in principle is a de-risking policy entailing a fall in sovereign and corporate bond risk premia (of long bonds), thus lower bond risk premia, and a lower risk premia that the financial intermediaries request on the loan supply side.[29] Thus, UMP is supposed to work through the channel of UMP, as increase of balance sheets of the CB, and eventually generating lower (risky) loan rates that banks offer to households and firms. We consider those effects as linked to UMP and do not treat the change of CB's balance sheets separately which will, however, be done in the RS-VAR study in sect. 6. Here, the actual transmission of the shock 2. is assumed to go through the lower credit spread — the lower loan rate of banks as compared to the policy rate. All four types of shocks 1. - 4. will be studied separately in the context of the RS-VAR analysis of sect. 6.

## 5.1 Scenario 1: Deflationary regime with negative output gap - success of credit supply policy

In our first macroeconomic scenario we consider a scenario with large negative shocks to the macro variables, moving the initial values of the macro state variables away from the steady state, but allowing a large positive shock to credit flows enacted through UMP. First there is an increase of central bank's balance sheets, which is enacted through the form of purchases of assets such as sovereign bonds, and maybe corporate bonds (as in the case of the Euro area). Yet, this entails a rise of asset prices and a fall of bonds yields, in particular a decline of term spreads of treasury bonds, which subsequent spillovers to private bond yields and lower loan rates charged by banks.[30]

To study this credit supply effect with impact on loan rates and credit spreads, we consider initial macro conditions such as $\pi(0) = -0.01$; $y(0) = -0.03$; $l(0) = 13.2$, with $\beta_3 = 0.03$. Note that UMP is viewed here as credit supply shock affecting credit flows, risk premia and credit spreads and lower loan rates, and made identifiable through an increasing credit flows that moves up to $l(0) = 13.2$. This de-risking of asset returns entails credit spread effects such as depicted in figure 4. The results of this type of shock on our four macro variables of interest are shown in figure 3.

[29] Due to the de-risking of ass returns, the yields of corporate bonds, due to a fall of risk premia might also fall, and equity premia are likely to drop. For stylized facts, see Faulwasser et al (2018) Annex 2.

[30] For stylized facts on this mechanism, see Annex 2, see also Faulwasser et al. (2018).

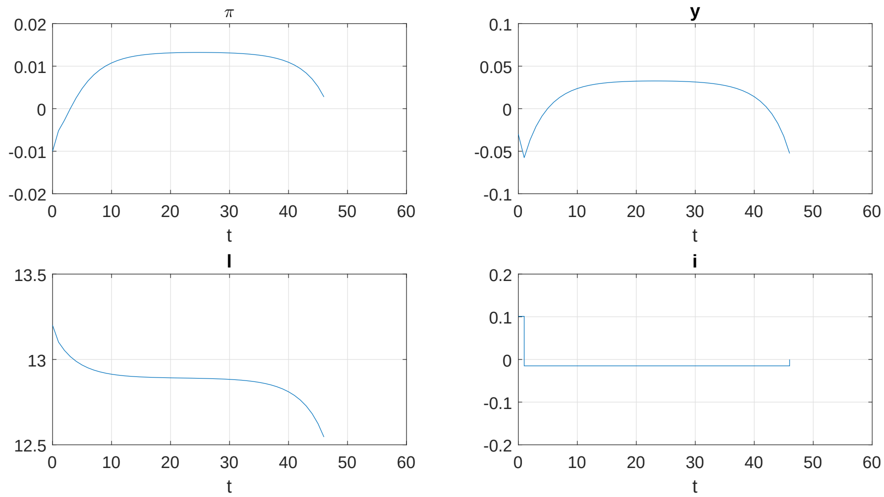


Figure 3: Results for $\pi(0) = -0.01; y(0) = -0.03; l(0) = 13.2, \beta_3 = 0.03$; deflationary regime with negative output gap, defeating the ELB through QE

The main monetary policy change here in figure 3 is we have introduced, as in Gertler and Karadi (2015), a positive credit shock, by setting $l(0) = 13.2$, which is equivalent to an UMP, increase of the central bank's balance sheets by purchasing private assets and governments bonds, affecting economy wide asset returns.

Subsequently, as figure 1 already indicated, the credit spread moves down with a positive credit shock, see beginning of credit spread size in figure 4. The UMP makes the credit flows stay up and the credit risk and credit spread to come down and then stay constant. In addition, as figure 3 shows, the inflation rate and output gap are mean reverting and move toward their steady states.[31] Yet, as the credit flow gap becomes negative (moves down at some point at the end) the credit spread starts rising again, producing also a contractionary effect on the output gap and inflation rate, see figures 3 and 4 after 35-40 periods.

Thus, after the credit flow falls below its threshold, roughly at period $t = 35 - 40$ again, all the macro variables are affected adversely. Note, however, we have also assumed here that the constraints on the credit demand are relaxed through the fact that we have $\beta_3 = 0.03$, so those stabilizing forces (for example through macroprudential policy, MPP) were activated as well, for details see below.

In sum, the case of a deflationary economy, resulting from strong negative shocks, and an endogenous jump of risk premia and credit spreads, can be managed by UMP, lifting the credit flows by using an important tool of UMP, the increase in credit flows to $l(0) = 13.2$. The subsequent nonlinear reduction of credit spreads, and the reduced credit constraints, with a positive feedback

[31] Here too we by-pass to model specifically the slowly recovering banking system and improving asset markets which are likely to aid to reduce the risk premia supporting this way the recovery of the output gap and the success of inflation targeting.

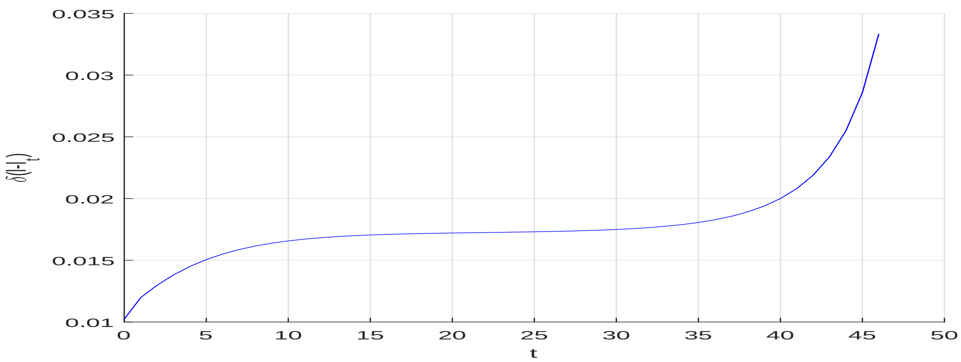


Figure 4: Credit spread associated with credit flows

effects of credit flows through $\beta_3 = 0.03$, reverse the negative output gap and negative inflation rate.[32] Yet new perils can arise as the credit flow is passing through its threshold from above and becomes negative.

Note, however, that this recovery effect is arising not from the policy rate but rather dominantly from the reduction of credit spreads in association with rising credit flows. On the other hand the inflation rate is, see upper left chart in figure 3, is due to the nonlinear Phillips curve, whereby the inflation rates are only slowly rising when the output gap is recovering. On the other hand beyond period $t = 35 - 40$, new adverse perils can arise when the credit gap becomes negative.

## 5.2 Scenario 2: Deflationary regime with negative output gap – lack of credit supply

Next we consider the case of a negative shock to the credit flows. We interpret this case that there is no – or not sufficient – UMP policy. We start with a mild recession and thus a small negative output gap, but a positive inflation rate. We assume the following initial conditions and parameters, for $\pi(0) = 0.03$; $y(0) = -0.03$; $l(0) = 10.8$; $\beta_3 = 0.03$. The negative shock to the credit flow is represented by the initial $l(0) = 10.8$.[33] Figure 5 shows the results of the negative credit shock. Note that the credit flow is below its steady state value.

As mentioned though we do not model explicitly the asset market and the balance sheets of the banking system, the negative credit shock in the credit market has recently been studied in many papers where it is pointed out that the negative credit shock can come from a decline in asset prices, affecting the banks balance sheets, in the form of reducing their net worth, triggering a fire sales of assets, reducing asset prices further, causing risk premia to rise. For such a mechanism sketched, see Brunnermeier and Sannikov (2014a), Grauwe and Macchiarelli (2015), Schleer and Semmler (2016) and Gross et al. (2017).[34]

[32] Note here too the role of the asset market and conditions of the financial intermediaries are also important.

[33] Again this situation can arise due to a negative net worth shock of financial intermediaries as in Brunnermeier and Sannikov (2014b).

[34] In the latter work a mechanism is also econometrically estimated in a regime change model where banks reduce

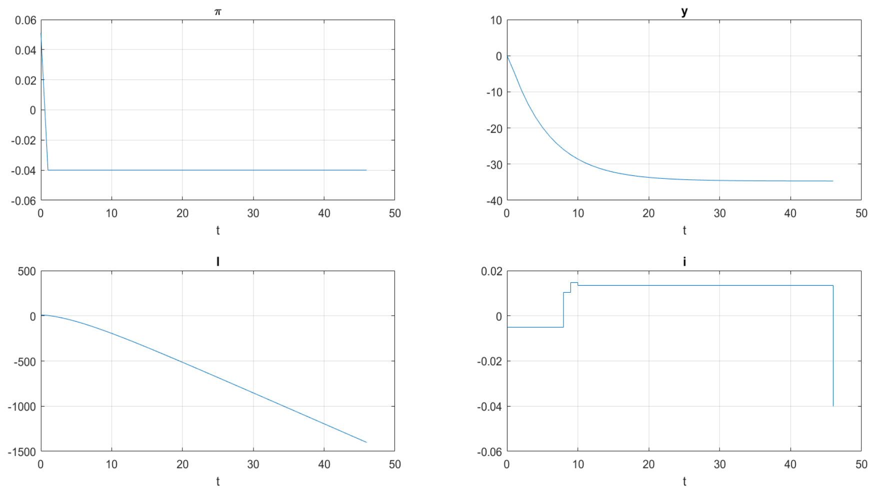


Figure 5: Results for $\pi(0) = 0.03; y(0) = -0.03; l(0) = 10.8$; no or insufficient QE, insufficient credit supply, but $\beta_3 = 0.03$

As figure 5 shows there is some some instability arising due to the insufficient QE and insufficient credit flows. It is natural that risk premia are rising when output gap is negative, asset prices falling and there are in addition non-performing loans and thus there is a regime switch to high credit spread, as a result of declining credit flow which is moving below some threshold, as in figure 1 and figure 4 at the end of the graph.

The insufficient increase of credit flow through UMP, creating a further fall of credit flows, generates a jump into a regime of high credit spreads, which entails a reduction in output. This is likely to generate then also eventually negative inflation rates, reaching possibly a floor, due to the nonlinear Phillips-curve. As concerning our credit spread variable and risk premia we can observe in this case a rapid rise of the risk premia and credit spread accompanied by a fast decline of credit flows, not depicted here.

Note also that in this case we observe that the ELB is only partially binding. This effect of small negative changes in the credit flows generating large risk premia, rising credit spreads and credit contractions could also occur if there is a slow and too early tapering of UMP. This is in particular a peril if the economy and the financial market transactions and trading has been locked to a low credit cost economy for long period of time.

their loan supply when they are highly leveraged and are in a bad regime.

### 5.3 Scenario 3: Regime with low credit flows - credit demand policy

Next, we explore a stronger effect of credit flows on the output gap, setting[35] $\beta_3 = 0.15$. This falls into the wider range of unconventional monetary policy measures that are related to macroprudential policies (MPP). We assume that credit flows are low and close to the the threshold $l(0) = 12.8$, since we want to explore the effect of stimulating credit demand.

In the current scenario the UMP can aim at stimulating credit demand whereby credit demand constraints are relaxed. This can occur, for example by reducing collateral requirements, allowing for a higher loan-to-value ratio in real estate mortgages, or relaxing borrowing standards through central banks' regulations and guidelines. Many of those measures fall into the area of macroprudential policy (MPP).

We thus explore the movements of macro variables by using initial conditions and parameters such as : $\pi(0) = 0.05$; $y(0) = 0.04$; $l(0) = 12.8$ ; $\beta_3 = 0.15$.

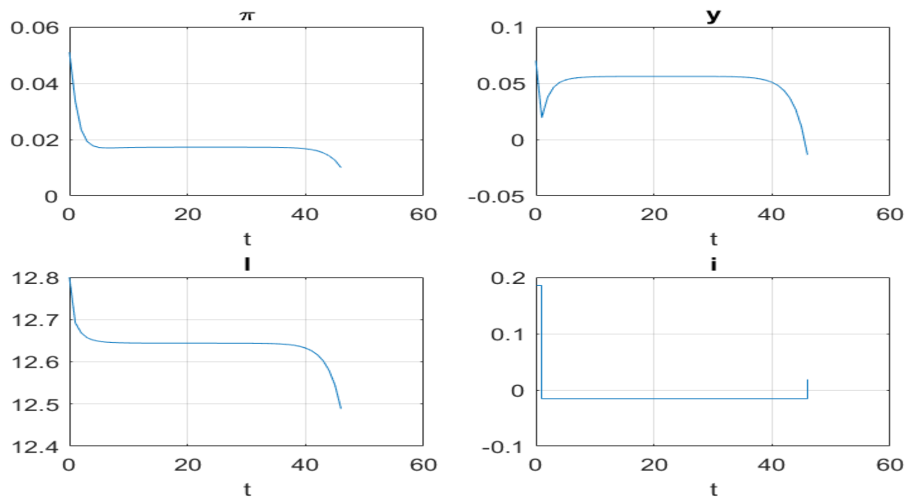


Figure 6: Results for $\pi(0) = 0.05$; $y(0) = 0.04$; $l(0) = 12.8$ ; $\beta_3 = 0.15$; disinflation dynamics, credit expansion through credit demand, credit flows go down, policy rate moves to ELB, but output stabilization

The results are presented in figure 6. We observe a small disinflation dynamics, credit flow moves down, the policy rate moves to ELB, but output stabilized through credit demand policy. Hereby credit demand constraints are sufficiently relaxed and credit cost is kept down.

Though here macro prudential policies seem to be working, which of course assumes that the temporary contraction of the output gap, see the chart for the output gap in figure 6, is presumably

[35] Note that Ajello et al. (2016), appendix, explore a parameter uncertainty of $\beta_3$ =+(-) 0.28 and its effect on the stabilization of the variables.

not accompanied by an asset price fall and banking instability, as in scenario 3.[36] This positive result in scenario 4 at least holds as long as the credit flow is kept relatively high. As it moves further down, the credit spread starts rising again, as in figures 3-5 and as before, after the credit flow falls below its threshold, roughly at period $t = 38 - 40$, all the macro variables are affected adversely.

## 5.4 Scenario 4: Change of the long-run natural rate – requires adjustments in targets

Recently many academics predicted the downward movement in the long-run natural rate, in particular after 2008-9. Economists used either filtering methods to show those trends to a lower natural rate (see Laubach and Williams (2013, 2016)), or elaborated on theories to explain such presumed facts: such as excess savings and diminishing investment demands (Summers, 2014), demographic factors, productivity decline, measured as direct productivity or total factor productivity.[37]

Thus, in the next scenario we explore the effect of such down ward trend in the natural rate. In monetary policy models this has been undertaken in terms of regime change models Foerster (2014). We are first using a natural rate $r = 0.03$, as before many had suggested for the longer run. The results for $r = 0.03$ are shown in figure 7, which are as expect. With credit expansion the inflation rate stabilizes at 0.0133, output gap at 0.0331, and the policy rate moves to ELB.

Next we let the natural rate go down to $r = 0.005$, as some literature has suggested, see Eggertsson et al. (2017) and Benigno and Fernaro (2017).

As figure 8 shows, moving the natural rate to $r = 0.005$, requires a higher steady state value of credit flows. Note that $l^*$ is now 13.1 instead of 12.8. But the decline in the natural rate also lowers the inflation target, and lowers the output target. Moreover the policy rate has to come down further, as compared to figure 7, so as to stabilize the economy. The ELB has moved down further as compared to the case of a higher natural rate of figure 7.[38] Thus if the natural rate moves down, this requires adjustments in the central banks' targets.

In both natural rate variants we have not depicted the credit spread movements which behave very similarly to figure 4. As the credit gap becomes negative the credit spread starts rising again, as in figure 4, and after the credit flow falls below its threshold, here roughly at period $t = 32 - 38$, all the macro variables are affected adversely.

Overall, the above scenarios illustrate the perils of strong negative shocks to inflation and output

[36] The scenario4 may, however, point to the limits of macroprudential policies, as fine tuning policies. Others have also expressed doubts whether macroprudential policies are available and sufficient. See Gourio et al. (2017: 1) where they state with respect to the US: "Many countries such as the United States have a limited set of macroprudential tools, and suffer from dispersion of regulatory authorities The tools are difficult and slow to adjust, and their effects remain fairly uncertain".

[37] Some recent work expresses the view that demand constraints for a protracted period of time can turn into supply constraints, namely when demand is weak, the constraints in the product, labor and financial markets are extensive, for example credit constraints are severe (since collaterals are down, and risk premia up) and households and firms can borrow less and thus expenditures for R&D, innovation, skill building and productive activities are declining, affecting the supply side, i.e. generating declining productivity growth, see Benigno and Fernaro (2017).

[38] Note that, as discussed in sect. 3, the regime change to a different natural rate will also make the control variable, the policy rate, jumping.

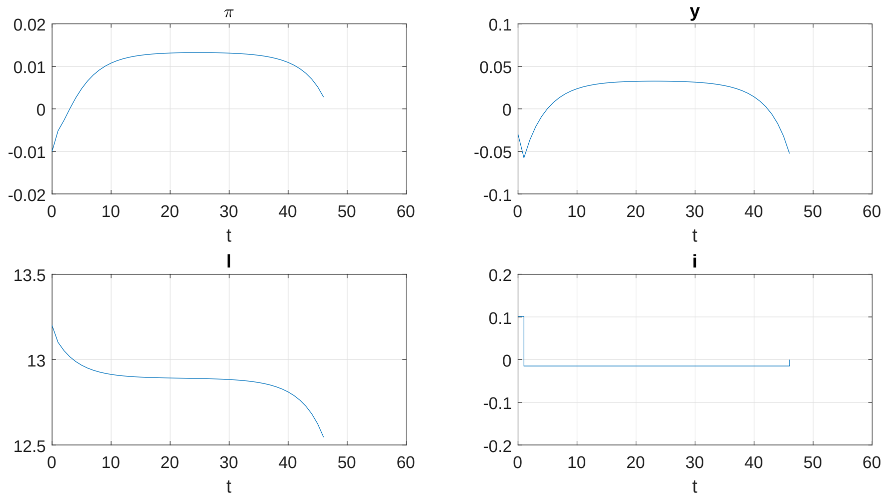


Figure 7: Results for $\pi(0) = -0.01$; $y(0) = -0.04$; $l(0) = 13.2$ (note that $\hat{l}$ is still at 12.8) ; $\beta_3 = 0.03$; deflation dynamics, but credit expansion, stabilizes inflation rate at 0.0133, output gap at 0.0331, and the policy rate which moves to the ELB, UMP thus reduces credit spread, and achieves output and inflation stabilization, with the natural rate, $r = 0.03$, and the policy rate is about zero.

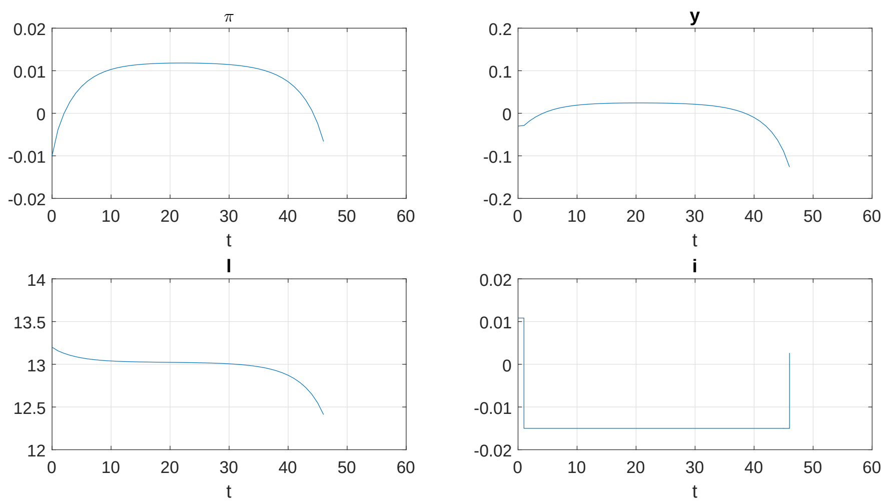


Figure 8: Results for $\pi(0) = -0.01; y(0) = -0.04; l(0) = 13.2$ (note that $\hat{l}$ is now at 13.1 instead of 12.8) ; $\beta_3 = 0.03$; the natural rate is $r = 0.005$; first with deflation, but credit expansion, inflation rate stabilize at 0.012, output gap at 0.025, the policy rate moves to the ELB; QE thus reduces credit spread, and achieves output and inflation stabilization; but the policy rate is moving further into a negative region.

gap when accompanied by low credit flows and worsening of credit conditions.[39] The perils come from the interaction of credit flows and the risk premia, credit spreads and credit costs, that can, or cannot, be reversed by interest rate or UMP. Though there are scenarios a success of mean reverting policies, but as shown, central banks do not seem to be always able to control the private sector dynamics through UMP. The controllability appears to depend on the state or regime of the business cycles, the expansion or contraction of credit flows, the effectiveness of credit supply through the banking system, the reduction of the constraints of credit demand (role of $\beta_3$) and what shocks there are to the credit flow variable. What adds uncertainty is what the targets should be when the natural rate changes. As shown in figures 7 and 8 central banks need to adjust targets if the natural rate has changed.

# 6 Empirics using a regime-switching VAR

Since the proper empirics on a change of the long-run natural rate is still missing, particular due to an insufficient quality of long time series data, we restrict ourselves to an RS-VAR estimation without attempting to specify a time varying natural rate, using shorter time series data at monthly frequency. We use monthly data (January 2003 to April 2016) of the Euro area.

Empirically, we look at four types of shocks and exploring their effects: 1. conventional monetary policy shock (policy rate changes), 2. UMP as change of the CB's balance sheet (pure QE, see scenario 1 of sect. 5), 3. loan supply shocks affecting directly the credit spread and loan rates of banks (represented also by scenario 1, figure 4[40]), and 4. loan demand shock (reducing the credit constraints, increase of $\beta_3$, see scenario 3 in sect. 5). Thus, here in the RS-VAR, we have decoupled UMP, as change of the CB's balance sheet, from the asset market and credit spread effects captured in shocks 3.- 4. All shocks are summarized for our RS-VAR in table 2, rows 1-4, each of the shocks affecting six macro variables.[41]

The RS-VAR model structure, with 2 lags, can be written as follows.

$$y_t = c_r + \sum_{i=1}^{p} A_r y_{t-i} + B_r z_t + u_{rt} \tag{9}$$

where $y_t = (y_{1t}, ..., y_{Kt})'$ is a vector of dimension $K \times 1$ comprising $K$ endogenous variables, $c_r$ are the intercept coefficients under the two regimes ($r = 1, 2$), $A_r$ are $K \times K$ matrices of coefficients, and $B_r$ are $K \times G$ coefficient matrices loading an exogenous variable vector $z_t = (z_{1t}, ..., z_{Gt})'$ of length $G$. The $u_{rt}$ is a $K$-dimensional error term whose covariance matrix $E(u_{rt}u'_{rt}) = \Sigma_r$ is allowed to be regime-specific, too. For the linear variant of eq. 9 without regime dependence we let the $r$ subscripts drop.

The macro variables that the vector $y$ contains include real GDP in natural log (ln) differences

[39] On the dangers of a possibly arising debt deflation through this situation, see Ernst et al. (2017).

[40] Note that though figure 4 represents a rise in spread, one would obtain a declining spread corresponding to credit flow increase.

[41] For details of the following RS-VAR estimation, impulse-response functions, and data sources, see Faulwasser et al. (2018).

Table 2: Sign restriction settings for linear and regime switching model-based impulse response analysis

| # | Description | Real GDP growth | Price inflation | Nominal GDP growth | Bank loan volume growth (new business) | Bank interest rates (new business) | ECB Total Assets | Short-term interest rate |
|---|---|---|---|---|---|---|---|---|
| | | RGDP | INF | NGDP | NBV | NBI | ECBTA | STN |
| 1 | Conventional expansionary monetary policy shock (price-based) | 0 | 0 | + | + | - | + | -25bps |
| 2 | Unconventional expansionary monetary policy shock (volume-based) | 0 | 0 | + | + | - | +5% | - |
| 3 | Positive loan supply shock (price-based) | 0 | 0 | + | + | -25bps | 0 | 0 |
| 4 | Positive loan demand shock (volume-based) | 0 | 0 | + | +5% | + | 0 | 0 |

month-on-month (MoM), HICP inflation lnMoM, new business bank loan volume flows to the nonfinancial private sector lnMoM, banks' new business loan rates, ECB total assets in lnMoM, and a nominal short-term interest rate (3-month Euribor). Our choice of employing flow-based measures (credit flows) and interest rates instead of stock-based measures corresponds to the theoretical model since the loan volume variable is supposed to reflect credit to new business (and households) instead of stocks or changes of stocks.[42]

Slightly modifying our theoretical model, we take in the empirics not the credit gap as variable driving the credit spread but the output gap, which is easier to measure and much work has been done here to obtain robust measures of gaps.[43] To measure the output gap, we use the procedure by Jarociński and Lenza (2016) who operate with a Bayesian dynamic factor model for the euro area to imply the estimates of the unobservable output gaps which are consistent with observed inflation dynamics .

Based on the Jarociński and Lenza (2016) we derive a 0-1 indicator, which is 1 if the output gap is positive and zero otherwise. The results that we present in the following are robust to the various different output gap and regime inference schemes as presented in Gross and Semmler (2017). The RS-VAR is done with sign restrictions, displayed as in table 2. Note that rows 2 and 3 of table 2 corresponds to scenarios 1 and 2 (loan supply shocks) of sect. 5, and the row 4 corresponds to scenario 3 (loan demand shock) of sect. 5. The shocks of row 1 are not evaluated in sect. 5 because there the policy rate is endogenous.

To reveal the linear and nonlinear model's dynamics we have simulate sign-restricted impulse

[42]See Biggs et al. (2009) who develop a theoretical model that highlights this point and shows that consumption and investment flows are related primarily to new lending rather than to the stock or changes in the stock of loans.

[43]In the Annex 2 we show that they behave quite similar over the business cycle.

responses (SR-IRs).[44] To derive the impulse responses from the regime-switching models, we take the coefficient sets and covariance matrix estimates that are specific to the regimes of the regime-switching version of the VAR and simulate the impulse responses assuming that the regimes keep prevailing.[45]

We have simulate the above mentioned four shock scenarios, whose results are summarized in table 3. All four scenarios are positive shock scenarios and they correspond to a conventional interest rate-based monetary policy shock (CMP), an unconventional volume-based monetary policy shock (UMP as change of CB's balance sheets), a loan supply shock (LS), and a loan demand shock (LD), the LS works through the loan rate - interest rate spread, and the LD through relaxing the credit constraints, a volume effect. There are no constraints imposed on real GDP and inflation in any of the scenarios. A positive constraint is under all shock scenarios imposed on nominal GDP which is an off-model variable whose paths are proxied by the sum of real GDP growth and inflation during the simulation. Under the LS and LD scenarios the shocks are meant to originate more directly in relation to the banking system instead of the central bank, in which case the central bank total assets and the short-term interest rates are in fact not constrained.

Overall, the first three shock scenarios reflect supply side-type shock scenarios which can be seen by the fact that bank interest rates are assumed to fall or are shocked negatively. In addition to the responses of the core model variables, two off-model variables' reactions are shown, that is, the aforementioned nominal GDP proxy as well as a credit spread which is defined as the difference between the loan interest rate and the short-term money market rate. That variable corresponds to the credit spread $\delta$ in the theoretical model, its called NBISTNspread in table 3.

The table 3 summarizes all our results of the RS-VAR and impulse-responses.[46] We report in table 3 the differential effects of contractions and expansions, R2-R1. Across all four shock scenarios, the response of inflation is positive and it is more positive under an assumed expansion regime, both on impact in the first month and in cumulative terms after 18 months. This outcome was not pre-informed by any sign constraints, and is as robust a finding as in Gross and Semmler (2017); also when considering various different measures of economic slack to inform the regime process.

The nominal GDP response was constrained to be positive; yet we see the same feature that was not pre-informed insofar as the nominal GDP response is more positive under the assumed expansion regime; under all four shock scenarios. Real GDP responses are generally positive, and by the end of the 18-month period are again more positive under the assumed expansion regime. Concerning nominal loan flow growth, we see a similar pattern as for nominal GDP, that is, positive responses, which are more positive under the expansion regime.

With respect to the credit spread responses (NBISTNspread), we can observe that they are negative and quite persistent under all scenarios,[47] meaning that lending conditions ease not only because level interest rates fall but also the spreads on top, reflecting in turn that the borrowers'

[44] As an entry point to the literature related to sign-restricted SVARs see Faust (1998), Canova and Nicoló (2002), and Uhlig (2005), for details of our results see Faulwasser et al (2018).

[45] See e.g. Ehrmann et al. (2003) who use the same regime-dependent impulse response simulation scheme. Other model settings are conceivable, whereby the regime process would be endogenous, for shocks to possibly imply, depending on their size, a transition between regimes.

[46] The corresponding figures of the IRs can be found in Faulwasser et al. (2018).

[47] This is reported in the impulse-response figures in Faulwasser et al (2018), Annex 4.

Table 3: Differences of cumulative effects – responses for recession and expansion regimes after 18 months (differential effects of contractions and expansions, R2-R1)

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Scenario | Conventional expansionary monetary policy shock (price-based) | Unconventional expansionary monetary policy shock (volume-based) | Positive loan supply shock (price-based) | Positive loan demand shock (volume-based) |
| RGDP | -0.06 | -0.22 | -0.97 | -1.48 |
| INF | -1.14 | -2.08 | -0.78 | -0.91 |
| NGDP | -1.16 | -2.27 | -1.75 | -2.47 |
| NBV | -9.51 | -17.73 | -4.61 | -4.31 |
| NBI | -1.95 | -3.04 | -3.22 | -9.28 |
| ECBTA | 13.47 | 20.76 | 11.13 | -11.93 |
| STN | -3.74 | -6.14 | -3.96 | -15.62 |
| NBISTNspread | 1.73 | 2.99 | 0.67 | 6.03 |

default risk would fall under the scenarios.It is noteworthy to observe for (NBISTNspread) in table 3 that under all shock scenarios, the differential between the contractions and expansion regime-conditional response of credit spreads is positive, meaning that the fall in spreads is more negative under the expansion regime, except under the loan supply shock, where the effects are roughly similar in contractions and expansions.

# 7 Conclusions

The paper demonstrates that if we allow for a two regime switches in a nonlinear monetary policy decision model with credit flows, this produces notable challenges in solving the model globally. If we have a NLQ model, the methods for solving LQ models are not sufficient. On the other hand, the linearization of macro models, will eliminate the nonlinearities and out of equilibrium propagation and magnifying mechanisms which one might want to preserve in order to explore proper policies. Though the model is small scale it is similar in spirit to more complicated large scale macro econometric models which many central banks currently employ. In the context of the small scale NLQ model essential issues such as the need and effectiveness – as well as the ineffectiveness– of the UMP can be assessed.

Such nonlinearities pertaining to the regime switching in risk premia and credit spreads can be found in much recent empirical macroeconomic work. Credit cycles with the perils of endogenous risk premia, credit spreads and instability of credit were put forward by Kindleberger and Aliber (2005) and Minsky (1986). Minsky in particularly stressed the negative co-variation of credit expansion and risk premia and credit spreads. We solve our NLQ model for finite horizon decision making through some new numerical techniques The parameters of our proposed nonlinear model are estimated for Euro area data using an output gap and credit gap estimated by the recently developed Hamilton filter. Though all parameters are estimated with confidence bands, there is still some uncertainty of some parameters, in particular surrounding the drivers of credit flows and credit spreads.

We explore a variety of macroeconomic scenarios exhibiting different conditions as impacted by shocks, different types of credit conditions, and parameter variations. Our macroeconomic scenarios in particular illustrate the perils of credit cycles characterized by expansion and contraction of credit flows and regime switching in risk premia and credit spreads. This is is mainly studied for bad states of the economy characterized by negative output gaps and negative or very low inflation rates. Though there are scenarios of mean reverting effects of policies, as in traditional macro models, but as shown, central banks do not seem to be always able to control the private sector dynamics, even through unconventional monetary policy. The controllability appears to be state dependent, dependent on credit flows and credit conditions, such as the loan rate - policy rate compression, the credit constraints and credit demand (role of $\beta_3$) and initial conditions such as the size of the credit flow increase. As we have shown there are easily tipping points which can be triggered in our our scenarios, without mean reversion in the dynamics. Note also that though in or NLQ model the UMP is working through the asset market but asset market miss-pricing is not defined as direct policy target. There is a variety of asset market miss-pricing which is not easily targeted, but credit flows drivers can more conveniently be targeted.

Our RS-VAR and the impulse responses make more precise how the credit spread (NBISTNspread) behaves over the two regimes – contractionary versus expansionary regimes (R2-R1). There are for all shocks positive regime differentials. This means that the positive sign of the difference of the spread of in the contractionary versus expansionary regimes (R2-R1) shows that it is easier for the central bank to reduce spreads in expansions than in recession. Under the direct loan-demand shock, the difference between the spread responses under the two regimes is most pronounced, while under the direct loan supply shock scenario the credit spread compression is least pronounced, which means that loan supply shocks are almost equally effective in contractions and contractions.

As far as the exit from the UMP is concerned, it is apparent that not only small changes in the variables could create regime switches in the other variables with far reaching behavioral perils coming from the economic agents. Small decreases in credit flows and financial market reaction of agents can give rise to switches in credit spreads and it could endanger the tapering. What were safe assets could then now be unsafe assets, with repricing of risk and large risk premia, triggering a large shift in portfolio holdings in the financial markets, which significant financial - real interaction effects.

It is this effect, as well as the occurring credit flow reduction and credit spread rise, that presumably might make a too earlier tapering of UMP too costly and one could have unwanted side-effects such as credit tightening from financial intermediaries, rise of risk premia and lending rate to policy spread.[48] On the other hand, there are also perils if the credit flows move too far away from their mean which could give rise to accelerated credit contractions and rapid rise of credit spreads, the Minsky-Kindleberger moment.

Furthermore, as some have argued regarding the Euro area,[49] there could be more cautionary measures against excess credit flows and asset price inflation in some regions and sectors that are

[48] Another helpful policy is of course, as also Bernanke (2017) states, fiscal policy to stabilize the economy.

[49] See Brunnermeier and Sannikov (2014b).

over-stimulated and more stimulation in other sectors and regions in the euro area. Thus, a more selected credit flow policy across the Euro area – maybe more constrained in the North and less constrained in the South – would have been advisable.

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# Annex 1: The dynamics with borrowing constraints – The role of credit volume policies

The middle equation of equation (1), and in difference form in equation (7), need some further derivation. There are numerous studies on endogenously generated borrowing constraints for agents that want to borrow. How agents are endogenously constrained by the swings in asset value is presented in Kiyotaki and Moore (1997), for agricultural farming, and for a model with industrial production in Miller and Stiglitz (1999), among others.

Formally borrowing constraints for the agents in an economy could be formulated as follows:

$$l_t = \phi(q_t k_t) \tag{10}$$

with $q$, asset price, $l$, the loans taken on as liability and $\phi$ the fraction of collateralized assets, defining the borrowing constraints. Thus, the borrowing is constrained by the value of the collateral and $\phi$ the collateralized fraction of the asset. In Kiyotaki and Moore (1997) being concerned with agricultural production, the constraint is driven by the harvest in the last period, and in Miller and Stiglitz (1999) by the last period's sales of the firm.[50]

In Wu and Zhang (2017) the borrowing capacity is driven by a fraction of the value of capital as in (10), determined by both the volume of capital and Tobin's q, the value of a unit of capital. Spending for consumption is derived from the first order condition of the Euler equation through an (infinite time) optimization problem, but the borrowing capacity, depending on the value of assets as well the fraction of collateralized assets, enters the consumers' budget constraints. Thus relaxing the budget constraints, for example through an extension of lending facilities, via an increase of the loan to value ratio, affecting $\phi$, allows for an ease of borrowing and decline of the shadow interest rate in their model. They also show how the credit constraint get relaxed through QE, entailing a decline of the shadow rate to an even negative region so that the credit cost can move even below the ZLB.

Another interesting version is suggested in Eggertsson and Krugman (2012). They study an endowment economy and focus on consumers only – on savers with a high discount rate, and borrowers with low discount rate. The size of borrowing could be high, for the borrowers when the discounted income is high. Yet when the asset value is the collateral for borrowing, and the asset value falls, this entails a lower borrowing, and a switch from the high to a low borrowing case, with consumption spending reduced. This collateral value shock and the switch from high the low borrowing of households is what they call the Minsky deleveraging effect. This could give in their view rise to a cumulative downward spiral, with asset value and income falling, and real debt rising— the Fisher debt deflation process.

In our model of system (5), in continuous time, and (7), in discrete time form, we have thus a term $\beta_3(e^l - \hat{l})/\hat{l}$ included that represents the above considerations of constrained borrowing. We propose that the excess (positive) credit gap strongly co-varies with the asset prices (stock market and real estate, as in Jorda et al. 2011, 2012), and a fraction of assets are collateralized as in Wu

[50] Stiglitz (2018) in a recent review article on macro theory claims that the analysis of the great recession, with its dynamic financial-real interaction, cannot be properly analyzed without studying the role of credit constraints.

and Zhang (2017). We assume, however, that in the economy there is only a fraction of economic activities that are eligible to obtain collateralized loans. For example $\beta_3 = 0.03$ can mean that $\phi = 0.3$ and only 10 percent of agents can obtain collateralized loans, see scenarios 2 to 5. In scenario 6 the latter ratio is then increased to 50 percent through Central Banks lending facilities. Note that whenever the excess credit is rising (increase of the positive credit gap), for example through CBs' increase of borrowing facilities the output gap is likely to close faster. In other words, the credit gap $\beta_3(e^l - \hat{l})/\hat{l}$, besides its effect on the credit spread, and direct effect on the output gap, aids to overcome loan rationing. Surely, a number of macro prudential policy tools will have their impact on this term, see scenario 6.

Note that our inclusion of the excess credit gap term is closely related to Eggertsson and Krugman (2012), where credit volume policies also become important, and resembles Wu and Zhang (2017), where a term such as $\beta_3(e^l - \hat{l})/\hat{l}$ is derived from a (consumer) budget constraint, however, there of an infinite horizon decision model, see their derivation of the Euler equation with bond issuing and their local linearization study in their appendix A.1. In all of these cases where there is collateral constrained borrowing, heterogeneity and fragmented capital markets, a volume oriented credit policy and macroprudential policy tools might also be advisable, see Brunnermeier and Sannikov (2014b).

# Annex 2: Credit spread, shadow interest rate, credit flows and QE

Much recent literature use a computed shadow rate as replicating the movement of the risk premia and credit spread, in particular to give some foundation of negative interest rates. For the US economy, as well as for the euro area, there is extensive empirical literature that point to a strong co-movements of credit spread measures and the shadow interest rate, see Wu and Zhang (2017) for the US and for the EU Lemke and Vladu (2017) and Mouabbi and Sahuc (2018).

We first want to establish some stylized facts related to credit spread measures supporting our model of sections 3 - 4, for both the US as well as the euro area.. In the context of our model the following is assumed to hold: 1) a strong negative co-movements of credit spread (shadow interest rate) and credit flows, 2) a strong negative co-movement of the QE (in the US called LAPP and APP in the EU) with credit spreads, and 3) a strong positive co-movement of credit flows and QE. Those three claims can be seen to hold in our figures 14-16 for US data.

In Figure 14 we use smoothed data for BBB bond yields, as a measure for credit spread, and the flow of new loans to household and the non-financial business sector. A clear negative co-variation is observable, though with some phase shift, i.e. loan peaks occur later.

Figure 15 shows the BBB bond yields, measure of credit spread, and how they were driven down by the effects of QE since 2009. Note that for the effect of QE policy we use the inverted log of the FED's balance sheets.

Figure 16 establishes the again smoothed credit (annual) credit flows, and the inverted log of FED's balance sheets. A quite strong correlation between those two are observable.

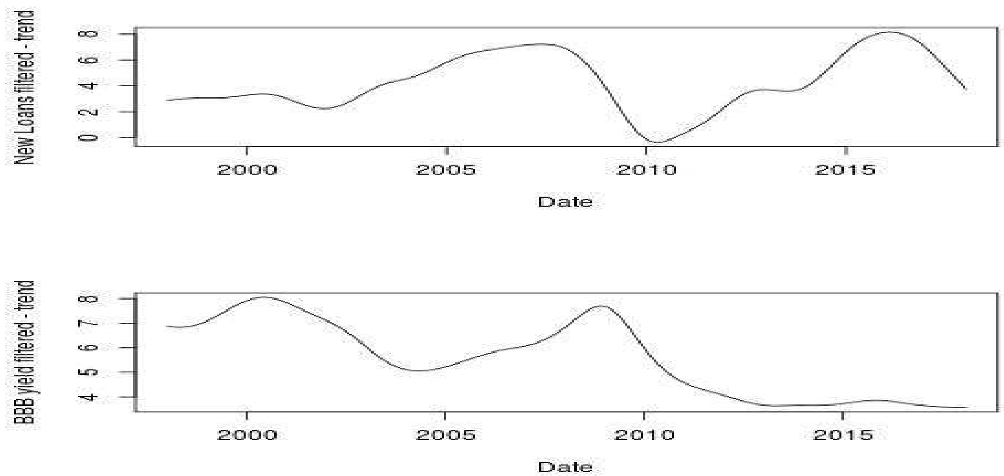



Figure 9: US credit flows and credit spread (shadow rate) represented by BBB bond yields; upper graph: BBB bond yields, lower graph: credit flows (time varying trend), data from FRED

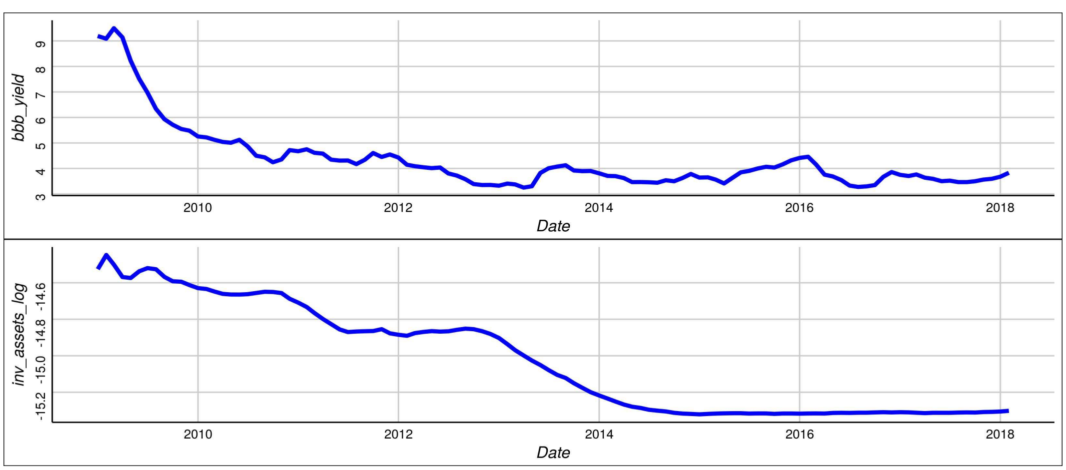



Figure 10: BBB bond yields and QE in the US, since 2009, upper graph: BBB bond yields, lower graph: inverted log of FED balance sheet assets, data from FRED

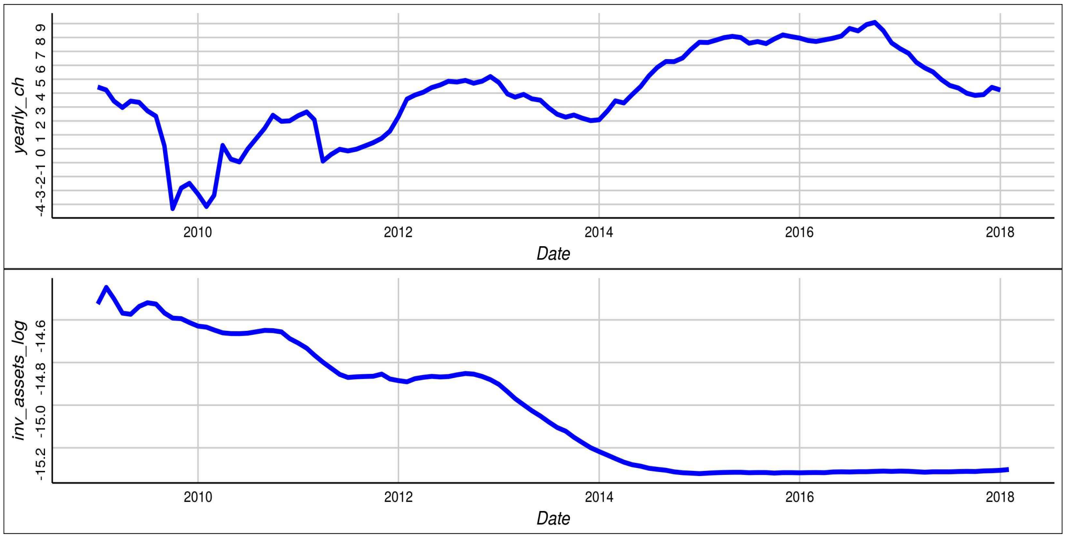



Figure 11: Credit flows and QE since 2008, upper graph: annual credit flows; lower graph: inverted log of FED's balance sheets, source FRED

For the euro area similar results are obtained. Figure 17 shows the mirror image of credit spreads and credit flows. When credit flows are high credit spreads are low.

For the euro area also holds that the credit spread was made declining through the QE policy, though this has set in later than in the US see figure 18. Due to the lack of corporate bond market we measure in the euro area the credit spread by the banks' lending spread to firms, see figure 18.

In figure 19 we can observe a strong co movement of credit flows (lower panel) and the QE policy (upper panel). Again as regarding QE policy and credit flows, in the euro area, we can see the same co-movement as in the US, with increased asset volume in the balance sheets of the ECB (upper panel, inverted scale, figure 19) the credit flows are going up, figure 19 (and credit spreads going down, figure 18).

But there is a particular period observable between 2012-13, where QE and the asset purchasing program is retarding, entailing a further decrease of credit flows and a temporary increase in credit spreads. This is presumably related to the sovereign debt crisis in the Euro area.

Other authors have studied similar effects of QE and the central banks' balance sheets, but study the effect on the shadow rate instead credit spreads. Theoretical as well as empirical studies for the US show a strong negative co-movement of the shadow rate and QE, see Wu and Zhang (2017). Their shadow rate is computed for two regimes, for normal and bad times. For the normal times the shadow rate is obtained from an estimation of the policy rate using the Taylor rule. Thereby it is assumed that asset purchases of the central bank are just normal and the CB bank does not increase its balance sheets. Yet in a bad regime when the policy rate reaches the ZLB a shadow rate is computed by taking into account estimates of the term structure risk premium, liquidity premium, and adjustments for bond premia. In the model by Wu and Zhang (2017) the monetary policy of QE type is affecting the shadow rate as follows:

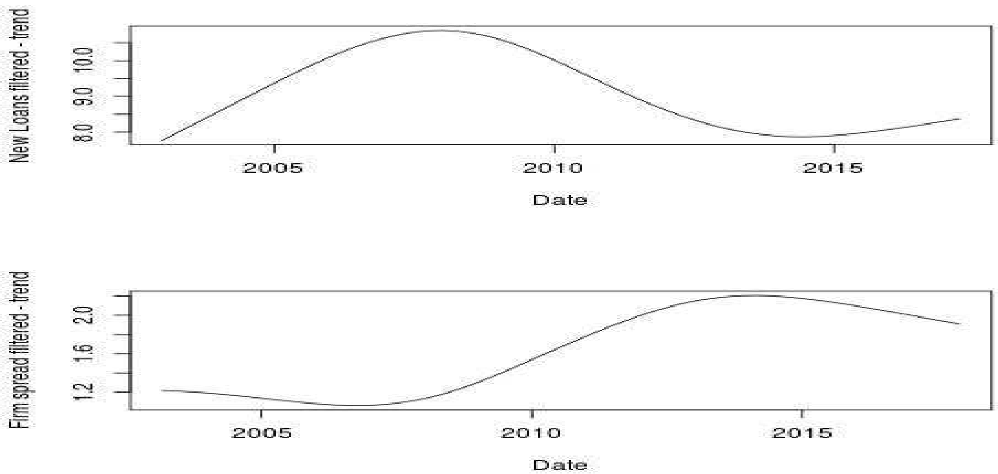



Figure 12: Credit flows and credit spread in the Euro area, data source, ECB

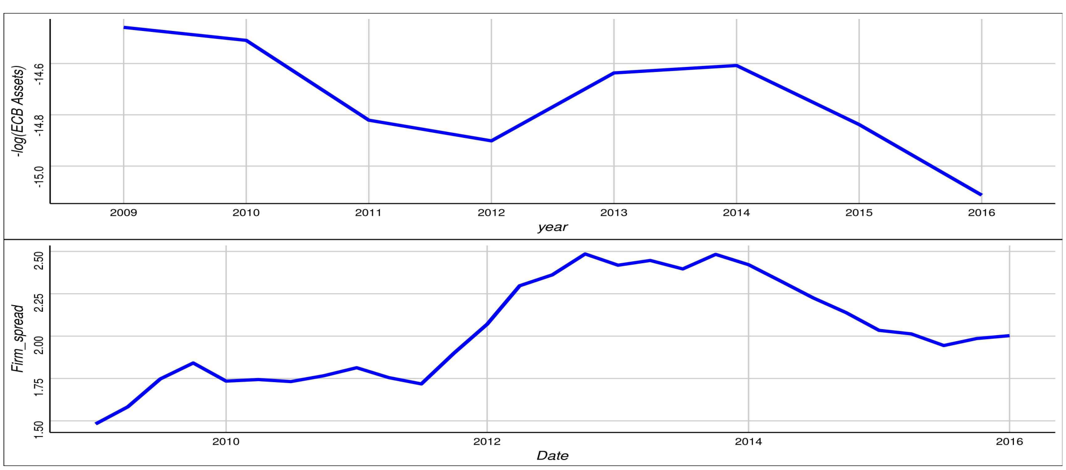



Figure 13: ECB balance sheets and credit spread

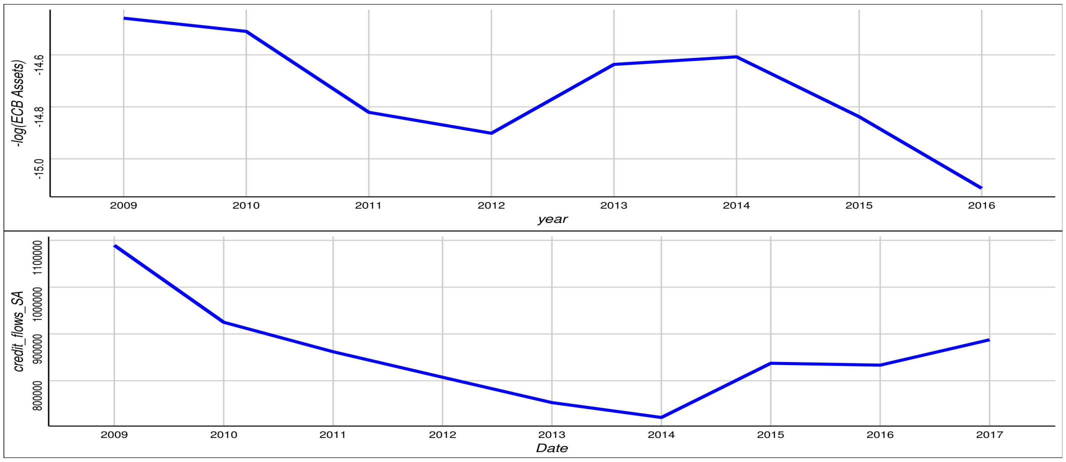



Figure 14: ECB balance sheets (upper panel) and credit flows (lower panel)

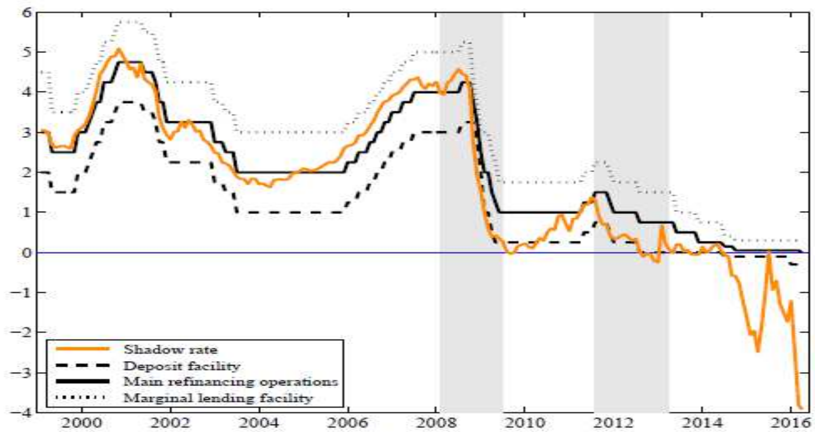
$$r_t^B = r_t + rp - \zeta(b_t^{CB} - b^{CB}) \tag{11}$$

Hence at normal times $b_t^{CB} = b^{CB}$ one has $r_t + rp$ and monetary policy operates through the Taylor rule, and $\zeta$ is a positive coefficient. When the policy rate reaches the ZLB, $r_t = 0$, the bond rate becomes $r_t^B = s_t + rp$ with $s_t < 0$, due to the CB's asset purchasing program. Hereby, in the first step $rp$ taken as a constant risk premium that can be made stochastic.

Those linkages are similar in our model context. In Wu and Zhang the equ. (10) allows for a negative shadow rate when the ZLB is reached. In our case, when we have QE and $(e^l - \hat{l}) > 0$, the shadow rate, can be negative given by the optimal policy rate $i_t$ which could be negative (but so could be the credit spread in figure 1 under the impact of QE). This corresponds to what has been observed for the euro area where at some time period after 2014, where the Deposit Facility, see figure 20, and also the EONIA became negative. This entailed that the bond yields for bonds of shorter maturity became negative, see Lemke and Vladu (2017), see also figure 20.

In our model of system (5) we allow, as is also in figures 5 and 7 observable, the credit spread, due to a rising risk premia $\delta(l)$, jumps up for $(e^l - \hat{l}) < 0$ , with $\hat{l}$ as threshold, defining the credit gap. This would increase the markup on the policy rate $i_t$, see equ. (8), figure 1 and lower panel of figure 3 and figure 5. This case is less considered in Wu and Zhang (2017) since they start their study only with the downward trend of a shadow rate, with 2009. and define the time before 2009 as normal times, with $b_t^{CB} = b^{CB}$. By using data before 2009, what we also want to show is that there is, as in figures 14 and 17, a strong (negative) co-movement of the credit flow and credit spread.

Note that our case the optimal policy rate itself could also be negative – or positive as in cases of figures 8 and 9, yet the dynamics is unstable. Whenever, however, through QE we have $(e^l - \hat{l}) > 0$, i.e. credit spread would move down toward zero, see figure 1. The optimal policy rate $i_t$ could become negative even if the policy rate from the Taylor rule goes to zero as in equ. (10). The




*Note:* Gray bars denote CEPR-defined recessions.

Figure 15: EU shadow interest rate and other interest rates, from Mouabbi and Sahuc (2017)

optimal negative interest rate and the QE impact on the spread allow then to reduce the output gap and lift the inflation rate. Yet, the actual real interest is also affected by the inflation rate, depending on the inflation rate, see the nominal interest and inflation rate in figures 3 to 11.

For the Euro area a shadow rate $s_t$ has also been computed by Mouabbi and Sahuc (2017), which is presented in figure 20, turning negative since 2014. In the euro area the shadow rate was driven down by the Asset Purchasing Program (APP), for which there was also a forward guidance.

The shadow rate for the euro area, computed in Mouabbi and Sahuc (2017), roughly replicates the figures for the US shadow rate by Wu and Zhang (2017). The former use a principle component and dynamic factor model to extract information on the shadow rate.

# Annex 3: Numerical Treatment of the model

## 1. Generic set up– Finite-horizon decision making with two regime switches

We solve the following finite-horizon discounted decision problem, with the above two nonlinearities, as a finite horizon optimal control problem (OCP):

Table 1: Parameters for system (1) and OCP (12).

| | | | | | |
|---|---|---|---|---|---|
| $\rho$ | 0.03 | $\beta_1$ | -0.18 | $\gamma_1$ | 0[t] |
| $\alpha_1$ | -0.67 | $\beta_2$ | 0.45 | $\gamma_2$ | 0.81 |
| $\alpha_{21}$ | -0.21 | $\beta_3$ | $0, 0.03, 0.15$ | $\gamma_3$ | -0.48 |
| $\alpha_{22}$ | 0.43 | $r$ | 0.03 | $\gamma_4$ | 0.5 |
| $\hat{l}$ | 12.8 | $\mu_2, \mu_3$ | $13.35, -13.34$ | $c_1, c_2$ | $0.72, -0.001$ |
| $c_3, c_4$ | $2.2, 10.33$ | $\lambda_{\pi,y,l}$ | $10^4$ | $\lambda_i$ | 1[b] |

$$\min_{i(\cdot)} \int_0^T \frac{1}{2} e^{-\rho t} \|\Delta(\tau)\|_\Lambda^2 \mathrm{d}\tau \tag{12a}$$

subject to (1)

$$i \in [-0.015, 1] \tag{12b}$$

$$\pi \in [-0.05, 1] \tag{12c}$$

$$l \in [-10^2, 10^2] \tag{12d}$$

$$y \in [-10^3, 10^3] \tag{12e}$$

$$\Delta(\tau) = \begin{bmatrix} \pi(\tau) - \pi_s & y(\tau) - y_s & l(\tau) - l_s & i(\tau) - i_s \end{bmatrix}^\top \tag{12f}$$

$$\Lambda = \begin{bmatrix} \lambda_\pi & 0 & 0 & 0 \\ 0 & \lambda_y & 0 & 0 \\ 0 & 0 & \lambda_l & 0 \\ 0 & 0 & 0 & \lambda_i \end{bmatrix} \tag{12g}$$

with $\lambda_\pi = \lambda_y = \lambda_l = 10^2$ and $\lambda_i = 10^{-2}$to be used as weights for the targets in equ. (5). The target point $[\pi_s, y_s, l_s]$ is a steady state of (1) as discussed below when we describe the numerical solution procedure.

We consider the parameter values as listed in Table 1. The data sources, the parameter value estimates and confidence bands are presented and discussed in section 4.

## 2. Computational strategy to find steady states

First, we need to compute a steady state for the proposed model with two switches(1). To this end, we introduce a state vector $x := (\pi, y, l)^\top$ which allows writing (1) at the steady state as

$$f(x, i) = 0,$$

where $f : \mathbb{R}^3 \times \mathbb{R} \to \mathbb{R}^3$. This is a nonlinear system of three equations and four unknowns.[51] We compute economically meaningful steady states solving the following simple problem numerically

[51] Note that the interest rate is here a control variable that helps to reduce the macroeconomic imbalances through

$$\min_{x_s,i_s} \|x_s - x_{ref}\|^2 \text{ subject to } f(x,i) = 0 \text{ and } (5b - 5g).$$

Here, $x_{ref}$ is a chosen economically reasonable reference value. This problem is solved using CasADI (Andersson (2013)) and IPOPT (Waechter and Biegler (2006)). This way we obtain

$$\pi_s = ..., y_s = ..., l_s = ..., i_s = ...$$

which are used then in the penalty function (5a). Solving OCP (5) entailed the following challenges:

- Smoothing out the discontinuities in $\delta(l)$ and $\alpha(y)$.
- Dealing with a possible instability of the dynamics of some differential equations, for example $l$ (for instance for $\gamma_1 > 0$).
- Requiring long horizon and discounting
- Dealing with multiple equilibria of the system

While the first challenge is addressed via smooth approximations form, the second one requires care in choosing the numerical algorithms for OCP discretization. The third and fourth challenge are treated in Annex 3. As to the multiple steady states, though we can state that - since our system is nonlinear– there are likely to be multiple steady states, this challenge is not so easy to handle. This issue is preliminary explored for a simplified system in Annex 3 that shows the possibility of multiple steady states for reasonably chosen parameters.

To solve our system (5) we are interested in solving the OCP for (12) for horizons of $T \approx 50-60$. As the dynamics (1) can be unstable, we employ a direct discretization using the open-source tools CasADI (Andersson (2013)) and IPOPT (Waechter and Biegler (2006)), all used in Matlab.

The ODE is discretized using a fixed-stepsize Runge-Kutta scheme of order 4/5 with 15 integration steps per shooting interval. The input $i$ is discretized as piece-wise constant function. For the different present results, we consider equi-distant shooting intervals of length $\Delta T = 10$, i.e. the number of shooting intervals equals the horizon length $T$, see Annex 3.

In other words, the OCP is discretized in both control and state variables such that the NLP to be solved reads as follows

(5a). We are not applying the descriptive Taylor rule as in Gali (2008) (sect. 4.3.1.1) where then in a New Keynesian linearized version the issue of determinacy and indeterminacy is discussed, an issue that is not coming up that in our NLQ model.

$$
\begin{aligned}
\min_{i_k, x_k} \sum_{i=0}^{N-1} \rho_k \|x_k - x_s,\, i_k - i_s\|_\Lambda^2 \qquad &(13a)\\
\text{subject to, for all } k = 0, \dots, N-1, \qquad &\\
x_{k+1} = f_d(x_k, i_k), \qquad &(13b)\\
x_0 = x(0) \qquad &(13c)\\
x_k \in \mathcal{X}, i_k \in [-0.015, 3], \qquad &(13d)
\end{aligned}
$$

where $x_k := (\pi(t_k), y(t_k), l(t_k))^\top$ is the discretized state variable, $i_k := i(t_k)$ is the discretized input, $\rho_k := e^{-\rho t_k}$, and $f_d : \mathbb{R}^3 \times \mathbb{R} \to \mathbb{R}^3$ is the state transition map arising from the employed fixed-stepsize Runge-Kutta scheme.[52]

As for the considered parameter values, the horizon length is limited, we do not employ a receding horizon approach as suggest in (Grüne et al. (2015)). Instead, we solve NLP (13) directly. However, as the construction of feasible initial guesses is some times challenging, one may need to solve simplified instances of NLP (13) to construct those guesses.

## 3. Long horizon and multiple equilibria

As to the numerical challenges of long horizons, the difficulties are that the construction of initial guesses for the control is crucial. To this end, apply the following algorithm: Set $k = 0$, $T(0) = 10$ and fix initial condition $\pi_0, y_0, l_0$. Fix initial guess for control $i_{guess}(0, t) \equiv 0$. For $k = 0 : N - 1$

- Solve OCP (5) for horizon $T(k)$, initial condition $\pi_0, y_0, l_0$ and guess l $i_{guess}(k, t)$.
- Construct $i_{guess}(k+1, t) = i^\star(k, t)$, for $t \in [0, T(k)]$. $i_{guess}(k+1, t) = 0$, for $t \in (T(k), T(k+1)]$.[53]
- Enlarge horizon $T(k+1) = T(k) + \Delta T$, $\Delta T = 10$.
- $k + 1 \to k$.

In this case we were interested in solving OCP (5) for a fairly large horizons of $T \approx 200 - 300$. As the dynamics of system (1) can be unstable, we again employ a direct multiple shooting using the open-source tools CasADI and IPOPT in Matlab. The ODE is discretized using a fixed-stepsize Runge-Kutta scheme of order 4/5 with 15 integration steps per shooting interval. The input $i$ is discretized as piece-wise constant function. For the different present results, we consider equidistant shooting intervals of length $\Delta T = 10$, i.e. the number of shooting intervals equals the horizon length $T$.

[52] A detailed and in-depth description of the employed numerical solution method is beyond the scope of the present paper. We refer the interested reader to standard references from the engineering literature, see (Diehl et al. (2006)). Moreover, we remark that we have neglected the multiple-shooting constraints for sake of a simplified exposition, for details see (Bock and Plitt (1984)).

[53] Superscript $(\cdot)^\star$ denotes optimal variables.

Table 2: Parameters for system (14) and OCP (5).

| | | | | | |
|---|---|---|---|---|---|
| $\rho$ | 0.03 | $\beta_1$ | $-0.04$ | $\gamma_1$ | 0 |
| $\alpha_1$ | $-0.02$ | $\beta_2$ | 0.157 | $\gamma_2$ | 0.02 |
| $\alpha_{21}$ | $-0.05$ | $\beta_3$ | 0.03 | $\gamma_3$ | 0.03 |
| $\alpha_{22}$ | 0.15 | $r$ | $-0.03$ | $\gamma_4$ | 0.57 |
| $\hat{l}$ | 0.1 | $\mu_3$ | 0.03 | $c_1$ | 100 |
| $c_2$ | 0.05 | $\lambda_{\pi,y,l}$ | $10^4$ | $\lambda_i$ | 1 |

As concerning the multiple equilibria, though we can state that - since our system is nonlinear– there are likely to be multiple steady states, but this challenge is not so easy to handle. This is only primarily explored in this paper, for a bit more simplified system. There is a possibility of multiple equilibria for reasonably chosen.

We consider the following system of nonlinear differential equations and with two regime switches:

$$\begin{bmatrix} \dot{\pi} \\ \dot{y} \\ \dot{l} \end{bmatrix} = \begin{bmatrix} \alpha_1 \pi + \alpha(y) \\ \beta_1 y - \beta_2(i + \delta(l) - \pi - r) + \beta_3(l - \hat{l}) \\ \gamma_1 l + \gamma_2 y + \gamma_3(i + \delta(l)) - \gamma_4 \pi \end{bmatrix} \tag{14}$$

We have a regime switching behavior of the inflation equation, $\alpha(y)$, and $\delta(l)$, the credit spread. we have also the term $\beta_3(l - \hat{l})$ in the output gap equation, representing the impact of the credit cycle (credit flows above or below some thresholds) on the output gap dynamics. Here however just in levels.

We consider the parameter values as listed in Table 2.

Note that steady states with $\pi_s = y_s = i_s = 0$ exist if and only if either $\gamma_1 = 0$ or if $l_s = 0$ and $\beta_2\delta(0) - r - \beta_3(\hat{l}) = 0$. Hence, we set $\gamma_1 = 0$ in the following.

- Case 1: $\pi_s = y_s = i_s = 0$. Setting $\dot{y} = 0$ and $\dot{l} = 0$ yields:

$$l_{s,1} = \hat{l} + \frac{\beta_2}{\beta_3}(\mu_3 - r), \quad \text{if } \delta(l) = \mu_3 \tag{15}$$

$$l_{s,2} = \hat{l} - \frac{\beta_2}{\beta_3} r, \quad \text{if } \delta(l) = 0 \tag{16}$$

  With $\hat{l} = 0.1$ this yields $l_{s,1} < 0$ and $l_{s,2} < 0$. Thus these steady states violate the state constraints and are neglected.

- Case 2: Considering our numerical approximation of $\delta(y)$ and $\alpha(y)$ and $\hat{l} = 0.1$, $\beta_3 = \mu_3$, we compute the steady state with $l_s = 0.2$;

$$\pi_s = 0.0;\ y_s = 0.0;\ l_s = 0.2;\ i_s = -0.011552. \tag{17}$$

- Case 3: Considering our numerical approximation of $\delta(y)$ and $\alpha(y)$ and $\hat{l} = 0.1$, $\beta_3 = \mu_3$, we compute the steady state with $l_s = 1.0$;

$$\pi_s = 0.0078;\ y_s = -0.0032;\ l_s = 1.0;\ i_s = 0.1506. \tag{18}$$

If one compares Case 2 and Case 3 one can observe that one obtains multiple equilibria: With respect to the policy rate one has a low level equilibrium ($i_s = -0.011552$) and a high level interest rate equilibrium ($i_s = 0.1506$) with different corresponding inflation rates, output gaps and credit flows.