Quantitative Easing and Risk Taking at the Zero Lower Bound

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Abstract

This paper identifies the impact of unconventional monetary policy using narrative sign restrictions and assesses its merits at the zero lower bound (ZLB) in a calibrated DSGE with endogenous riskiness driven financial frictions and counter-cyclical bank capital regulation.

In the empirical section the impact of unconventional monetary policy of the ECB is identified using narrative sign restrictions. Then I present a theoretical model to capture quantitative easing (QE) in a DSGE model featuring an occasionally binding zero lower bound and counter-cyclical macroprudential policy. I calibrate the model using optimal simple rules for both monetary and macroprudential policy. The model is closed by specifying feedback rules both for monetary and macroprudential policy with coefficients derived by an optimal simple rule problem. Solving the model for optimal coefficient provides a first validation of the the model since, optimal coefficients fit both historical Taylor-rule coeffcients as well as the Basel III type of counter-cyclical regulation. Finally, the model is used to assess QE's merits in presence of endogenous risk taking and optimal counter-cyclical bank leverage regulation.

The model successfully captures two channels of QE, the signalling and bank capital relief. First, by construction, the model is calibrated to match the impact of QE: due to an earlier and smoother transition from the ZLB to normal times implied yields drop and inflation expectations increase. Second, it predicts that QE shifts the return distribution in favor of banks.

The model explains why optimal counter-cyclical macroprudential policy should be reconsidered in light of unconventional policy. Simulations show that in absence of QE excessive risk taking at the ZLB is present. They also indicate that concerns of QE driven endogenous risk taking are unwarranted.

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1 Introduction

The aim of the paper is to illustrate endogenous risk taking at the zero lower bound (ZLB), and highlight the interplay of QE and financial stability.

Since the beginning of the financial crisis, all major central banks have expanded their operational tools to provide extended monetary accommodation to the recovery. In normal times the central banks pursue their inflation targets by setting the price of the central bank reserves, and thus by steering the short-term money market rates. The price of short-term financing propagates through the economy, influencing financial and macroeconomic conditions. However during and even after the financial crisis, the traditional operating framework of central banks proved to be insufficient to deliver the required accommodation, the prolonged and deep crisis has driven down the policy rate to its effective lower bound, the ZLB. Close to it, theory would predict that traditional transmission mechanism of the policy rate breaks down, as the short term rates cannot be lowered further causing inflation expectations to plummet. A constrained monetary policy carries potentially disastrous consequences. Therefore unconventional monetary policy measures, forward guidance, large scale asset purchases, quantitative easing (QE) were introduced.

This provided a new challenge to identify the impact of unconventional monetary policies. In search of the unconventional monetary policy shock, new methodologies were called upon, and new models were built.

In this paper I contribute to this research by proposing a new identification of the unconventional monetary policy based on the long run impact of yield changes on inflation expectations using narrative sign restrictions. The narrative identification combines event-studies and time series identification in an elegant manner.

Subsequently I build a DSGE model to capture the signalling and bank recapitalization channel of QE in presence of the ZLB and macroprudential policy. I innovate by reinterpreting the double moral hazard framework of Holmstrom and Tirole (1997) into an endogenous risk taking problem of the banks based on Adrian and Shin (2008).

The model featuring endogenous risk taking of banks will enable to highlight the drawbacks of prudence introduced by countercyclical macroprudential policy, showing that macroprudential policy that is optimal in normal times, reduces the effectiveness of QE, and thus hampers the recovery.

1.1 Event-Studies versus Longer Horizon Impact

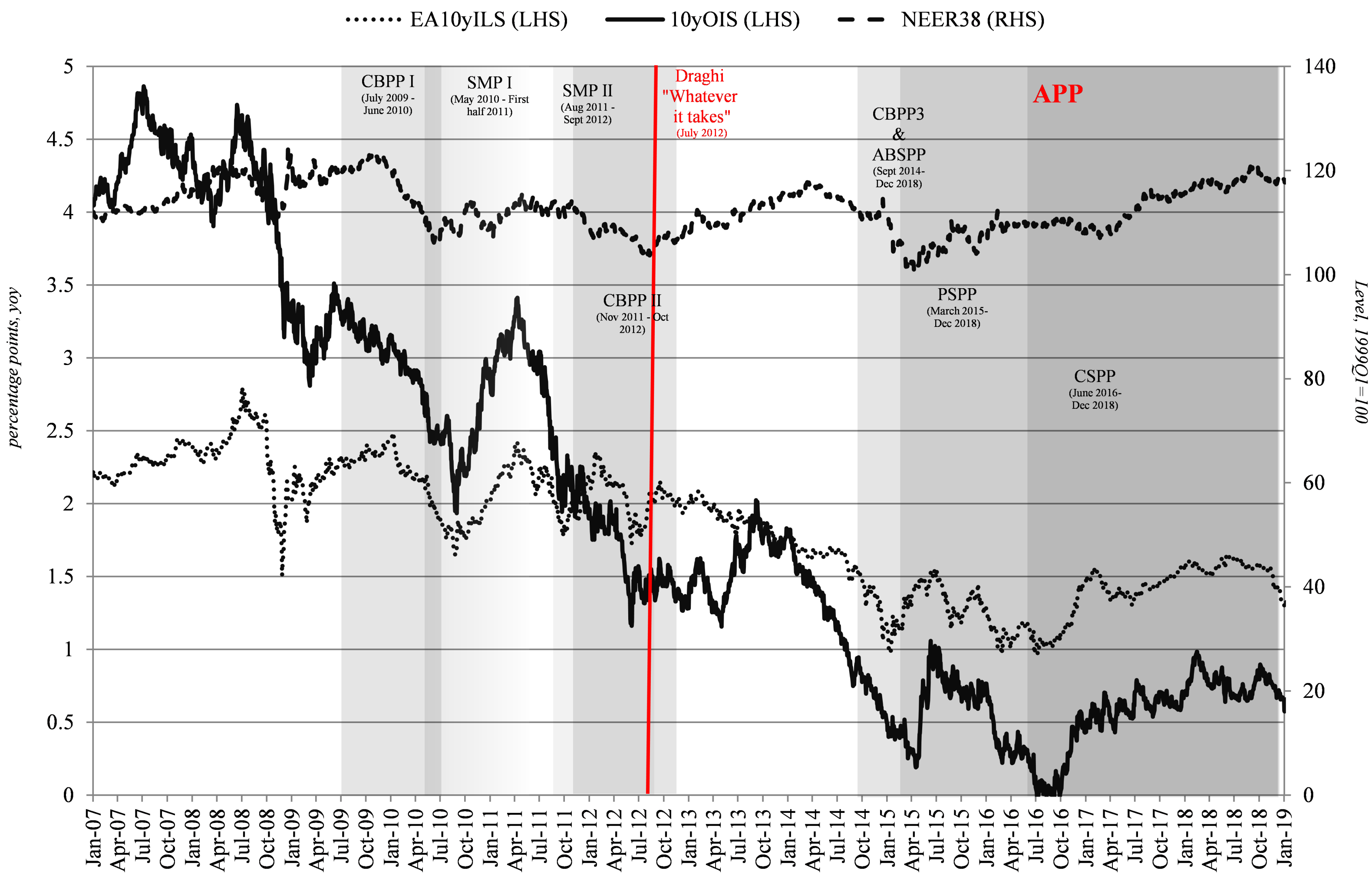
There exists a conflict about the long-run impact of quantitative easing in the econometric literature. Depending on the methodology used for identification, one finds either no long-run impact, or implicitly assumes permanent effects. The former position is taken by James Hamilton (2017), while the latter is implicitly embedded in event-studies.

Figure 1 shows the chronology of the ECB's asset purchases starting from 2007 and the evolution of the 10 year overnight interest rate, the risk free long term nominal yield, the

10 year market inflation expectations [1], and the nominal effective exchange rate. Simply by looking at the graph the downward trend of the long term yields is obvious, however it is difficult to support the claim that the downward trend in the long term yield was driven by the ECB's asset purchase programmes. Formulated in econometric terms: it is hard to claim if there were permanent downward shifts after each announcement and implementation of ever newer waves of purchase programmes. Especially, if one considers the period following the introduction of the public sector purchase programme (PSPP), largest in term of sheer size, long term yield seem to have increased, if anything, during the course of 2015. Looking at the inflation expectations, the picture is even more bleak for the supporters of unconventional monetary policy.

Consequently, there seems to be merits to the arguments, that asset purchase programmes were ineffective if one focuses on the long term impact. I argue, that this seemingly vanishing effect is due to intermittent and heterogeneous character of unconventional monetary policy shocks. Zooming in using daily data on the collection of announcements and implementations unconventional policy's impact is obvious. Figure 2 illustrates that on impact long term yields dropped, while market implied inflation expectations increased on average.

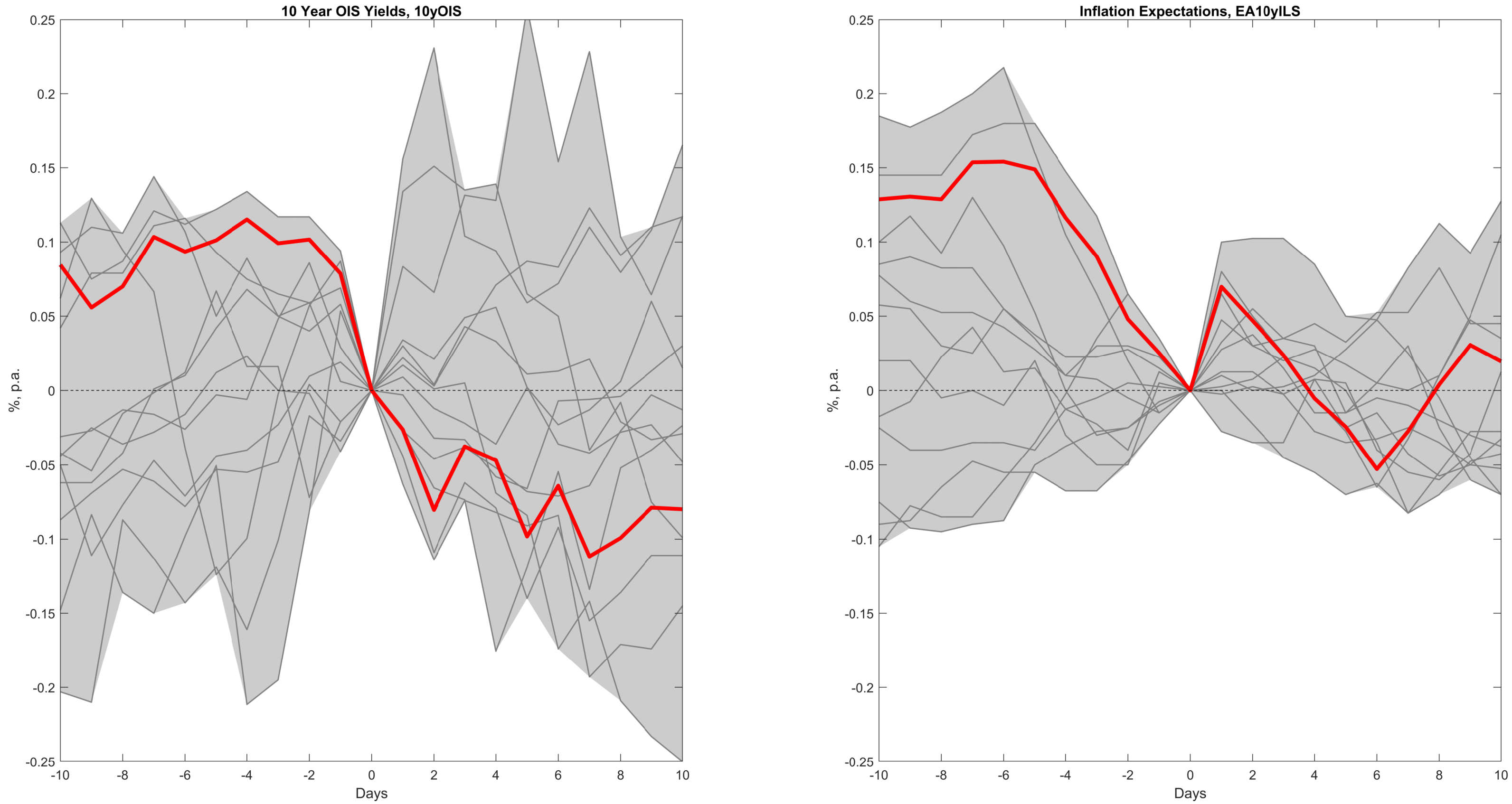
[1] That is the middle point of the bid-ask swaps for the 10 year inflation rate.



Sources: Author and Harmann/Smets (2019) and ECB.

Notes: EA10yILS stand for 'EA Inflation-linked swap for 10 year horizon' (daily spot), 10yOIS stands for the OIS swap rate for a 10 year horizon, NEER38 stands for the nominal effective exchange rate of the Euro against its 38 largest trading partners, CBPP stands for 'Covered bond purchasing program'; SMPs are 'Securities Markets Programs'; OMTs are 'outright monetary transactions'; ABSPP stands for 'asset-backed securities purchase program'; PSPP is the 'Public sector purchase program'; APPs are simply 'Asset purchase programs'.

Figure 1: ECB Asset Purchases since 2007



Notes: Grey lines represent individual announcement and implementation effects,measured in p.a. % and changes compared to the day of ECB policy action.
The red line shows the weighted average announcement effect, using the size of QE at announcement as weight. EA10yILS stand for EA Inflation-linked swap for 10 year horizon (daily spot), 10yOIS stands for the OIS swap rate for a 10 year horizon.

Figure 2: The Impact of ECB QE Announcements and Implementations

Figure 2 shows the range of the event study impact of unconventional monetary policy announcements and implementations on the 10 year OIS yields, left panel, and on the same horizon market based inflation expectations, the right panel.

The grey area on Figure 2 show the range of the evolution of the 10 year OIS and the market inflation expectations for 10 years based on swaps around the ECB's policy actions. The the red line shows the weighted average announcement and implementation effects, where the weights are the respective sizes of QE packages. The left panel clearly shows that long term yields declined in response to QE: they started to drop a bit before the announcement, and had the largest movement around the date of announcement and implementation. On the right panel the impact is showing an increase of inflation expectations. No wonder that high frequency identification, i.e. event study based research has found strong support for the ECB's QE measures. Andrade et al. (2016) surveyed the event based identification and found an average impact of 43 bps on 10 year government yields for every 10% GDP equivalent purchases. The impact on inflation expectations is less clear and is subject to measurement error.

Econometricians working with high frequency data are well aware of the challenge encountered when trying to identify long run impacts, as the signal driving permanent changes can be easily attributed to a random walk component, and thus to noise or other shocks. How much the noise, and with it the impact of not identified shocks drives the result is difficult to tell (Hamilton, 2017). Therein lies the largest caveat of event-based monetary policy identifications: if the policy shock has permanent impact on higher frequencies, then the lack of identifiability at lower frequencies implies that other non-identified shocks, and possibly other noisy permanent shifts in the opposite direction must have nullified the impact[2]. However the benefits of clean identification on higher, event-study frequencies seem to dominate over the concerns that the long-run effects are not apparent at lower frequencies, as the event-study based studies are as popular as never before. [3]

A new addition to Bayesian VAR based identifications, the narrative sign restrictions enables to bridge the two opposing sides. It can be used to overcome the implicit problematic lack of long-run impact of unconventional measures if used cleverly as it enables a rich lag dependence, while maintains the clear identification properties and benefits of an event-study, relying on the the narrative component. In this paper I propose a novel identification of long-run impact of QE in daily frequency BVAR that can be translated to quarterly series: I identify the ECB's QE impact with the help of sign restrictions on the long run co-integrating component between the euro area long term yields and inflation expectations, while I cater to the event-based approach using narrative restrictions around the announcement dates of the ECB's QE, and in particular of the different measures of the APP.

[2]Hassler proposed to use partially integrated processes to overcome the discrepancies of stationary versus non-stationary processes (Hassler, 1993). Being an elegant and interesting alternative it is worth mentioning, however it does not provide answer to permanent shifts. It does not answer the question, if we identify semi-permanent shifts in higher frequencies, why do not we observe them over prolonged time?

[3]For the ECB's Asset purchase programme see the review of Andrade et al. (2016) and Hartmann and Smets (2018).

1.2 Quantitative Easing and Macroprudential Policy Theory

The use of quantitative easing as an unconventional monetary policy tool has been investigated well before the Great Recession. The discussion based on the prolonged close to zero interest environment in Japan has spur theoretical models calling for modelling of asset purchases and unconventional monetary policies. The first papers exploring unconventional monetary policies were qualitative in nature and focused on credit conditions (Fuhrer and Moore, 1995; Orphanides et al., 1998). Monetary policy effectiveness at the ZLB has been the interest to researchers both in theoretical and semi-structural models. Already the early generations of DSGE models explored the ZLB ,e.g. Coenen and Wieland (2003); Coenen et al. (2004), highlighting the stabilizing role of monetary policy and calling for early adjustment to avoid the ZLB constraint. In these models money directly played a role, either entering the utility functions of agents and thus influencing decisions, or indirectly through the no arbitrage conditions on capital markets, quantitative easing translated to altering real money balances, that influenced agent's behavior. The role of quantity of money aggregates made QE a complementary tool at the ZLB. [4] However in the debate about inflation targeting that followed, the quantity of money has lost its importance. The inter-temporal price of money, and more specifically of the safe asset began to be the single monetary policy tool as inflation targeting and inflation expectation targeting became the primary monetary paradigm. This has been reflected in the modelling literature, first with the seminal paper of Taylor (1993) on the empirical fit of the Taylor rule, then with the reemergence of New Keynesian models. To improve the model fit New Keynesian models were expanded with nominal frictions and imperfect competition, culminating in the second generation of DSGE models of the era by Christiano et al. (1998) and Smets and Wouters (2007). This generation of DSGE model had not only superior fit to the data, as price rigidities and monopolistic competition enabled a larger persistence, but provided fruitful insight into the role of monetary policy stabilization policies. This generation became the workhorse DSGE model in central banks, and was not only used to study the ZLB (Woodford et al., 2003; Coenen and Wieland, 2003), but to explore the central bank asset purchases as well. Although the academic research has offered competing alternatives to model the role to financial markets in business cycle, this generation of DSGE models did not incorporate financial frictions, and lacked a financial sector, unlike the models of Bernanke et al. (1999); Gertler and Karádi (2011); Iacoviello and Neri (2010) which building on the second generation of DSGEs introduced financial frictions, either through moral hazard in the allocation of savings to investment, or though risky credit through housing.

1.3 ECB's Unconventional Measures

The ECB's non-standard measures can be categorized based on their desired effect. The ECB's Economic Bulletin argues that "The aim of the non-standard measures introduced by the ECB

[4] For a detailed discussion on the origins of money in DSGE models with Monetary policy see Walsh (2017), for recent work motivating money in DSGEs consider Benchimol and Fourçans (2017) with non-separable money in the utility and Benchimol (2015), where money enters the production function.

before June 2014 was to remedy impairments in various stages of the transmission mechanism." (ECB, 2015, p.32.) These included unlimited provision of liquidity to the banking sector under the fixed rate full allotment, extension of the eligible collateral for the ECB's refinancing operations, extending the maturity of the balance sheet under longer-term refinancing operations, forward guidance, foreign currencies using liquidity swap agreements with other central banks and ultimately large scale asset purchases, quantitative easing.

The asset purchases of the ECB were augmented by a set of non-standard measures directly aimed at providing credit easing to the economy. This meant that the non-standard measures were implemented not only to repair the transmission of monetary policy stance to the financial market, but to provide additional stimulus in the economy at the effective lower bound.

Table 1 provides an overview of the asset purchase programmes of the ECB.[5] Albeit the asset purchases only capture only one aspect of the ECB's monetary policy stance, and were implemented in different environments, they share one key property. The underlying mechanism is the same, all central bank asset purchases meant an expansion of the balance sheet and purchase of financial assets and to help to overcome the ailing credit allocation of banks. [6] My analysis focuses on the asset purchases aimed at repairing the bank transmission channel, and to provide credit to the real economy, modelling it through alleviating financial frictions in investments. Table 1 also collects the announcement and implementation dates, which I will use to identify the QE shocks, implicitly arguing that movement in the variables on the dates were dominated by the unconventional monetary policy shock.

1.4 Macroprudential Policy During the Crisis

The great recession has highlighted the need to analyze financial intermediaries' risk taking behaviour impacts the economy and how financial regulation can be used to increase financial stability. In the subsequent debate on endogenous risk taking in macro models approached bank risk taking either from a bank run perspective, as in Angeloni and Faia (2013) or from a balance sheet perspective Collard et al. (2017). However the endogenous risk taking at the zero lower bound has not been explored before.

Recent work on interaction of monetary policy and financial stability emphasizes the credit cycle and the "risk-taking channel" of monetary policy. The narrative on the adverse effects of unconventional monetary policy has captured the policy debate even more as the large scale asset purchases took place. There has been numerous empirical work the risk taking channel, policy by the research of the BIS [7] and the IMF on the topic [8]. From a theoretical point of view the coordination game has been studied by on optimal interaction in a DSGE by Binder et al. (2017), while optimal monetary policy in presence of macroprudential policy by Collard

[5]For an outstanding and extensive review of the ECB's monetary policy see Hartmann and Smets (2018).

[6] ECB's former chief economist Peter Praet argued that: "This crucial role of the banking system explains why many of our monetary policy interventions during the crisis were aimed at repairing the bank lending channel."

[7]For further reference see Borio and Lowe (2002); Borio and Drehmann (2009); Borio et al. (2011); Borio and Zhu (2012); Borio (2014).

[8]See for example the recently published IMF database on macroprudential polices in Alam et al. (2019)

et al. (2017) and in a continuous setup by Van der Ghote (2017). Angeloni and Faia (2013) My paper extends this literature by studying to what extent behaviour of optimal macroprudential policy in normal times can be applied in the zero lower bound environment.

Angelini et al. (2011) show for the euro area that during "normal times", economy driven by supply shocks, macroprudential policy has limited role, albeit coordination between monetary and macroprudential policies is more beneficial than no-coordination. The coordination gains achieved are greater in "crisis times", where the economy is dominated by financial and housing market shocks. Their results highlight an important aspect of policy coordination: Use the instrument more closely related to the source of the shock to offset its impact.

Gelain and Ilbas (2017) study monetary and macroprudential policy interaction in an estimated model of Smets Wouters with Gertler Karádi type frictions. Their analysis highlights the pitfalls of ad-hoc loss function based studies, giving inconclusive results on the benefits of coordination. Their results indicate that are considerable gains from coordination if the macroprudential regulator has a common objective with monetary policy, sharing a sufficiently high weight on output gap stabilization. Furthermore they show that if the macroprudential mandate is focused credit growth, then non-coordinating macroprudential policy can reach better outcomes at stabilizing the financial cycle than under coordination with monetary policy.

Finally as Blanchard and Summers (2017) point out "low interest rates also have implications for financial regulation and macro prudential policy. [...] The main issue is the relation between low interest rates and risk taking." (Blanchard and Summers, 2017, p.12.). Theoretical evidence calls for prudence as moral hazard, agency issues, and gambling for resurrection, all lead to more risk taking when interest rates are low. However the drawbacks of being overly prudent are already shaping the understanding of the discussion about fiscal balances [9], and my work calls for contingent prudence at the zero lower bound.

[9] See for instance the analysis of the euro area in the book of Ubide (2017) and recent blog posts of Larry Summers (Furman and Summers, 2018).

Table 1: Overview of the ECB's Asset Purchase Programmes

Programme Name	**Policy Goal**	**Announcement**	**Launch**	**Termination**	**Current holdings (EUR mil.)**
CBPP I	Impaired interbank- and bank funding, Impaired bank lending channel	07.05.2009.	02.07.2009.	30.06.2010.	4229
SMP	Redenomination of risk and sovereign-bank nexus	10.05.2010.	10.05.2010.	06.09.2012.	62690
CBPP II	Redenomination of risk and sovereign-bank nexus	06.10.2011.	03.11.2011.	31.10.2012.	16390
OMT / London Speech	Redenomination of risk and sovereign-bank nexus	26.07.2012.			
ABSPP	Non-standard policies to address lower bound of rates	04.09.2014.	21.11.2014.	19.12.2018.	26096
CBPP III	Non-standard policies to address lower bound of rates	04.09.2014.	20.10.2014.	19.12.2018.	262141
PSPP	Non-standard policies to address lower bound of rates	22.01.2015.	09.03.2015.	19.12.2018.	2101932
CSPP	Non-standard policies to address lower bound of rates	10.03.2016.	08.06.2016.	19.12.2018.	178118

Sources: Author and Hartmann/Smets (2019).

Notes: Current holdings refer to the holdings as of 15.03.2019.

2 Identification of Asset Purchases Narrative Sign Restrictions

In order to combine the time-series and event study approaches, I will use narrative sign restrictions to identify the unconventional monetary policy shocks. In what follows I discuss the methodology and identification assumptions. Narrative sign restrictions were proposed by Antolín-Díaz and Rubio-Ramírez (2018) to identify structural VARs by means of economic theory and a prior assumptions about economic events, narrative sign restrictions. It combines set restriction identification of BVARs, in the form of sign restrictions, with importance restrictions called narrative restrictions. The time series perspective originates from the sign restrictions approach, either parameters, or impulse responses to structural shocks have to obey a commonly agreed sign. The narrative restrictions incorporate the event-study feature of the methodology, they focus on single or multiple events in the sample, where required importance restrictions, restrictions on historical variance decompositions' properties of a structural shock must be fulfilled.

Narrative sign restrictions constrain the structural parameters by ensuring that around key historical events the structural shocks and the resulting historical decomposition agree the established narrative.Antolín-Díaz and Rubio-Ramírez (2018)

My identification rests on the assumption that the events of the ECB's QE, collected in table 1, were driving the long-run movement of the variables and were the most important shocks on both the date of announcements and implementation, in terms of historical variance contribution.

To show how long-run restrictions can be introduced using narrative sign restrictions consider the following VAR for $t \in 1, T$:

$$y_t' A_0 = \sum_{l=1}^{p} y_{t-l}' A_l + c + \epsilon_t' \tag{1}$$

Where y_t is a time series, and ϵ_t are structural shocks following an iid standard normal distribution, by assumption.

Denote the collection structural parameters $\theta = [A_0, A_1, ..., A_p, c]$. Using the companion form, i.e. the stacked lagged variables $x_t' = \left[y_{t-1}', y_{t-2}', ..., y_{t-p}', 1\right]$, and the reduced from shocks $u_t' = \epsilon_t' A_0^{-1}$, then we can write the model in terms of the reduced form parameters:

$$y_t' = x_t' B + u_t' \tag{2}$$

Where, the reduced form covariance matrix reads $\Sigma = (A_0' A_0)^{-1}$. Given the existence of a structural form, by implicitly assuming that A_0 is invertible, it is easy to get from the structural parameters θ to the reduced from parameters B and Σ.

We can define the impulse response and historical variance decomposition functions, as $L_{i,j,h}(\theta)$ and $H_{i,j,t,t+h}(\theta)$ respectively, which map the structural parameters of the model into the respective representations. They capture the impulse response of shock j on variable(s) i over the horizon h, or in case of the historical variance decomposition, the historical variance contribution of shock j of the observed unexpected movements in variable(s) i over the period from t to $t+h$.

The general idea behind narrative sign restrictions identification of SVARs is to find all structural parameters, θ, that satisfy certain properties of the IRFs and historical variance decomposition. In practice this boils down to a sequential set restrictions of the parameter space of the posterior of a Bayesian VAR, estimated on the reduced form of the VAR. Sign restrictions in practice are best implemented, as shown by Arias et al. (2014); Antolín-Díaz and Rubio-Ramírez (2018), by finding rotations on the QR decomposition of the reduced form covariance matrix (Σ) that satisfy the sign restrictions on impulse response function. Then the narrative restrictions can be applied, keeping only the set of parameters that also satisfy the importance restrictions. To implement narrative sign restrictions one has to start with a prior for the VAR that best fits the ex ante properties of the data. Then one can estimate the Bayesian VAR, resulting in a posterior of the reduced form parameters B and Σ. This posterior is the unidentified parameter space. To implement narrative sign restrictions, one perform the following algorithm on the unidentified sign restrictions. Draw a pair of B and Σ from the posterior, draw an orthogonal rotation matrix Q from the set of orthogonal matrices. Check if the SVAR implied by the rotation matrix satisfies the restriction, and keep if it does, discard the draw if it does not. If the sign restrictions are satisfied, calculate the historical variance decomposition for the period of the narrative restriction, and check if the restriction on the historical variance decomposition are met. If met, then assign an importance weight $\frac{1}{\omega(B,\Sigma,Q)}$ to the draw, (B, Σ, Q), that is approximated based on the proportion of a draws that would meet the restrictions given a standard normal shock. This is to re-weight the posterior, with the relative frequency of the shock occurring in the unconditional likelihood. Then keep repeating until the required number of draws is not reached. Once it has been met, then draw with replacement from the draws, i.e. (B, Σ, Q) with the importance weights $\omega(B, \Sigma, Q)$. Antolín-Díaz and Rubio-Ramírez (2018) This way the model will respect the information in the data, given a model is unlikely in light of the likelihood, it will be weighted with this unlikeliness.

2.1 Identification Strategy

The literature on unconventional monetary policy has identified three primary channels through which unconventional measures impact the real economy: First, the signalling, that links outright asset purchases to expectations of future inflation, second, the portfolio re-balancing channel, that focuses on how liquidity injection alters the optimally desired portfolio of economic agents, and finally, the implicit banking recapitalization channel, that tells that banks benefit from the resulting asset price increase. (Andrade et al., 2016, p.14.)

The empirical model is aimed to capture the first one, the impact of unconventional monetary policy shocks on yields and inflation expectations. To this end I identify the impact of asset purchases on the 10 year overnight interest rate and the same horizon market based inflation expectations, derived from swaps. As sign restrictions, I impose that an expansionary monetary policy identified on a daily frequency, permanently lowers the nominal int erst rate and increases the inflation expectations. Based on this identification I proceed to estimate its elasticity of between changes of the nominal yields and inflation expectations.

To this end, I require that the impulse response function defined the long run component, i.e. permanent impact of a shock j on variable(s) i:

$$L_{i,j,\infty}(\theta) = \left(A_0' - \sum_{l=1}^{p} A_l' \right)^{-1} \tag{3}$$

has to meet the sign restrictions. The long run component of any VAR can be obtained from the Beveridge-Nelson decomposition. Morley has shown that for macroeconomic data the Beveridge-Nelson decomposition provides an optimal estimate of the permanent component of the time series model, under the assumption that the permanent component follows a random walk and the unconditional expectation of the transitory component is zero. (Morley, 2011) It is important to note, in order for the Beveridge-Nelson decomposition to be proper, y_t needs to be an integrated process. To that end the model will be estimated in levels for inflation and interest rates and log-levels for the exchange rate, and the prior will be chosen to be a Minnesota prior. The choice of the Minnesota prior is important as it the reflects the a priori belief that the data contains as many unit roots as data series, because the model of the prior is centered around independent unit roots, but allows for cointegration. due to non zero tightness of the covariance matrix. The Beveridge-Nelson decomposition is aimed at capturing the permanent trend component, long-run forecast of the level of a series, beyond a deterministic trend.

$$BN_t = \lim_{T\to\infty} E\left[y_{t+T} - T\mu | y_t\right] = y_t + \lim_{h\to\infty} \sum_{h=1}^{T} E_t\left[\Delta y_{t+h} - \mu\right]. \tag{4}$$

where μ is the deterministic time trend, i.e. the drift. Denoting first differenced, stationary martingale drift component of y_t as x_t[10]:

$$x_t = \Delta y_t - \mu \tag{5}$$

Imposing a sign restriction on the permanent component of the Beveridge-Nelson decomposition of the VAR implicitly states that shocks have a permanent impact. This permanent impact on the daily frequency will translate to the permanent impact at lower, e.g. at quarterly frequencies. Failing the long run assumption, and having an eigenvalue for the respective root 0,99 rather than above one, will translate to 60% of the impact to be washed out over 90 days, i.e. in a quarter. I identify an expansionary unconventional monetary policy shock by the signs on the long run sign of the impulse response function: it lowers the long term bond yields while increases inflation expectations.

To explain why it constitutes an expansionary monetary policy shock, let us investigate the

[10]For further reference on the Beveridge Nelson decomposition please see Oh et al. (2008); Hamilton (1994).

relative response of nominal yields and inflation expectations. Given the Fisher equation for the 10 year horizon, the following has to hold by definition:

$$i_t^{10Y} = r_t^{10Y} + E_t\left[\pi_t^{10Y}\right] \tag{6}$$

The long run sign restriction that the nominal interest rate lowers and that the inflation expectation increases as a response of unconventional monetary policy shock implies that the long term real interest rate has to compress permanently. Take the extreme case, that the nominal yields are not changing, i.e. the upper bound of the identification set, then the identifying assumption that the inflation expectations have a positive sign, implies that the real interest rate was lowered by the amount of the movement of the inflation expectations. The other extreme is when the inflation expectations do not respond but the nominal yields compresses, then the real rate has to track the movement in the nominal rates. In both cases the elasticity between the two variables is lower than 0. Therefore the sign restriction assumption spans all possible cases when the real interest rate permanently lowers, and the elasticity between the two variables is negative. The impact on the real rate is also relevant from the theoretical perspective. As the Taylor principle prescribes, that the nominal interest rate has to move more than one on one to inflation expectations. This insight nests the idea that in order monetary policy to have stabilizing effect, conditional a downward sloping Phillips curve, real return have to compress as a response to a monetary policy action. But in order to eliminate any theoretically incompatible shocks from the set, and give rise to other shocks necessary for the narrative identification I impose two further identifying restriction, both meant to capture macro shocks. Long run macro shocks have to have drive all variables exchange rates, inflation expectations and the long-run yield. Short run macro shocks are assumed to have only temporary effect on impact, moving yield and inflation expectations in the same, and exchange rate in the opposite direction. Note for the unconventional monetary policy shock no restrictions on the exchange rate will be set, as events of unconventional monetary policy shocks could have moved it both ways. If market expectations about break up of the euro area have been eliminated, then the euro should appreciate against its currency peers. Whereas quantitative theory of money would predict a depreciation (Walsh, 2017). Table 2 summarizes the identification of the sign restrictions.

Table 2: Sign Restrictions Identification

Sign Restrictions on Impulse Responses

Variable \ Shock	Long-run Macro Shock	Monetary Policy Shock	Short-run Macro Shock
10yOIS	+	+	+*
NEER 38	+		
EABEIR	+	-	+*

*: Short run, on impact restrictions to impulse responses are applied, long run is left undetermined.

Sign restrictions are a set identification, meaning that only model specifications will be kept that satisfy them. Although it is desirable to only keep a very limited fraction of candidate models, they can be too loose for proper identification if a wide range of possible models are accepted, translating to broad credible intervals. To further strengthen the identification, I implement additional narrative restrictions.

The narrative restrictions capture the insight that unconventional monetary policy shocks were overwhelming on the days of the ECB's announcement and implementation of assets purchases. The literature separates the two effects calling the stock effect the former and the flow effect the latter. To align with the practices of stream of research using event study based identification of monetary policy shocks, my narrative approach entails that both the stock and flow effect have been an overwhelming contributor to the observed unexpected movements in all variables on the days of announcement and implementation. Overwhelming means that the absolute value of the historical variance contribution on the specific day stemming from the unconventional monetary policy shock was larger than the sum of absolute contributions from all the other shocks, formally :

$$|H_{j,t,t+1}(\theta)| > \sum_{k \neq j} |H_{k,t,t+1}(\theta)|, \tag{7}$$

where j is the shock of the unconventional monetary policy and k stands for all the other shocks, t is the date of announcement and implementation according to Table 1. The data-set consists of daily frequency of the euro area 10 year overnight interest rate, the nominal effective exchange rate of the euro against 38 of its largest trading partners, and the euro area swap implied break even inflation expectations for 10 years. The sample of the exercise is from 01/09/2005 to 31/12/2018.

2.2 Empirical Results

A recurring pattern found in simple monetary VARs is the price puzzle. It describes the quite common result of a naive identification that nominal interest rates and inflation move the same direction following a monetary policy shock. This movement is incompatible with theory, as a monetary policy shock has to move the policy rate contrary to inflation expectation. Reasons for this seemingly erroneous result are, either a wrong identification, when monetary policy shocks are mistaken for domestic demand shocks, or the misinterpretation of the structural shock via the shock covariance decomposition. An example would be ordering based Choleski factorization, where the timing restriction especially in quarterly VARs may impose a hard to justify delayed response of other variables to a policy change, in those situations sign restrictions' relative weaker identification might be a better approach. (Canova, 2011) To illustrate this I have estimated a model using alternative identification techniques. Table 3 collects the empirical results. The first alternative is the traditional frequentist approach, where the structural identification relies on the appropriate decomposition of covariance matrix. Since the unite root cannot be rejected for the data and this identification requires stationarity in its simplest form, the data has to be first differenced. where the ordering of the variables is pivotal. I identify the unconventional monetary policy shock on the long term yield, the 10 year OIS.

To allow for contemporaneous reactions of all variables, the long-term yields are placed last in both specification following Christiano et al. (1998, 2005); Altig et al. (2011). This also means that the central banks' information set was complete, and other variables responded with a day delay. Both Choleski and triangular factorization deliver tight confidence interval, showing the estimation uncertainty is nicely controlled through the more than 13 years of daily data. However the tight confidence bands highlight the shortcoming of ordering based identification, these are exact identification techniques.

This implies that the identification eliminates all degrees of freedom, and only one true data generating model is admitted. Therefore the resulting uncertainly represented by the confidence intervals capture only estimation uncertainty, and are thus too tight. In simple terms this means that the modeller is extremely confident about being wrong. Indeed, both identification suffer from the price puzzle, as the estimated mean elasticity of interest turns out to be positive albeit insignificant in both cases.

The second group of models combine Bayesian priors with Choleski factorization. Bayesian techniques alleviate the problematic of unit roots, therefore, estimating a model in levels is innocuous. Using the Minnesota prior without and with stochastic volatility still suffers from the price puzzle, and illustrates that the prior specification cannot overcome the misinterpretation of the likelihood via the identification imposed by ordering. Therefore, it serves as another evidence that the exact identification is the reason, why both frequentist and Bayesian models relying on them deliver unfavourable results.

Employing only sign restrictions alleviates these concerns, the estimated median long term elasticity is negative, -1.78, however it comes at the cost of extreme dispersion. The credible intervals, reported for the middle 90 percentile, by construction exclude zero, but show very long negative tails where the lower 5 percent quaintle shows very strong impact as -37. The reason behind the broad credible intervals and uncertain estimates of the elasticity is the weak identification imposed by set restrictions.[11] The model uncertainty indicates that the identification from the set restrictions imposed by only signs is not enough to pin down a good model.

Narrative sign restrictions help to overcome the model identification issue. If one keeps only models that satisfy the narrative conditions, that QE shocks were overwhelming on the days of announcement and implementation, then the credible intervals shrink and the elongated compresses the credible intervals to a range of 1.5, and the median elasticity is found to be -1.19.

[11] This is also reflected in the relatively high acceptance rate of the draws: 0.1%, meaning that approximately 10^6 draws from the posterior with uniform Q rotation matrix will result in 1000 accepted draws.

Table 3: Estimation Results: Long Term Yield and Inflation Expectation Elasticity

Model	**Frequentist**		**BVAR with stochastic volatility**	**BVAR with Minnesota prior**		
Identification	Triangular factorization with the ordering: NEER38, EA10yILS, 10YOIS	Choleski factorization with the ordering: NEER38, EA10yILS, 10YOIS	Choleski factorization with the ordering: NEER38, EA10yILS, 10YOIS	Choleski factorization with the ordering: NEER38, EA10yILS, 10YOIS	Sign restrictions on the long run	Narrative restrictions with sign restrictions on the long run
Implicit assumption	Variables have a unit contemporaneous impact to own structural shocks.	Monetary policy observes all variables.	Monetary policy observes all variables.	Monetary policy observes all variables.	Monetary policy causes opposing permanent changes in long term yields and inflation expectations.	Monetary policy causes opposing permanent changes in long term yields and inflation expectations. QE announcemnets and implementations were overwhelming and dominant.
Data	Stationary, first differenced		Stationary, first differenced	Levels		
Inflation expectations and Long term yields elasticity	0.0523	0.0383	0.0252	0.0321	**-1.7839**	**-1.1943**
CI	-0.1073 0.1487	-0.0206 0.0806	-0.2748 0.2025	-0.0038 0.0627	-0.1242 -37.3695	-0.6523 -2.1380

Notes: Elasticities are the Mean estimates for the frequentist, and the Median for the Bayesian methods. CI stands for confidence intervals refere to 5% and 95% percentile respectively, while in case of BVAR models the credible intervals reflect the 5% and 95% percentiles. EA10yILS stand for 'EA Inflation-linked swap for 10 year horizon' (daily spot), 10yOIS stands for the OIS swap rate for a 10 year horizon, NEER38 stands for the nominal effective exchange rate of the Euro against its 38 largest trading partners.

Source: Author's calculations.

The primary objective of the empirical investigation was to identify the long run impact of unconventional monetary policy on long run yields and inflation expectations.

The set restriction based Bayesian VAR, with narrative sign restrictions delivered convincing results, by combining the merits of high frequency event studies with the (long term) dynamics of the time series perspective. Incorporating the narrative component, the identification ensured that the shock is not contaminated by other contemporaneous events. While imposing the sign restrictions on the long run guaranteed that the estimated responses do not die out over time and can be transferred to economic analysis at the business cycle frequency. In what follows, I build a DSGE model that captures the signalling channel of QE. Then I calibrate the QE response to match the -1.19 estimated elasticity of inflation expectations and long term yields when the central bank balance sheet expands. This way I directly calibrate the model to the identified signalling channel of QE. In light of endogenous risks, I will study the interaction of unconventional monetary policy and macroprudential policy.

3 The Model

This section describes the structure of the model and the decision problems the agents of the economy are facing. The model builds on the asymmetric information based banking model of Meh and Moran (2010) and Christensen et al. (2012) with occasionally binding constraint on the policy rate following Guerrieri and Iacoviello (2015), and central bank asset purchases similar to Gertler and Karádi (2011).

The model is closest in spirit to Christensen et al. (2012), in the sense that endogenous riskiness of the banking sector plays a crucial role, but whereas Christensen et al. (2012) impose the a dependency of the project riskiness on the credit-to-GDP gap, in this model risk taking will be endogenously decided. The financial intermediary's decision about monitoring will be shown to have an endogenous riskiness representation.

Furthermore similar to Gertler and Karádi (2011) unconventional monetary policy will overcome the financial frictions by providing direct funds to projects financed by issuing currency. While the impact of unconventional monetary policy will be calibrated to match emprical evidence, the focus will be on the impact of unconventional monetary policy on risk taking, and macroprudential policy.

The presentation here follows the main ingredients of the model. First, I discuss the New Keynesian Model core following Christiano et al. (2005). Second, the financial block is presented, that acts as a financial friction through the financing of investments of the economy and gives rise to banks capital and thus role of macroprudential regulation along the endogenous risk taking. Finally, I characterize the conduct of monetary policy and role of the occasionally binding zero lower bound and the augmenting large scale asset purchases at the lower bound, paying attention to the calibration of macroprudential and unconventional monetary policy rules. A key contribution of my analysis is the investigation of the interplay of unconventional monetary policy with endogenous risk taking in presence of counter-cyclical macroprudential regulation.

3.1 New Keynesian Core of the Model

The non-financial side of the model follows the New Keynesian model of Christiano et al. (2005) This core incorporates the financial contract that regulates the interaction between three classes of agents: households, entrepreneurs, and bankers. Each class has a population mass η^h, η^e and $\eta^b = 1 - \eta^h - \eta^b$, respectively.

The economy consists of three goods: First and most importantly, capital goods are produced by entrepreneurs, with a technology facing idiosyncratic uncertainty and underlies the one side of the double moral hazard problem. Second, intermediate goods are produced by monopolistically competitive firms facing nominal rigidities. Third, final goods are assembled by competitive firms using the intermediate goods.

The financial contract describes the financial frictions arising due to the double moral hazard between entrepreneurs, bankers and ultimately households. Two moral hazard problems affect the investments. First, entrepreneurs may influence their technology's probability of success and may choose projects with a low probability of success to derive private benefits. The agency problem can be mitigated with monitoring, as it helps reduce this problem, but does not eliminate it completely. As a result, banks require entrepreneurs to commit their own net worth and participate in the project. The second moral hazard problem arises between banks and households. Households making their consumption savings decision can only save by holding money, by purchasing capital goods entrepreneurs or by depositing their savings into banks. Furthermore households lack the ability to monitor entrepreneurs, they have to delegate this task to the bankers. However, monitoring activity is private and costly, and bankers may choose not to monitor, as they bare the costs directly, but the risks are mostly passed to households. As a result, households require banks to have skin in the game and commit their own net worth, their capital to entrepreneurs' projects. (Meh and Moran, 2010) Another interpretation of the monitoring cost, that I will rely on follows Adrian and Shin (2008). In their paper they argue that the cost of monitoring is analogous to a VaR constraint, that captures how the bankers trade off the greater option value of holding a riskier asset, i.e. low monitoring, against the higher expected payoff from participating in a more secure project, i.e. high monitoring effort. I formally derive this relationship.

The double moral hazard framework implies that over the business cycle, the dynamics of bank capital affect how much banks can lend, and the dynamics of entrepreneurial net worth affect how much entrepreneurs can borrow. (Meh and Moran, 2010)

The financial friction impairs the financing of investment projects that produces capital for the intermediate goods producers. Nominal frictions are modelled following Calvo, with partial indexation of intermediate goods and wages to past inflation. The model assumes that final goods are produced by a perfectly competitive firm, that combines intermediate goods as inputs. The intermediate goods are produced by monopolistically competitive firms facing nominal frictions. Furthermore, households are subject to nominal wage rigidity when maximizing their inter-temporal utility. Finally, monetary policy is conducted by a central bank using an interest rate rule in normal times and credit targeting rule at the ZLB. In what follows, I review the households' and the intermediate firm's optimization problem, and discuss the final good producers.

3.1.1 Households

Household choose consumption, allocate money holdings between currency and bank deposits and supply units of specialized labour, choose a capital utilization rate and purchase capital goods. Household i's expected lifetime utility is

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[log(c_t^h - \gamma c_{t-1}^h) - \psi \frac{{l_{it}^h}^{1+\eta}}{1+\eta} + \zeta log(M_t^c/P_t) \right] \tag{8}$$

where c_t^h is final good consumption in period t, $\gamma \in [0,1)$ captures the strength of habit formation in consumption n ($\gamma = 0$ gives the standard time-separable utility function), l_{it}^h is the hours worked, M_t^c/P_t is the real money balances, the real value of currency held. The household begins period t with (nominal) money holdings M_t and receives a lump-sum money transfer X_t from the central bank. Then household has to then allocate the currency between short term bank deposits D_t and outright holding of currency, i.e. cash M_t^c, so that the budget equation holds: $D_t + M_t^c = M_t + X_t$. The central bank thus can directly influence the amount of monetary instruments in the economy by changing X_t. In making this decision, the household has to consider the tradeoff between the utility obtained from holding currency and the return on bank deposits, that is the risk-free rate $1 + r_t^d$. Similar to Christensen et al. (2012) I assume that idiosyncratic risks on deposits at the bank level is diversified away, following Carlstrom and Fuerst (1997) and Bernanke et al. (1999), implicitly ruling out a risk premium compensation for defaultable deposits in contrast to Clerc et al. (2015) or modelling the deposit insurance or liquidity provision by shadow banks as in Nuño and Thomas (2017). Both approaches provide opportunities of future extensions.

Households make capital utilization decisions as in Christiano et al. (2005). The per period budget constraint of the household consists of the following: the household consumes c_t^h, purchases new capital goods i_t^h priced q_t and carries over money balances into the next period M_{t+1}. At the beginning the period t a representative household owns capital stock k_t^h and provides capital services $u_t k_t^h$ with u_t the utilization rate. Capital provides a rental income $r_t u_t k_t^h$ and incurs a capital utilization cost $\nu(u_t)k_t^h$, where $\nu(.)$ is a convex function with the calibration as in Christiano et al. (2005) . Household i receives labor income for the hours worked l_{it} with the real wage $(W_{it}/P_t)l_{it}$, profits Π_t in form of dividends from the intermediate goods producing firm, as well as return on deposits held in the bank $(1 + r_t^d)D_t/P_t$. Thus the budget constraint for the household i is given by:

$$c_t^h + q_t i_t^h + \frac{M_{t+1}}{P_t} = (1 + r_t^d)\frac{D_t}{P_t} + r_t u_t k_t^h - \nu(u_t)k_t^h + \frac{W_{it}}{P_t} l_{it} + \Pi_t + \frac{M_t^c}{P_t} \tag{9}$$

with the respective Lagrange multiplier λ_t for marginal utility of consumption.

The capital stock is denoted in beginning of period notation, depreciates at a constant rate δ and evolves according to:

$$k_{t+1}^h = (1-\delta)k_t^h + i_t^h \tag{10}$$

The optimal choice for the control variables $c_t^h, M_t^c, u_t, M_{t+1}$ and k_{t+1}^h of the household i is given by the first-order conditions of the Lagrangian:

$$\frac{1}{c_t^h - \gamma c_{t-1}^h} - \beta\gamma E_t\left[\frac{1}{c_{t+1}^h - \gamma c_t^h}\right] = \lambda_t; \tag{11}$$

$$\zeta\frac{1}{M_t^c/P_t} = r_t^d\lambda_t; \tag{12}$$

$$r_t = \nu'(u_t); \tag{13}$$

$$\lambda_t = \beta E_t\left[\lambda_{t+1}(1 + r_{t+1}^d(P_t/P_{t+1})\right]; \tag{14}$$

$$\lambda_t q_t = \beta E_t\left[\lambda_{t+1}\left(q_{t+1}(1-\delta) + r_{t+1}^d u_{t+1} - \nu(u_{t+1})\right)\right]; \tag{15}$$

3.1.2 Labor Market

The wage setting flows the New Keynesian benchmark of Erceg et al. (2000) and Christiano et al. (2005), in that it assumes that household i supplies a specialized labor, and labor packers hires it in a perfectly competitive market,and combines them to a composite labour input using a Dixit-Stiglitz aggregating technology:

$$H_t = \left(\int_0^{\eta^h} l_{it}^{\frac{\xi_w-1}{\xi_w}} di\right)^{\frac{\xi_w}{\xi_w-1}}, \xi_w > 1. \tag{16}$$

The labor packers demand can be expressed as:

$$l_{it} = H_t\left(\frac{W_{it}}{W_t}\right)^{-\xi_w} \tag{17}$$

where W_{it} is the wage for each labor type, W_t is the aggregate wage, i.e. the unit price of composite labor input H_t. Labor is combined in a perfectly competitive environment, which gives the following aggregate wage:

$$W_t = \left(\int_0^{\eta^h} W_{it}^{1-\xi_w} di\right)^{\frac{1}{1-\xi_w}} \tag{18}$$

Wages are subject to nominal frictions. Each period, household i receives a signal to re-optimize its nominal wage with probability $1-\phi_w$, while with probability ϕ_w the household indexes its wage to the steady-state inflation. The reoptimizing household chooses his desired wage anticipating the wage dynamics, $W_{it} = \pi W_{it-1}$ in case re-optimization does not occur. The first-order condition for the reoptimizing household is:

$$\tilde{W}_t = P_{t-1}\frac{\xi_w}{\xi_w - 1}\frac{E_t \sum_{k=0}^{\infty}(\beta\phi_w\pi^{-\xi_w})^k(-\partial U/\partial l_{it}(\cdot_{t+k}))H_{t+k}w_{t+k}^{\xi_w}\Pi_{s=0}^{k}\pi_{t+s}^{1-\xi_w}}{E_t \sum_{k=0}^{\infty}(\beta\phi_w\pi^{-\xi_w})^k\lambda_{t+k}H_{t+k}w_{t+k}^{\xi_w}\Pi_{s=0}^{k}\pi_{t+s}^{\xi_w-1}}, \tag{19}$$

where $w_t = W_t/P_t$ is the real wage and $-\partial U/\partial l_{it}(\cdot_t)$ is the partial derivative of the utility function with respect to hours worked. It represents the marginal disutility of providing l_{it} work. Given wages the actual hours worked is determined by Equation 17.

3.1.3 Final Good Production

Perfectly competitive firms produce the final good by combining intermediate goods using the standard Dixit–Stiglitz aggregator:

$$Y_t = \left(\int_0^1 y_{jt}^{\frac{\xi_p - 1}{\xi_p}} dj\right)^{\frac{\xi_p}{\xi_p - 1}}, \xi_p > 1, \tag{20}$$

where y_{jt} denotes the time t input of the intermediate good indexed by $j \in (0, 1)$, and ξ_p is the constant elasticity of substitution between intermediate goods. The first-order condition maximizing the profit gives the demand for good j given the relative price and aggregate production:

$$y_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\xi_p} Y_t. \tag{21}$$

Given the zero-profit condition one can derive the usual definition of the final-good price index:

$$P_t = \left(\int_0^1 p_{jt}^{1-\xi_p} dj\right)^{\frac{1}{1-\xi_p}}. \tag{22}$$

3.2 Intermediate Good Production

Firms that produce intermediate goods operate under monopolistic competition and face nominal rigidities in their price setting. The use the following production technology when producing good j:

$$y_{jt} = \begin{cases} z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\theta_e} h_{jt}^{b\theta_b} - \Theta & \text{if } z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\theta_e} h_{jt}^{b\theta_b} \geq \Theta \\ 0 & \text{otherwise} \end{cases} \tag{23}$$

where k_{jt} and h_{jt} are the amount of capital and labor services, respectively, used by the firm j at time t. Furthermore, $h_{jt}^{e\theta_e}$ and $h_{jt}^{b\theta_b}$ are labor services from the entrepreneurs and bankers, following Carlstrom and Fuerst (1997) labor services from entrepreneurs and bankers ensure that these agents will always have a non-zero wealth to pledge in the financial contract. Θ is the fixed cost of production, and z_t is an aggregate technology shock, that follows an auto-regressive process of order 1:

$$log(z_t) = \rho_z log(z_{t-1}) + \epsilon_{zt} \tag{24}$$

where $\rho_z \in (0,1)$ and $\epsilon_{z,t}$ is an i.i.d. structural shock with mean 0 and standard deviation σ_z. Cost minimization given the production function will provide the first order conditions that determine the rental rate of capital and wage for each type of agent, that is:

$$\min_{k_{jt},h_{jt},h^e_{jt},h^b_{jt}} r_t k_{jt} + w_t h_{jt} + w^e_t h^e_{jt} + w^b_t h^b_{jt} \text{ subject to 23,} \tag{25}$$

$$r_t = \lambda^y_t \; z_t \theta_k k^{\theta_k - 1}_{jt} h^{\theta_h}_{jt} h^{e\theta_e}_{jt} h^{b\theta_b}_{jt}, \tag{26}$$

$$w_t = \lambda^y_t \; z_t \theta_h k^{\theta_k}_{jt} h^{\theta_h - 1}_{jt} h^{e\theta_e}_{jt} h^{b\theta_b}_{jt}, \tag{27}$$

$$w^e_t = \lambda^y_t \; z_t \theta_e k^{\theta_k - 1}_{jt} h^{\theta_h}_{jt} h^{e\theta_e - 1}_{jt} h^{b\theta_b}_{jt}, \tag{28}$$

$$w^b_t = \lambda^y_t \; z_t \theta_b k^{\theta_k - 1}_{jt} h^{\theta_h}_{jt} h^{e\theta_e}_{jt} h^{b\theta_b - 1}_{jt}. \tag{29}$$

Where, λ^y_t is the marginal costs, i.e. the Lagrange multiplier on the intermediate good production function 23. Price-setting follows Calvo with partial indexation, each firm receives a signal to reoptimize its price with a fixed probability $1-\phi_p$, if it cannot ϕ_p, then the firm indexes its price to the previous period's aggregate inflation. Thus after k periods of no reoptimization the firm's price would be:

$$p_{jt+k} = \Pi^{k-1}_{s=0} \pi_{t+s} p_{jt}, \tag{30}$$

where $\pi_t = P_t/P_{t-1}$ is the aggregate rate of price inflation in period t. A reoptimizing firm chooses $\tilde{p_{jt}}$ to maximize expected profits subject to 21 and 30, formally:

$$\max_{\tilde{p_{jt}}} E_t \sum_{k=0}^{\inf} (\beta\phi_p)^k \lambda_{t+k} \left[\frac{p_{jt+k} y_{jt+k}}{P_t + k} - \lambda^y_{t+k} y_{jt+k} \right] \text{ subject to 21 and 30 .} \tag{31}$$

From the optimization problem the first order condition for the optimal price yields:

$$\tilde{p_t} = \frac{\xi_p}{1-\xi_p} \frac{E_t \sum_{k=0}^{\inf} (\beta\phi_p)^k \lambda_{t+k} \lambda^p_{t+k} Y_{t+k} \pi^{\xi_p}}{E_t \sum_{k=0}^{\inf} (\beta\phi_p)^k \lambda_{t+k} \lambda^p_{t+k} Y_{t+k} \pi^{\xi_p - 1}}. \tag{32}$$

Where the symmetry of price setting has been exploited as in Calvo (1983).

3.3 Capital Good Production

Entrepreneur possess the technology to produce capital goods. The investment technology is subject to an idiosyncratic shock: an investment of size i_t final goods yields Ri_t units of capital if the project succeeds, and zero units if it fails. [12] The project size i_t, capital investment, is treated as the dynamic variable determined by the financial contract linking the entrepreneur and the bank. Returns from entrepreneurial projects are publicly known.

Following Holmstrom and Tirole (1997) the entrepreneurial projects are subject to a moral hazard problem: entrepreneurs can privately choose between two different project outcomes.

[12] Note that parameter R is the scale of the project technology, its per investment unit total return measured in consumption goods is $(q_t/q_{t-1}-1)*R$. Therefore the production technology of the entrepreneur is a constant return to scale.

Although the project returns the same amount of investments, given good realization of the idiosyncratic shock i.e. success, the choices the entrepreneur makes can influence the outcome. The "good" project outcome corresponds to the high effort behaviour of the entrepreneur. In this case the entrepreneurial behaviour makes the project to have a high probability of success, denoted α_t, at the expense of the entrepreneur delivering zero private benefits. The "bad" project outcome realizes when the entrepreneur decides to "shirk", then the project has a lower probability of success $\alpha_t - \Delta\alpha$, $\Delta\alpha > 0$ and provides the entrepreneur with private benefits proportional to the project size $q_t b_t(\mu_t) i_t$. The differences between the two project outcomes and the private benefit captures the severity of the entrepreneurial moral hazard.

The private benefit is assumed to be a function of the monitoring intensity employed by the bank and lies in the range $b_t \in \left[0, \bar{B}\right]$. Given monitoring intensity μ_t the entrepreneur will choose the project outcome with the highest private benefit $b_t(\mu_t)$ possible. Favara (2006) has shown that alone this assumption can lead to cyclical dynamics in an OLG model, where during a boom, i.e. when entrepreneurs have high net worth,the incentives of the banker to monitor the project are weak. Reduced monitoring has the additional effect of inducing entrepreneurs to propose high private benefit, low monitoring projects that would not get financed, i.e. would not pass bankers ex ante evaluation in periods of "normal" control activity.

Private benefits are assumed to be decreasing in monitoring intensity, they have a maximum given no monitoring, but follow a non-linear decline. This is meant to reflect that the marginal efficiency of monitoring reduces.

$$b = \bar{B} \cdot (1 + \chi * \mu_t)^{-\epsilon_b} \tag{33}$$

Figure 3 illustrates the relationship between private benefit and monitoring intensity for the calibration of the model.

In the model the banker will choose a continuous monitoring effort (μ_t) facing constant marginal costs. The monitoring decision is central to the financial contract as it mitigates the entrepreneurial moral hazard. Monitoring is not only costly and private, but it represents the risk taking of the bank given the leverage constraint. However the relationship that lower monitoring implies higher risk taking is not granted, as the risk taking will also depend on the return on investment, and therefore the price of the investment goods. Section TBA studies the impact of a positive technology shock on bank risk taking.

Macroprudential regulation will require the banker to have skin in the game on the project. This creates the trade off central to the problem, the higher option value of the riskier project against the higher expected payoff of 0, the good project. The next section reviews the financial contract in detail and links the monitoring intensity to risk taking.

3.4 The Financial Contract

The financial contract regulates funding of capital good investments, saving households finance bankers by supplying short term deposits. Bankers allocate credit according to the financial

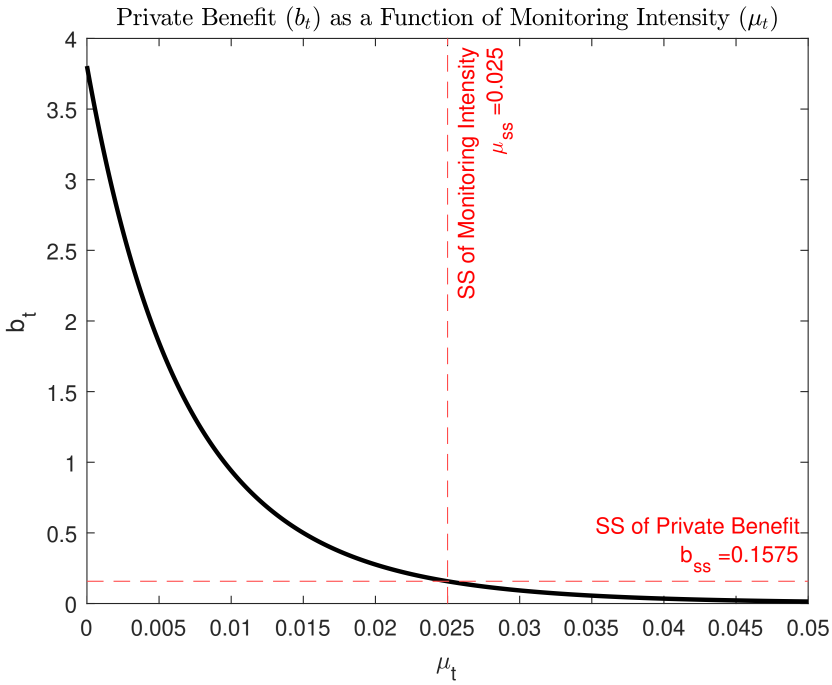


Figure 3: Relationship between Private Benefit and Monitoring Intensity

contract that makes all agents ex-ante incentive and participation compatible. Although the contract does not allow default, it ensures that only investment projects are financed, where entrepreneurs and bankers are compensated for their good, for the former, and costly, for the latter, behaviour while attracting funds from households. In contrast to Bernanke et al. (1999), where the financial accelerator works through the spread on external financing premium, in this setup the financial contract determines the size of investments in equilibrium. In spirit it is more closely related to Gertler and Karádi (2011), where the endogenous leverage constraint arises due to net worth accumulation of the contracting agents, but differs insofar as the financial friction due to credit origination affects investments, the flow, and not capital, the stock. As in Meh and Moran (2010) the agency problem introduces endogenous constraints the financial contract determines the size of investments. Therefore the financial friction works thought combined balance sheet of contracting parties households, bankers and entrepreneurs and not the price of the risk as in Gertler and Karádi (2011).

Following Christensen et al. (2012) the financial environment is based on the model of Holmstrom and Tirole (1997): contracting agents face the double moral hazard problem arising from private benefit and costly state verification. In order to be able to talk about (ex-ante) bank default probability, I rewrite the incentive compatibility constraint of the banks' using the idea for the Value-at-Risk constraint introduced in Adrian and Shin (2008). The banks' incentive compatibility constraint will then be used to determine the banks' risk exposure limit, and hence the (ex-ante) banks' probability of default. The financial contract is represented by the following optimization problem:

$$\max_{\{i_t, R_t^e, R_t^b, R_t^h, a_t, d_t, \mu_t\}} q_t \alpha_t R_t^e i_t \tag{34}$$

s.t. :

$$q_t \alpha_t R_t^e i_t \geq q_t(\alpha_t - \Delta\alpha) R_t^e i_t + q_t b(\mu_t) i_t \tag{35}$$

$$q_t \alpha_t R_t^b i_t - \mu_t i_t \geq q_t(\alpha_t - \Delta\alpha) R_t^b i_t \Longleftrightarrow \Gamma_t = \frac{\mu_t}{q_t(e^\kappa - 1)} \tag{36}$$

$$q_t \alpha_t R_t^b i_t \geq (1 + r_t^a)\, a_t \tag{37}$$

$$q_t \alpha_t R_t^h i_t \geq \left(1 + r_t^d\right) d_t \tag{38}$$

$$R = R_t^e + R_t^b + R_t^h \tag{39}$$

$$a_t + d_t - \mu_t i_t = i_t - n_t - (QE_t Y_t)_{|r_t^d = 0} \tag{40}$$

$$i_t - n_t - \tau\, (QE_t Y_t)_{|r_t^d = 0} = \gamma_t^g a_t \tag{41}$$

Equation 34 states the contract's objective to maximize entrepreneur's expected share of the investment project given the constraints representing the double moral hazard framework.

The first type of moral hazard emerges because entrepreneurs can influence their investment projects' probability of success, either by exerting effort and choosing a project with high probability of success (α_t), or by choosing a project with low probability of success ($\alpha_t - \Delta\alpha$) and enjoy private benefit (b_t). The entrepreneurial moral hazard is driven by two factors the difference in the probabilities ($\Delta\alpha$) and private benefits given the banks' monitoring intensity ($b_t(\mu_t)$). Facing monitoring an entrepreneur can decide choose to run the project shirking, thereby lowering the probability of success and taking a private benefit. The optimal financial contract is designed to incentivize the entrepreneur to behave and choose the 'good' project. Therefore the incentive compatibility constraint of the entrepreneur,equation 35, ensures that he weakly prefers the "good" project outcome to the "bad" given the monitoring intensity. Where q_t is the real price of capital in period t in terms of units of consumption, α_t is the probability of success of the project given high entrepreneurial effort, ($\alpha_t - \Delta\alpha$) the probability of success given low effort, R_t^e is the return per unit of investment project pledged to the entrepreneur, $b_t(\mu_t)$ is the private benefit the entrepreneur enjoys given low effort and i_t is the scale of the project.

The second type of moral hazard is the standard costly state verification problem. Banks possess the monitoring technology, that can identify "bad" projects. As in Holmstrom and Tirole (1997) bank monitoring can mitigate the moral hazard problem by limiting the ability of entrepreneurs to divert resources, however bank monitoring incurs a private cost (μ_t) . A bank is required to have a skin-in-the-game in the investment projects to police entrepreneurs in order to attract loanable funds, but given monitoring is costly, the bank now has a private incentive not to monitor adequately. This creates the second incentive compatibility constraint for the banks.

The banks' incentive compatibility constraint, equation 36, ensures that bankers are motivated to monitor the entrepreneurs, ensuring a high success probability of the project for their share of the project returns and bearing the monitoring costs in contrast to forgoing monitoring and facing lower success probability.

The bankers' incentive compatibility constraint can be read as standard a'la Holmstrom and Tirole costly state verification problem, it can be reformulated using the Value-at-Risk consideration of the banker as a function that relates bank default probability to monitoring intensity:

$$\Gamma_t = \frac{\mu_t}{q_t(e^k - 1)}. \tag{42}$$

The other elements of the financial contract are standard. Both bankers and households need to meet their participation constraints. Households have to be indifferent between holding the share of the project and the short term deposit at the banks (r_t^d), equation 37. Equation 38 tells that bankers have to earn a return equivalent to their market-determined outside option and return (r_t^a). The market clearing conditions constitute two equations, the return sharing and the balance sheet condition. Equation 39, the return sharing equation states that the overall return on the investment project is shared across entrepreneurs, bankers and households depending on where the severity of the moral hazard is more expressed. Equation 40 represents the balance sheet of the bank and tells that loanable funds available to a banker, its own capital (a_t) and the deposits it attracted (d_t), net of the monitoring costs ($\mu_t i_t$), are sufficient to finance the lending to the entrepreneur, that is the size of the investment project net the net worth of the entrepreneur and quantitative easing at the zero lower bound. ($i_t - n_t - (QE_tY_t)_{|r_t^d=0}$). Finally, the leverage requirement specifies that the loan provided by the bankers cannot be larger than the maximum regulatory leverage times the bank capital ($\gamma_t^g a_t$). Note the term $(QE_tY_t)_{|r_t^d=0}$ that captures the impact of quantitative easing at the zero lower bound as the fraction of aggregate output. In the next section I discuss the modelling of quantitative easing in detail.

The optimal contract will constitute to the following equations entering the model solution. Combining the two incentive compatibility constraints 34 and 35 as well as the return sharing constraint 39 as they hold with equality in optimum we get:

$$R_t^e = \frac{b(\mu_t)}{\Delta\alpha} \tag{43}$$

$$R_t^b = \frac{\mu_t}{q_t \Delta\alpha} \tag{44}$$

$$R_t^e = R - \frac{\mu_t}{q_t\Delta\alpha} - \frac{b(\mu_t)}{\Delta\alpha} \tag{45}$$

(46)

3.5 Endogenous Financial Risk Taking

As highlighted before, the bankers' incentive compatibility equation, Eq. 36, has two representations. It can be read as standard monitoring intensity a'la Holmstrom and Tirole, or it can be rewritten using Value-at-Risk consideration of the banker as a function that relates bank default probability to monitoring intensity. The latter formulation is following Adrian and Shin (2008).

To represent the Value-at-Risk inherent to bankers let us introduce the expected payoff of the project to the bankers per unit of invested equity in the "good" and "bad" outcome, respectively: $r_{H,t} = R^b_t \alpha_t$ and $r_{L,t} = R^b_t(\alpha_t - \Delta\alpha)$. Then it follows:

$$r_{H,t} - r_{L,t} \geq \frac{\mu_t}{q_t}, \tag{47}$$

which holds with equality for the optimal contract in equilibrium.

Under general conditions, shown by Adrian and Shin (2008), one can write the probability of bank default in the equilibrium as:

$$\Gamma_t = \frac{r_{t,H} - r_{t,L}}{e^{\kappa} - 1}, \tag{48}$$

where Γ_t is the short hand notation for the cumulative generalized distribution function for the optimal contract.[13]

The term $r_{H,t} - r_{L,t}$ in the Value-at-Risk interpretation captures the consideration of return on equity of the banker. By committing bank capital to the project, bankers trade off the greater option value of holding the riskier project, i.e. lower probability of success project while saving monitoring costs, against the higher expected pay off from holding the more secure project (Adrian and Shin, 2008, p. 15).

Substituting in for $r_{t,H} - r_{t,L}$ in the optimum, the probability of default of the banks becomes equation 36:

$$\Gamma_t = \frac{\mu_t}{q_t(e^{\kappa} - 1)}. \tag{49}$$

The bank default probability is endogenously determined as it results from the optimal contract. This representation is stark contrast to the interpretation of bank default risk based on the success probability of the project, that is constant in the model. I interpret the former as (endogenous) financial risk taking and the latter economic risk. Bank default probability will deviate from the project default probability, as it is determined by the optimal choice of the banker satisfying the ex ante incentives constraint of the financial contract, while the economic risks are constant. Risk taking therefore in this model is endogenous in contrast to the endogenous economic riskiness is imposed by assumption in Christensen et al. (2012).

As Equation 49 shows, the financial risk taking will be determined by the equilibrium relationship of the asset prices, q_t, and monitoring intensity, μ_t. Their ratio however is jointly determined with the rest of the economy. The default probability is decreasing in monitoring intensity, as $\partial q_t / \partial \mu_t < 0$ for the calibrations considered, that is monitoring mitigates the moral

[13] Adrian and Shin (2008) approach the expression from the leverage constraint, and introduce the parameter θ, that links leverage to Value-at-Risk. To arrive to 48, I forgo to discuss the leverage constraint, as it is enough to assume, that the probability of default under "bad" and "good" projects are $\Gamma(z) = e^z$ and $\Gamma(z) = e^{z-\kappa}$, respectively. Here $\Gamma(z)$ is a generalized extreme value distribution, furthermore it needs to hold that the difference of the expected payoffs is constant in the range of optimal contracts, which is true by design as $\Delta\alpha$ is constant.

hazard and thus increases the equilibrium price of capital.

3.6 Entrepreneurs and Bankers

As in Meh and Moran (2010), there exists a continuum of risk neutral entrepreneurs and bankers. As the model has no default in equilibrium, a fixed fraction of fraction $1 - tau^e$ of entrepreneurs and $1 - tau^b$ of bankers leave the economy. Exiting entrepreneurs and bankers sell their net worth to households at the real price of capital q_t, and consume the accumulated wealth. Exiting agents are replaced by new ones with zero assets. Surviving agents do not consume but save all capital goods. Following Meh and Moran (2010) the representative entrepreneur starts every period with capital goods k_t^e. Capital goods are rented to intermediate-good producers,this along with the value of the undepreciated capital and the wage received from labour services w_t^e constitute the net worth in period t. Therefore the net worth available to entrepreneurs is the following:

$$n_t = (r_t + q_t(1 - \delta))k_t^e + w_t^e. \tag{50}$$

Each entrepreneur then engages in a capital-good producing project, investing all net worth n_t and attracting external financing $i_t - n_t$ as loans from bankers. A successful project yields an earning $R_t^e i_t$ in capital goods, while an unsuccessful project yield zero return. Unsuccessful entrepreneurs exit the economy, do not consume. As in Meh and Moran (2010) saving the entire earning is an optima choice due to risk neutrality and the high returns. Correspondingly a representative banker starts period t with holdings k_t^b capital goods and rents capital services and labour to firms producing intermediate goods. Once the bank has received all its different sources of income it has net worth:

$$a_t = (r_t + q_t(1 - \delta))k_t^b + w_t^b. \tag{51}$$

The bank then finances the project investing its own net worth a_t in the project. A successful project yields a payment of $R_t^b i_t$ in capital goods to the bank along satisfying the conditions of the financial contract. At the end of the period, bankers with successful projects and having received the signal to exit the economy sell their net worth to households and buy and consume final (consumption) goods.

3.7 Timing of Events

Aggregate shocks realize at the beginning of the period. Capital and labour services are used allocated to produce intermediate goods and using intermediate goods final consumption goods are produced. Households make the savings decision, allocating the period savings into banks and real money balances. Entrepreneurs and bankers meet and agree on the financial contract: bankers use their net worth and their deposits to finance the project of size i_t, entrepreneurs choose which project to pursue, to either exert high effort or to shirk, given the monitoring effort of the contracting bank. The financial contract makes all parties incentive and participation compatible, overcoming the double moral hazard problem. Successful project return Ri_t units of capital and these are shared across the three agents according to the terms of the financial contract. Exiting banks and entrepreneurs sell their shares to households, and consume their respective net worth. Households purchase the capital aligned with their consumption savings decisions. Finally, all markets clear.

3.8 Aggregation

Following Meh and Moran (2010) and Christensen et al. (2012) the aggregation is standard. As the net worth across entrepreneurs and bankers has no effect on the endognous risk taking and monitoring decision, and thus on investment, the aggregate level of investments become the sum of the individual projects:

$$I_t = \gamma_t A_t + N_t, \tag{52}$$

where A_t is the aggregate level of bank capital and N_t is the aggregate level of entrepreneurial net worth. Total lending in the aggregate is $I_t - N_t$. The net worth accumulation of bankers and entrepreneurs follows from the summation of the net worth dynamics of the agents 50 and 51:

$$N_t = [r_t + q_t(1-\delta)]\, K_t^e + \eta^e w_t^e; \tag{53}$$

$$A_t = [r_t + q_t(1-\delta)]\, K_t^b + \eta^b w_t^b, \tag{54}$$

where K_t^e and K_t^b denote the capital good held at the beginning of the period t by bankers and entrepreneurs, η^e and η^b are population masses of entrepreneurs and banks, so that the following holds:

$$K_t^h = \eta^h K_t^h,\ K_t^e = \eta^e k_t^e,\ K_t^b = \eta^b k_t^b. \tag{55}$$

As discussed before successful entrepreneurs and banks survive to the next period with probability τ^e and τ^b. Surviving agents save all their net worth due to risk–neutral preferences the high return on the projects. Therefore the capital stock holding of the respective agents in period $t+1$ in beginning-of-period notation is the following:

$$K_{t+1}^e = \tau^e \alpha R_t^e I_t; \tag{56}$$

$$K_{t+1}^b = \tau^b \alpha R_t^b I_t. \tag{57}$$

Exiting banks and entrepreneurs are selling their net worth at the price of q_t and consume the value of their available wealth. This results in the following aggregate consumption of of entrepreneurs and banks:

$$C_t^e = (1-\tau^e) q_t \alpha R_t^e I_t; \tag{58}$$

$$C_t^b = (1-\tau^b) q_t \alpha R_t^b I_t. \tag{59}$$

To illustrate how the project size affects the endogenous capital position of the agents consider substituting (52) into (56) and (57):

$$N_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\, \tau^e \alpha R_t^e(\gamma_t A_t + N_t) + \eta^e w_{t+1}^e; \tag{60}$$

$$A_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\, \tau^b \alpha R_t^b(\gamma_t A_t + N_t) + \eta^b w_{t+1}^b. \tag{61}$$

Equation (54) illustrates the bank capital channel, originally introduced in Christensen et al. (2012), in the model: ceteris paribus, an increase in aggregate investment I_t, e.g. due to QE, increases earnings for the banking sector due to the size effect. As the cake grows even with the shares fixed everyone has higher returns. This direct bank recapitalization will through a retained earnings leads to an increase bank capital in the next period, that all else equal further increases lending and investment in the subsequent periods. This mechanism helps to describe the propagation of the effects of QE into the future. Furthermore it is worth noting that bank capital A_t affects the evolution of net worth of entrepreneurs through its effect on aggregate investment.

3.9 Monetary and Macroprudential Policy

In normal times monetary policy follows a Taylor rule of the type:

$$r_t^d = \left[(1-\rho_r)\, r^d + \rho_r r_{t-1}^d + (1-\rho_r)\left[\phi_\pi(\pi_t - \bar{\pi}) + \phi_y \hat{y}_t)\right] + \epsilon_t^{mp}\right]_+ \tag{62}$$

, where ρ_r is the interest rate smoothing, r^d is the steady state level of nominal interest rate, ϕ_π and ϕ_y are the coefficients for the inflation and output gap, respectively. Finally, $\epsilon_m p$ is the monetary policy shock.

The policy rate is subject to an occasionally binding constraint at the zero lower bound, implemented by the piecewise linear solution package of occbin by Guerrieri and Iacoviello (2015). This methodology has the disadvantage that agents do not react in anticipation of the zero lower bound constraint, the focus of the study however lies in the periods once the constraint is binding. More importantly the guess verify approach of occbin accounts for the expectation formation's role in the solution, taking the timing of the lift off and the both the preceding and succeeding dynamics into account.[14]. At the zero lower bound monetary policy changes instrument and employs asset purchases similar to Gertler and Karádi (2011).

I assume that unconventional monetary policy follows simple rule responding only to the total credit-to-GDP gap, in line with the ECB's objective to repair impaired bank lending channel, and extend credit to real economy. Therefore the QE response function is of the form:

$$QE_t = \langle \phi_{QE} \cdot \left[\frac{(I_t - N_t)}{Y_t} - \frac{I_{ss} - N_{ss}}{Y_{ss}}\right] + \epsilon_{QE,t}/Y_t \rangle \Big|_{r_t^d = 0} \tag{63}$$

[14] The occbin toolbox uses piecewise linear approximation of the policy function. To find the expectations, i.e. the forward looking solution of the model it assumes the model converges back to the unconstrained steady state and iterates backward through the discrete length of periods at the zero lower bound to find a solution.

, where QE_t is the large scale asset purchases as percentage of GDP in form of investment financing, ϕ_{QE} is the response of asset purchases to the total credit gap in terms of GDP, denoted by $\left[\frac{(I_t-N_t)}{Y_t} - \frac{I_{ss}-N_{ss}}{Y_{ss}}\right]$. It is important to highlight that despite both the macroprudential policy and unconventional monetary policy responds to the credit to GDP gap, QE fully overcomes the financial friction, while macroprudential policy only changes the leverage constrait, altering the financial friction, but not eliminating it. [15]

Note that at the zero lower bound the central bank directly finances projects, purchasing investment goods, without having the technology to monitor them. The severity of the moral hazard, thus in return, will be set by banking monitoring activity, while the project size, and thus investment will be financed by central bank asset purchases. Furthermore asset purchases will have a positive impact on real price of capital. The financial contract is not written to be state contingent, therefore bankers do not take the asset purchases into consideration when entering the contract.

Furthermore I assume, that the central bank forgoes all profits on its investments, as it pays out all returns on its share of the project to the households as a lump sum monetary transfer on top of the currency issued X_t. A balance sheet representation of the financing of investments helps to illustrate how central bank asset purchases affect the economy.

On figure 4 it becomes clear how central bank asset purchases overcome a credit constrained economy. In normal times, when there are no asset purchases, households allocate their across capital good purchases from exiting banker at a price q_t, real money balances M_t/P_t, and short term deposits D_t/P_t, paying the risk free rate r_t^d. Bankers fund their assets, i.e. the loans they provide to entrepreneurs and expenses they face when engaging private monitoring $\mu_t i_t$ [16], by their net worth a_t and deposits from households. Finally entrepreneurs hold the project that they finance with their equity, net worth n_t and debt $i_t - n_t$. At the zero lower bound central bank asset purchases directly expand the size of the project.

In the simulation exercise I assume macroprudential policy is follows a counter cyclical capital regulation policy based on an optimal simple rule that maximizes welfare for households under commitment. Commitment means that the macroprudential policy follows an optimal simple rule around the steady state, weighting potential states of the economy with their asymptotic probability under the ergodic distribution of the economy. This implies that the macroprudential policy is not state contingent, optimal decisions are made at the initial, steady state of the economy, and cannot be re-optimized as a discretionary policy maker would. Since the sizes of the shocks of the economy are small, the model will fluctuate around the steady state asymptotically and give close to zero probability to the states at the zero lower bound constraint. This allows to argue that the optimal simple rule under normal times is a very close approximation to the policy that would take the non-linearity of the zero lower bound into consideration[17].

[15] And indeed if QE would be allowed to operate in normal times, macroprudential policy would

[16]Therefore these expenses are captured on the asset side of their balance sheet.

[17]Since the probability of hitting the zero lower bound is close to zero, the conditional expectations operator at the steady state can disregard of the potential constrained monetary policy.This assumption is in line with the well documented evidence that the great recession was a black swan event, and lied beyond the 95 percentile

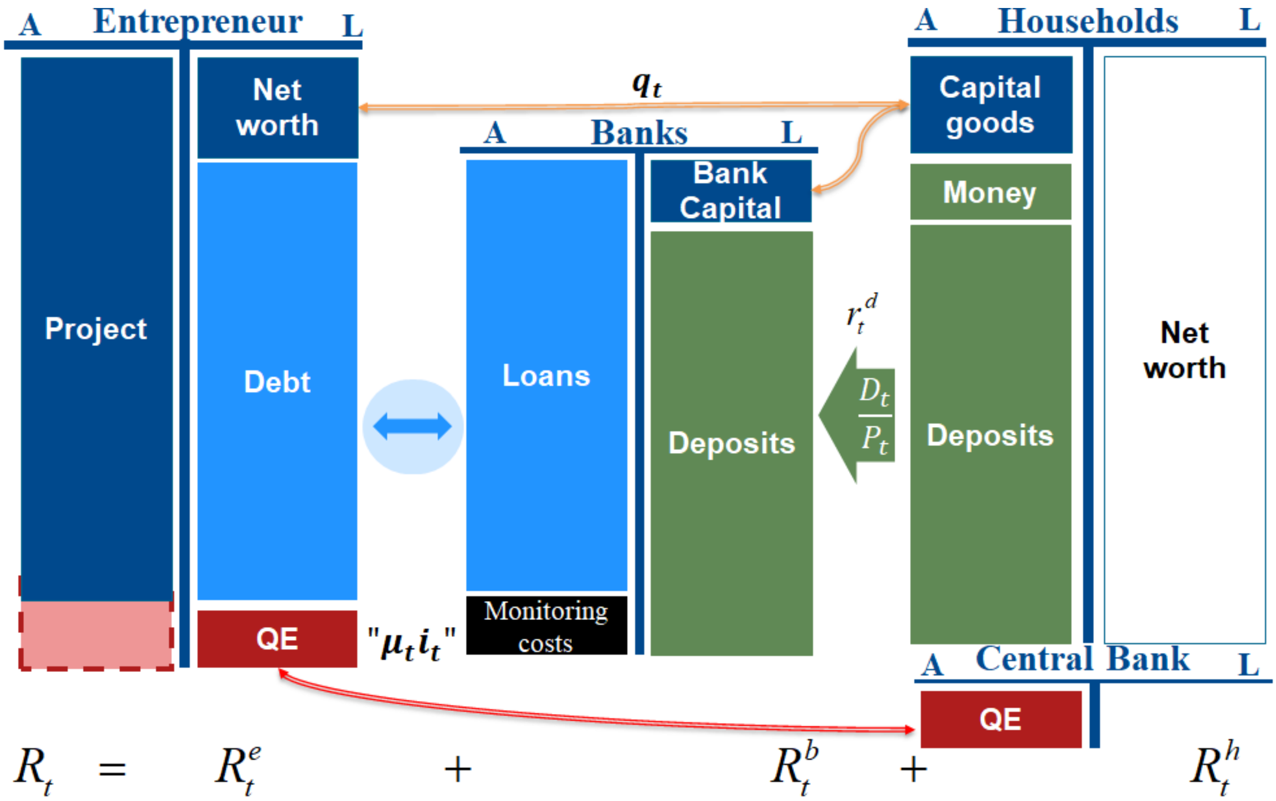


Figure 4: Balance Sheet Representation the Financing of Investments

Notes: The central bank asset purchases are indicated in red. The red arrow indicates that the central bank does not receive remuneration for participating the financing of investments. Yellow arrows represent the flow of capital goods of exiting entrepreneurs and bankers net worth purchased by households, dark blue bars are assets comprising of investment goods, and net worth, light blue arrow highlights the financing contract that regulates the size of bank loans, and entrepreneurial debt. Private monitoring, and related resources are in black. Finally, green color represents monetary assets, real money balances, short term deposits at the bank paying the nominal risk free interest rate, as there are no defaults. Finally returns of the investment project is shared across the entrepreneur, banks and households according to $R = R_t^e + R_t^b R_t^h$. (Source: Author)

As highlighted before, macroprudential policy is counter cyclical, it tightens capital regulation requiring banks to lower their leverage in an expansions and eases capital requirements allowing banks to raise leverage in downturns. On the interaction of monetary and macroprudential policy in normal times I explore two alternatives.

First, I consider a joint optimization, where monetary policy and macroprudential policy coordinate and jointly optimizes welfare by implementing a policy mix loading on inflation, output and credit-to-GDP gaps. Given other parameters of the model this specification results in a macroprudential policy that is counter cyclical to the extreme, making a policy close to infinitely elastic to the credit-to-GDP gap, while monetary policy that recovers regular coefficients of the Taylor rule. Second, I suppose there exists a sequencing of policy implementations. I assume optimal monetary policy is designed first, and macroprudential policy takes monetary policy as given and maximizes welfare by an optimal simple rule, that reacts to overall credit-to-GDP.

Therefore the required capital leverage ratio of banks, γ_t^g is specified as follows:

$$\gamma_t^g = \gamma_{ss}^g + \omega \cdot \left[\frac{(I_t - N_t)}{Y_t} - \frac{I_{ss} - N_{ss}}{Y_{ss}} \right] \tag{64}$$

4 Calibration

The calibration of the model for the policy exercise is presented in this section. Following convention the household sector as well as the final and intermediate good production sectors are similar to those of Christiano et al. (2005) and Smets and Wouters (2007).

The discount factor β is set to 0.995, implying a steady state annual real interest rate of 2%, with an inflation target of 2% a steady state nominal interest rate of 4%. The parameters of the utility function are 0.65 for the habit, 0.455 for labour disutility ψ, and 0.429 for elasticity of labour η, and 0.00183 for log real money balances (η). Following the literature I calibrate the households capital utilization in steady state, that $u_s s$, then the parameter related to capital utilization (ϑ_a) is set to 0.5. (Meh and Moran, 2010)

The Calvo price and wage-setting parameters calibrated following in Christiano et al. (2005). Thus, the elasticity ofsubstitution between intermediate goods η_p and the elasticity of substitution between labor types η_w are set to their standard values, 6 and 21. The probability of not re-optimizing for the intermediate good producers is 0.60 while that for labour packers, in the wage setting is 0.64. The share of capital in the production function of intermediate-good producers θ_k, is equal to the common value of 0.36. Giving small share in production to the labour income of bankers and entrepreneurs ensures that their net worth dynamics will be reflecting their capital returns from the project, therefore the share of labor input for intermediate production is allocated mostly to households and the rest is equally distributed between entrepreneurs and bankers. This results in a parameter θ_h of 0.639999 and $\frac{(1-\theta_h-\theta_k)}{2}$ for θ_e and

of the credible intervals of estimated DSGE models used for policy making up to the time. Furthermore this greatly simplifies the determination of the optimal simple rule parameters, as only the Jacobian of the normal times will matter. determine the optimal parameter.

θ_b respectively. Fixed cost are set such that steady state profits from the intermediate goods production are zero.

The parameter governing the double moral hazard has been calibrated following Meh and Moran (2010), resulting in the steady state monitoring (μ_{ss}) equal 0.025. Other parameters linked to investments scale the economy (R, τ^e, tau^b). Thus targeting a steady state share of investment of output of 0.23 the value, and an aggregate capital to output ratio of 12, I set the τ^e and τ^b to 0.7. R, the project return scale is calibrated to be equal to the steady state growth rate of the economy 2%, thus over time no single project will dominate the economy. Parameters governing the entrepreneurial moral hazard are standard, he success probability is calibrated to 0.993, to match the quarterly failure rate of projects documented by Carlstrom and Fuerst (1997), and the difference of the success probability of the project ($\Delta\alpha$) to be 0.35. The level of maximum private benefit ($\overline{B}$) is calibrated to 3.08 this along the steady state monitor intensity give a steady state leverage of $\gamma_g = 12.5$, implying that in steady state bank capital is 8.0% of the total assets.

Finally, the link between endogenous benefits and monitoring is calibrated to ϵ_b 10, while the sensitivity of entrepreneurial private benefit to monitoring intensity (χ) has been set to 15. This ensures that the ex ante default probability that banks engage, i.e. the capital at risk derived from the Value at Risk constraint is equal to the capital ratio required by the macroprudential authority (8%). This calibration matches the way the bank Value-at-Risk concept was used by Adrian and Shin (2008), where they focused on the "special case" [...] "in which the leverage constraint can be expressed as a Value-at-Risk constraint in which a bank adjusts in balance sheet so that its equity capital is just sufficient to meet its Value-at-Risk" (Adrian and Shin, 2008, p.22).

In this section, I discuss the assumptions regarding monetary and macroprudential policy in normal times and then at the zero lower bound and explore the possible ways of coordination, followed by a discussion of the results arising from the coordination exercises. The methodology applied is most similar to that of Gelain and Ilbas (2017). First I discuss the setup in normal times and then explore the yero lower bound environment.

The central bank follows an inflation targeting regime. Its objective function is linked to household welfare:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[log(c_t^h - \gamma c_{t-1}^h) - \psi \frac{{l_{it}^h}^{1+\eta}}{1+\eta} + \zeta log(M_t^c/P_t) \right]. \tag{65}$$

By trying to achieve the first best allocation,i.e. the Ramsey policy, the central bank follows an optimal simple rule in normal times of the form Equation (62). The functional form of the optimal simple rule implies that, to some extent, the central bank also would like to keep some stability in the short term interest rates, stabilize output and achieve its inflation target.

I assume macroprudential policy is welfare optimizing similar to monetary policy, furthermore there is no established approach of representing macroprudential policy in the form of a

Table 4: Calibration of Model Parameters

β	Discount factor	0.995
γ	Habit formation parameter	0.65
ζ	Utility from log real money balances	0.00183
ψ	Parameter related to labour supply	0.455
η	Labour disutility	0.429
ϑ_a	Capital utilization	0.5
π_{ss}	Steady state level of inflation	$1.02^{0.25}$
$\xi_w\phi_w$	Parameter governing nominal rigidities wage setting	21, 0.64
ξ_p, ϕ_p	Parameter governing nominal rigidities of the intermediate producer	6; 0.6
η_h, η_e, η_b	Measure of agents that are HH, entrepreneurs, bankers	0.9; 0.07; 0.03
θ_h	Share of household labor in production	0.639999
θ_k	Share of capital in production	0.36
θ_e	Share of entrepreneurial labor in production	$\frac{(1-\theta_h-\theta_k)}{2}$
θ_b	Share of bankers' labor in production	$\frac{(1-\theta_h-\theta_k)}{2}$
R	Overall return of the investment project given success	1.02
τ_b	Survival probability of bankers (as agents)	0.7
τ_e	Survival probability of entrepreneurs (as agents)	0.7
μ_{ss}	Steady state monitoring effort	0.025
α_{ss}	Steady state probability of success given high effort,bank success probability	0.99
$\Delta\alpha$	Difference in probability of success between high and low effort	0.35
ϵ_b	Parameter linking probability of success to monitoring	10
χ	Sensitivity of entrepreneurial private benefit to monitoring intensity	15
$\bar{B}$	Maximum level of private benefit	3.8
σ_z	Standard deviation of the technology shock	0.0035
σ_{mp}	Standard deviation of the monetary policy shock	0.0016
σ_{bk}	Standard deviation of the bank capital shock	2.5
ρ_r	Short term interest rate smoothing in the Taylor rule	0.9
ρ_π	Parameter on inflation deviation from target in the Taylor rule	1.85
ρ_y	Parameter of output-gap stabilization in the Taylor rule	0
ρ_z	AR(1) coefficient for the technology shock	0.95
ρ_{mp}	AR(1) coefficient for the monetary policy shock	0
ρ_κ	AR(1) coefficient of the bank capital (valuation) shock	0.9
ρ_{qe}	AR(1) coefficient of the QE shock process	0.9
τ	Inefficiency parameter of public investment	0.9
ω	Response of macroprudential authority to deviations from credit-to-GDP SS	-32.4589
ϕ_{QE}	Parameter governing the QE/Central bank balance sheet reaction	-1.45

simple loss-function[18]. It achieves it's goal of household welfare optimization using the leverage ratio as an instrument, reacting to credit to GDP as in Equation (64).

4.1 Interaction of Monetary and Macroprudential Policy in Normal Times

When designing the optimal simple rule I start by discussing the perfect coordination between the policy makers, the second best solution to any friction. Note the first best would be the Ramsey policy, where ever period the central planner has the capacity instrument can be set to achieve optimal welfare. An optimal simple rule is an imperfect, yet good enough

[18]In the literature macroprudential policy is either assumed to be welfare optimizing or optimizing an ad-hoc loss function on the financial cycle, I model the macroprudential policy as welfare optimizing

approximation of the Ramsey policy, thus it is the second best. Under coordination I mean that both monetary and macroprudential policy jointly optimize their response function of the Taylor and counter cyclical response rule to maximize welfare. In contrast to Meh and Moran (2010), who document a complimentarity of instruments, under full coordination I find a separation of objectives. Macroprudential policy will choose to be extremely responsive to the credit-to-GDP gap, setting $\omega = -1650.28$ while monetary policy parameters recover a standard Taylor type rule, well documented in the literature, resulting in coefficients of $\rho_r = 0.84$, for interest rate smoothing, $\phi_\pi = 1.73$ and $\phi_y = 0.34$. The value of welfare, i.e. the objective function under cooperation is 0.0678. The only parameters that is lower in the optimum, than reported under standard Taylor rule estimates is the interest rate smoothing parameter. This result is mostly driven by the lower frequency stabilization property of macroprudential policy. Recall that macroprudential policy by stabilizing credit-to-GDP, also stabilizes credit, net worth and bank capital, the low moving determinants of investment volatility. As the low frequency drivers of investment volatility is best offset by taming the financial cycle, monetary policy does not need to pursue a strong interest rate smoothing, and can be apply a less persistent interest rate rule.

In the policy exercise and the final calibration however I will assume a sequencing of the optimization of policies. This rests on the observation, that when the concept of inflation targeting monetary policy design has been established macroprudential policy was not considered as an anti-cyclical policy, and even if it was modelled, it was assumed to be time invariant. Subsequently once financial stability has become a concern for policy makers, central bank mandates have been already established, and macroprudential polices were designed taking monetary policy as given. Therefore the sequencing of policy optimization implies, that monetary policy is the first mover and macro-prudential policy optimizes given monetary policy. I first optimize the Taylor rule for monetary policy and then macroprudential policy. The resulting coefficient is displayed in Table 5.

Table 5: Welfare Optimizing Policy Parameters

Parameter	Coordination	Monetary Policy First	Macroprudential Policy Second
ρ_r	0.34	0.93	0.93
ϕ_π	1.73	1.43	1.43
ϕ_y	0.34	0.27	0.27
ω	-1650.28	0	-32.46
Welfare loss	0.0678	10.1743	0.4332

If monetary policy moves first, it chooses an optimal simple rule with coefficient close to the standard Taylor rule. This result further supports the application of Taylor principle in medium scale DSGE models, even when financial sector is modelled in detail, as the primary trade-off monetary policy faces is mainly driven by markup dispersion, i.e. prices deviating from marginal costs, and the financial cycle is of secondary importance. The coefficient for interest rate smoothing is $\rho_r = 0.93$, while the other policy parameters are $\phi_\pi = 1.43$ and $\phi_y = 0.27$. The value of welfare, i.e. the objective function under cooperation is 10.1634. Given these parameters macro prudential policy will choose the optimal response. The resulting welfare is still worse than under cooperation, however the improvement is substantial over the time invariant policy. The resulting elasticity should be compared to the BIS recommended guidance on setting the countercyclical capital buffer. According to the BIS's "Guidance for national authorities operating the countercyclical capital buffer" there is a floor for inaction for macroprudential policy, as long as the credit-to-GDP gap is below 2%, afterwards the countercyclical capital buffer should should increase linearly to 2,5% once the credit-to-GDP gap is 10%. This implies a tightening of the minimum regulatory capital ratio of 0.3125% for every 1% increase of the credit-to-GDP gap. In my calibration the macroprudential response of -32.46 on the leverage ratio translates to capital regulation tightening of 0.213% for every 1% increase of the credit-to-GDP gap. This results in locally similar elasticities compared to the Basel III recommendations as it can be seen on Figure 5. (*Basel III: A global regulatory framework for more resilient banks and banking systems - revised version June 2011*, 2011)

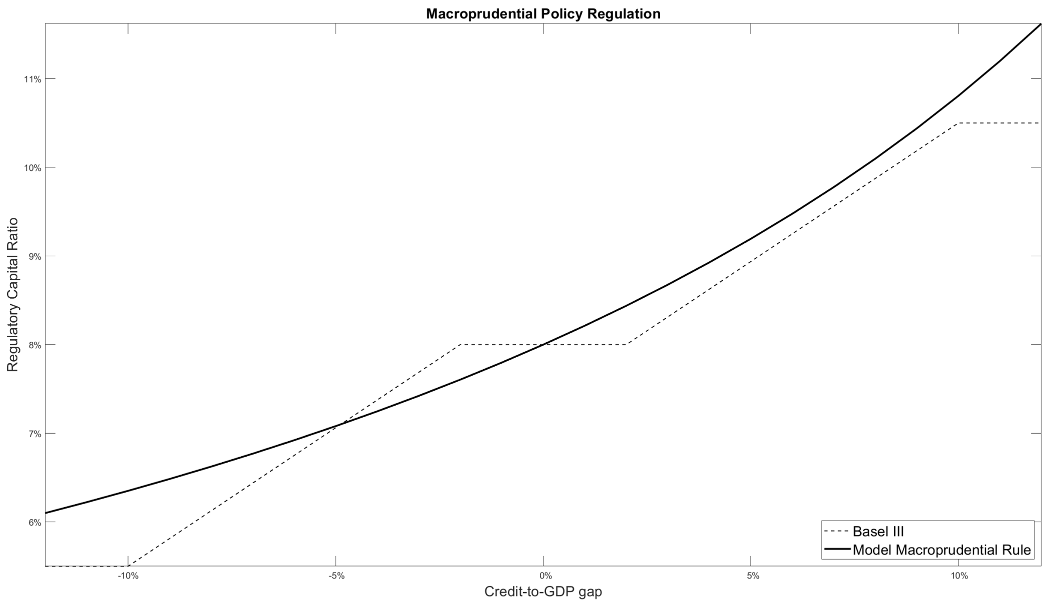


Figure 5: Macroprudential Policy According to Basel III vs Model's Optimal Simple Rule

4.2 Calibration of QE

In order to calibrate the ϕ_{QE}, the parameter governing the central bank balance sheet reaction, the model has to be solved given a scenario that necessitates the activation of QE. That means, the model will have to be pushed to the ZLB and the impact of QE should be compared to the counterfactual, where the economy is stuck in the liquidity trap. The calibration of the ϕ_{QE} is what determines the activation of QE in response to credit-to-GDP shortfall. As identified in the empirical section, the core idea of the calibration that the elasticity between inflation expectations and long term yield should be matched during periods when QE is expanding. Not that despite QE only activates at the ZLB, due to the deterministic simulation the whole path of the IRF to the crisis scenario will be dependent of the parameter ϕ. Thus to find the calibrated parameter, the model under both ZLB with QE and without has to be estimated and compared to find the impact of changes in the long term OIS yields on the long term inflation expectations in periods where QE is expanding. It boils down the a moment condition on the IRFs of the two regimes:

$$\sum \frac{\frac{\Delta 10Y\Pi_t^{exp}}{\Delta 10YOIS_t^{exp}}|_{\Delta QE_t>0}}{\sum \mathbb{1}_{\Delta QE_t>0}} = -1.19 \tag{66}$$

Thus resulting in a parameter governing the central bank balance sheet reaction to the credit-to-GDP gap of -1.45. Another cross check of the calibration is to compare implied moments. Since it is intended to capture the efficacy of QE, the calibration indeed reproduces estimated QE effect on yields, on impact a 10% GDP equivalent increase in purchases reduces overnight 10 year yields by 68 bps. This is in line with the range of 10-175bps of estimates for the impact of QE reported by Andrade et al. (2016, p.14.).

5 Experiments

I begin with baseline experiments in normal times designed to illustrate how the model behaves. First, I explore how the model responds to a negative technology shock in normal times, then I study the dynamic response of the core variables to a bank capital quality shock. Second, I consider a crisis experiment in line with Gertler and Karádi (2011), aimed at capturing some aspects of the basic features of the great recession. Here I focus on the role of endogenoussk taking, how bank capital limits investments, and how macroprudential policy responds to bank capital shortfall. Finally, I explore the implications of the zero lower bound on nominal interest rates, highlighting the role of central bank asset purchases in moderating the crisis, and studying the interaction of unconventional monetary policy, endogenous risk taking, and counter-cyclical macroprudential regulation.

5.1 Risk Taking in Normal Times

Let us first explore the model dynamics in normal times, when the monetary policy is unconstrained and follows a Taylor rule. To understand the interaction of bank default probability and the moral hazard in the economy let us study the impulse response function of the model to a negative technology shock in normal times, shown on Figure 6. In the simulation the persistence of the technology is set to 0.95. Technology shock size is calibrated to match output growth volatility of 2.903.

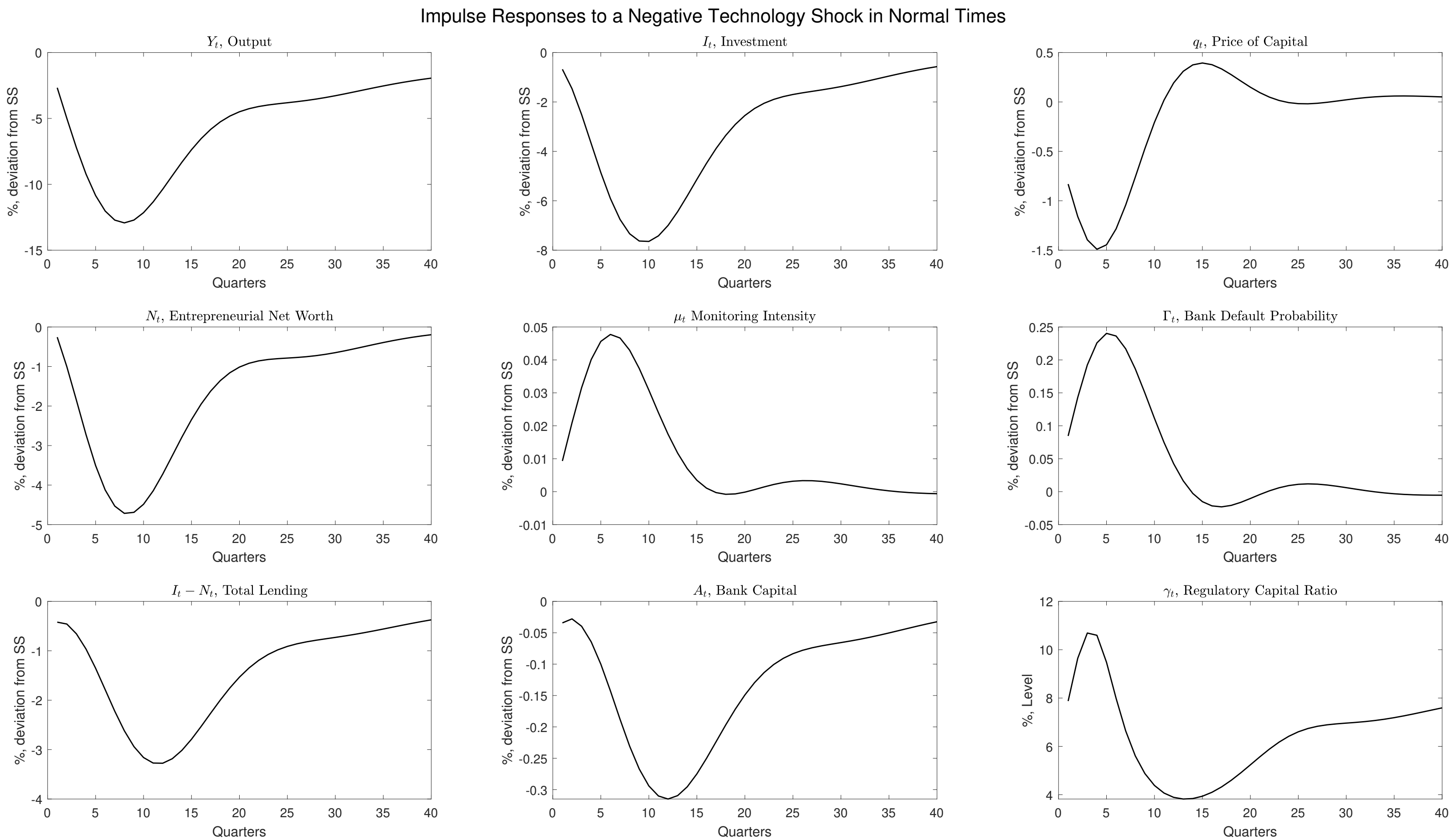


Figure 6: Impulse Responses to a Negative Technology Shock in Normal Times

A negative technology shock implies that the return on capital decreases unexpectedly, to a rate lower than in steady state. This lowers investment, output and the real price of capital, shown on the first row of the chart. However as both price of capital and investments decrease, the source for repreneurial net worth also shrinks, this tratranslates into a reduction of the net worth of the entrepreneurs. As entrepreneurs have less net worth to pledge, the incentives of the banker to monitor the project become stronger. However the reduction in monitoring intensity does not translate into a increduced financial risk taking, into ex ante bank default probability. A also increaseslthough low higher monitoring intensity mitigates moral hazard, the slack of and for capital goods delivers lower real price of capital in all states of the world offsetting the risbenefits of monitoring. As entrepreneurial net worth shrinks and bankers monitor more total credit in the economy also responds, albeit with a period delay. Declining credit being the primary source of bank revenue along an increased monitoring will reduce bankers' net income and will cause bank capital to contract as well. The model furthermore captures the pro-cyclicality of the Basel III regulation. On impact as the credit-to-GDP gap is positive. Output declines faster than credit, the denominator of the credit-to-GDP shrinks more than the numerator, thus credit-to-GDP gap increases in the first period, and starts declining consecutively as credit conditions deteriorate. This is reflected in the regulatory capital ratio, that initially tightens before loosening. This pro-cyclicality regulation is well understood, and usually brought up as a counter argument against over reliance on the credit-to-GDP gap(Babić and Fahr, 2019). In conclusion, responding to a negative technology shock endogenous financial risk taking decreases despite of the reduced monitoring effort, asset prices o declinesfset the examitigatedral hazard.

5.2 Risk Taking in Response to Bank Capital Shortfall

Now turning to the crisis experiment. The initiating disturbance is a decline in bank capital quality, and thus a reduction in bank capital. In line with Gertler and Karádi (2011) I introduce a shock to the quality of intermediary capital that produces an enhanced decline in the bank capital, this simplified capital quality shock enables to capture the broad dynamics of the sub-prime crises. Similar to Gertler and Karádi (2011) there is both an exogenous and endogenous component to the decline in asset values that the shock generates. The exognous component is the initial decline in capital quality, that reduces the quantity of bank capital. In the simulations I assume a persistence of the bank capital quality shock of 0.9 and calibrate the size of the shock to have a peak response in investments of -1% from the steady sate, implying a standard deviation of 1.15

The endogenous, second round effects emerge due to the deterioration of bank net earnings primary driven by the drop in total lending.

The weakening of bankers' balance sheets induces a drop in total lending, reducing total investments, causing the real price of capital to increase, as it becomes increasingly scarce. The endogenous increase in q_t is in contrast to Gertler and Karádi (2011), and highlights how asset prices can be counter-cyclical once credit inter-mediation fails to provide enough lending to finance investments producing capital goods. Another reason why the real price of capital increases is because the reduction in bank capital quality compresses investments making future investments scarce in expectation, increasing the expected return on capital, and thus driving up the price q_t.

Focusing to endogenous financial risk taking, although bankers endogenously cut back on monitoring effort to curtail expenses, the endogenous riskiness overall declines. This shows that banks benefit more from the price impact on their real option, than the aggrevation of the moral hazard their monitoring causes. Beyond savings on monitoring expenses, bank capital accumulation is also bolstered by the accommodative monetary policy, that responds mostly to the drop in inflation. Inflation lowers after a bank quality shock reflecting an expected consumption shortfall that households suffer as a consequence of investment shortfall.

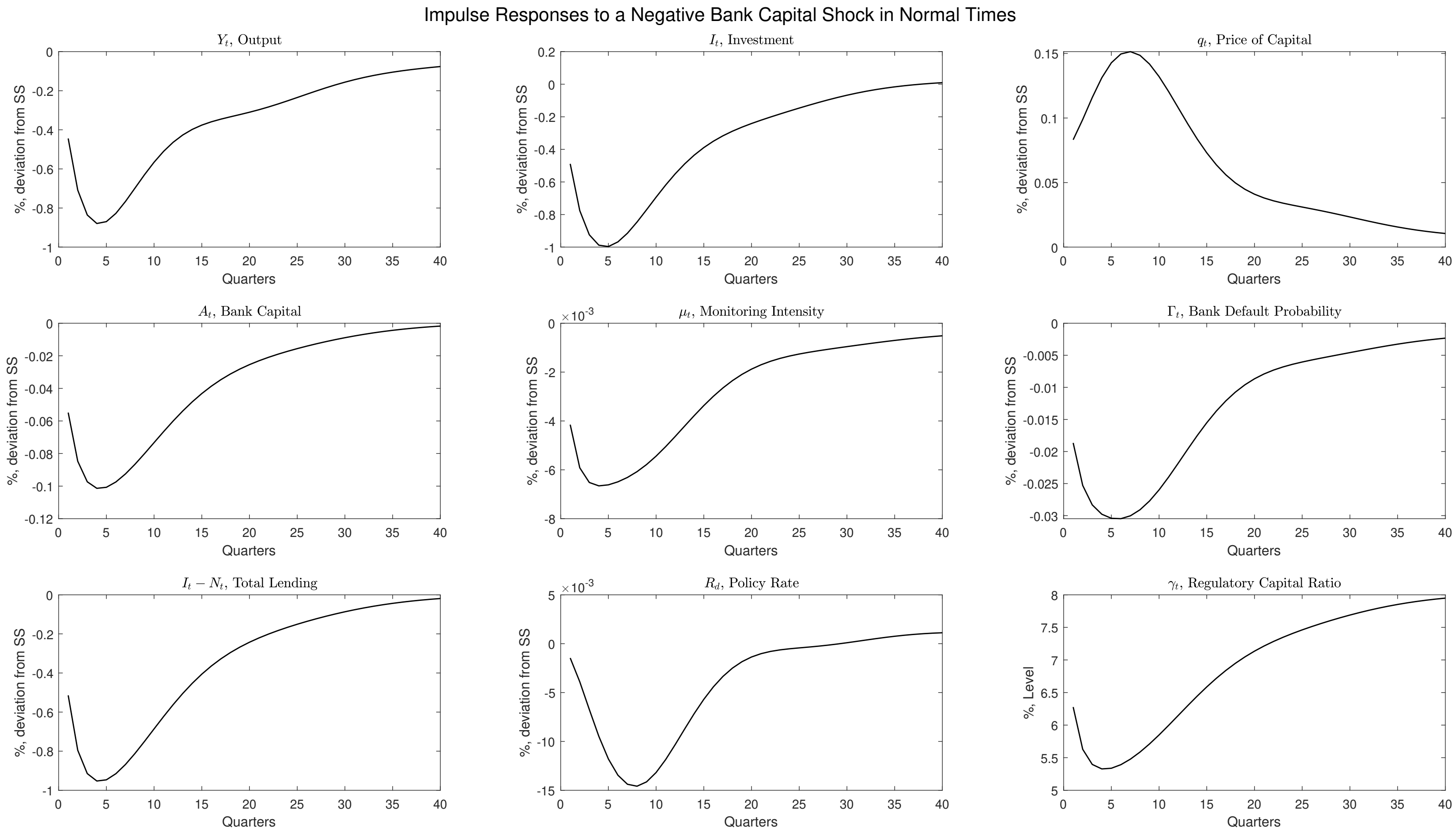


Figure 7: Impulse Responses to a Positive Bank Capital Shock in Normal Times

As bank capital declines bankers have to shrink their balance sheet contemporaneously. They can achieve a smaller balance sheet by cutting back on monitoring and loans, both are undesired from a macroeconomic perspective. Therefore a welfare maximizing countercyclical capital regulator will lower the required regulatory capital, tracking the evolution of the bank capital, and total credit gap. Note however, that a credit-to-GDP gap based macroprudential policy although mitigates the impact of bank capital scarcity, by allowing a higher leverage will not translate to increased financial risks. As endogenous financial risks are driven by the price of capital and monitoring intensity, let us focus on their response.

The pecuniary externality of cutting back the amount of total lending will drive up the price of capital goods. While cutting back on monitoring will worsen the moral hazard with the entrepreneurs. The overall impact of bank deleveraging however points towards the reduction of overall financial risk taking. Banks optimally reduce the amount of risk they engage, once their capital becomes scarce. They give out credit that is less monitored worsening the moral hazard, but engage in less lending overall, that drives up prices and makes them optimally take less risk. This reduced financial risk taking is reflected in their overall reduction of bank default probability. As due to shortage of loans in the economy, investments that would have been financed if bank capital would not be scarce, do not get undertaken, the economy will slow down. Output gap will reduce and with inflation starts falling forcing the central bank to react by cutting the policy rate. The -1% reduction in bank capital, under the calibration considered, translates in a peak monetary policy rate response of around -1%. A lower policy rate, lowers the deposit rate of household savings and thus reduces bankers' expenses and speeds up bank capital accumulation. As bank capital scarcity abates financial risk taking slowly increases and converges back to its steady state. The key mechanism in the transmission of the shock is the scarcity of bank capital. As bank capital drops it becomes the tight constraint in the economy. And as QE is designed by assumption to overcome the financial accelerator mechanism of the double moral hazard problem, it is the optimal response to the friction.

6 Risk Taking in Times of Crisis

The impact of the zero lower bound on financial risk taking is a novel concept. The common narrative is, that lower interest rates increase incentives for risk taking. In what follows, I show that this insight is erroneous. As shown in the previous section, endogenous financial risk taking reduces if bank capital drops following a capital quality shock, i.e. bank equity scarcity is the cause of the recession. Therefore if risk taking is an optimal decision based on the context that has caused the ZLB. In what follows I assume that the ZLB has been hit due to bank capital quality deteriorating. There is ample literature on the sources of the great financial crisis, but a fundamental character shared across all narratives is a drop in bank capital. In what follows I will first explore how the liquidity trap, i.e. the fact that the short term rate is at its ZLB, impacts financial risk taking. I will show that endogenous financial risk taking will detach from the channel of the bank capital scarcity. A the ZLB banks will take on more risks than they would without the liquidity trap. Second, I will use the ZLB, liquidity trap as the baseline compared to which the impact of QE will be considered. I argue that in order to assess the impact of unconventional measures, one should have the right counterfactual in mind. Having built a DSGE model enables the consideration of policy counterfactual. The micro founded theory basis makes structural modelling robust to the Lucas critique. In measuring the impact of the unconventional asset purchases, I emphasise that the effects should be evaluated against the right counterfactual, that is the zero lower bound dynamics of the economy without unconventional policies. To solve the model at the zero lower bound I employ the occbin toolbox by Guerrieri and Iacoviello (2015). The occbin is a toolbox to simulate non-linear regimes of occasionally binding constraints, using an interative backward solution approach based on the piecewise linear approximation of the policy function.

This method suffers from limitations that constrain its use for welfare analysis. First, any first order approximation based welfare analysis will be invalid, as future risks are not taken into account, widely understood by economists. Second, due to the iterative backward solution the length the economy spends at the zero lower bound will be endogenous to the policy function. The discrete time of switching between the regimes creates a non-linearity to the policy parameters that renders first order, Jacobian based optimal solution techniques invalid. Third, due to fact that unconventional monetary policy works by overcoming the financial accelerator problem, while macroprudential capital regulation only influences the degree of financial friction, will render the question should the central bank employ asset purchases or only use macroprudential policies trivial. Unconventional monetary policy will always enable a resource allocation closer to the first best, than macroprudential policy. This can be limited up to the degree set by a fixed inefficiency term τ, but the specific way QE is modelled in this framework will deliver that it is the optimal action, irrespective of the zero lower bound or not. Furthermore, the specific policy rule assumed for QE, i.e. the credit-to-GDP gap targeting rule destines it to be a close, although not perfect substitute to macroprudential policies. Thus any welfare based analysis would support the use of QE and the degree of substitution will be implicitly determined by the inefficiency term. Due to these three arguments, I forgo to study optimal macroprudential policy at the zero lower bound, and leave it to future work[19].

However, most importantly for the exercise considered, the piecewise linear approximation enables to study the impact of asset purchases on the expectations related to the zero lower bound. Once the economy is at the constrained regime, agents properly anticipate the evolution of the economy, and its return to the unconstrained model. This means that expectations of the impact of unconventional policies on the timing, profile and policy path following the lift-off play a dominant role in the dynamics of the model. The solution for agent's expectations using perfect foresight and backward iteration from the unconstrained regime all allow for the analysis considered here. Therefore occbin allows to make statements about the impact of asset purchases on the anticipated time spent at the zero lower bound, and about QE's impact on

[19] The literature on optimal QE policy is still developing. Nakov and Karádi (2019) explore the optimal QE exit policy in the Gertler Karádi model, albeit only conditionally to one shock, while Richard (2017) characterizes the optimal QE response, focusing on the portfolio re-balancing channel.

dynamics of the economy following lift off[20].

6.1 Risk Taking at the Zero Lower Bound

First let us explore the comparison of the zero lower bound with the unconstrained economy, where short term rates can fully accomodate the ensuing recession following a bank capital quality shock. Figure 8 shows the impact of a constrained monetary policy has on the economy, once it has hit the zero lower bound. The solid line shows the model of unconstrained monetary policy, without asset purchases, i.e. no QE. The dashed line shows the model that is subject to the ZLB, but has no QE to counter it. The latter serves as the liquidity trap counterfactual to which the effectiveness and impact of the unconventional monetary policy it be measured. Figure 8 illustrates that a ZLB has devastating consequences for inflation expectations and thus for the stability of the economy.

[20]With exception of precautionary motives that the economy will be at the zero lower bound again, to make statements about that, one could use regime switching DSGE based on local perturbation method implemented in RISE (Maih, 2015). I consider occbin more fitting for the task, as RISE suffers from non-uniqueness of the perturbation and difficulties about the endogenous modelling of the switching probabilities.

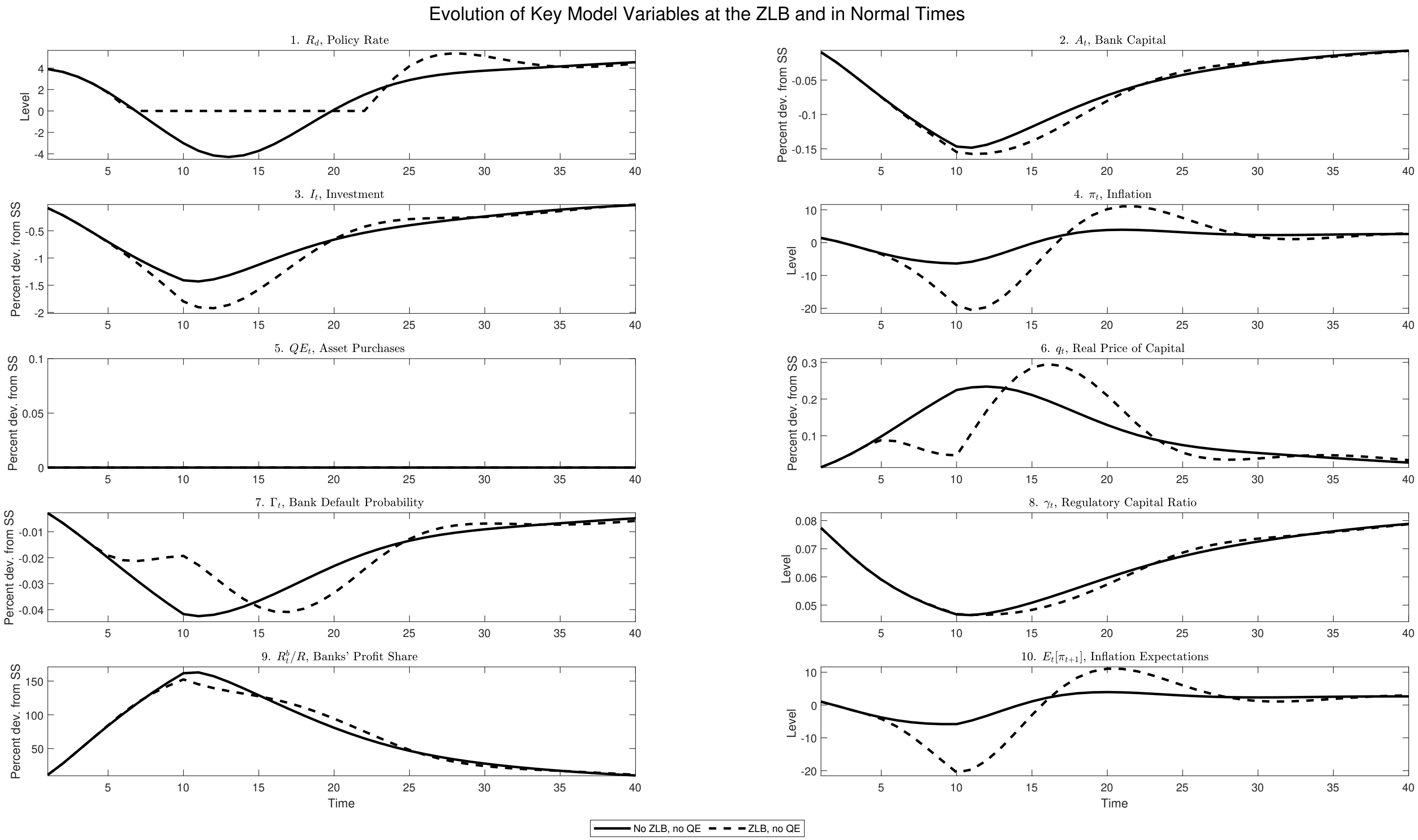


Figure 8: Zero Lower Bound versus the Unconstrained Economy

I build the crisis scenario shocking the economy with an unexpected sequence of bank capital quality shocks of 2 standard deviations spread across 10 periods. The reason for so many periods of negative shocks is to capture two observations. First, the clean up of toxic assets from bank balance sheet required multiple years and the provisions for future losses and additional litigation expenses were only built up gradually. Second, the long sequence has technical properties that it enables the economy to spend reasonable periods at the zero lower bound without requiring to assume a stochastic volatility, i.e. risk shock for the bank capital. Arguably the latter approach would be closer to reality, but due to the linear first order solution of the model, a risk shock would not change model behaviour and would only change the size of the shock imposed. In the first order, a larger shock, accounting for the autoregressive property of the shock, is effectively equivalent to a longer sequence of smaller shocks. The drop in bank capital induces a recession as it was discussed before. The deterioration of bank capital makes the financial friction more severe, as the moral hazard, and specifically the participation constraint of banks becomes more binding. The balance sheet amplification is through the real price of capital, and its deterioration. Responding to the recession the regulatory capital requirements follow the optimal simple rule and loosen the capital requirements down to approximately 5%. Interestingly the constrained monetary policy does not induce an accelerated cut of the capital regulation. This is due to the fact that the drop in investments that happens as soon as the ZLB is hit, in period 7, does not change the speed of deterioration of the total credit-to-GDP ratio compared to the no constrained monetary policy case. Bank capital not only drops slightly faster once the ZLB is hit, but more importantly recovers slower compared to the unconstrained economy. If monetary policy is bound at the ZLB, banks will have costs to cover that would not be there should they be able to finance their borrowings at the negative rates. The ZLB thus makes the bank capital scarcity more pronounced as without negative rates, banks will cut back even more on lending and that deteriorates their future profitability even further.

At the ZLB, the traditional link of investment scarcity and the real price of capital vanishes. It breaks down mainly due to inflation expectations plumeting dragging with them the real prices of capital.

Under the unconstrained monetary policy regime, i.e. solid chart, investments mirror the drop of bank capital. In this regime the transmission is the usual: the scarcity of investments causes capital to be amortized more than replaced, causing real price of capital to surge.

Under the unconstrained case, banks proportionally cut back on risk taking as their bank capital drops. This is because the link between bank capital scarcity and the real price of capital is retained. Therefore, financial risk taking follows the profile of bank capital. As bank capital becomes scarce, investments drop, real price of capital increases, and this induces banks to take less risks. Banks endogenously decide to take less risks, as the real price of the option not to monitor becomes more painful.

Exploring the regime with the ZLB, the primary difference to the unconstrained regime is the deflationary pressure the liquidity trap causes. Due to a constrained monetary policy, inflation cannot be smoothed out and drops greatly. It reaches its through around halfway at the ZLB, at a rate of -20%. The direct effect of a deflation is the drop in the inter-temporal return on capital, that is the real price of capital. This is also reflected in the worsening of profitability of bank default, affecting endogenous financial risk taking. Banks initially will not be able to cut back on risks as they would do otherwise.

The drop of endogenous risk taking is still present, but it is halted and postponed due to deflationary pressures. This is what constitutes to increased risk taking, the low capital demand environment reduces the incentives for banks to monitor and thus deteriorates the financial friction, making banking business comparatively more risky. Banks would want to cut back on risk taking, but the deflationary pressure limits their ability to do so. Endogenous risk taking flattens out at the ZLB. From period 5 to 10 the bank default probability is slightly increasing. Banks desiring to take less risks due to the scarcity of capital find themselves in a deflationary environment. The deteriorating capital markets causes them to bear more risks: as real capital prices do not increase, despite of the scarcity of capital, banks recognize the inherently more risky business they engage with. Other way to look at it is from the bank's expected earnings: the demand for investments decreases as capital prices drop, despite of the scarcity of capital. The deflation and linked deflationary expectations pushes down demand for assets today, as they will be worth more tomorrow, thus decreasing the price of capital today, relative to the unconstrained case. Overall, in line with the literature the model features the liquidity trap, the ZLB aggravates the recession.

6.2 Risk Taking and QE

Now let us turn to the comparison of the zero lower bound with the economy with QE, where the central bank responds to deterioration of credit availability due to shortfall of bank capital following the same sequence of capital quality shocks as before. Figure 9 shows the impulse response function of key variable to the crisis scenario under three alternative specifications. The solid line shows the model of unconstrained monetary policy, without asset purchases,the dashed line when monetary policy is subject to the ZLB, but has no QE to counter it, finally, the red line shows the model when central bank asset purchases can be activated at the ZLB to provide accommodation.

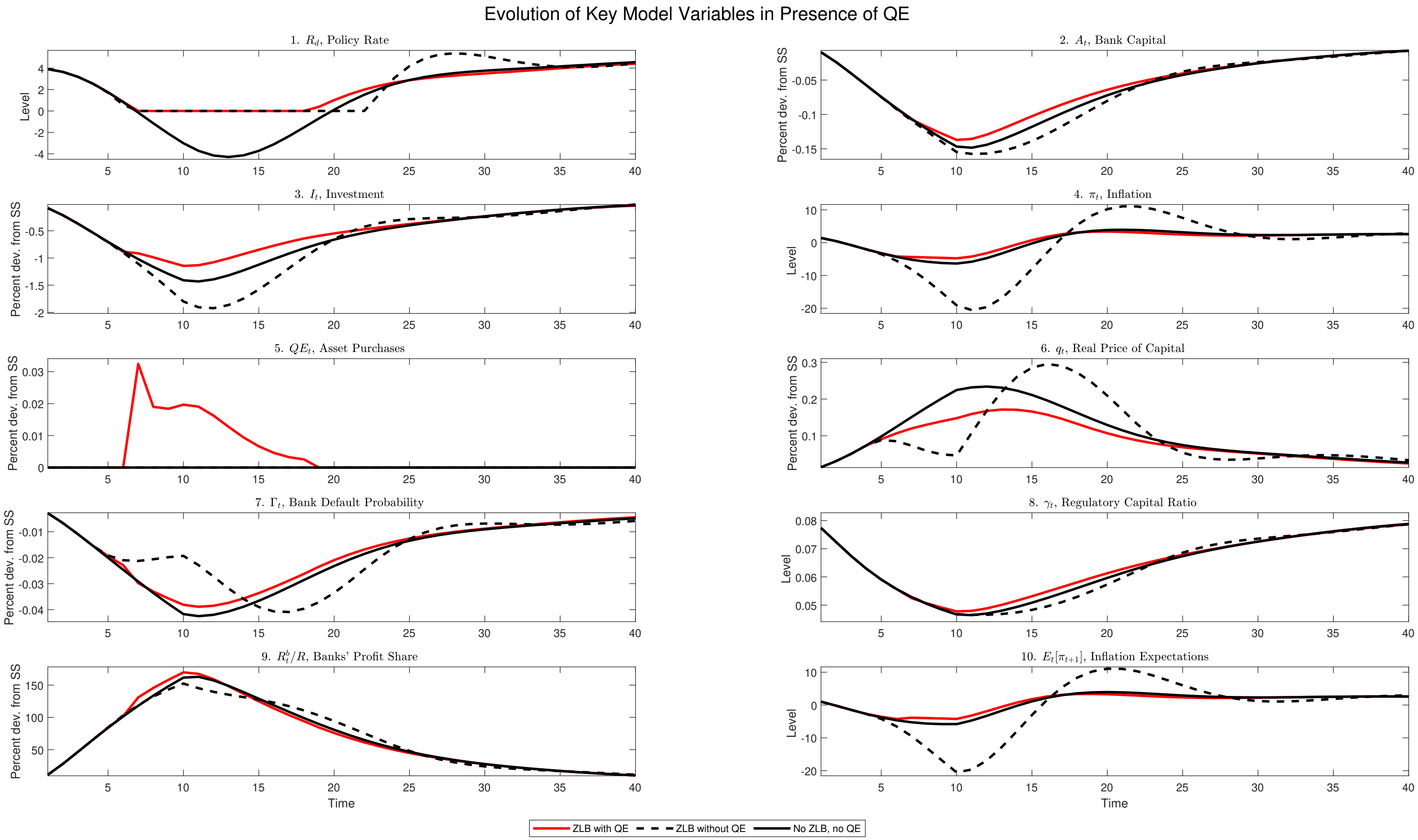


Figure 9: Zero Lower Bound versus the Unconstrained Economy

The sequence of bank capital shocks hitting the economy is the same, 2 standard deviation evenly distributed across 10 periods. The long series of unanticipated negative bank capital quality shock makes the economy hit the zero lower bound. More importantly even when QE is present the economy spends 10 periods in the constrained regime. The calibration of the QE response induces an initial spike in asset purchases peaking at 3% of the GDP, in period 7, as the economy hits the ZLB. The initial increase is followed by a small reduction. This is due to the fact, that QE financed investments directly increase GDP what leads to lower credit-to-GDP gap, as the GDP increases proportionally more compared to a slower moving credit[21]. After the QE response stabilizes the central bank balance sheet shrinks back gradually to its steady state.

The evolution of the short term rate before the ZLB illustrates that anticipated impact of hitting the ZLB cannot be captured in the simulation. However once the ZLB hit, and QE activates the two regimes differ sizably. The IRFs indicate that QE is more efficient stabilizing the economy than the short term rate. First, central bank asset purchases enables the economy to escape the ZLB earlier than under the constrained, no QE regime. Second, the short term lifts off earlier than even the unconstrained model. These findings are mainly driven by the property that QE overcomes the financial accelerator plaguing investments, while the unconstrained short term rate merely operates subject to it. Recall that central bank asset purchases are direct financing investment projects, circumventing the credit constraint the economy suffers due to bank capital shocks. It is worth pointing out that the short term rate lifts off from the ZLB before the central bank accommodation has been withdrawn. Therefore the model generates the observed pattern seen in the US, where short term rates signal a tightening, while the central bank balance sheet is still alleviated.

The direct impact of QE is reflected in the IRF profile of investments. Comparing it to the both alternatives, QE ameliorates the drop in investments the most. Note that an increase in investments will have primary and secondary effects that stabilize the economy. First, higher investments allows for less shortfall in the physical capital of the economy, smoothing out the real economic impact of the bank capital quality shock. A lower drop in capital reduces the marginal costs' deviation from steady state. The latter translates through the Phillips curve into a smoother inflation profile. This is the direct channel.

The indirect channel is through faster bank re-capitalization. A higher investments allow banks to recapitalize faster. QE increases asset prices compared to the constrained economy: a higher real price of capital enables a faster recapitalization of banks. If QE is activated, as the short term rate is constrained at the ZLB does not turn into a deflationary spiral, reducing the desire to postpone investments. The missing deflation translates to higher asset prices that eventually support banks. A faster bank recapitalization addresses the source of the recession faster.

[21]Note that this is an equivalence, and therefore as long as total credit responds less than GDP to QE, the initial increase will always be followed by a reduction. This undesirable property of the credit-to-GDP has been pointed out in relation to cyclicality of macroprudential measures, and has been widely criticized in policy circles.

QE increases the total size of the investment project, banks are happy to participate: this is reflected in the banks' profit share compared to both alternatives being the highest. Banks become better capitalized under QE than either alternative. Andrade et al. (2016) call this channel the implicit bank recapitalization channel of QE.

Turning to endogenous risk taking, one can see that contrary to the existing narrative, QE reduces bank default probability compared to the correct counterfactual of ZLB without QE. QE eliminates the volatility of endogenous risk taking. Though supporting asset prices and bank capital accumulation. Endogenous risk taking tracks better the profile in unconstrained economy, showing that QE can enable the same risk taking pattern of banks as they would follow if the short rate was not constrained. In comparison the the unconstrained short rate alternative banks take slightly more risk, as visible comparing the red and black line in the bank default probability IRF. Note that this is not driven by the real price of capital, i.e. by asset prices. Capital is less scarce if QE activates, as investments is higher, while deflationary expectations are subdued. These two contributions explain the lower peak of the real capital price response than under either alternative[22]. But then if asset prices are lower how come that banks take more risk than the unconstrained regime? They cut back on monitoring intensity. Banks decide to monitor less, as the project size increases, and they see that they can capture more of the profits, without taking on additional risks. Banks free ride the price and investment size impact of QE.

Focusing on macroprudential policy when QE is active, the regulatory capital ratio displays tightening compared to the counterfactual. This tightening is driven by an increase in credit-to-GDP, recall that total credit excludes QE, thus the increase in credit is mostly due to banks intermediating more funds. Counter-cyclical capital regulation tracks bank capital's IRF, highlighting the tight connection between the two. Recall that both variables are co-determined, either by bank capital accumulation equation and the countercyclical macroprudential policy rule linked to credit-to-GDP deviation from steady state. The channel through which QE impacts macroprudential policy is through the implicit bank recapitalization. It highlights that the operational target of credit-to-GDP creates tightening when the financial risks are indeed lowered. This observation is an important insight. The model shows that optimally designed macroprudential policy will tighten at the ZLB in response to QE, whereas the endogenous financial risk taking is reduced. Macroprudential policy will be overly prudent at the ZLB in response to QE driven credits. Although overall the counter-cyclical regulation is loosening, recognizing the scarcity of bank capital and allowing less bank equity to lever up to higher credit level, the impact of QE compared to the right counterfactual supports the observed pattern in real life, that macroprudential policies tighten when central bank asset purchases are active. This simulation illustrates that an optimal macroprudential policy for normal times is inadequate for the environment of the ZLB. Most importantly it creates prudence where prudence is not warranted. As seen before, QE increases asset prices, but doing so it eliminates

[22]The IRF of the real price of capital shows that the red line has lower amplitude than either alternative. The no ZLB, no QE, i.e. the unconstrained economy is higher than the red, while ZLB without QE, i.e. dashed line, peaks with a delay.

the deflationary pressures, and enables a more desirable risk taking of banks, reflecting the scarcity of bank equity more. The asset price impact of QE does not indicate heightened endogenous risk taking, on the contrary it reduces bank risk taking. In such an environment the optimal macroprudential rule can be considered to be overly prudent and thus more discretion is desired.

6.3 Macroprudential Policy as a Function of Financial Risk Taking

The question naturally emerge, how much would the economy and the result change if macroprudential policy was to respond to bank risk taking. To explore this alternative I have replaced the macroprudential policy rule to respond to the deviation of endogenous financial risk taking from its steady state instead of credit-to-GDP gap. Thus the required capital leverage ratio of banks become:

$$\gamma_t^g = \gamma_{ss}^g + \omega_\Gamma \cdot [\Gamma_t - \Gamma_{ss}] \tag{67}$$

Starting by optimizing the reaction function given monetary policy an interesting result emerges. Macroprudential policy responds to the extreme to bank risk taking similar to the coordination case[23]. This indicates the that macroprudential policy should optimally eliminate any movement in risk taking. While monetary policy is optimal for economic stabilization, macroprudential policy should only focus on endogenous financial risk taking, not weighting any costs against benefits. However such corner solutions are difficult to quantify for policy purposes. Therefore a reasonable middle ground has to be found. To account for the extreme sensitivity of capital regulation to financial risk taking I calibrate the macroprudential policy function's response to endogenous financial risk taking, ω_Γ, to -324, i.e. ten times that of the optimal simple rule based on credit-to-GDP gap replicating Basel III regulation[24].

Conducting the same crisis exercise with all other parameters left unchanged one can provide a policy counterfactual, what would have been the economy's evolution had macroprudential policy been responding to endogenous risk taking. The resulting IRFs are shown on Figure 10.

[23]An unconstrained optimizer fails and diverges, while a constrained optimizer chooses the lower bound.

[24]Conducting sensitivity analyses shows that results remain qualitatively similar, quantitatively less or more pronounced depending a less or more responsive macroprudential policy

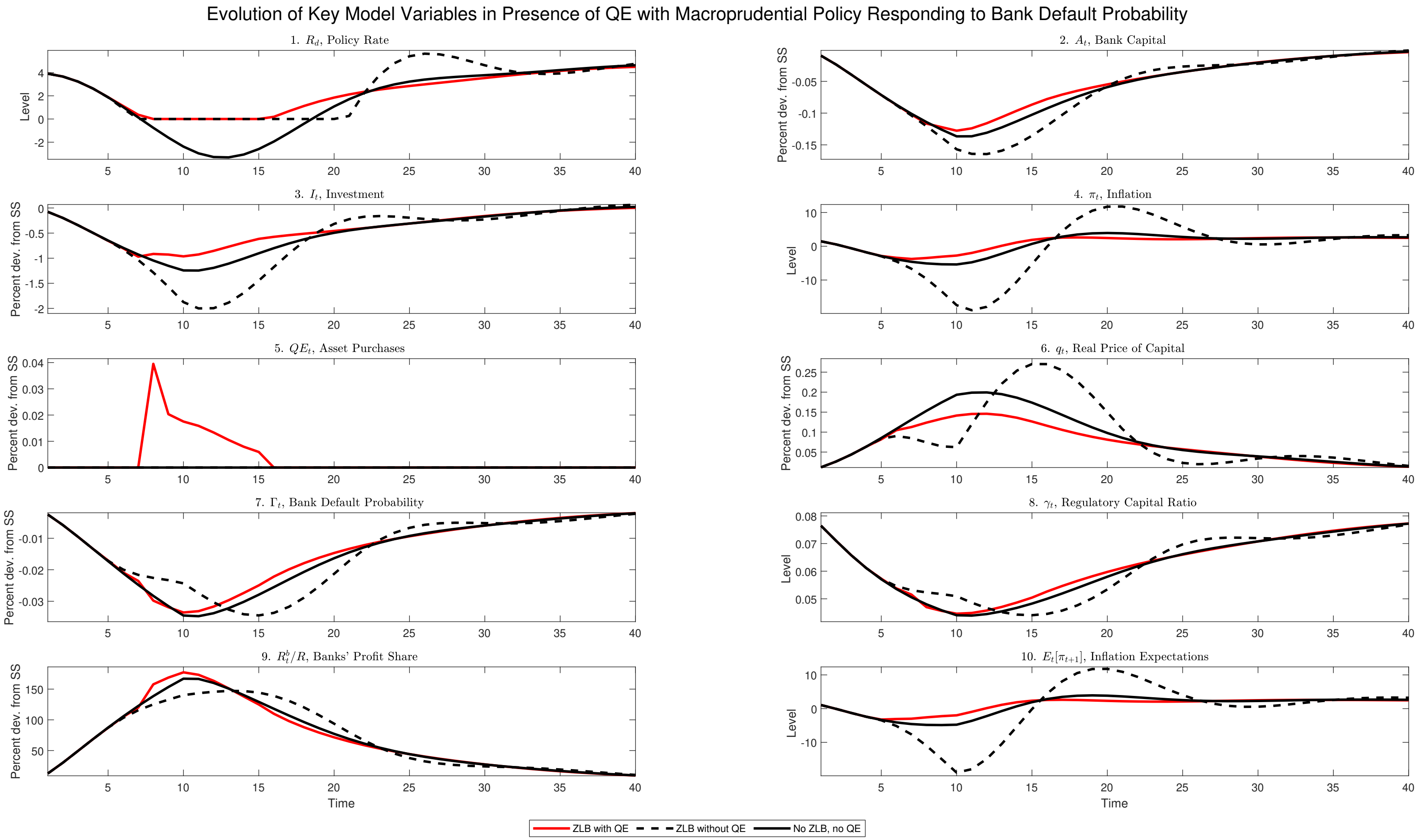


Figure 10: Zero Lower Bound versus the Unconstrained Economy when Macroprudential Policy responds to Financial Risk Taking

Focusing on capital regulation, we see that the unconstrained case follows almost the same pattern as before. As bank capital becomes scarce, banks reduce their credit provision, and in line with it they reduce the amount of financial risk they engage. Therefore it is no surprise that macroprudential policy loosens in response to bank capital scarcity. However once the ZLB is hit, the macroprudential policy stance changes. While before, there would be limited impact of the ZLB on macroprudential policy, now macroprudential policy directly responds to deteriorating outlooks at the ZLB, and correctly identifies a higher risk taking banks engage, and tightens in response. The higher capital requirements reduce the double moral hazard by forcing bankers to monitor more,in other words, in the deflationary environment macroprudential policy tightens enforcing lower risk taking. All this is visible on the IRF of regulatory capital through periods 7 to 12, where the dashed line is now above the black, and red, and it used to be aligned, and the IRF of bank default probability that does not increase at the ZLB but can decline further. The lower risk taking is a sign of lower financial frictions, and enables an improved credit allocation compared to the Basel III policy rule.

And this is aligned with the ultimate objective of macroprudential policy: financial stability. Macroprudential policy should indeed should tighten when financial risk taking increases.

This improved credit allocation is observed in depth of the deflation, where deflation in the ZLB regime instead of dropping below -20% now only hits -15.8%. Compared to Figure 9 the swings in inflation and the real price of capital are thus slightly reduced. It indicates that macroprudential policy, by changing the objective at the ZLB could have supported the smoothing of the business cycle.

Turning to the interaction of macroprudential policy with asset purchases it shows that QE will become even more effective compared to the Basel III rule. Even in presence of asset purchases macroprudential policy follows almost the same profile as under the unconstrained regime, not tightening in response to asset purchases. It is worth highlighting that not only the ZLB without QE regime benefits from changing the target of macroprudential policy, but unconventional monetary policy becomes more efficient if macroprudential policy has an alternative objective. The strongest indication is the earlier lift off from the ZLB when QE is activated. Under the credit-to-GDP driven macroprudential rule the ZLB lasts 11 periods. Changing the objective of macroprudential policy to financial risk taking shortens the ZLB to 9 periods. In line with this central bank can withdraw the asset purchase support from the economy earlier as well. The size of asset purchases on impact peak slightly higher, stabilize around the same level, but then decline earlier.

Changing the macroprudential policy objective thus has large impact on the economy and asset purchases. Changing the objective from credit-to-GDP to endogenous financial risk taking improves the efficacy and thus the business cycle stabilization of monetary and unconventional policy.

7 Policy Relevance

This model provides the first structural exploration of the interplay asset purchases and risk taking. It combines a DSGE with VaR interpretation of bank risk taking and highlights that narrative fallacies can create false policy responses.

The simulations of the model to negative bank capital shock provides evidence that bank capital scarcity will hamper endogenous risk taking in normal times. Lower risk taking implies, that projects that would have been financed otherwise, will not get founded, thus a counter-cyclical capital regulation is right in creating incentives for higher risk taking by lowering the regulatory leverage ratio. This chain of interactions changes markedly at the ZLB, where the constrained monetary policy creates deflationary pressures, and thus through the channel of real price of capital increases in incentives for banks to engage more risks.

QE by supporting asset prices, breaks this dynamics. It not only reduces endogenous risk taking through asset the signalling channel, but enables banks to recapitalize faster. A higher bank capital leading to lower credit-to-GDP gap however calls for a macroprudential tightening in response to QE. I show by simulating the asset purchases in presence of a macroprudential policy that responds to risk taking that focusing on the right objective is the key. The drawbacks of implementing a macroprudential policy that was primarily designed for normal times are apparent. Macroprudential policy that is optimal under normal times is counteracting QE at the ZLB as it hampers business cycle stabilization.

The Basel III replicating macroprudential policy tightens in response to central bank asset purchases, while a macroprudential policy focusing on the right aspect of financial stability, endogenous risk taking, supports business cycle stabilization both when large scale asset purchases are active and both when they are not. These results call for a macroprudential policy that it is state dependent, and pursues financial stability contingent the state of the economy.

These results do not state that discretionary macroprudential policy is better than rule based, however they convey an important insight. Rules that were optimal in normal times, might be harmful at the ZLB. Therefore as it was necessary to reconsider the monetary policy tool-set at the ZLB, that eventually lead to the wide employment of large scale asset purchases, it might be necessary to reconsider the rule based approach to macroprudential policies as well.

Future research avenues should explore the interaction of optimal QE with optimal state dependent macroprudential policy, and contrast it to discretionary monetary and macroprudential policies.

Being concerned about financial risk taking due to moral hazard should not hinder flexibility of policy action, as focusing on the right objective can lead to improved outcomes.

8 Conclusion

In this paper I have proposed a novel identification for the impact of unconventional monetary policy. It combines time-series econometric analysis with event studies using narrative sign restrictions to reconcile the efficacy of QE in the euro area. I highlighted the impact of identification on the results, and argued why long run sign restrictions and narrative restrictions are the set restrictions that deliver the right estimate. The long run restrictions capture the persistence needed to find time series evidence, while narrative restrictions validates event studies. I found that for a percentage point drop in the long term yield, the same horizon inflation expectations increased by 1.19 percent.

Subsequently I have developed and calibrated a medium-scale DSGE model for the euro area which features not only the relevant transmission channels of non-standard monetary policies, but captures endogenous financial risk taking and counter-cyclical macroprudential policy as well. In particular, the framework allows to separate economic risk, i.e. the default probability of investment projects, from endogenous financial risks, i.e. bank default probability. I have shown that introducing a continuous monitoring effort, one can reformulate the double moral hazard framework underlying the financial friction as a value-at-risk decision of banks. Doing so one can express the ex ante default probability of banks as a function of the monitoring intensity and real asset prices. The medium scale DSGE model presented in this paper enables to study the interaction of standard monetary and macroprudential policy. Exploring the optimal simple rule in normal times by allowing monetary policy to be the first mover and macroprudential policy the second, I recovered the standard Taylor rule coefficients and a macroprudential policy rule responding to credit-to-GDP similar to the Basel III regulation.

The model was used to examine the response of risk taking to standard technology and monetary policy shocks in normal times. The paper explored the nexus of endognous risk taking, monetary and macroprudential policy at the ZLB. I highlighted that the model should be calibrated measuring the effectiveness of unconventional monetary policy against the right counterfactual, the economy without QE but featuring the ZLB. The model was used to explore how endogenous financial risk taking evolves at the ZLB, when QE is inactive. In response to the liquidity trap asset prices drop and endogenous risk taking increases. The simulations have shown that a Basel III type optimal macroprudential policy will not respond to increased risk taking at the ZLB. The model is used to assess QE's merits in presence of endogenous risk taking and counter-cyclical bank leverage regulation.

The model successfully captures two channels of QE, the signalling and bank capital relief channels. The first is what I calibrate the model to, the second arises endogenously as banks can recapitalize faster in presence of QE, as it increases asset prices and banks take advantage of it. On the interaction of unconventional monetary policy with macroprudential policy the model delivers the observed result that macroprudential policy tightens while QE is activated. In comparison to the counterfactual the Basel III, i.e. the macroprudential policy that is optimal at normal times, tightens. Should however macroprudential policy target not the financial cycle, but bank risk taking, the economy recovers faster. The ZLB period shortens, as macroprudential policy eases compared to the no QE regime. This result highlights that a macroprudential policy objective matters for economic stabilization. An optimal macroprudential policy that leans against the financial cycle can be improved by allowing discretion at the ZLB and changing the objective to (stabilizing) bank risk taking.

The model explains why optimal counter-cyclical macroprudential policy should be reconsidered in light of unconventional policy. Simulations show that in absence of QE financial stability and excessive risk taking at the ZLB are present, and concerns of QE driven endogenous risk taking are unwarranted. Overall, QE has beneficial impact for financial stability, as it enables banks to build capital faster, it supports aggregate demand and with it pushes up asset prices creating valuation gains for banks. Banks do free ride the QE driven asset price increase as they cut back on monitoring effort, albeit the benefits outweigh the costs. QE eliminates the liquidity trap and with it the combats deflationary expectations of the true counterfactual and enables the economy to return earlier to its equilibrium.

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