Fiscal and monetary policy interactions in a low interest rate world*

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Abstract

We analyse fiscal and monetary policy interactions when interest rate policy is hampered by the zero lower bound (ZLB) in an environment where expectations are formed with perpetual learning. The ZLB induces a deterioration of economic performance and raises the risk of persistent lowflation that can disanchor inflation expectations and lead to debt-deflation. Systematic use of quantitative easing (QE) can partially substitute for interest rate easing and, if sufficiently aggressive, can maintain average inflation in line with the central bank's goal. By compressing term-premia on long-term interest rates, QE creates fiscal space that facilitates expansionary fiscal policy and reduces debt-deflation risk. The ZLB can be counteracted with less aggressive balance sheet expansions if somewhat negative policy rates are feasible, if more countercyclical fiscal policy can be activated, or if the central bank can credibly communicate a clear inflation goal. Timidity in implementing QE and excessively debt averse fiscal policies are counterproductive.

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1 Introduction

In a low interest rate environment, the zero lower bound (ZLB) hampers interest rate policy and poses a major challenge for central banks. Faced with a recessionary shock, the central bank may not be able to lower its policy rate sufficiently to support a robust economic recovery.[1] This raises the risk of episodes of sustained low inflation, subpar growth and debt deflation. Equilibrium real interest rates appear to have declined significantly over recent decades.[2] As a consequence, the ZLB will likely be frequently encountered in downturns going forward.[3]

In a low rate environment, the deployment of quantitative easing (QE) compensating for the ZLB on policy rates can no longer be seen as an unconventional measure. Since the global financial crisis, and even more so in the wake of the Covid-19 pandemic, central banks of numerous advanced economies have relied on QE to provide additional monetary policy accommodation and mitigate the ZLB. QE policies compress longer-term interest rate premia and boost asset prices. Thus, they can serve as a substitute for short-term interest rate reductions when current and expected short-term rates are constrained.

Fiscal-monetary policy interactions are more pronounced at the ZLB, drawing attention to the potential benefits from enhanced coordination of fiscal and monetary policies in a low interest rate environment. By reducing longer-term interest rates, QE policies lower the cost of financing of government debt, thus counteracting rising government debt ratios in downturns that would induce a tighter fiscal stance in response. In this manner, QE policies can enable a more accommodative fiscal stance, which in turn supports monetary policy in stabilising the economy at the ZLB.

Against this background, we develop a small model with the aim to study fiscal-monetary interactions at the ZLB. The model follows the semi-structural

[1]Notable illustrations of this challenge in environments with model-consistent expectations include Fuhrer and Madigan (1997) and Gust et al. (2017).

[2]See Holston et al. (2017), Fries et al. (2018) and Clarida (2019) for documentation of the decline in equilibrium real interest rates appear across advanced economies.

[3]Another important aspect is that permanently lower levels of interest rates imply that higher levels of public debt have become easier to sustain. The debt service of sovereigns in major advanced economies declined over the last 20 years in spite of large increases in debt to GDP ratios (Furman and Summers (2020)). At the same time, higher levels of public debt obviously scale up the impact of central bank's policies both on the interest rate bill of the government and on nominal GDP that in turn influence the dynamics of public debt. More generally, the reduction in monetary policy space through the ZLB, as well as of fiscal space as a result of high levels of public debt, may necessitate a more comprehensive, consistent, and coordinated approach to policy making (Gaspar et al., 2016).

approach to analysing robust interest rate policy of Orphanides and Williams (2007), extended to account for central bank balance sheet policies, fiscal policy and government debt dynamics. Agents rely on a perpetual learning technology to form expectations, acknowledging imperfect knowledge of the structure of the economy and the central bank's policies. This allows us to pay special attention to the concern that by complicating inflation control the ZLB may lead to episodes of persistently low inflation that risk disanchoring inflation expectations with potentially destabilising macroeconomic consequences.[4] The model focuses on the interaction of central bank balance sheet policy and public debt dynamics. Specifically, we asses how the activation of balance sheet policy affects the conduct of fiscal policy and government debt dynamics. Likewise, we analyse how the use of fiscal policy influences the conduct and the effects of balance sheet policy. In this vein, we try to capture the unintended side effects of balance sheet policies on the profitability of financial intermediation by monitoring the evolution of term premia as a measure of the returns from maturity transformation.

We analyse fiscal and monetary policy with stochastic model simulations and scenario simulations. In the stochastic simulations we feed the model with a sequence of random structural shocks to demand and supply. The scenario simulations consider a deep recession comparable to one triggered by the coronavirus that many advanced economies are currently experiencing, with unemployment rates rising sharply and persistently. Such a deep and persistent recession can also be seen as relevant to describe the dynamics that followed the GFC in the US or either the GFC or the Sovereign debt crisis in the euro area.

Our analysis yields the following main findings:

First, a low natural rate of interest implies significant constraints for monetary policy, giving rise to a frequently binding policy constraint and worse macroeconomic outcomes with persistent deviations of inflation and unemployment from their steady state levels. Fiscal policy has to intervene more aggressively to compensate for less potent monetary policy, giving rise to higher and more volatile public debt. Second, the systematic use of countercyclical balance sheet policy by the central bank can mitigate the ZLB, yielding more stable inflation and output. It also contributes to more stable fiscal deficits and public debt levels, as central bank balance sheet policies take some of the burden off fiscal policy. This comes at the cost of long spells of negative term premia, eroding profits accruing to finan-

[4] A ZLB-induced downward bias in mean inflation outcomes has been noted by Coenen et al. (2004) and Mertens and Williams (2019).

cial intermediaries from maturity transformation and potentially raising financial stability risks in the longer term. Third, debt-averse fiscal policy harms economic stability while more aggressive countercyclical fiscal policy in combination with central bank balance sheet policy can enhance it without bringing about more unstable debt trajectories. Fourth, a credible inflation goal that facilitates the formation of inflation expectations can mitigate the stabilisation costs associated with the ZLB and reduces the need for aggressive QE. However it does not fully substitute for QE, which warns against relying solely on expectations channels to stabilize the business cycle. Finally, combining moderately negative policy rates with central bank balance sheet policy also appears to improve economic stability, mainly by further containing the rise in public debt during downturns. It also limits the occurrence of negative term premia hence limiting the side effects of balance sheet policies on the profitability of maturity transformation activities.

The remainder of the paper is organised as follows. Section 2 reviews the relevant literature. Section 3 presents the structure of the model. Section 4 lays out the design of the simulation exercises, including the model calibration, the learning based expectation formation and the set up of the stochastic simulations. In Section 5, we present the setup for simulating the calibrated model. Section 6 presents results of illustrative simulation exercises considering different approaches to the conduct of monetary and fiscal policy in a low interest rate environment. Section 7 concludes.

2 Related literature

We contribute to three broad strands of literature. First, we contribute to the literature on the implications of the ZLB for the effectiveness and conduct of monetary policy. Reifschneider and Williams (2000), Orphanides and Wieland (2000), Eggertsson and Woodford (2003), Williams (2009), Kiley and Roberts (2017), Gust et al. (2017) and Andrade et al. (2018) show how the ZLB becomes a greater constraint for monetary policy when nominal rates are low. The main policy implication drawn in these studies is the need for targeting strategies that allow for a more accommodative stance of monetary policy over the business cycle, e.g. in the form of a higher inflation target or price-level targeting. In this paper, we focus instead on the role of unconventional monetary policy in alleviating the ZLB. We go beyond the implication of a low r^* and a more binding ZLB for macroeconomic stability by analysing the implications for debt stability and in particular the risk of debt-deflation. By considering expectations formation under learning as opposed to full rationality, we explore a new channel, the unanchoring of expectations, through which a low level of r* and a more binding ZLB constraint can undermine macroeconomic and debt stability.

Second, we contribute to the literature on the macroeconomic effects of unconventional monetary policy. There is a growing empirical literature on the effects of QE policies on long-term interest rates and the macroeconomy. Overall, this literature suggests that QE lowers long-term interest rates primarily through a portfolio-rebalancing channel on the term premium and has expansionary effects on output and inflation. See Borio and Zabai (2016), Carlson et al. (2020) and Bernanke (2020) for recent surveys. This evidence stands in contrast to theory from the perspective of the baseline New Keynesian model (Eggertsson and Woodford (2003), Woodford (2012) reflecting the classic Wallace neutrality result: in frictionless economies balance sheet operation of the central bank would be irrelevant for financial market and real economy outcomes as they are fully offset by investor arbitrage, as shown in the classic paper by Wallace (1981). A meaningful role for central bank asset purchases in current macroeconomic can only be engineered by introducing financial frictions which are relaxed by the central bank intervention (Gertler and Karadi (2011), Gertler and Karadi (2013)). We develop a semi-structural model where QE affects the real economy through its impact on on term premia capturing the portfolio rebalancing effect highlighted in the empirical literature.

Third, we contribute to the literature on the interaction of fiscal and monetary policy. An important strand of this literature focuses on question of regime, whether monetary dominance or fiscal dominance prevails (Sargent and Wallace (1981), Leeper (1991), Sims (1994), Cochrane (2001), Woodford (2001), Leeper and Walker (2012)). Under monetary dominance, fiscal policy ensures the stability of the public debt while the central bank focuses on price stability, while under fiscal dominance the fiscal authority does not adjust deficits to ensure debt stability which is instead ensured by the monetary policy at the expense of price stability. Another strand of literature has focused on the interactions of fiscal and monetary policy within a regime of monetary dominance where the central bank is focused on price stability. These includes studies on the role of fiscal policy to enhance macroeconomic stability (Benigno and Woodford (2004), Leith and Wren-Lewis (2005), Gali and Monacelli (2008)), including the question on the role of fiscal policy at the ZLB (Eggertsson and Woodford (2006), Christiano et al.

(2011), Coenen et al. (2013), Sims (2016)). Our analysis is also grounded on a set-up of monetary dominance, focusing on the interactions of monetary and fiscal policies and rules in a low interest rate environment. Our paper is closely related to Coenen et al. (2020) who also analyse combining balance sheet policies of the central bank and fiscal policy through simulations of the ECB New Euro Area Wide model (NAWM II). While our results are qualitatively consistent with theirs, our semi-structural model, which is simpler, focuses on the core mechanisms at play. In addition, our model's expectation formation allows for explicit deviations from model consistent rational expectations. This limits the ability of the central bank to stabilise inflation through an implausibly powerful expectation channel.

3 The model

Our starting point is the perpetual learning model of Orphanides and Williams (2007), extended to include unconventional monetary policy at the ZLB, fiscal policy and government debt dynamics. The model features long-term interest rates affecting aggregate demand. Long-term rates reflect expectations of short-term rates but are also influenced by central bank bond purchases and government debt dynamics through the term premium. The model also features fiscal policy with the primary budget deficit affecting aggregate demand and responding to unemployment through a fiscal policy reaction function. Government debt dynamics are driven by the primary deficit as well as by the dynamics of interest rates, inflation and real output growth.

3.1 Phillips Curve, IS Curve and long-term interest rates

The Phillips curve takes the standard hybrid form:

$$\pi_t = \phi_\pi \pi_{t-1} + (1 - \phi_\pi) E(\pi_{t+1}) + \alpha_\pi (u_t - u^*) + e_{\pi,t} \tag{1}$$

Inflation (π_t) depends on lagged and expected future inflation as well as on the unemployment gap, i.e. the deviation of the unemployment rate from its steady state level ($u_t - u^*$). $e_{\pi,t}$ is an i.i.d. supply shock.

The IS curve is also in standard hybrid form, but features long-term interest rates instead of short-term ones:

$$u_t = \phi_u u_{t-1} + (1-\phi_u)E(u_{t+1}) + \alpha_u(r^l_t - r^{l*}) + \alpha_f(pb_t - pb^*) + e_{u,t} \qquad (2)$$

The unemployment rate is a function of its own lag and its expected future value. It depends negatively on the deviation of the long-term real interest rate r^l_t from its equilibrium level r^{l*} and positively on the deviation of the primary fiscal balance ratio to GDP pb_t as determined by the fiscal policy reaction function specified below from its equilibrium debt-stabilising level pb^*. $e_{u,t}$ is an i.i.d. demand shock.

From the IS curve we can back out real GDP growth based on Okun's law:

$$g_t = g^* - \alpha_{OL}(u_t - u_{t-1}) \qquad (3)$$

where g^* is steady state real GDP growth.

Long-term interest rates are determined by a standard term structure equation. They reflect the expected future path of short-term rates and the term premium. The nominal short-term rate i_t pins down the real short-term rate $r^s_t = i_t - E(\pi_{t+1})$ and hence the real and nominal (L-period ahead) long-term rate as the average real (nominal) short-term rates plus the term premium τ_t:

$$r^l_t = E\left(\frac{1}{L}\sum_{j=0}^{L} r^s_j\right) + \tau_t, \quad i^l_t = E\left(\frac{1}{L}\sum_{j=0}^{L} i_j\right) + \tau_t \qquad (4)$$

The equilibrium level of the long-term real interest rate is given by the natural rate of interest plus the equilibrium level of the term premium: $r^{l*} = r^* + \tau^*$.

To capture the role of quantitative easing on longer-term interest rates, we follow Li and Wei (2013) and posit that the term premium is a positive function of the amount of public debt in private hands:

$$\tau_t = \tau^* + \alpha_\tau\left(\frac{b_t}{d_{t-1}} - \frac{b^*}{d^*}\right) \qquad (5)$$

where b_t are the period t announced public debt holdings by the central bank and d_{t-1} is the outstanding stock of public debt in period $t-1$ that is only observed in period t. d^* and b^* are respectively the steady state level of the government debt and of the central bank government bond holdings (as a ratio to GDP).[5]

[5] This approach is a stylized representation of a rich literature that allows for imperfect

Central bank bond holdings and government debt both affect the term premium through the net supply of bonds to the public. Importantly, central bank bond purchases can remain effective even if the long-term bond yield has reached its zero lower bound by absorbing government bond issuance arising from fiscal expansion.[6] Moreover, in line with term structure models referred to above, b_t should be thought of as reflecting the announced bond purchases of the central bank affecting financial markets immediately through a stock effect. For this reason we allow central bank purchases to affect the term premium immediately, while we assume that the effect of a change in public debt occurs with a lag when it is observed.

The QE reaction function is in terms of the announced stock of bond holdings rather than the flow of bond purchases. We therefore assume that changes to the stance of central bank balance sheet policy take effect immediately rather than through a sequence of purchases spread over various quarters. That way we aim to capture the stock effect of balance sheet policies that operates through the total expected amount of asset purchase programmes.

3.2 Monetary policy, fiscal policy and public debt

Conventional monetary policy is implemented through the short-term nominal interest rate. We assume that the central bank sets nominal short-term rates based on an inertial Taylor rule. There is a zero lower bound preventing the policy rate to take on negative values. The ZLB is captured by defining the policy rate as the maximum of the Taylor rule rate i_t^T, and zero:

$$i_t = max[i_t^T, 0] \tag{6}$$

substitutability of assets with different duration, cf. Modigliani and Sutch (1967), Tobin (1969), Andrés et al. (2004) and Vayanos and Vila (2021). In recent years, this modelling approach has been incorporated in models employed for policy analysis by various central banks, cf. D'Amico et al. (2012), Ihrig et al. (2018), Sudo and Tanaka (2018), Rostagno et al. (2019) and Kawamoto et al. (2021).

[6] This is particularly relevant in the context of the Covid-19 recession where the expansion of fiscal support by advance economies led to sharp increases in the net debt issuance by sovereigns. In 2020, the Federal Reserve, the ECB and the Bank of Japan purchased public debt in quantities of above 50 percent of the net debt issuance by the US, euro area and Japanese treasuries, respectively. Such purchases push down term premia and reduce the effective interest rate service of this newly issued public debt.

The Taylor rule rate is given by:

$$i_t^T = \theta_i i_{t-1} + (1 - \theta_i)[r^* + \pi^* + \theta_\pi(\pi_{t-1} - \pi^*) + \theta_u(u_{t-1} - u^*)] \tag{7}$$

The Taylor rate responds to deviations of inflation from target and of the unemployment rate from its steady state level. There is interest rate smoothing, captured by the autoregressive term i_{t-1}. In steady state, the nominal interest rate is given by the sum of the natural rate r^* and the inflation target π^*.

Unconventional monetary policy takes the form of a quantitative easing (QE) rule for the announced stock of central bank government bond holdings as a ratio to GDP (b_t):

$$b_t = \begin{cases} \zeta_b b_{t-1} + (1 - \zeta_b) b^* + \zeta_c cc_t & \text{if } i_t = 0 \\ \zeta_b b_{t-1} + (1 - \zeta_b) b^* & \text{otherwise} \end{cases} \tag{8}$$

The QE rule assumes that a countercyclical QE response $\zeta_c cc_t$ is activated when the policy rate is constrained by the ZLB, i.e. if i_t^T is below or equal to zero. For simplicity we maintain the same form of countercyclical policy response in QE policy as in interest rate policy. Specifically, we set the countercyclical term equal to the countercyclical component of the Taylor rule above:

$$cc_t = \theta_\pi(\pi_{t-1} - \pi^*) + \theta_u(u_{t-1} - u^*) \tag{9}$$

The parameter ζ_c then determines the intensity of the countercyclical QE response.

The QE rule is further assumed to be inertial, in line with the inertia in QE policies observed in reality, with the parameter ζ_b determining the degree of inertia. If conventional monetary policy is not constrained by the ZLB, the central bank is assumed to let announced bond holdings slowly run down without responding to economic conditions. b^* represents the steady state holdings of government bonds by the central bank. Note that since GDP is observed by the central bank only with a lag, the ratio b_t should be thought of as referring to the GDP forecast based on previous period's level and growth rate of GDP.

The fiscal policy rule is expressed in terms of the primary balance as a ratio of GDP (pb_t) and is given by:

$$pb_t = \rho_{pb} pb_{t-1} + (1 - \rho_{pb}) pb^* + \psi(u_{t-1} - u^*) + \delta(d_{t-1} - d^*) \tag{10}$$

Following Bohn (1998) we assume that fiscal policy aims to stabilise both the business cycle and the public debt. Specifically, the primary balance decreases when unemployment rises above its steady state level as the government provides fiscal stimulus. At the same time, the primary balance increases when debt is above its steady state level, reflecting debt stabilisation motives. Moreover, we assume that the fiscal reaction function, like the conventional and unconventional monetary policy reaction functions, is inertial so that today's deficit also depends on its previous period's level. pb^* is the steady state primary deficit ratio. Note also here that since GDP is observed by the fiscal authority only with a lag, the ratio pb_t refers to the GDP forecast based on previous period's level and growth rate of GDP. This means that we need to back out the realised primary balance based on realised GDP growth for the government debt accounting.

The dynamics of the public debt-to-GDP ratio are given by the standard recursive debt-accumulation equation:

$$d_t = \frac{100 + i_t^d}{100 + g_t + \pi_t} d_{t-1} - pb_t^r \tag{11}$$

i_t^d is the debt service cost of the government which we assume to be linked to the long-term yield through an empirical partial adjustment equation: $i_t^d = \rho_{pb} i_{t-1}^d + \lambda i_t^l$. pb_t^r which is equal to the announced primary balance adjusted for the government's forecast error in nominal GDP: $pb_t^r = \frac{100+g_{t-1}+\pi_{t-1}}{100+g_t+\pi_t} pb_t$.

The debt-stabilising steady state primary balance ratio is given by $pb^* = (r^* + \tau^* - g^*)d^*$

3.3 Model calibration

The calibration of the model parameters is informed by the previous literature and empirical evidence. In the simulation analysis we consider different calibrations of the policy rules and of the structural parameters for policy comparisons and robustness checks. These alternative calibrations are presented and discussed below in the respective context. In the following, we provide the motivation for our choices for the baseline calibration.

The steady-state variables are fixed at $r^* = 0.5$, $u^* = 4$, $\pi^* = 2$, $g^* = 1.5$ and $\tau^* = 1$. We further set $d^* = 100$ and $b^* = 10$, implying steady state levels of government debt and of the central bank balance sheet of 100% of GDP and 10% of GDP, respectively. The implied steady state level of the primary balance ratio is $pb^* = 0$.

We calibrate the backward-lookingness of the Phillips and IS Curves to $\phi_\pi = \phi_u = 0.5$ in line with Orphanides and Williams (2007). The slope of the Phillips Curve is set at $\alpha_\pi = 0.1$, in line with recent evidence of a flattening.[7] The elasticity of the unemployment rate to the long-term real interest rate in the IS curve is calibrated as $\alpha_u = 0.2$, reflecting the fact that this is the elasticity to the long-term interest rate as opposed to the short-term rates.[8]

We set the fiscal deficit impact multiplier at $\alpha_f = -0.15$ which corresponds to a dynamic peak output multiplier of 0.4 in our model. This is in line with the empirical literature, taking into account that we are looking at the multiplier of the primary deficit which reflects the average of spending, tax and transfer multipliers. [9]

We assume that the average maturity of government debt is 5-years, which is roughly in line with average maturities of marketable debt across major advanced economies. The long-term interest rate in our model is therefore a 5-year bond yield so that $L = 20$. In the term premium equation, α_τ is calibrated to -0.05. This implies that central bank bond purchases of the scale of 1% of GDP reduce, for a given level of government debt, the term premium by 5bps, in line with the empirical estimates of term structure models in Li and Wei (2013). Empirical estimates of the impact of QE measures implemented in the wake of the GFC sometimes suggest a smaller effect,[10] so we also consider smaller values of α_τ in the robustness checks.

[7]For recent surveys on this question, see Hooper et al. (2019) and McLeay and Tenreyro (2020).

[8]This calibration is based on the following consideration. The estimated interest rate elasticity of the unemployment rate with respect to the short rate is around 0.04 according to Orphanides and Williams (2007). The impact of a 100 bps shock to the policy rate on the 5-year bond yield is about 20 bps in our model under the baseline calibration. This in turn implies an elasticity of the unemployment rate to the long rate which is about five times larger than that to the short-rate, i.e 0.2. Put differently, by calibrating the IS curve slope to 0.2 in our model we can reproduce an impact of a 100 bps change in the short rate on the unemployment rate of 0.04, consistent with the estimates of Orphanides and Williams (2007)

[9]See Gechert and Rannenberg (2018) for a recent survey and meta analysis of the literature on fiscal multipliers.

[10]For instance, the term structure estimates reported in Li and Wei (2013) suggest that a 1% of GDP increase in central bank holdings of the outstanding government bond in the wake of the post-GFC QE measures reduced 10-year Treasury yields by 7 bps, compared to 10 bps in Li and Wei (2013). The Koijen et al. (2017) estimates for the euro area are around 4 bps. The ECB quantitative easing conducted between March 2015 and December 2017, that added up to about 15 percent of GDP, led to a 65 basis points decline in government bond yields on average with a larger effect, however, at the periphery of the euro zone. For a survey of the empirical evidence on the impact of QE measures on long-term interest rates, see Bernanke (2020) and Rostagno et al. (2019).

We calibrate the parameters in the Taylor rule at $\theta_i = 0.85$, $\theta_\pi = 1.5$ and $\theta_u = -2$. This is the standard inertial version of the Taylor (1999) rule with a long-run response to deviation of inflation from target of 1.5 and to the output gap of 1. We map the output gap to the unemployment gap setting Okun's law coefficient $\alpha_{OL} = 2$ following Orphanides and Williams (2007) and in line with recent cross-country evidence reported in Ball et al. (2017).

For the QE reaction function, there is little guidance from the existing literature. The main parameter of relevance is the countercyclical response parameter ζ_c. We consider a range of of possible values between 0.5 and 3 to document the sensitivity of our results to the choice of this key parameter. This range for ζ_b implies a range of QE reaction coefficients of 0.75 to 4.5 for the inflation gap and of 1 to 6 for the unemployment gap. As a baseline calibration, we choose $\zeta_c = 1.0$, implying a response of 3 to the inflation gap and of 4 for the unemployment gap, which goes a long way towards stabilising the economy without excessive usage of the QE tool. The parameter ζ_b which determines the speed at which bond holdings run off the balance sheet is calibrated to 0.85. This implies a half-life of the balance sheet of about one year, in line with the high degree of inertia in QE policies observed in reality.[11]

In the fiscal rule, we set $\rho_{pb} = 0.7$, $\psi = -0.25$ and $\delta = 0.025$. This calibration is in line with the empirical literature on linear fiscal policy reaction functions (Bohn (1998), Taylor (2000), Everaert and Jansen (2018)).[12] In the simulation exercises, we also consider more countercyclical fiscal rules (larger ψ and more debt-averse fiscal rules (larger δ).

Finally, we calibrate the partial adjustment of the government interest expenses to long-term bond yields as $\rho_{pb} = 0.$ and $\lambda = 0.3$. This calibration is in line with the empirical association between effective government interest expenses and 5-year benchmark bond yields in the United States and implies a long-run pass-through of bond yields to interest expenses of 1, which further implies that i_t^d and i_t^l are

[11]By implication, under such a high degree of persistence the central bank will not have to sell bonds to bring about balance sheet normalisation. Return of the balance sheet to steady state is instead brought about by maturing bonds passively running off the balance sheet. This assumption is also in line with the way central banks have approached QE policy normalisation in practice.

[12]Some studies provide evidence suggesting that fiscal rules, in particular the reaction to debt, might be non-linear with the reaction decreasing in the level of debt reflecting "fiscal fatigue" (Ghosh et al. (2013), Everaert and Jansen (2018)) and might vary over time due to changes in borrowing costs, growth and inflation (Mauro et al., 2015). As the focus of this study is on the interaction of monetary policy, in particular QE, and fiscal policy and debt dynamics, we leave the exploration of such non-linearities to future research and focus on linear specification of the fiscal rule.

equal in steady state.

4 Expectations: Perpetual learning

We depart from the traditional rational expectations assumption where agents know every detail of the true model and assume instead that real world private agents form expectations using an estimated forecasting model. Specifically, following Orphanides and Williams (2007), we posit that private agents engage in perpetual learning, that is they re-estimate their respective models using a constant-gain least squares algorithm that weighs recent data more heavily than past data. In this way, these estimates allow for the possible presence of time variation in the economy, including in the natural rates of interest and unemployment (though, for simplicity, these are assumed to be fixed in our illustrations). Given the structure of the model with the presence of the five year real interest rate in the IS curve, private agents need to forecast inflation, the unemployment rate, and the policy rate for up to 20 quarters into the future.

We formalise the learning through a VAR representation of the model. The predictable components of inflation, the unemployment rate, and the interest rate in the model each depend on a constant and one lag each of the inflation rate, the interest rate and the unemployment rate. We assume that agents construct multi-period forecasts from the estimated VAR. Specifically, the expected long-term real rate is actually produced through L-periods ahead forecasts of short-term rates and inflation in the VAR, to preserve the no-arbitrage link between short- and long-term rates.

To fix notation, let Y_t denote the 1 x 3 vector consisting of the inflation rate, the unemployment rate, and the interest rate, each measured at time t: $Y_t = (\pi_t, u_t, i_t)$. Let X_t be the 4 x 1 vector of regressors in the forecasting model: $X_t = (1, \pi_{t-1}, u_{t-1}, i_{t-1})$. Finally, let c_t be the 4 x 3 vector of coefficients of the forecasting model. Using data through period t, the least squares regression parameters for the forecasting model can be written in recursive form:

$$c_t = c_{t-1} + \kappa_t R_t^{-1} X_t (Y_t - X_t' c_{t-1}), \tag{12}$$

$$R_t = R_{t-1} + \kappa_t (X_t X_t' - R_{t-1}) \tag{13}$$

where κ_t is the gain parameter. Under the assumption of least squares learning with infinite memory, $\kappa_t = 1/t$. To formalise perpetual learning we replace the decreasing gain implied by the infinite memory recursion with a small constant gain, $\kappa > 0$.

To calibrate the relevant range for $\kappa > 0$ we follow Orphanides and Williams (2007) who examined how well different values of κ fit the expectations data for inflation ,the unemployment rate and federal funds rate the from the Survey of Professional Forecasts (SPF). They find that VAR based forecasts discounting past data with discount factors corresponding to κ in the range 0.01–0.04 yielded forecasts closer on average to the SPF than the forecasts obtained with lower or higher values. Evidence from micro data from the Reuters/Michigan survey of consumers (Malmendier and Nagel, 2015) and from DSGE model estimation (Milani, 2007) yield similar results, suggesting a value of κ of 0.02. Against this background, we choose $\kappa = 0.02$ as the baseline calibration of the gain parameter.

5 Simulation setup

5.1 Stochastic simulations

We use the model to perform a number of illustrative simulations. We simulate the model under a random sequence of demand shocks $e_{u,t}$ and supply shocks $e_{\pi,t}$, while setting all policy shocks to zero. The standard deviations of the demand and supply shocks are respectively set as $\sigma_{e_{u,t}} = 0.4$ and $\sigma_{e_{\pi,t}} = 0.8$.[13] In the simulation exercise we generate time series of length 500 (125 yeas) from the equations of the model and repeat the simulation 500 times (we then end up with 500 replications of time series of size 500 observations each).

The learning mechanism uses as starting values a VAR of the unemployment rate, inflation rate, and the short-term nominal interest rate, extracted from the reduced-form VAR representation of the model under model-consistent expectations and abstracting from the ZLB.[14] By doing so, we equip our agents with the

[13] These standard deviations obtain when calibrating empirical IS and Phillips curves as in Orphanides and Williams (2007) over the last 20 years using the break-even 5-year yield as a measure of the ex-ante 5-year real rate.

[14] More specifically, we solve the linear version of the model (without the ZLB) in Dynare and extract the equations for inflation, the unemployment rate and the short-term nominal interest rate from the reduced-form VAR representation of the RE equilibrium. This 3-variable VAR can be thought of as a smaller scale version of the reduced-form VAR representation of the model under model-constistent expectations.

knowledge of the model-consistent forecasting equations (absent the ZLB), but allow learning about the VAR parameters based on observed simulated outcomes. The coefficients of the 3-variable VAR are indeed updated according to the mechanism outlined in section 4, and the model is then consistently used to generate expectations of inflation, the unemployment rate and the interest rate that feed into our model. We discard the first 100 observations as burn-in period. The results we report are thus based on 500 samples of length 400 (100 years).

The ZLB together with private agents' learning process injects a nonlinear structure into the model that may generate explosive behavior in a stochastic simulation of sufficient length for some policy rules that would do a good job of stabilising the economy under RE. One possible cause of such explosive behavior is that the forecasting model itself may become explosive. We take the view that in practice private forecasters reject explosive models. We implement this by imposing mildly stabilising bounds on the forecasts. Specifically, we impose the restriction that if the VAR-based forecast path of the inflation rate or the unemployment rate exceeds in absolute value six times the empirical standard deviation of the respective variable, then the forecast path is instead taken from an AR model.[15] As this constraint on the forecasting model is not always sufficient to rule out explosive behavior, we further impose, following Orphanides and Williams (2007), the same bounds on the simulated levels of inflation and unemployment that we impose on the forecasts. Overall, these constraints on the model are sufficient to avoid explosive behavior and are very infrequently invoked.[16]

5.2 Recession scenario

In order to assess the issues from a different, complementary perspective, we also use the model to conduct a number of illustrative scenario analyses. Specifically, we simulate a severe recession, comparable to the coronavirus recession, under different assumptions about the ZLB and about the conduct of QE and fiscal policy. The scenario analysis is designed as a controlled sequence of shocks to the IS curve (instead of the random shocks used in the simulations). It is also based on simulated trajectories, each one starting from the last simulated value in the

[15]Following Orphanides and Williams (2007) we also require stationarity of the forecasting VAR. Specifically, the forecasting VAR or AR is not updated if its maximum root is above the critical value of 0.99, which occurs extremely rarely.

[16]The bounds are hit in less than 0.01% of the simulation periods. The only exception is the model with a ZLB and without QE which displays more instability, with the bounds being hit in less than 1% of the simulation periods.

simulation exercise. By doing so, the starting point of the IRFs can be thought of as drawn randomly from the steady-state distribution of the model. Importantly, this also includes agents' expectations based on what they learned during the simulation exercise, including the risk that persistent deviations inflation from the central bank's goal may disanchor inflation expectations.

The "severe recession" is implemented as a shock of size 4 to the IS curve, that is, an increase in the unemployment rate of 4 percentage points (bringing the unemployment rate to 8%). The shock is further assumed to be highly persistent, with an autoregressive coefficient of 0.9.

6 Some simulation results

In the following, we report simulation means and standard deviations of the key model variables as summary statistics of the outcomes for several illustrative simulation exercises. Specifically, in each simulation we compute the first two moments of the unemployment rate, the inflation rate, the level of government debt, the primary deficit and of the scale of QE. We also compute how many times the ZLB is binding for the short-term nominal interest rate and how often the term premium has been negative as a rough gauge of the cost of implementing QE policy.

6.1 Learning, the ZLB and low r^*

We first assess the role of learning, the ZLB and the level of r^* in our simulations. To this end, we first simulate the model with the baseline calibration but inactive QE policy. We then consider deviations from the baseline calibration to illustrate the role of learning-based expectations formation, the presence of the ZLB and the level of r^*.

The starting point of our experiments consists in simulating the model without learning. This means consistently using the 3-variable VAR based on model-consistent forecasting equations described in section 5.1 throughout the entire simulation, without updating the VAR parameters. To illustrate the functioning of the learning mechanism, we then compare these results with those obtained by letting agents depart from the RE representation by learning from the actual observations produced by the model. To illustrate the role of the ZLB in the simulation outcomes, we consider the case where no ZLB constraint is present, allowing policy rates to fall into negative territory without bound if indicated by the interest rate reaction function. We further simulate the model for a higher level of r^*, 2% as opposed to 0.5% under our baseline calibration, in order to demonstrate the role of a lower level of equilibrium real interest rates for the relevance of the ZLB constraint in the economy.

The results reported in Table 1 show that there are significant biases in the key outcome variables under the baseline calibration, reflecting the large number of periods with a binding ZLB constraint (16%). Specifically, there is an upward bias in the unemployment rate (0.52 percentage points) and a downward bias in the inflation rate (−0.36 percentage points). At the same time, there are upward biases in the debt ratio (almost 10 percentage points) and in the primary fiscal balance (0.36 percentage points).

These biases are the consequence of the combination of learning-based expectations, the ZLB and a low level of r^*, as shown in the results obtained when simulating the model under the alternative calibrations. In the case without learning, outcomes are unbiased on average and standard deviations are much lower, reflecting greater stability of the economy. Similar results are obtained when removing the ZLB constraint and when raising the level of r^* in the simulations.[17] This confirms the notion that a lower level of r^* considerably compounds the constraints posed by the ZLB under a conventional calibration of the expectations formation mechanism and of the volatilities of supply and demand shocks hitting the economy.

The deviations from steady state in Table 1 in the presence of the ZLB constraint reflect a significant risk of debt deflation, i.e the combination of rising debt and deflation. Figure 1 shows for each simulation the combination of the average public debt (over GDP) and inflation level, revealing that under baseline learning with ZLB there is a large number of simulations that usher in such debt-deflation outcomes. These instances are not present in the simulations without learning, without ZLB and with a higher level of r^*.

How the ZLB limits the stabilising capacity of monetary policy under realistic assumption about expectations formation (i.e. learning) and currently prevailing low levels of r^* becomes also visible in the recession scenario. To this end, we simulate the model once with a binding ZLB and once without, allowing policy rates to fall deep into negative territory. As Figure 2 shows, without a ZLB, nominal policy rates would be cut to up to -6% in a recession of the depth we

[17]Note that the primary fiscal balance averages around 1.5% in this simulation, reflecting the higher level of pb^* under a steady state real interest rate of 2%.

consider. The shortfall in monetary stimulus is clearly visible in the trajectories of unemployment and in particular inflation, which rise/fall more strongly and recover considerably more slowly when the ZLB is binding. In particular, public debt increases much more in the wake of the recession, rising up to 40 percentage points above baseline under a binding ZLB constraint compared to 20 percentage points without the ZLB. The stronger rise in public debt reflects the combination of higher interest rates, a weaker economy and initially also higher deficits.

The simulations also illustrate how the debt dynamics feed back into the real economy. When the public debt ratio rises to a high level as a result of adverse macroeconomic developments and interest rates constrained by the ZLB, the fiscal reaction function requires fiscal authorities at some point to run large primary fiscal surpluses in order to bring public debt back under control. This happens in the recession scenario simulations after about three years (12 periods). This fiscal tightening slows down the economic recovery, which in turn feeds back adversely into the dynamics of the public debt ratio. The ZLB constraint therefore gives rise to a mutually reinforcing adverse feedback loop between economic conditions, debt and fiscal policy. Economic slumps push up the debt inducing a fiscal tightening which in turn reinforces or prolongs the economic slump.

6.2 The role of QE

We next assess the stabilising role of QE policy. To this end, we simulate the baseline model where ZLB may bind and the central bank can resort to a QE policy and compare the outcome with that of the model considered above where there is no QE. In doing so we consider different levels of intensity of QE by considering different calibrations of the parameter ζ_c which determines the countercyclical element of the QE rule. Specifically, we consider three calibrations, corresponding to a relatively timid QE rule ($\zeta_c = 0.5$), a baseline QE rule ($\zeta_c = 1.0$) and a relatively aggressive QE rule ($\zeta_c = 2.0$). The results reported in Table 2 show that the activation of QE has highly stabilising effects. The biases in the unemployment rate, the inflation rate and also in public debt and in the primary fiscal surplus are significantly reduced already for a timid QE rule. For the baseline QE rule the biases are nearly eliminated, while they fully disappear for the aggressive QE rule. Activation of QE policy also significantly reduces the standard deviations of the model variables, in particular of the public debt.

At the same time, reflecting the additional degree of freedom for monetary policy provided by the QE tool and the associated greater macroeconomic stability, the ZLB is on average less often binding. The number of times policy rates hit zero is around 6% under the baseline QE rule, compared to 16% when QE is never activated. However, these benefits of an active use of balance sheet policy by the central bank do not come free of charge. The last column of Table 2 shows that in about 3% of the simulation periods, term premia are compressed to negative levels as a consequence of QE policy. This implies pressure on financial intermediaries whose profits accrue from maturity transformation which could give rise to financial stability risks not captured in our model.[18]

Figure 3 further shows that QE largely eliminates debt-deflation risks which loom large when QE is not activated. The charts show that already the timid QE reduces this risk dramatically. The baseline and the aggressive QE policies yield very few simulations that feature above debt ratios above steady state and deflation.

In order to flesh out the stabilising role of QE policy in a recession scenario, we compare the model dynamics under the timid and baseline QE policy as well as under the no QE case. The results reported in Figure 4 show that QE significantly benefits macroeconomic stability in a deep recession. The unemployment rate and the inflation rate recover much faster when QE is activated compared to a situation where the central bank does not deploy QE. The charts further reveal that bond purchases also provide relief for fiscal policy. In particular, the activation of QE considerably flattens the trajectory of the public debt, mitigating its rise by lowering interest rates and containing the economic slump. As monetary policy now takes on a greater role in stabilising the economy and also helps stabilise the debt, fiscal policy can afford to take a more accommodative stance, reflected in lower fiscal surpluses in the late phase of the recovery. QE policy hence benefits in particular public debt stability without explicitly aiming to do so. This in turn benefits economic stability as it enables fiscal policy to take a more accommodative stance in the recovery.

6.3 Fiscal rules

We next explore how different fiscal rules affect economic performance in the face of a low r^* and the ZLB constraint. First, we consider the case of a more debt

[18]See for instance Borio et al. (2017) who report estimates showing that steeper yield curve increase bank's profits.

averse fiscal authority that aims to bring debt back to its steady state or target level in a faster way than assumed under our baseline calibration. Specifically, we assume a fiscal rule that responds more strongly to the deviation of debt from its steady state level by setting $\delta = 0.075$ which is three times the level under the baseline calibration. The simulation results, reported in Table 3 show that such a policy has detrimental economic consequences. The ZLB is twice as often binding (13%), requiring more active QE policy as reflected in a much larger level of announced bond holdings (on average 17%) and resulting a much higher number of periods with negative term premium (10%). Still, average unemployment rates are higher and inflation rates lower than under the baseline fiscal rule. The debt-averse fiscal policy does not even lower the level of public debt, which is slightly higher than under the baseline fiscal rule.

Second, we consider more countercyclical fiscal rule, tripling the fiscal response to the unemployment rate to 0.75. The stochastic simulation results suggest that a fiscal policy that is more countercyclical in an indiscriminate fashion does not improve outcomes compared to the benchmark fiscal rule. The biases in the unemployment rate and the inflation rate are the same. Only public debt averages slightly higher and so does QE reflecting somewhat greater need to use QE in order to counteract adverse feedback effect from higher debt on the economy under such a fiscal rule.

Third, we consider a fiscal policy rule that provides extra fiscal stimulus only when policy rates are stuck at the ZLB. The extra-accommodative fiscal rule takes the following form:

$$pb_t = \rho_{pb} pb_{t-1} + (1 - \rho_{pb}) pb^* + \psi(u_{t-1} - u^*) + \delta(d_{t-1} - d^*) - \Psi_{ZLB} + \epsilon_{pb,t} \quad (14)$$

The additional term Ψ_{ZLB} means that fiscal policy provides additional accommodation proportional to the extent to which policy rates are constrained by the ZLB, captured by the deviation between actual policy rates and the target policy rate according to the Taylor rule. In the simulations, we set $\Psi_{ZLB} = 1.0$, implying that at the ZLB, the fiscal authority increases the primary deficit by 1 percentage point of GDP.

The simulation results suggest that such extra accommodative fiscal policy at the ZLB can be beneficial. It marginally reduces the biases in the unemployment rate and the inflation rate. In particular, it reduces the instances of the ZLB by about a third and lowers average scale of the QE intervention as well as the number of periods with a negative term premium to a mere 1%. This reflects the reduced burden on both conventional and unconventional QE policy in stabilising the economy when such a fiscal rule providing additional stimulus only at the ZLB is in place.

The role of fiscal rules also shows clearly in the recession scenarios. Figure 5 shows the recession scenario simulations for the baseline fiscal rules, the debt avers fiscal rule and the fiscal rule providing extra stimulus at the ZLB. The simulation results show that such a debt-avers fiscal rule policy is counter-productive also in a recession scenario. The consequence is less fiscal accommodation, reflected much smaller fiscal deficits, translating into higher unemployment and much lower inflation compared to baseline. At the same time, the public debt trajectory is not very different from that under the baseline fiscal rule, reflecting the self-defeating nature of such a policy. The scale of the QE intervention is considerably larger and the long-term nominal rate is stuck at the ZLB for almost four years, reflecting the greater burden on monetary policy that arises from a fiscal rule that puts a relatively higher weight on debt stability as opposed to economic stability.

By contrast the fiscal rule providing extra accommodation when policy rates are stuck at the ZLB is associated with a faster recovery in a severe recession scenario. Unemployment and inflation rates return faster to baseline than under the baseline calibration. Also nominal long-term rates lift off sooner while the central bank has to deploy QE in smaller does, reflecting the reduced burden on monetary policy under such a fiscal rule discussed before.

6.4 Negative interest rates

We next consider the possibility of breaking through the ZLB and lower policy rates to moderately negative levels in case of need, as many central banks have done over the past years. Specifically, we consider the case where policy rates are not constrained by the ZLB but by an ELB of -0.5% or -1%. Depending on the structure of the financial system, negative interest rates may have adverse effects that have made a number of central banks reluctant to adopt them. Our model does not capture these side effects. The aim of our experiment below is simply to illustrate the possible relative improvement in macroecononomic performance if somewhat negative rates are feasible and potential side effects are deemed to be small.

Simulating the model under negative ELBs and keeping all else at baseline suggests that negative rates can help to improve macroeconomic and debt stability in a low interest rate environment (Table 4). Considering first negative rates with QE, we find that a negative ELB helps reduce the adverse bias in economic and debt dynamics arising from the ZLB in a way similar to the introduction of QE. While there are still significant biases for a moderately negative ELB of -0.5%, the biases are largely eliminated for an ELB of -1%. Considering the combination of negative rates and QE, we find that combining a moderately negative ELB of -0.5% with QE can bring the economy back to steady state on average over the simulations. Further lowering the ELB to -1% does however not appear to bring additional benefits.

6.5 A credible π^*

An important reason why the ZLB leads to a deterioration of economic outcomes is that when the central bank is unable to provide sufficient accommodation to counteract deflationary shocks, persistent downward misses of inflation from the central bank's goal will be observed by economic agents. In a learning environment, these misses will lead to inflation expectations being disanchored to the downside, raising the real-long-term interest rate even more than what the ZLB would imply, if expectations remained better anchored.

By activating QE and mitigating the downward bias on inflation, the central bank is better able to keep inflation expectations well anchored. To illustrate the importance of this mechanism, in this section we consider the benefits of a fully credible long-term inflation goal. To this end, we amend the learning algorithm, imposing an anchoring of long-run inflation expectations at π^*=2% while allowing the learning algorithm to continue to rely on past data for tracking other parameters of their forecasting model.[19]

The simulation results suggest that such a credible π^* can enhance macroeconomic stability, resulting in a further reduction in the biases in unemployment and inflation (Table 5). The instances of the ZLB are halved and so is the intensity of QE required to stabilise the economy (down from 12% to 11%) which also reduces the occurrence of negative term premia to just 1%. The simulations also reveal that a fully credible π^*=2% is not sufficient to serve as substitute for QE. Without the use of QE as a monetary policy tool, significant adverse biases in economic

[19] This can be considered as a theoretical best case associated with the announcement of an explicit symmetric 2% inflation goal by an Inflation Targeting central bank (Orphanides and Williams (2004)).

outcomes remain even when long-run inflation expectations are anchored at the level of the inflation target.

Figure 6 compares the baseline recession scenario simulation with the case of a credible inflation goal. In the baseline, without a credible goal, long-term inflation expectations become somewhat disanchored, implying higher real-interest rates and less accommodative interest rate policy which necessitates a more aggressive expansion of the balance sheet. With a credible inflation goal, even with less QE, economic outcomes are better and the debt ratio is lower in the aftermath of the recession.

6.6 Central bank profits

From a consolidated public sector balance sheet perspective, the central bank QE policy implies swapping long-term government debt for reserves. The central bank buys government debt earning the yield on that debt i_t^d and pays the short-term rates i_t on reserves. This opens another channel for fiscal-monetary interactions when the central bank uses QE as a policy tool.

In order to assess the relevance of this channel, we add central profits to the model. Central bank profits are in practice affected by many factors, such as the management of the asset portfolio and the profit payout schemes, which are not captured in our simple model. We rely instead on a tractable yet realistic approximation. Specifically, we assume that the central bank profits as a ratio to GDP cbp_t are given by:

$$cbp_t = \bar{b}_t(i_t^d - i_t) \tag{15}$$

The central bank earns the spread of the yield on government debt over the short rate on its government debt holdings $\bar{b}_t$. For the latter, we assume that announced debt purchases are implemented over the next four quarters, so that actual debt holdings of the central bank are given by a four-quarter moving average of announced debt holdings. Note that when introducing central bank profits, the debt-stabilising steady state primary balance ratio becomes $pb^* = (r^* + \tau^* - g^*)d^* - cbp^*$ where $cbp^* = \tau^* b^*$. Under our calibration, $cbp^* = 0.1\%$ and therefore $pb^* = -0.1\%$.

The simulation results shown in Table 6, suggest that central bank profits are not an important channel for the effects of QE. The average outcomes of inflation unemployment, debt and QE are hardly affected. The only noticeable difference is in the primary balance, which now is in deficit on average as expected.

7 Conclusions

In an environment of low equilibrium real interest rates, the ZLB represents a major constraint for conventional monetary policy conducted by adjusting the setting of short-term policy interest rates. Absent additional policy tools, the difficulty in reducing real interest rates decisively in response to recessionary shocks can lead to episodes of persistently low-inflation, disanchoring inflation expectations, and debt deflation. Not only average inflation is lower that the Central Bank's goal and average unemployment is higher than its non-stochastic natural rate, but also public debt ends up being higher and less stable.

The activation of QE can improve macroeconomic stability considerably when short-term interest rate policy is constrained. By compressing term premiums, large-scale purchases of government bonds lower longer-term interests rates even when short-term rates are constrained. QE can serve as an imperfect substitute for short-term rate reductions. By reducing the cost of refinancing government debt, QE significantly enhance the stability of the public debt thus enabling additional fiscal accommodation which, in turn, can facilitate recovery from recessions.

Timidity in implementing QE is counterproductive. The ZLB-induced debt-deflation bias is better mitigated with QE policies that are more aggressive. While this comes at the cost of more frequent spells of negative term premia, potentially raising financial stability risks, the benefits for financial stability of a lower and more stable public debt should also be factored in. Indeed, we show that a better coordination between fiscal and monetary policies implies a lower and more stable public debt.

The design of fiscal rules is more consequential when monetary policy is constrained by the ZLB. Excessively debt-averse fiscal rules are counterproductive. By contrast, extra-accommodative fiscal policy when short-term interest-rate policy is constrained, in combination with central bank balance sheet expansion, can enhance both economic and fiscal stability.

To the extent moderately negative rates can be implemented, combining them with QE policy can also enhance macroeconomic stability while reducing the need for aggressive QE. Negative interest rates can limit the incidence of negative term premia and further contain the rise in public debt during downturns.

To the extent the central bank can facilitate the formation of inflation expectations with a clearer communication of a credible long-term inflation goal, it can also enhance macroeconomic stability and reduce the need for aggressive QE to counteract the ZLB. However, a credible inflation goal does not fully substitute for QE, which warns against relying exclusively on expectations mechanisms to stabilize the economy.

In a low interest rate environment, the ZLB makes countercyclical policies more complicated. However, with appropriate activation of available monetary policy tools, and better coordination of fiscal and monetary policies the adverse effects of low interest rates can be mitigated.

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Table 1
The ZLB and the level of r^*

	u	π	d	pb	ZLB
$r^* = 0.5\%$					
Mean	4.52	1.64	109.66	0.36	0.16
Std	0.89	1.67	12.64	0.78	
$r^* = 0.5\%$ *without learning*					
Mean	4.01	2.00	100.59	0.04	0.01
Std	0.52	1.40	5.52	0.60	
$r^* = 0.5\%$ *without ZLB*					
Mean	4.02	2.03	100.51	0.03	0.00
Std	0.56	1.61	6.68	0.62	
$r^* = 2\%$					
Mean	4.02	2.04	100.27	1.51	0.01
Std	0.56	1.62	7.50	0.66	

Notes: The table shows stochastic simulations means and standard deviations for alternative calibrations of the role of the ZLB constraint and of r^*. The column ZLB provides the share of simulations where the ZLB constraint was binding.

Table 2
QE at different scales

	u	π	d	pb	b	ZLB	$\tau < 0$
No QE, $\zeta_c = 0$							
Mean	4.52	1.64	109.66	0.36	10.00	0.16	0.00
Std	0.89	1.67	12.64	0.78	0.00		
Timid QE, $\zeta_c = 0.5$							
Mean	4.07	1.87	101.37	0.05	11.65	0.09	0.01
Std	0.57	1.64	7.08	0.62	2.36		
Baseline, $\zeta_c = 1$							
Mean	4.03	1.96	100.75	0.04	11.98	0.06	0.03
Std	0.56	1.63	6.99	0.62	3.68		
Aggressive QE, $\zeta_c = 2$							
Mean	4.01	2.02	100.44	0.03	12.76	0.04	0.04
Std	0.57	1.62	7.03	0.63	5.90		

Notes: The table shows stochastic simulations means and standard deviations for alternative calibrations of the cyclical response parameter in QE reaction function. The columns ZLB and $\tau < 0$ provide respectively the share of simulations where the ZLB constraint was binding and of simulations where the term premium was negative.

Table 3
Fiscal rules

	u	π	d	pb	b	ZLB	$\tau < 0$
Debt averse fiscal rule							
Mean	4.17	1.80	101.03	0.11	16.67	0.13	0.10
Std	0.88	1.95	6.82	1.17	10.23		
More countercyclical							
Mean	4.03	1.96	101.33	0.04	12.15	0.06	0.04
Std	0.51	1.67	9.52	0.89	4.07		
Extra stimulus only at ZLB							
Mean	4.02	1.97	102.38	0.03	11.47	0.04	0.01
Std	0.58	1.59	7.56	0.62	2.69		
Memo: Baseline							
Mean	4.03	1.96	100.75	0.04	11.98	0.06	0.03
Std	0.56	1.63	6.99	0.62	3.68		

Notes: The table shows stochastic simulations means and standard deviations for alternative calibrations of the fiscal rule. The columns ZLB and $\tau < 0$ provide respectively the share of simulations where the ZLB constraint was binding and of simulations where the term premium was negative.

Table 4
Negative interest rates

	u	π	d	pb	b	ELB	$\tau < 0$
$ELB = -0.5\%$ without QE							
Mean	4.17	1.84	102.90	0.10	10.00	0.08	0.00
Std	0.63	1.63	7.78	0.62	0.00		
$ELB = -1.0\%$ without QE							
Mean	4.04	1.96	100.87	0.04	10.00	0.03	0.00
Std	0.56	1.62	6.80	0.61	0.00		
$ELB = -0.5\%$ with QE							
Mean	4.02	2.00	100.54	0.03	11.01	0.03	0.01
Std	0.56	1.62	6.84	0.62	2.41		
$ELB = -1.0\%$ with QE							
Mean	4.02	2.02	100.49	0.03	10.54	0.01	0.01
Std	0.56	1.62	6.78	0.62	1.56		
Memo: Baseline							
Mean	4.03	1.96	100.75	0.04	11.98	0.06	0.03
Std	0.56	1.63	6.99	0.62	3.68		

Notes: The table shows stochastic simulations means and standard deviations extending the model to allow for negative interest rates. The columns ELB and $\tau < 0$ provide respectively the share of simulations where the ELB constraint was binding and of simulations where the term premium was negative.

Table 5
Credible inflation target

	u	π	d	pb	b	ZLB	$\tau < 0$
Credible π^* without QE							
Mean	4.23	1.83	105.12	0.23	10.00	0.07	0.00
Std	0.72	1.60	10.06	0.75	0.00		
Credible π^* with QE							
Mean	4.01	1.97	100.51	0.03	11.04	0.03	0.01
Std	0.56	1.57	6.20	0.61	2.62		
Memo: Baseline							
Mean	4.03	1.96	100.75	0.04	11.98	0.06	0.03
Std	0.56	1.63	6.99	0.62	3.68		

Notes: The table shows stochastic simulations means and standard deviations extending the model to allow for a credible π^* anchoring long-run inflation expectations in the learning algorithm. The columns ZLB and $\tau < 0$ provide respectively the share of simulations where the ZLB constraint was binding and of simulations where the term premium was negative.

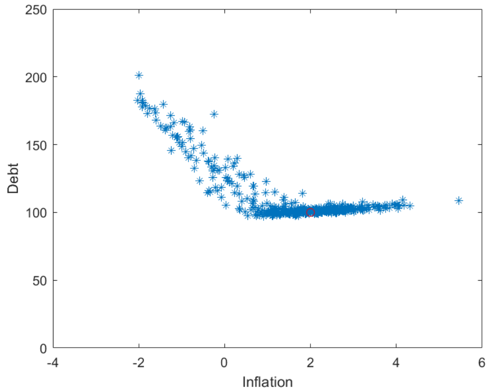
Table 6
Central bank profits

	u	π	d	pb	b	cbp	ZLB	$\tau < 0$
QE with CB profits								
Mean	4.03	1.96	100.76	-0.06	11.91	0.10	0.05	0.03
Std	0.72	1.60	10.06	0.75	3.56	0.08		
Memo: Baseline								
Mean	4.03	1.96	100.75	0.04	11.98	0.00	0.06	0.03
Std	0.56	1.63	6.99	0.62	3.68		0.00	

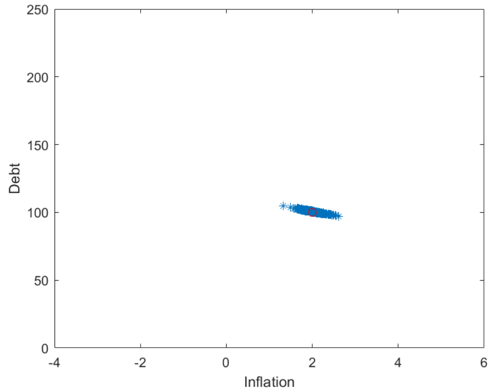
Notes: The table shows stochastic simulations means and standard deviations extending the model to allow for central bank profits. The columns ZLB and $\tau < 0$ provide respectively the share of simulations where the ZLB constraint was binding and of simulations where the term premium was negative.

Figure 1: **Debt deflation, the ZLB and r^***

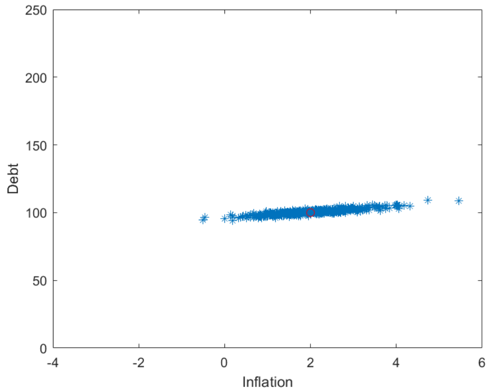
(a) r^*=0.5%



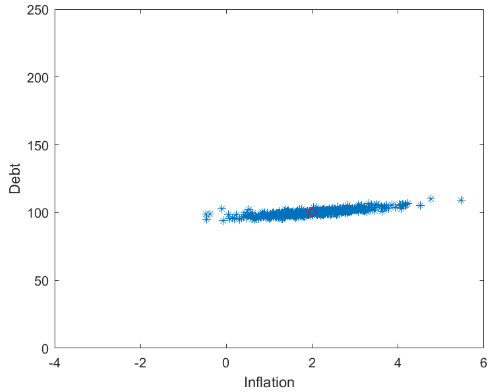
(b) r^*=0.5%, no learning



(c) r^*=0.5%, no ZLB

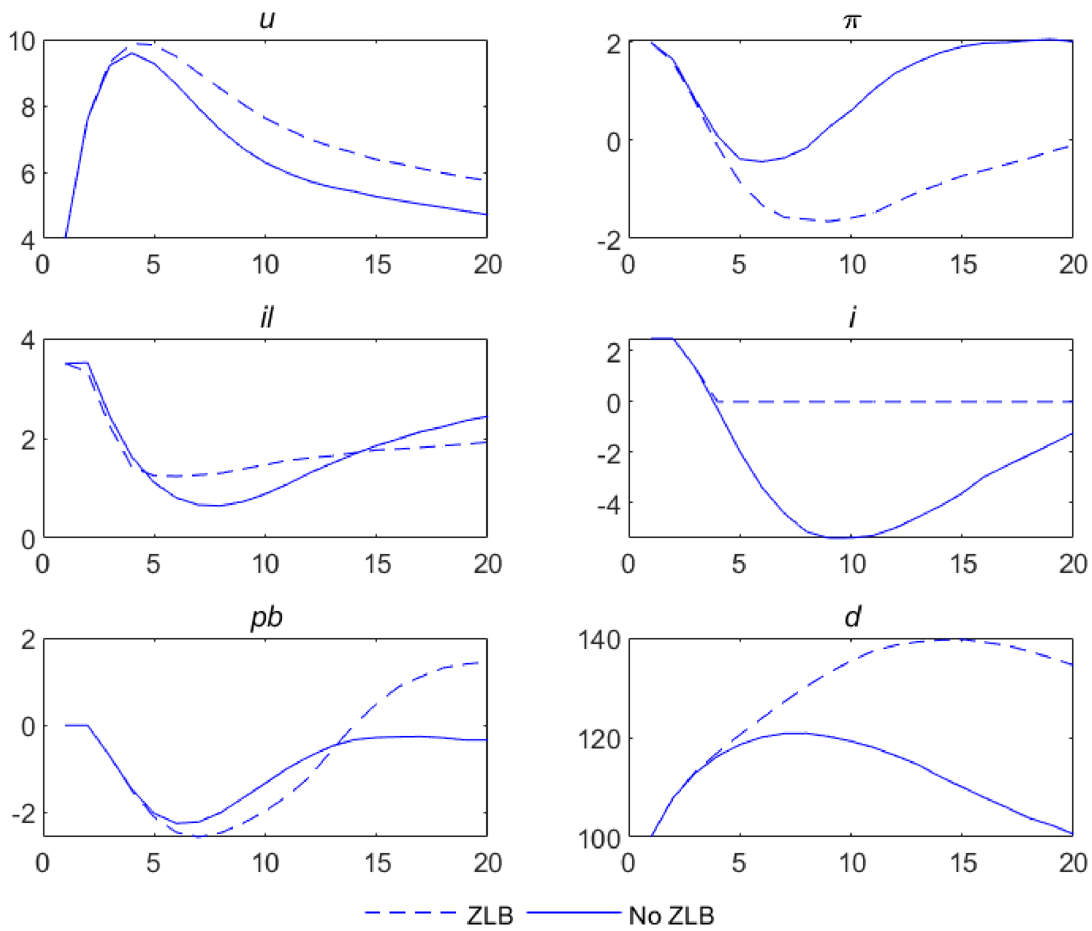


(d) r^*=2%



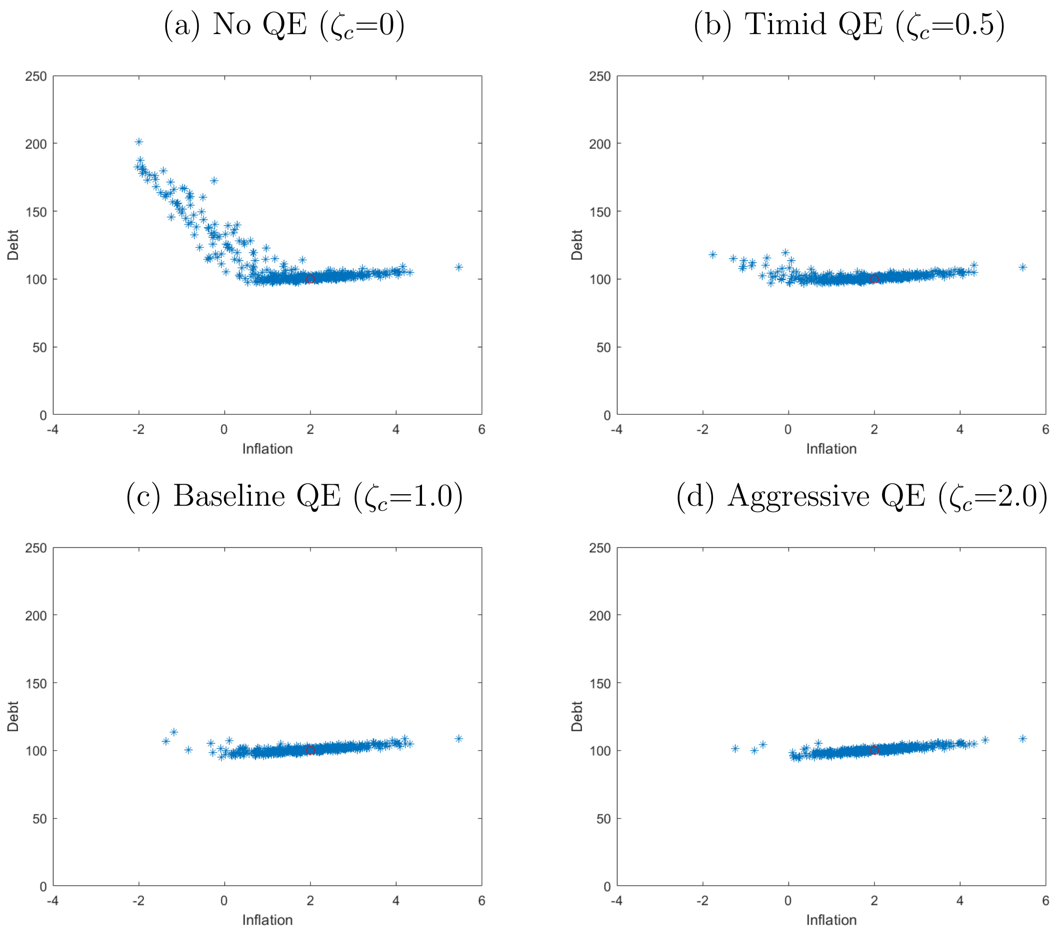
Notes: The scatter plots show average debt-over-GDP and inflation outcomes of stochastic simulations for different assumptions about the role of learning in expectations formation, the presence of the ZLB and the level of r^*.

Figure 2: **The ZLB in a deep recession**



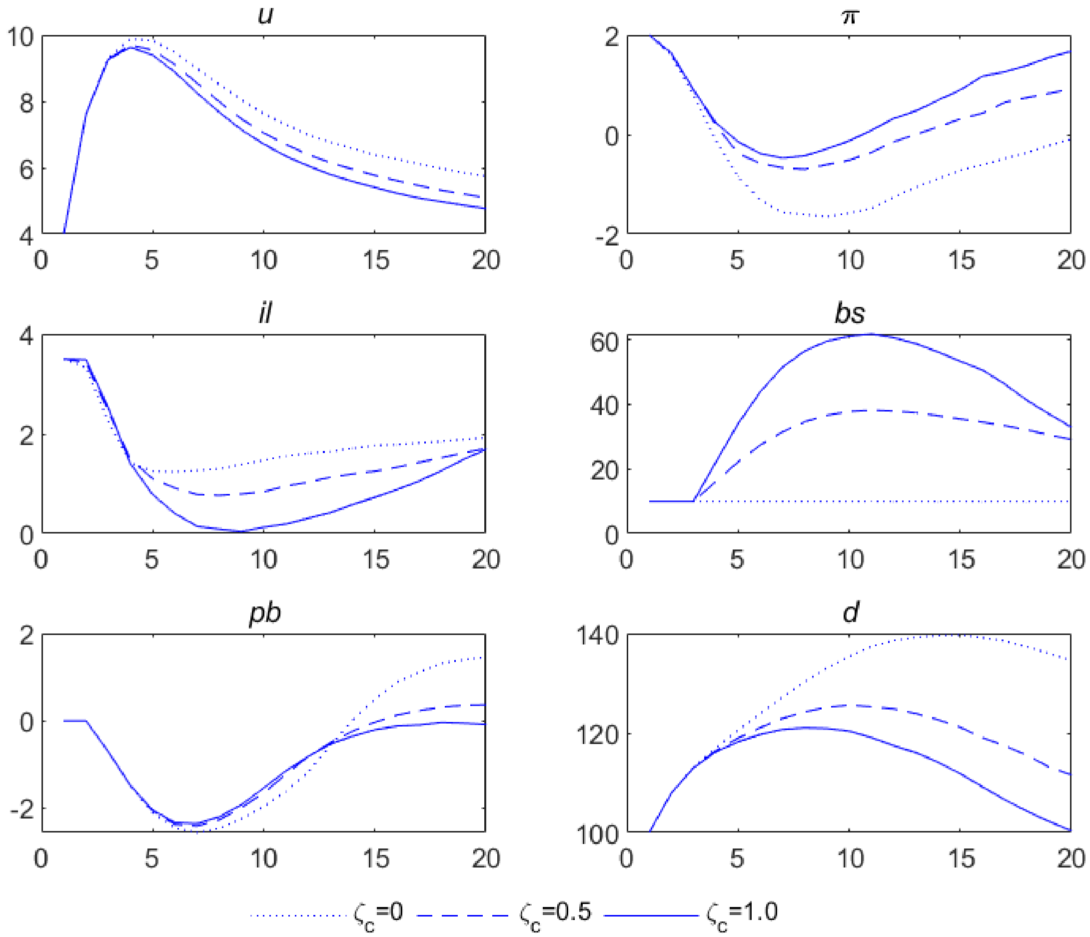
Notes: The chart shows impulse responses to a 4 percentage point shock to the unemployment rate with persistence 0.9 (severe recession scenario) without ZLB (solid line) and with ZLB (broken line).

Figure 3: **Debt deflation and QE**



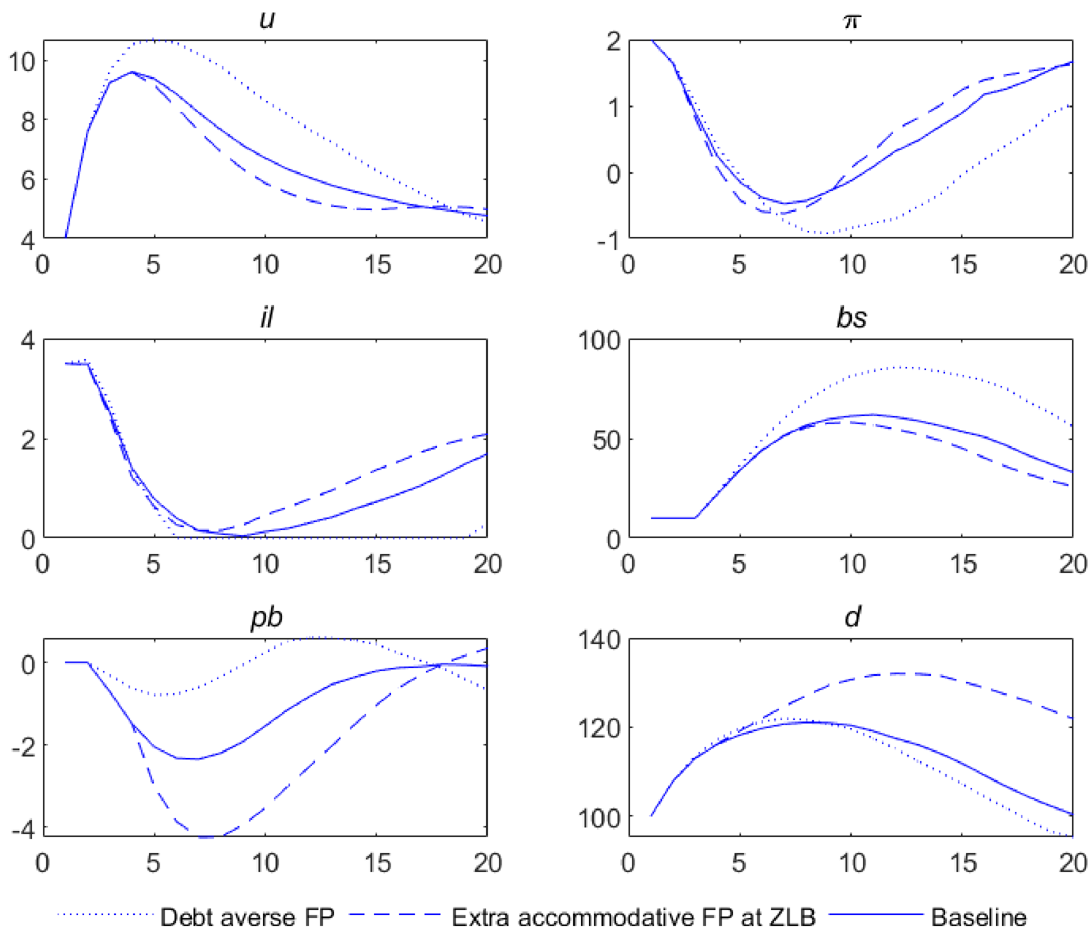
Notes: The scatter plots show average debt-over-GDP and inflation outcomes of stochastic simulations for different assumptions about the intensity of QE.

Figure 4: **The role of QE in a deep recession**



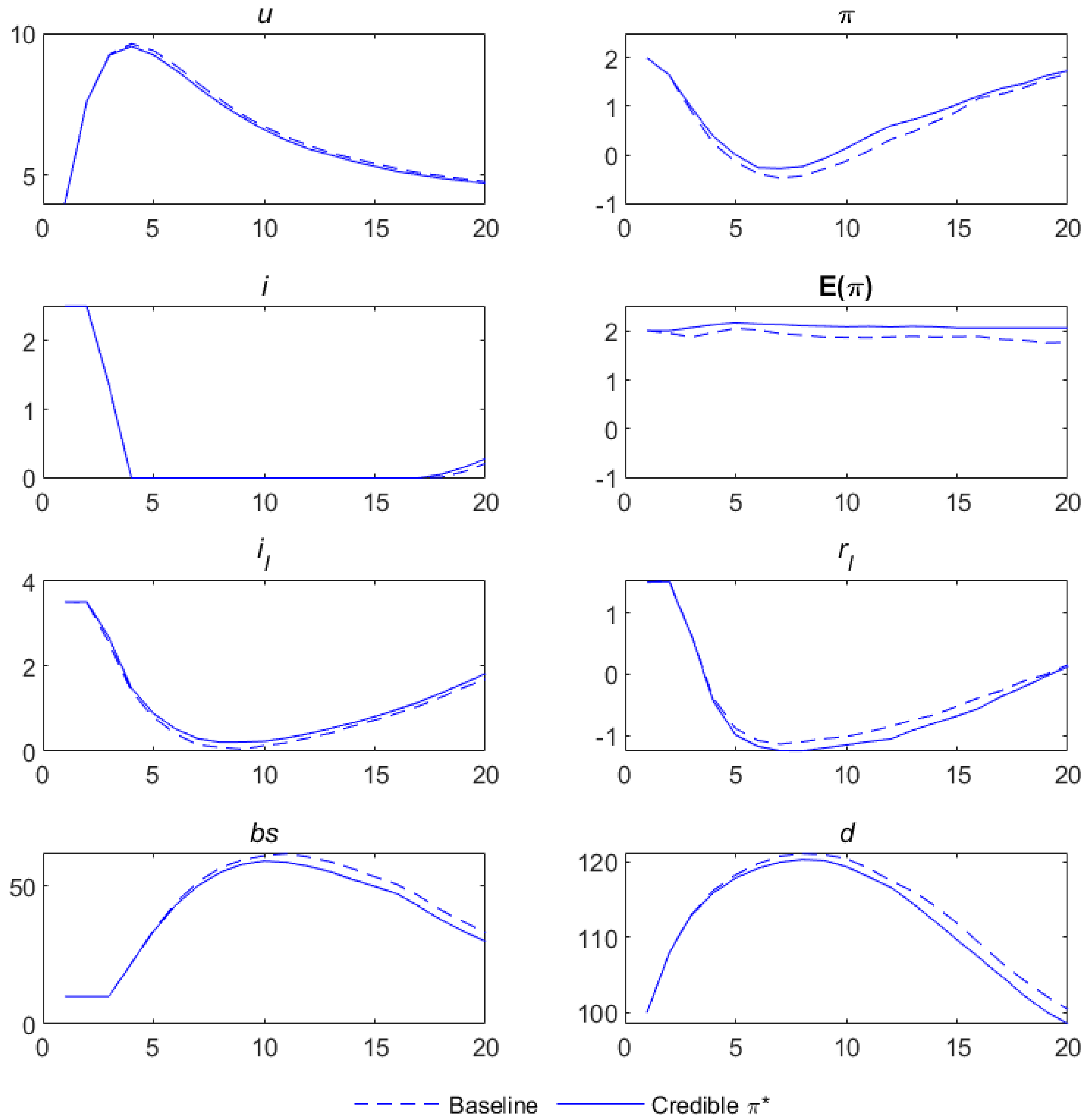
Notes: The chart shows impulse responses to a 4 percentage point shock to the unemployment rate with persistence 0.9 (severe recession scenario) with and without QE.

Figure 5: **Fiscal rules in a deep recession**



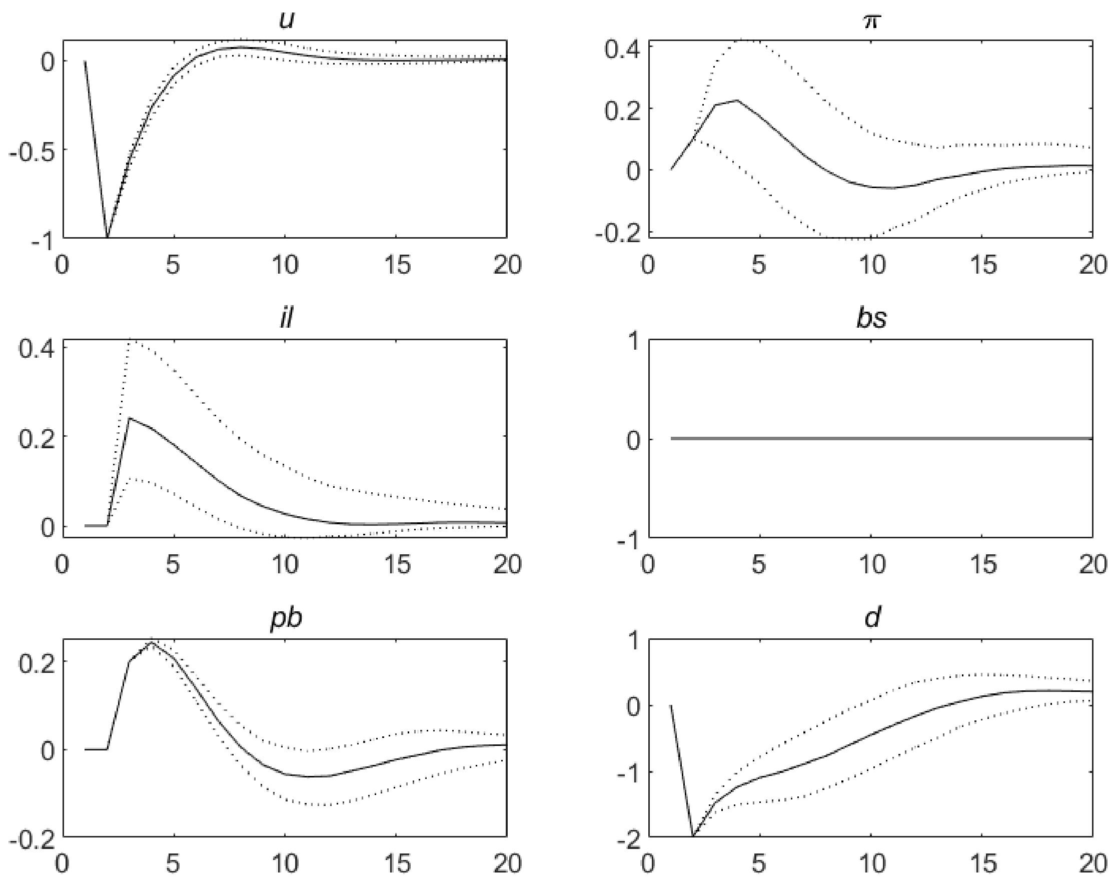
Notes: The chart shows impulse responses to a 4 percentage point shock to the unemployment rate with persistence 0.9 (severe recession scenario) with different fiscal rules.

Figure 6: **Credible inflation goal in a deep recession**



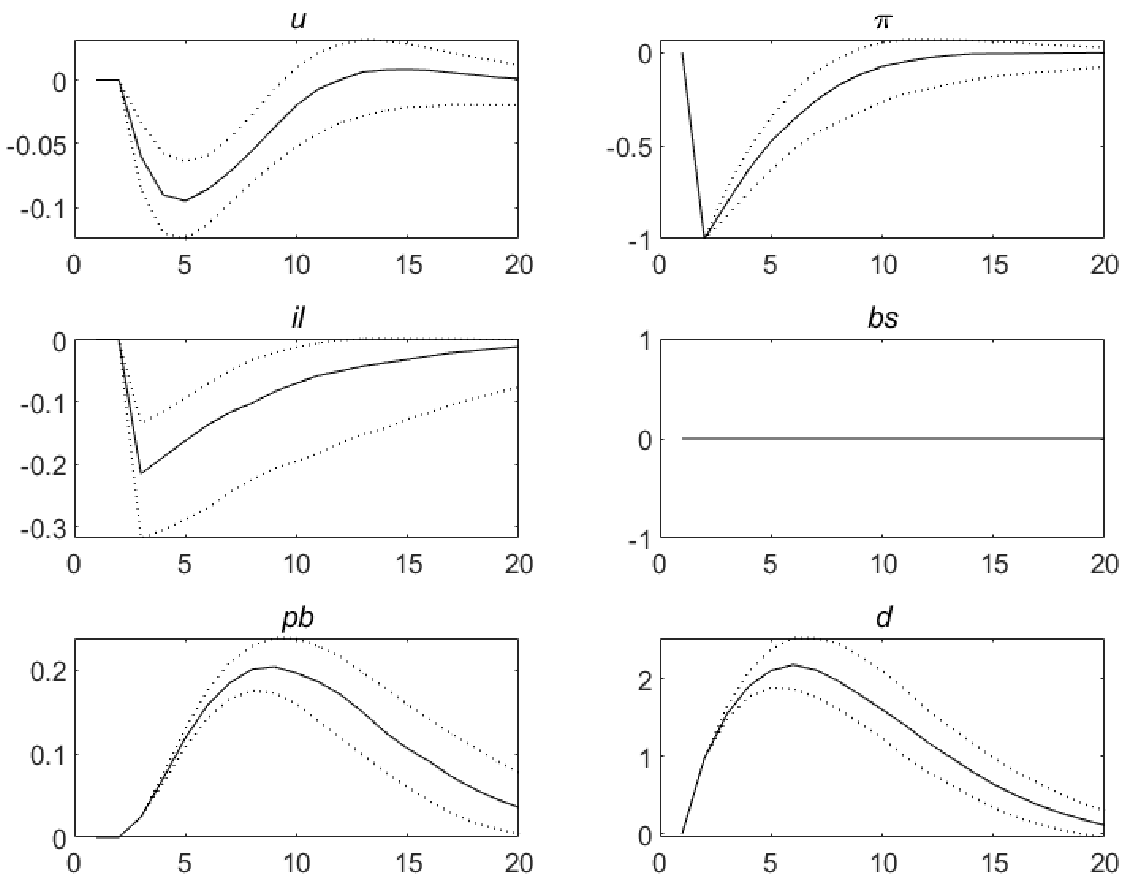
Notes: The chart shows impulse responses to a 4 percentage point shock to the unemployment rate with persistence 0.9 (severe recession scenario). The case of a clearly communicated and credible 2% inflation goal is compared with the baseline.

Figure A1: **IRFs demand shock**



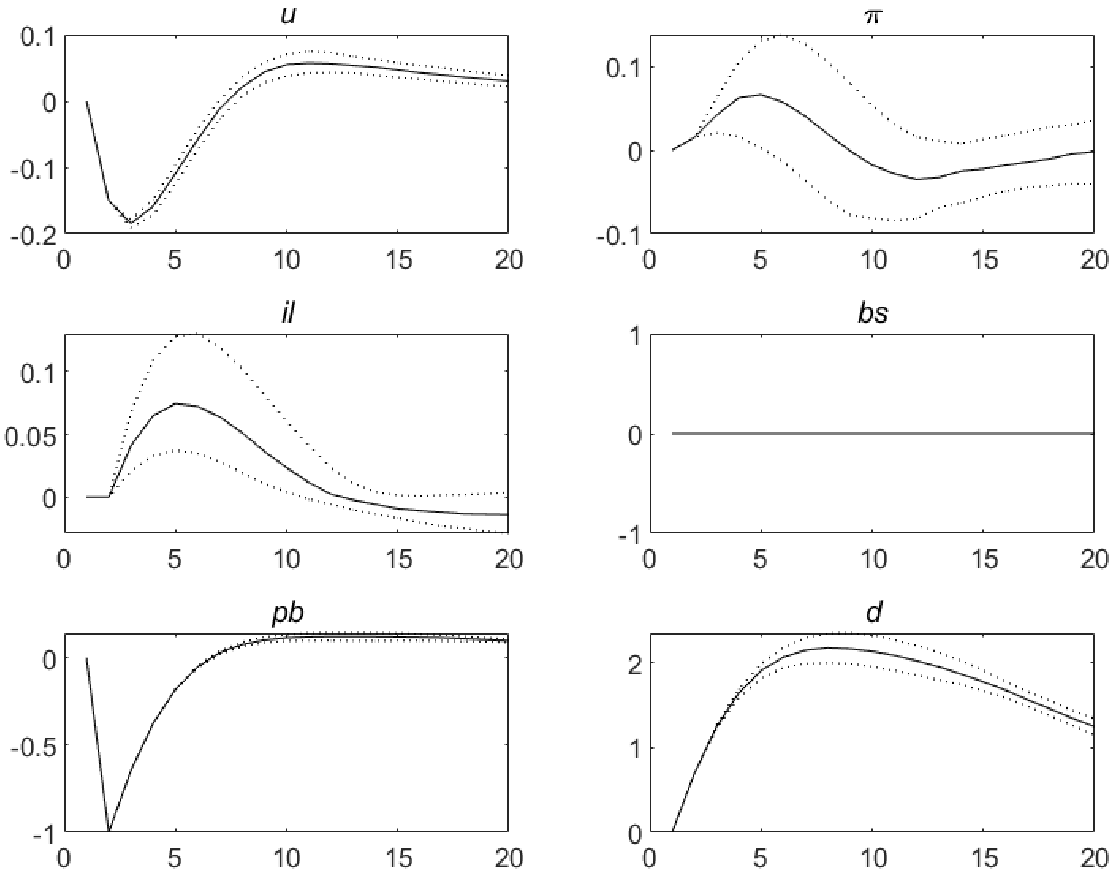
Notes: The chart shows impulse responses to a 1 percentage point drop in the unemployment rate (expansionary demand shock).

Figure A2: **IRFs supply shock**



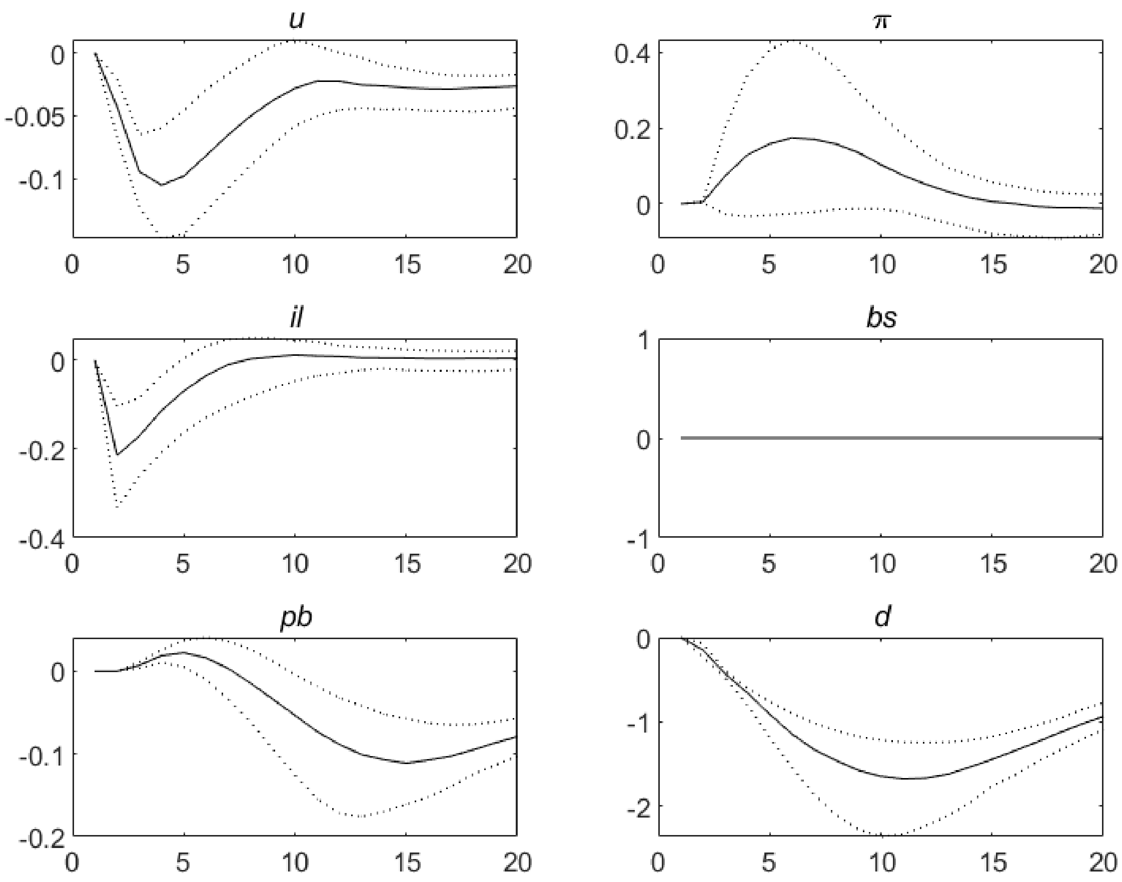
Notes: The chart shows impulse responses to a 1 percentage point drop in the inflation rate (expansionary demand shock).

Figure A3: **IRFs fiscal shock**



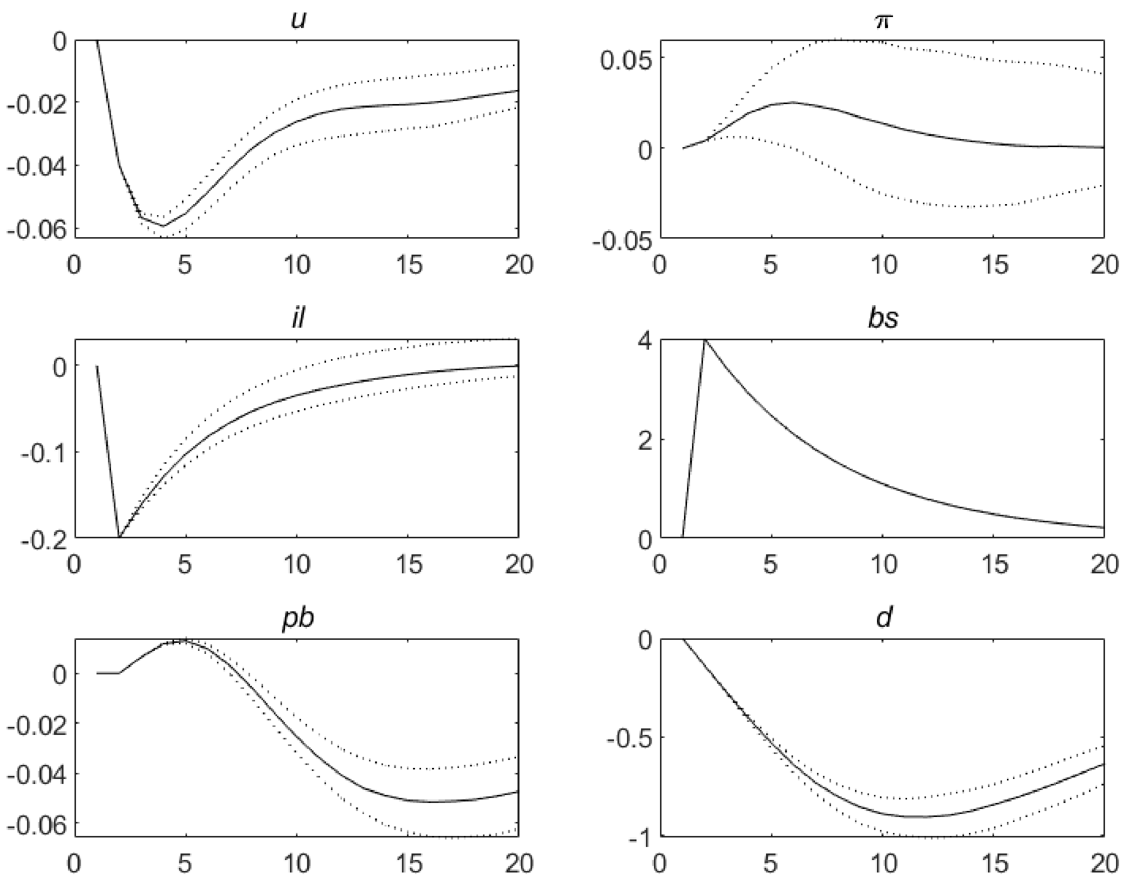
Notes: The chart shows impulse responses to a 1 percentage point drop in the primary fiscal balance ratio (expansionary fiscal shock).

Figure A4: **IRFs monetary policy shock**



Notes: The chart shows impulse responses to a 1 percentage point cut in the policy rate (expansionary monetary policy shock).

Figure A5: **IRFs QE shock**



Notes: The chart shows impulse responses to a 4 percentage point increase in announced central bank bond holdings (expansionary QE shock).