Fiscal and Monetary Policy Interactions in a Low Interest Rate World*

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We analyze 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 low inflation 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 QE if mildly 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 world, 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. As equilibrium real interest rates have declined significantly over recent decades,[2] this risk has grown.[3]

In such an environment, the deployment of quantitative easing (QE) compensating for the ZLB can no longer be seen as an unconventional measure. Since the Great Financial Crisis (GFC), and even more so in the wake of the COVID-19 pandemic, central banks of many 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 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

[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, Laubach, and Williams (2017), Fries et al. (2018), and Clarida (2019) for documentation of the decline in equilibrium real interest rates 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 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 policymaking (Gaspar et al. 2016).

stance, which in turn supports monetary policy in stabilizing the economy at the ZLB.

Against this background, we develop a small-scale model with the aim to study fiscal–monetary interactions at the ZLB. The model follows the semi-structural approach to analyzing robust interest rate policy of Orphanides and Williams (2007), extended to account for QE, 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 destabilizing macroeconomic consequences.[4] The model focuses on the interaction of QE and fiscal policy. Specifically, we assess how the activation of QE affects the conduct of fiscal policy and government debt dynamics. Likewise, we analyze how the conduct of fiscal policy influences the conduct and the effects of QE. In this vein, we try to capture the unintended side effects of QE on the profitability of financial intermediation by monitoring the evolution of term premia as a measure of the returns from maturity transformation.[5]

We analyze 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 with a sharp and persistent rise in the unemployment rate. Such

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

[5]Forward guidance, i.e., stating the intent or commitment to deliver a certain future path of policy rates, is an alternative tool central banks have employed to address the challenges of the ZLB; see, e.g., Filardo and Hofmann (2014). Evidence indicates that forward guidance has significant effects on market rates, but standard dynamic stochastic general equilibrium (DSGE) models grossly overstate the effectiveness of the policy (the "forward-guidance puzzle"; see Del Negro, Giannoni, and Patterson 2023). In our setup one could potentially represent (a form of perfectly credible) forward guidance through forcing agents' expectations on interest rates on a prespecified path. However, this would interfere with the learning process in the stochastic simulations and raise the question of how agents' forecasting model should look once monetary policy is normalized and forward guidance is abandoned. For these reasons, we see an analysis of forward guidance as beyond the scope of this paper.

a deep and persistent recession can be seen as relevant to describe the dynamics that followed the GFC in the United States or either the GFC or the sovereign debt crisis in the euro area.

Our analysis yields the following main findings.

First, a low equilibrium rate of interest implies significant constraints for monetary policy, giving rise to a frequently binding ZLB 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 QE 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 QE takes some of the burden off fiscal policy. This comes at the cost of occasional spells of negative term premia, eroding profits accruing to financial intermediaries from maturity transformation and potentially raising financial stability risks in the longer term.

Third, more debt-averse fiscal policy delivering a more rapid fiscal tightening when public debt rises harms economic stability without achieving more stable debt dynamics and increases the induced scale of stabilizing QE intervention by the central bank. An indiscriminately more countercyclical fiscal policy does not improve macroeconomic stability, but a more targeted countercyclical fiscal policy at the ZLB does so while reducing the induced usage of QE.

Fourth, combining moderately negative policy rates with QE further improves economic stability by creating a little more room for policy rate cuts during downturns. It also limits the occurrence of negative term premia and thereby the negative side effects of QE on the profitability of maturity transformation activities.

Finally, a credible inflation goal that facilitates the formation of inflation expectations can mitigate the stabilization 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. The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the model. Section 4 lays out the learning-based expectations formation. 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. Orphanides and Wieland (2000), Reifschneider and Williams (2000), Eggertsson and Woodford (2003), Adam and Billi (2006, 2007), Williams (2009), Gust et al. (2017), Kiley and Roberts (2017), Andrade et al. (2018), and Adam, Pfäuti, and Reinelt (2022) 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 analyzing 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 disanchoring 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 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), Bernanke (2020), and Carlson et al. (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) where the classic Wallace neutrality result holds: 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 QE requires the introduction of financial frictions such as credit constraints (Gertler and Karadi 2011, 2013; Sims, Wu, and Zhang 2023) or asset market segmentation (Chen, Cúrdia, and Ferrero 2012; Harrison 2017). We develop a semi-structural model where QE affects the real economy through its impact 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 the 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 2013). Under monetary dominance, fiscal policy ensures the stability of the public debt while the central bank focuses on price stability. Under fiscal dominance, the fiscal authority does not adjust deficits to ensure debt stability, which is instead ensured by 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. This includes studies on the role of fiscal policy to enhance macroeconomic stability (Benigno and Woodford 2004; Leith and Wren-Lewis 2005; Galí and Monacelli 2008), including on the question of the role of fiscal policy at the ZLB (Eggertsson and Woodford 2006; Christiano, Eichenbaum, and Rebelo 2011; Coenen, Straub, and Trabandt 2013; Sims 2016). Our analysis is also grounded on a setup 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, Montes-Galdón, and Smets (2020), who also analyze combining balance sheet policies of the central bank and fiscal policy through simulations of the European Central Bank's (ECB's) New 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 (RE). This limits the ability of the central bank to stabilize inflation through an implausibly powerful expectation channel.

3. The Model

Our starting point is the model of Orphanides and Williams (2007), extended to include QE 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.

We opt for a semi-structural model following many previous contributions (e.g., Rudebusch and Svensson 1999; Orphanides and Williams 2007) that focus, as we do, on comparing monetary policy strategies from a practical perspective. Semi-structural models are particularly suitable for such kind of analysis, as they combine conceptual rigor with the flexibility of time-series models. The equations that capture the adjustment of the private sector are consistent with fully microfounded models such as Smets and Wouters (2003) which we can combine with a realistic yet tractable modeling of monetary and fiscal policy. Semi-structural models are therefore useful tools to link the theory and practice of monetary policy, which is also reflected in the widespread use of such models by central banks.[6]

3.1 Phillips Curve, IS Curve, and Long-Term Interest Rates

The Phillips curve takes the standard hybrid form:

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

[6]See, e.g., Angelini et al. (2019) for an exposition of the ECB's semi-structural model of the euro area and a discussion of the benefits of using semi-structural macroeconomic models.

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:

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

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_t^l 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-stabilizing 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:

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

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 $r_t^s = i_t - E(\pi_{t+1})$ 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:

$$r_t^l = E\left(\frac{1}{L}\sum_{j=0}^{L} r_j^s\right) + \tau_t, \quad i_t^l = E\left(\frac{1}{L}\sum_{j=0}^{L} i_j\right) + \tau_t. \tag{4}$$

The equilibrium level of the long-term real interest rate is given by the equilibrium real 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:

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

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, both measured as ratios to GDP. 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).[7]

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.[8] 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. We therefore assume that announced changes to the stance of QE policy take effect immediately and in full rather than through a sequence of purchases spread over various quarters. That way we aim to capture the stock effect of QE that operates through the total expected size of asset purchase programs. For this reason we also allow QE to affect the term premium instantaneously, while we

[7]This approach is a stylized representation of a rich literature that allows for imperfect substitutability of assets with different duration, cf. Modigliani and Sutch (1967), Tobin (1969), Andrés, López-Salido, and Nelson (2004), and Vayanos and Vila (2021). In recent years, this modeling 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).

[8]This is particularly relevant in the context of the COVID-19 recession where the expansion of fiscal support by advanced 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 U.S., euro area, and Japanese treasuries, respectively. Such purchases hold down term premia and reduce the effective interest rate service of the newly issued public debt.

assume that the effect of a change in public debt occurs only with a lag when it is observed.[9]

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:

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

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. The response is with respect to the $t - 1$ realizations of these variables, as we assume that they are observed by the central bank with a lag. There is also 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^*.

The QE rule is formulated in terms of 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 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 is

[9]We need to have different timing assumptions about the impact of QE announcements and of debt issuance in order to be able to solve the model. The timing assumption chosen is motivated by the large evidence on significant immediate announcement effects of QE programs which we aim to capture in our analysis, while there is no similar evidence for the public debt issuance. That said, changing the timing assumption does not materially affect the results of the analysis.

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 stabilize 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 stabilization 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 the previous period's level and growth rate of GDP. This means that we need to back out the realized primary balance based on realized 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:

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

i_t^d is the interest rate paid on the outstanding stock of government debt which we assume to be linked to the long-term yield through an empirical partial adjustment equation: $i_t^d = \rho_d i_{t-1}^d + \lambda i_t^l$. This modeling approach reflects the fact that every period only a portion of the outstanding debt matures and has to be reissued at the prevailing level of the government bond yield. We take the level of the five-year government bond yield as a proxy of the rate that applies to the newly issued debt. pb_t^r is the realized primary fiscal balance which is equal to the announced primary balance adjusted for the government's forecast error in nominal GDP. Specifically, we have $pb_t^r = \frac{1+g_{t-1}+\pi_{t-1}}{1+g_t+\pi_t} pb_t$. Finally, the implied debt-stabilizing 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 with reference to the U.S. economy.

The time periods of the model are quarters, so we calibrate the model to quarterly data. In the simulation analysis we illustrate fiscal–monetary policy interactions by considering different calibrations of fiscal and monetary policy rules and of the structural parameters. 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 of the model.

The steady-state values of annualized variables are fixed at $r^* = 0.5\%$, $\pi^* = 2\%$, $g^* = 1.5\%$, and $\tau^* = 1\%$. We further set $u^* = 4\%$, $d^* = 100\%$, and $b^* = 10\%$, implying steady-state levels of government debt and of the central bank balance sheet of 100 percent of GDP and 10 percent 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 $\phi_\pi = \phi_u = 0.5$ following 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.[10] 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 rate.[11]

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 an average of government spending, tax, and transfer multipliers.[12]

We assume that the average maturity of government debt is five 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 five-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 percent of GDP reduce, for a given level of government debt, the term premium by 5 bps, in line with the empirical estimates of term structure models in Li and Wei (2013).[13]

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

[10] For recent surveys on this question, see Hooper, Mishkin, and Sufi (2019) and McLeay and Tenreyro (2020).

[11] 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 basis point (bps) shock to the policy rate on the five-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).

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

[13] For the 10-year Treasury yield, Li and Wei (2013) find a reduction of 10 bps. Other studies sometimes find somewhat smaller effects. For instance, Ihrig et al. (2018) find a reduction of 7 bps for the 10-year U.S. Treasury yield. For a survey of the empirical evidence on the impact of QE measures on long-term interest rates, see Rostagno et al. (2019) and Bernanke (2020). Considering smaller values of the term premium impact of QE within the range of empirical estimates did not materially affect the results of our analysis. The results of these robustness checks are available upon request.

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, Leigh, and Loungani (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 possible values between 0.5 and 2 to document the sensitivity of our results to the choice of this key parameter. This range for ζ_c implies a range of QE reaction coefficients of 0.75 to 3 for the inflation gap and of 1 to 4 for the unemployment gap. As a baseline calibration, we choose $\zeta_c = 1.0$, implying a response of 1.5 to the inflation gap and of 2 to the unemployment gap, which goes a long way toward stabilizing 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.[14]

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).[15] In the simulation exercises, we also consider more countercyclical fiscal rules (larger ψ) and more debt-averse fiscal rules (larger δ).

[14]By implication, under such a high degree of persistence the central bank will generally not have to sell bonds to bring about balance sheet normalization. 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 normalization in practice.

[15]Some studies provide evidence suggesting that fiscal rules—in particular, the reaction to debt—might be nonlinear, 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 nonlinearities to future research and focus on linear specification of the fiscal rule.

Finally, we calibrate the partial adjustment of the government interest expenses to long-term bond yields as $\rho_{id} = 0.7$ and $\lambda = 0.3$. This calibration is in line with the empirical association between effective government interest expenses and five-year benchmark bond yields in the United States and implies a long-run pass-through of bond yields to government interest expenses of 1, which further implies that i_t^d and i_t^l are 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 reestimate 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 equilibrium levels of interest and unemployment rates (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 formalize 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 of each variable. 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 1×3 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 4×1 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 4×3 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 formalize perpetual learning we replace the decreasing gain implied by the infinite memory recursion with a small constant gain, $\kappa > 0$.

To calibrate κ we follow Orphanides and Williams (2007), who examined how well different values of κ fit the expectations data for inflation, the unemployment rate, and the short-term interest 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 microdata 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 $e_{\pi,t}$. The standard deviations of the demand and supply shocks are respectively set as $\sigma_{e_{u,t}} = 0.4$ and $\sigma_{e_{\pi,t}} = 0.8$.[16] In the simulation exercise, we generate time series of length 500 (125 years) from the equations of the model and repeat the

[16] 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 five-year yield as a measure of the ex ante five-year real rate.

simulation 500 times (we then end up with 500 replications of time series of size 500 observations each).[17]

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.[18] By doing so, we equip our agents with the 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 three-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 of each simulation 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 stabilizing the economy under rational expectations. 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 stabilizing bounds on

[17]There are two dimensions across which sample moments may be influenced by the simulation setup—the number of stochastic simulations and the sample length, which are both limited by computing power. For comparison, the simulation analysis of the implications of the ZLB for monetary policy using the FRB/US and a DSGE model by Kiley and Roberts (2017) is based on 500 simulated samples of 200 quarters. The same simulation setup was adopted for the FRB/US simulations reported in Kiley (2018) and Bernanke, Kiley, and Roberts (2019). In our case, robustness checks suggest that estimated moments are by and large insensitive even when doubling the number of Monte Carlo runs or the sample size to 1,000. The results are available upon request.

[18]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 three-variable VAR can be thought of as a smaller-scale version of the reduced-form VAR representation of the model under model-consistent expectations.

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.[19] 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 rarely invoked.[20]

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 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 stochastic simulations). It is based on simulated trajectories, each one starting from the last simulated value in the stochastic simulation exercise. By doing so, the starting point of the impulse response functions 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 percent).

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[19]Following Orphanides and Williams (2007), we also require stationarity of the forecasting VARs and ARs. 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.

[20]The bounds are hit in less than 0.01 percent 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 percent of the simulation periods.

The shock is further assumed to be highly persistent, with an autoregressive coefficient of 0.9.

6. 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 government debt ratio, the fiscal primary balance ratio, and 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. These costs include in particular pressure on financial intermediaries whose profits accrue from maturity transformation which could give rise to financial stability risks not captured in our model.[21] Other costs of compressed term premia may include greater reaching for yield and greater fragility of banks, which may give rise to additional risks to financial stability.[22] Also, more microfounded models of QE frictions that operate via term premia imply that social welfare is affected by costs of using QE (Harrison 2017; Sims, Wu, and Zhang 2023).

6.1 Learning, the ZLB, and Low r^*

We first assess the role of learning, the ZLB, and the level of r^* for economic outcomes when there is no QE policy. 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 percent). There is an

[21] For conceptual models and evidence on the positive link between the slope of the yield curve and bank profitability, see, e.g., Alessandri and Nelson (2015) and Borio, Gambacorta, and Hofmann (2017). In the analysis of Brunnermeier and Koby (2018), QE reduces bond holdings of banks and hence the capital gains from policy rate cuts, thus raising the "reversal rate," which limits the expansionary effects of policy rate cuts.

[22] For instance, Hesse, Hofmann, and Weber (2018) find that QE impulses have persistent and large positive effects on stock prices, indicating increased risk-taking. Acharya et al. (2022) find that QE leaves banks more fragile and vulnerable to liquidity shocks.

Table 1. Learning, the ZLB, and r^*

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

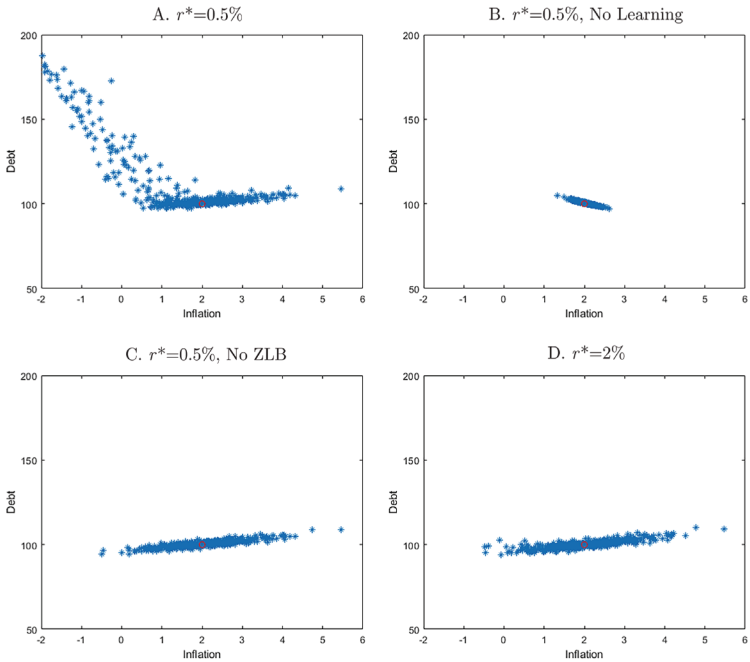
Note: The table shows stochastic simulations means and standard deviations for alternative calibrations of the role of learning, of the ZLB, and of the level of r^*. The column ZLB provides the share of simulations where the ZLB constraint was binding.

upward bias in the unemployment rate (0.52 percentage point) and a downward bias in the inflation rate (−0.36 percentage point). 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 point).

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 alternative calibrations (Table 1). In the case without learning, outcomes are unbiased on average and standard deviations are much lower, reflecting greater stability of the economy. Similar unbiased results are obtained when removing the ZLB constraint as well as when raising the level of r^* in the simulations.[23] This highlights the role of the

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

Figure 1. Debt Deflation, the ZLB, and r^*



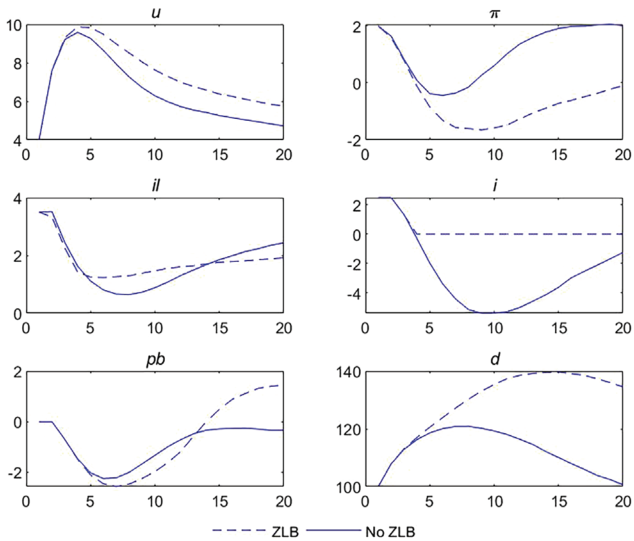
Note: The scatter plots show average debt-over-GDP and inflation outcomes of stochastic simulations for different assumptions about the role of learning in expectations formation, the presence of the ZLB, and the level of r^*.

ZLB in generating macroeconomic instability when expectations are formed under learning. It further confirms the notion that a lower level of r^* considerably compounds the constraints posed by the ZLB in line with the literature (e.g., Gust et al. 2017 and Kiley and Roberts 2017).[24]

The deviations from steady state in Table 1 in the presence of the ZLB 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

[24] Quantitatively compared with the results of Kiley and Roberts (2017), our analysis yields similar effective lower bound (ELB) frequencies as their DSGE simulations (17.4 percent) but fewer than their FRB/US simulations (31.7 percent).

Figure 2. The ZLB in a Deep Recession



Note: The figure 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).

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 stabilizing capacity of monetary policy under learning and low levels of r^* becomes also visible in the recession scenario. As Figure 2 shows, without a ZLB, nominal policy rates would be cut by up to –6 percent in a recession of the depth we 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. The simulations also illustrate how the debt dynamics feed back into the real economy. Fiscal authorities at some point run large primary fiscal surpluses in order to bring public debt back under control, which slows down the economic recovery. The ZLB constraint therefore gives rise to a mutually

Table 2. QE of Different Scales

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

Note: 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 was binding and of simulations where the term premium was negative.

reinforcing adverse feedback loop between economic conditions, public debt dynamics, and fiscal tightening.

6.2 The Role of QE

We next assess the stabilizing role of QE policy. To this end, we simulate the baseline model with QE and compare the outcome with that of the model considered above where there is no QE. In doing so we assess 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 ($\zeta_c = 2.0$).

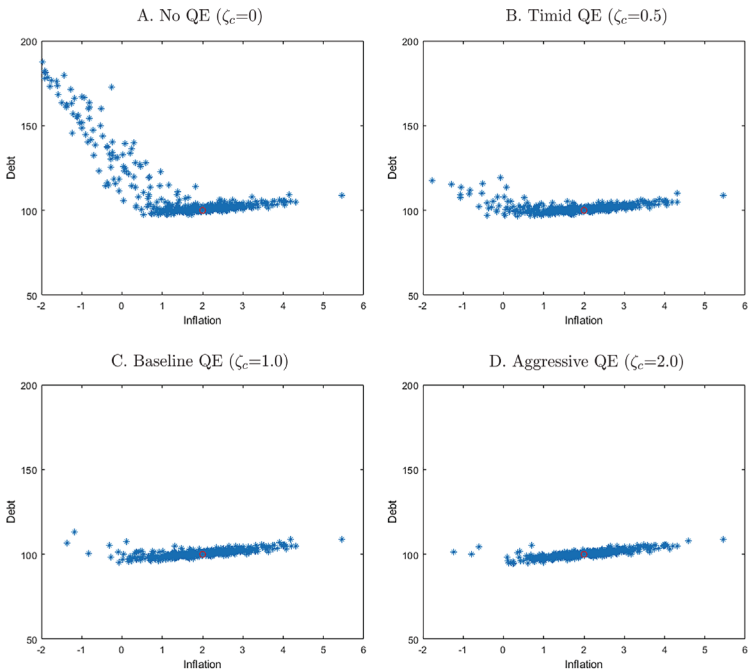
The results reported in Table 2 show that the activation of QE has highly stabilizing effects. The biases in the unemployment rate, the inflation rate, and also in public debt and in the primary fiscal surplus are significantly reduced already for a timid QE rule. For the baseline QE rule the biases 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 frequency of ZLB incidences is around 6 percent under the baseline QE rule, compared with 16 percent 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 percent of the simulation periods, term premia are compressed to negative levels as a consequence of QE policy in the baseline case.

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 a combination of public debt ratios above steady state and deflation.

In order to flesh out the stabilizing 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 with 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 stabilizing the economy and also helps stabilize 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.

Figure 3. Debt Deflation and QE

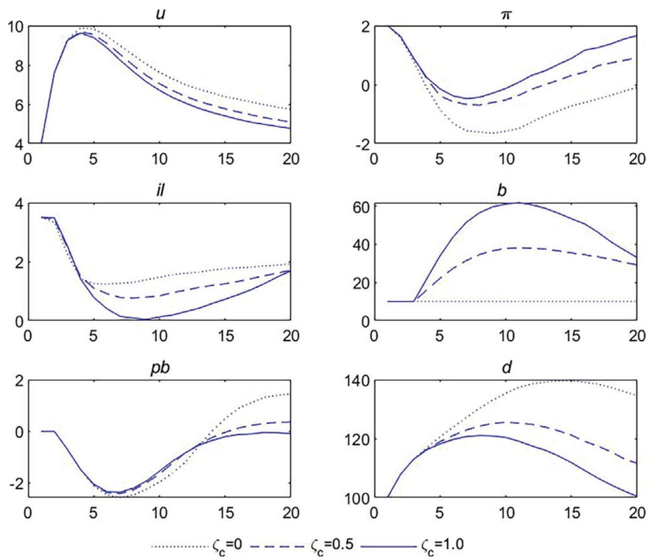


Note: The scatter plots show average public debt-over-GDP and inflation outcomes of stochastic simulations for different assumptions about the intensity of QE.

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-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 percent), requiring more active QE policy as reflected in a much larger level of

Figure 4. The Role of QE in a Deep Recession



Note: The figure shows impulse responses to a 4 percentage point shock to the unemployment rate with persistence 0.9 (severe recession scenario) for different scales of QE.

announced bond holdings (on average 17 percent) and resulting in a much higher number of periods with negative term premium (10 percent). 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 average level of public debt, which is even slightly higher than under the baseline fiscal rule.

Second, we consider a 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 with 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.

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		

Note: 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 was binding and of simulations where the term premium was negative.

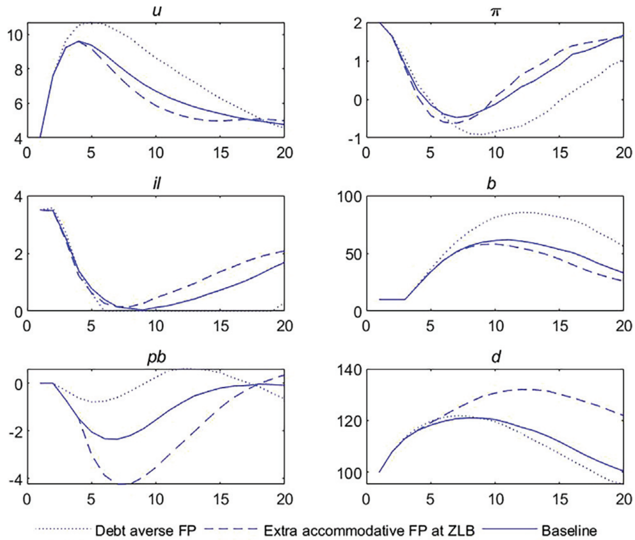
Third, we consider a fiscal policy rule that provides extra fiscal stimulus only when policy rates are stuck at the ZLB. The extra-accommodative fiscal rule at the ZLB takes the following form:

$$pb_t^{ZLB} = pb_t - \Psi_{ZLB}. \tag{14}$$

The additional term Ψ_{ZLB} means that fiscal policy provides additional accommodation when policy rates are constrained by the ZLB. In the simulations, we set $\Psi_{ZLB} = 1.0$, implying that at the ZLB, the fiscal authority runs a primary balance which is systematically 1 percentage point lower than otherwise, thus providing more stimulus.

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 the

Figure 5. Fiscal Rules in a Deep Recession



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

average scale of the QE intervention as well as the number of periods with a negative term premium to a mere 1 percent. This reflects the reduced burden on both conventional and unconventional QE policy in stabilizing the economy when such a fiscal rule providing additional stimulus only at the ZLB is in place.

The role of fiscal rules for macroeconomic stability is also reflected in the recession scenarios. Figure 5 shows the recession scenario simulations for the baseline fiscal rules, the debt-averse fiscal rule, and the fiscal rule providing extra stimulus at the ZLB. The simulation results show that a debt-averse fiscal rule is counterproductive also in a recession scenario. The consequence is less fiscal accommodation, reflected in much smaller fiscal deficits, translating into higher unemployment and much lower inflation compared with 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 doses, reflecting the reduced burden on monetary policy under such a fiscal rule.

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 percent or −1 percent. 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.[25] Our model does not capture these side effects. The aim of our experiment here is simply to illustrate the possible relative improvement in macroecononomic performance if mildly negative rates are feasible and potential side effects are deemed to be small.[26]

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 without 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 percent, the biases are largely eliminated for an

[25] See Neely (2020) for a discussion of the main concerns in this respect for the Federal Reserve, which—unlike other major central banks—did not adopt negative rates.

[26] For more elaborate conceptual and empirical analyses of the effectiveness of negative interest rates, see Eggertsson et al. (2019) and Smets, Onofri, and Peersman (2021).

Table 4. Negative Interest Rates

	u	π	d	pb	b	ELB	$\tau < 0$
	ELB = –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		

Note: 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 was binding and of simulations where the term premium was negative.

ELB of –1 percent. When considering the combination of negative rates and QE, we find that combining a moderately negative ELB of –0.5 percent with QE can bring the economy back to steady state on average over the simulations. However, further lowering the ELB to –1 percent does 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

Table 5. Credible Inflation Target

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

Note: 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 was binding and of simulations where the term premium was negative.

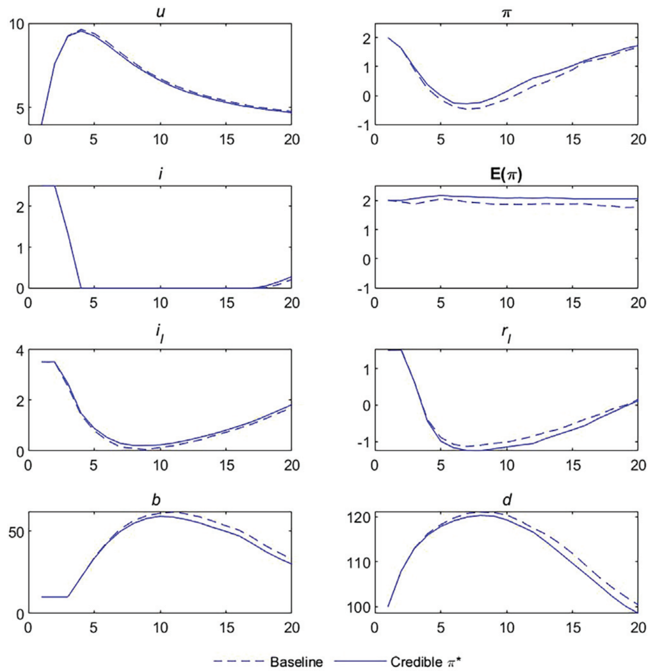
be observed by economic agents. In a learning environment, these misses will lead to inflation expectations being disanchored to the downside, raising the real long-term interest rate even more than what the ZLB would imply if expectations remained better anchored.

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 $\pi^* = 2\%$ while allowing the learning algorithm to continue to rely on past data for tracking other parameters of their forecasting model.[27]

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

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

Figure 6. Credible Inflation Goal in a Deep Recession



Note: The figure 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 percent inflation goal (solid line) is compared with the baseline (broken line).

of the ZLB are halved and so is the intensity of QE required to stabilize the economy (down from 12 percent to 11 percent), which also reduces the occurrence of negative term premia to just 1 percent. The simulations also reveal that a fully credible $\pi^* = 2\%$ is not sufficient to serve as substitute for QE. Without the use of QE as a monetary policy tool, significant adverse biases in economic 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 QE. 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 rate 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 bank 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-stabilizing 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, reflecting the steady-state primary deficit brought about by introducing central bank profits.

Table 6. Central Bank Profits

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

Note: 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 was binding and of simulations where the term premium was negative.

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 is average inflation below the central bank's goal and average unemployment higher than its equilibrium rate, but public debt also ends up being higher and less stable.

The activation of QE improves macroeconomic stability considerably in face of the ZLB. By compressing term premia, large-scale purchases of government bonds lower longer-term interests rates even when short-term rates are constrained. QE serves as an imperfect substitute for short-term rate reductions. By reducing the cost of refinancing government debt, QE significantly enhances the stability of the public debt, thus enabling additional fiscal accommodation which, in turn, facilitates the 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 taken into account in this context. Indeed, we find 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 at the ZLB, in combination with QE, can enhance both economic and fiscal stability.

To the extent that 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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