Macroeconomic and Fiscal Consequences of Quantitative Easing*

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This Draft: July 2, 2025

Abstract

Central banks have come under criticism for large balance sheet losses associated with quantitative easing (QE), and some observers have argued that QE helped fuel the post-COVID inflation boom. In this paper, we argue that the merits of using QE should be evaluated mainly on its ability to achieve core macro objectives as well for its effects on the consolidated fiscal position of the government and central bank, although losses can matter to the extent that they may weaken central bank credibility and independence. Using a DSGE model with segmented assets, we show how QE can provide a sizeable boost to output and inflation in a deep recession and liquidity trap, and can reduce public debt substantially. This is in sharp contrast to the rise in public debt that occurs under fiscal expansion, and makes QE an attractive tool in a high debt environment with limited fiscal space. There are more grounds for caution in using QE in a "shallow" liquidity trap in which the notional interest rate is only slightly negative: QE runs more risk of causing the economy to overheat, especially if forward guidance has a strong element of commitment, and runs more risk of generating sizeable central bank losses. Some refinements in strategy, including the use of escape clauses, can mitigate the risk of overheating.

JEL Classification: E1, E3, E5.

Keywords: Monetary Policy, Effective Lower Bound, Quantitative Easing, Central Bank Balance Sheet, Government Debt, New Keynesian Model.

*We are grateful for discussions with Andrew Levin and comments by our discussant Sarah Zubairy at the IMFs 5^{th} *Advances in Monetary Economics* conference (September 19, 2024), participants at a Nederlandsche Bank conference (April 10-11, 2024), Marianne Nessén (Sveriges Riksbank), as well as IMF staffers. This paper represents the view of the authors and not those of IMF Staff, IMF Management, or of the IMF Executive Board.

Contents

1 Introduction

The recovery from the COVID-19 pandemic and subsequent inflation surge have raised important questions about the tools and approaches policy makers should use to confront future recessions. On the fiscal side, the runup in public debt during the pandemic has further compressed fiscal space, compounding the pressures from unfavorable demographics. On the monetary side, many questions have been raised about the use of quantitative easing (QE) by central banks, including in the wake of sizeable central bank losses (Gopinath, 2023).

The use and implementation of QE merits particular attention in light of changing views about Philips Curve transmission. Policymakers deployed QE in 2020 to support recovery, but with the view that there was little upside inflation risk given the perceived flatness of the Phillips Curve. Moreover, QE was coupled with forward guidance about the policy rate path that involved some degree of commitment to keep policy rates low even after asset purchases had ended. But evidence from the recent high inflation experience suggests potentially significant nonlinearities in price and wage-setting that may have interacted with QE to fuel some of the inflation runup. And central bank forward guidance about QE may have inhibited a timelier liftoff of policy rates (Eggertsson and Kohn, 2023; Orphanides, 2023).

In this paper, we use a DSGE modeling framework to assess quantitatively the merits of using QE under different conditions and how the implementation of QE might be refined in light of recent experience. While QE was deployed initially by central banks during and after the Global Financial Crisis in the context of deep recessions, it was subsequently used to address ”lowflation” problems even after unemployment had edged closer to record lows. Accordingly, we consider the macroeconomic benefits of QE under these alternative economic conditions. Moreover, in gauging the fiscal consequences of QE, we focus heavily on the effects on the consolidated fiscal position of the government and central bank (i.e., the government's overall balance inclusive of interest payments plus central bank profits or losses). The consolidated position better captures the potential fiscal costs or benefits of QE from a societal perspective — this is what matters if the financial position of the central bank is irrelevant for its independence and decision-making. Even so, we also consider the implications of QE for the central bank balance sheet, as this may matter for assessing the merits of QE if such losses are viewed by the central bank as potentially affecting its credibility and weakening its independence.

Our DSGE modeling framework is well-suited to explore the benefits and costs of QE. We build on the literature incorporating bond market segmentation exemplified by Andres et al. (2004), Chen et al. (2012), Kiley (2014), and Kolasa and Wesolowski (2020) to allow QE to affect term premiums. Following Erceg et al. (2024), we make two key modifications of this framework to give QE an important role in a slump when inflation falls below the central banks target and the short-term policy rate becomes constrained by the effective lower bound (ELB). First, our model embeds behavioral discounting as in Gabaix (2020) to mitigate the “forward guidance puzzle,” so that the central bank can’t simply rely on announcements about the future policy rate to achieve its objectives when constrained by the ELB for a protracted period. Second, it incorporates a nonlinear Phillips Curve as in Harding, Linde, and Trabandt (2022, 2023), which allows the model to capture possible overheating risks from QE or “commitment -based” forward guidance meant to amplify its effects. The model also allows for price and wage stickiness and real rigidities to better match empirical evidence on monetary transmission. Finally, we assume that stabilization of public debt in the long run is achieved by adjusting distortionary taxes on labor income. All in all, these features prove helpful in identifying potential risks from QE, including on the fiscal side.

We begin by showing that QE is likely to have substantial macroeconomic benefits in a deep recession when the policy rate is pinned at the ELB for a prolonged period, even while calibrating the model so that the effects of asset purchases on term premiums are fairly modest from the perspective of the empirical literature.[1] Moreover, QE tends to significantly improve the consolidated fiscal position of the government. In particular, the debt-to-GDP ratio falls as the faster output recovery boosts the primary balance, debt service costs fall due to lower interest payments, higher bond prices make issuance of new debt cheaper, and increases in the aggregate price level lower the real value of existing debt. The central bank also typically makes profits as it purchases long-term assets that pay a premium over their refinancing cost.

These favorable fiscal implications make QE an attractive tool for providing stimulus in an environment of high public debt. We use our model to provide a comparison of the effects of a fiscal expansion that is modeled as a rise in government spending. Strikingly, while a 10 percent of GDP asset purchase program by the central bank reduces the debt/GDP ratio about 7 percent after three years, a rise in government consumption scaled to generate the same output path would raise debt by 3 percent – a whopping 10 percent swing. As we show, aside from the direct impact of higher spending on the fiscal deficit, this reflects that fiscal impetus boosts wages and hence labor income tax revenue by less, leaves private consumption and hence sales tax revenue largely

[1] In a meta-analysis, Fabo et al. (2021) notes that the effectiveness of QE is found to be notably smaller by academics than central bank economists. We benchmark our model to their evidence excluding central banks, thus taking a conservative view on the effectiveness of QE.

unchanged, and does not decrease the cost of servicing and issuing debt as its effect on inflation and bond prices is small.

These arguments should not be construed as meaning that QE alone can be deployed to fight a recession without the support of fiscal expansion. In practice, there are probably some limits to how much the central bank can depress term premiums if already low, and central banks may be legitimately concerned about the balance sheet risks – or other political economy risks – that they might incur through large balance sheet expansion. Even so, our results do make a strong case for using QE aggressively in a deep liquidity trap at least as an important component of the overall policy response.

Next, we move on to analyze QE in a "shallow" liquidity trap, where interest rates are pinned at zero mainly because inflation and inflation expectations are running persistently below target, although output is only modestly below potential. A number of countries faced such conditions before the pandemic. In particular, QE was used by several central banks due to their concern that inflation would otherwise run below target for several years, hence posing downside risks to inflation expectations and ultimately undermine the credibility for the inflation target. QE was typically accompanied by forward guidance that had some aspects of commitment: central banks indicated that they would amplify the stimulus from QE by in effect promising not to lift rates until sometime after asset purchases had ended.

We show that the benefits of a given-sized QE program tend to be considerably smaller in this environment than in a deep liquidity trap. Moreover, even if there are benefits if the economy evolves roughly in line with the modal outlook, QE in a shallow trap can pose eventual overheating risks if the economy recovers faster than expected. In particular, the "commitment" aspect of QE can amplify overheating, especially if there are significant nonlinearities in the Phillips Curve – corroborating the concerns raised by Orphanides (2023) that QE can make it difficult to respond nimbly to overheating pressures.

We further demonstrate that QE in a shallow liquidity trap can lead to large central bank losses if an earlier recovery scenario materializes – reflecting that the central bank incurs substantial duration risk, and then takes a big hit when forced to tighten to contain inflation. These losses can be particularly high if the term premiums are already compressed when QE is introduced.

The smaller macro benefits of QE identified in our simulations, more substantial overheating risks, and large risk of central bank losses may be enough to dissuade a central bank from engaging in QE in a shallow liquidity trap – especially given some potential costs of unwinding QE subsequently through QT, including potential financial stability risks (Acharya and Rajan, 2024). Even so, moving away from commitment-based forward guidance and hence allowing the policy rate to follow the normal reaction function can keep overheating risks quite contained. And the implication that the consolidated fiscal balance improves is quite robust, even when the central bank experiences large losses. So while the size of QE should be appropriately calibrated to mitigate overheating risks, some QE may be helpful even in a shallow liquidity trap under some circumstances.

While most of our analysis is conducted in a deterministic setting, we also complement it by using stochastic simulations in which the model's underlying shocks are calibrated to match the macroeconomic volatility and comovements observed over the 1960-2019 period. This sample – which encompasses the Great Inflation episode – in effect poses a severe test of QE-driven overheating risks and scope for large central bank losses. Despite that, we find that probability of reasonably calibrated QE to induce large consolidated fiscal losses is small.

The remainder of the paper is organized as follows. Section 2 presents the quantitative macroeconomic model with real rigidities and gradual nominal price and wage adjustment, and discusses how we calibrate it to match empirical evidence of the transmission of QE and conventional fiscal stimulus on inflation, output and the term-premium, focusing on the U.S. and Euro area. Section 3 discusses our results for QE and conventional fiscal policy in severe recessions when the shadow rate is well below the ELB, comparing the effects of QE with conventional fiscal stimulus, with a particular focus on the impact of the consolidated fiscal position for given boost to output by the two policy tools. In Section 4, we assess the limits of QE in a shallow trap, highlighting the risks of overheating and sizable central bank losses, especially if the term premium is already compressed and asset purchases are very big, and if they involve a central bank commitment to keep the policy rate low for long. Section 5 uses stochastic simulations to evaluate the risks around the modal outlook. Finally, Section 6 provides some concluding remarks.

2 Quantitative Model

The quantitative model that we develop for this study builds on Erceg et al. (2024), casting it in a closed economy setup and extending in several directions. Compared to a standard DSGE model, our framework has the following features. First, we assume bond market segmentation similar to Chen et al. (2012). This ensures that short- and long term bonds are imperfect substitutes and that, by affecting the term premiums, asset purchases (quantitative easing) by the central bank have real effects. Second, we allow for a moderate degree of cognitive discounting in the spirit of Gabaix

(2020) to mitigate the so-called forward guidance puzzle (see Del Negro et al., 2012). This creates the need to complement interest rate policy with additional tools, such as QE or fiscal expansion, when the policy rate becomes constrained by the effective lower bound. Third, we incorporate strategic complementarities in price setting to allow for a lower sensitivity of inflation in recessions (the "missing deflation puzzle") as well as its surge during fast recoveries (see Harding, Lindé and Trabandt, 2022, 2023).

Relative to the model in Erceg et al. (2024), we make two additional modifications to feature empirically realistic transmission of both standard monetary (interest rate) and fiscal (government consumption) policy shocks. First, we allow for habit formation in consumer preferences to obtain a gradual and hump-shaped peak effect on output following an easing of the short-term interest rate. As the model is largely Ricardian and excludes endogenous capital formation, habit formation moderates the crowding out of private spending following an increase in government consumption and hence allows the model to better align with the empirical evidence on the effects of fiscal policy on output. Second, we allow for gradual nominal wage adjustment to moderate the effects on inflation of policies for an empirically realistic degree of price adjustment and to obtain more realistic behavior of wages and profits (see Christiano, Eichenbaum and Evans, 2005; Bilbiie and Trabandt, 2023). These two modifications are important to appropriately capture the response of fiscal revenue, which mainly relies on proportional taxation of consumption and labor income, to shocks and policies.

Below we provide an overview of the model. For any variable X_t: $x_t = X_t/P_t$ denotes its real value, where P_t is the aggregate price level, and x denotes x_t's steady state. We will also occasionally use a bar to distinguish aggregate quantities that agents take as given when they make their individual choices. Naturally, in equilibrium we have $x_t = \bar{x}_t$.

2.1 Households

The two types of households are labeled "restricted" and "unrestricted", and indexed with $j \in \{r, u\}$, respectively, with $\omega_r \in (0, 1)$ denoting the share of restricted households. The lifetime utility maximized by household of type j is given by

$$U_t^j = \mathbb{E}_t^j \sum_{s=0}^{\infty} \beta_j^s \exp\{\varepsilon_{t+s}^d\} \left[\exp\{\varepsilon_{t+s}^c\} \log(c_{t+s}^j - \varkappa \bar{c}_{t-1+s}^j) - \frac{(n_{t+s}^j)^{1+\varphi}}{1+\varphi} \right], \quad (1)$$

where $\beta_j \in [0, 1)$ is the subjective discount factor, $\varkappa \in [0, 1)$ is the external habit formation parameter, and $\varphi > 0$ is the (inverse) Frisch elasticity of labor supply.

Household preferences in consumption c_t^j (adjusted for habits that depend on aggregate consumption of the same type of agents $\bar{c}_t^j$) and labor n_t^j are perturbed by the discount factor shock ε_t^d, which we describe in more detail later, and the consumption preference shock ε_t^c, which is assumed to follow a stationary AR(1) process. In the lifetime utility maximand (1), $\mathbb{E}_t^j$ indicates the expected value operator under the subjective expectations of type j households. We allow for deviations from rational expectations by following Gabaix (2020) in assuming that households can be myopic.[2]

There are two types of nominal assets in the model economy, short-and long-term bonds, and we indicate their holdings by agents of type j as B_t^j and $B_{L,t}^j$, respectively. Following Woodford (2001), we model long-term bonds as perpetuities paying an exponentially decaying coupon $1, \kappa, \kappa^2, \ldots$ starting in the period following issuance, where $\kappa \in (0, 1]$. By absence of arbitrage, $P_{L-s,t}$, i.e., the current price of a long term bond issued s periods ago, then has to be related to the price of a newly issued perpetuity $P_{L,t}$ via $P_{L-s,t} = \kappa^s P_{L,t}$. A convenient implication is that we only need to keep track of the long-term bond price issued contemporaneously, as prices of all past vintages can be easily recovered using the preceding formula. This structure also means that the yield to maturity on long-term bonds, which we will also refer to as the long-term rate, is simply $R_{L,t} = \kappa + 1/P_{L,t}$.

Unrestricted households can trade both types of bonds, but have to pay transaction costs ζ_t to hold position in long-term markets. These considerations translate into the following flow budget constraint

$$\begin{aligned} &P_t \left(1 + \tau_t^c\right) c_t^u + B_t^u + \left(1 + \zeta_t\right) P_{L,t} B_{L,t}^u + T_t^u \\ &\qquad = R_{t-1} B_{t-1}^u + \left(1 + \kappa P_{L,t}\right) B_{L,t-1}^u + W_t \left(1 - \tau_t^n\right) \bar{n}_t^u + D_t^u + \Xi_t^u, \end{aligned}$$

where τ_t^c denotes the sales (VAT) tax rate, τ_t^n is the labor income tax rate, T_t stands for lump sum taxes, D_t denotes dividends from monopolistically-competitive firms, R_t is the short-term policy rate, and $W_t \bar{n}_t^u$ denotes pre-tax labor income, inclusive of net insurance payments insulating households from idiosyncratic income risk (see more details below). The bond holding adjustment costs are rebated lump sum through Ξ_t^u and they are assumed to satisfy

$$\frac{1 + \zeta_t}{1 + \zeta} = \left(\frac{P_{L,t} b_{L,t}^u}{P_L b_L^u}\right)^{\xi}, \tag{2}$$

[2] More specifically, when anticipating the future, households shrink their expectations toward the economy's steady state. Formally, for any variable X_t that households of type j take as given during optimization, its perceived law of motion is $X_{t+1} - X = m_j \mathbb{G}^X(\mathbf{X}_t^s - \mathbf{X}^s, \boldsymbol{\epsilon}_{t+1})$, where $\mathbf{X}_t^s$ is a vector of aggregate state variables, $\boldsymbol{\epsilon}_t$ is a vector of innovations to stochastic processes driving the economy, $\mathbb{G}^X$ is the equilibrium aggregate policy function for variable X_t, and $0 \leq m_j \leq 1$ is a cognitive discounting parameter for agent j, with $m_j = 1$ corresponding to the standard case of rational expectations.

with $\xi > 0$.

In contrast, restricted households trade only in long-term bonds and their transaction costs are negligible. Their budget constraint is then

$$P_t \left(1 + \tau_t^c\right) c_t^r + P_{L,t} B_{L,t}^r + T_t^r = \left(1 + \kappa P_{L,t}\right) B_{L,t-1}^r + W_t \left(1 - \tau_t^n\right) \bar{n}_t^r + D_t^r. \tag{3}$$

2.2 Wage Setting

We assume that labor supplied by individual households is differentiated and aggregated by perfectly competitive labor unions according to a constant elasticity of substitution aggregation function controlled by parameter $\phi_w > 0$. The homogeneous labor services sold to firms are then given by the following formula

$$n_t = \left(\int_0^1 n_t(h)^{\frac{1}{1+\phi_w}} dh\right)^{1+\phi_w}, \tag{4}$$

where h indexes individual households.

Wages are set by labor unions in a Calvo-style staggered fashion. Each period, a randomly selected fraction $1 - \theta_w$ of households get their nominal wage reset, while the remaining households mechanically index their wages to steady state inflation π. While resetting wages, labor unions do it on behalf of all households, taking into account aggregate rather than household-type specific preferences.[3] This leads to the following optimization problem

$$\max_{\tilde{W}_t} \ \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\Lambda_{t+s} \exp\{\varepsilon_{t+s}^w\} \Pi^s \frac{\tilde{W}_t}{P_{t+s}} - \frac{\exp\{\varepsilon_{t+s}^d\}}{1+\varphi} \left(\frac{\tilde{W}_t}{W_{t+s}}\right)^{\frac{\phi_w}{1-\phi_w}\varphi} n_{t+s}^{\varphi}\right] \left(\frac{\tilde{W}_t}{W_{t+s}}\right)^{\frac{\phi_w}{1-\phi_w}} n_{t+s}, \tag{5}$$

where $\tilde{W}_t$ is the newly set wage and ε_t^w is a wage cost-push shock that follows a stationary AR(1) process. Note that, since we assume that labor unions are not myopic, the problem above uses the rational expectations operator $\mathbb{E}_t$.

For tractability, we also assume the existence of perfect insurance schemes against idiosyncratic income risk associated with staggered wage setting. This ensures that all households of a given type make the same consumption and asset choices, and allows us to write their labor income net of insurance payments as $W_t \bar{n}_t^j$.

[3] This means in particular that labor unions evaluate labor income flows using population-weighted marginal utility of consumption Λ_t and discount them with population-weighted discount factor β.

2.3 Firms

Perfectly competitive firms combine inputs into final goods according to

$$\int_0^1 G\left(\frac{y_t(i)}{y_t}\right) di = 1, \tag{6}$$

where we parameterize the Kimball aggregator as in Dotsey and King (2005) by assuming

$$G(x) \equiv \frac{\phi}{1+\psi}\left[(1+\psi)x - \psi\right]^{\frac{1}{\phi}} - \frac{\phi}{1+\psi} + 1, \tag{7}$$

with $\psi \leq 0$. This specification implies that the steady state (gross) markup μ equals $\frac{\phi}{(1-\phi)(1+\psi)+\phi}$, and it nests the standard Dixit-Stiglitz (1977) aggregator for $\psi = 0$.

Intermediate inputs are produced by monopolistically competitive firms indexed by i and operating a production function that is linear in labor

$$y_t(i) = \exp\{\varepsilon_t^z\} n_t(i) - f, \tag{8}$$

where ε_t^z denotes a productivity shock (driven by a stationary AR(1) process) and $f > 0$ is a fixed cost of production. Every period these firms face a fixed probability θ_p of price reoptimization, with non-resetting firms indexing prices to steady state inflation. We additionally assume that marginal costs faced by firms are distorted by a cost-push shock ε_t^p, which follows an exogenous stationary AR(1) process.

Assuming no myopia and firm ownership by restricted and unrestricted agents in proportion to their shares in the population, the problem of reoptimizing firms becomes

$$\max_{\tilde{P}_t} \mathbb{E}_t \sum_{s=0}^{\infty} (\theta_p)^s \frac{\Lambda_{t+s}}{P_{t+s}} \left(\tilde{P}_t \pi^s - \exp\{\varepsilon_{t+s}^p - \varepsilon_{t+s}^z\} W_{t+s}\right) y_{t+s}(i), \tag{9}$$

where $\tilde{P}_t$ is the newly reset price.

2.4 Fiscal Authority

The fiscal authority operates subject to the following nominal flow budget constraint

$$B_t^f + P_{L,t} B_{L,t}^f + \mathcal{T}_t + \Phi_t^c = R_{t-1} B_{t-1}^f + (1 + \kappa P_{L,t}) B_{L,t-1}^f + P_t g_t, \tag{10}$$

i.e., it finances its expenditures (net of taxation $\mathcal{T}_t$ and profits made by the central bank on its asset portfolio Φ_t^c) by issuing nominal short-term bonds B_t^f and long-term bonds $B_{L,t}^f$.

As the government issues bonds of different maturity, measurement of consolidated government debt necessitates taking a stand on the valuation of long-term debt. We adopt the spirit of the government debt statistics, which are based on face rather than market value of debt,[4] and value long-term government debt by discounting the outstanding stock of long-term bonds with $\frac{1}{1-\kappa}$, so that the consolidated government debt level as share of annualized trend GDP is defined as

$$GD_t^{con} = \frac{B_t^f + \frac{1}{1-\kappa} B_{L,t}^f}{4 P_t Y}. \tag{11}$$

Importantly, our measure of the consolidated fiscal position GD_t^{con} is not mark-to-market, which would be $B_t^f + P_{L,t} B_{L,t}^f$. This implies that we exclude direct revaluation effects and that central bank purchases of long-term bonds on the secondary market, which change the price of outstanding long-term bonds, has no direct impact on GD_t^{con}. Even so, we have checked that neither any qualitative nor significant quantitative longer-term aspects (say after 5 years) of the results for GD_t^{con} are notably affected by reasonable alternative definitions, including a mark-to-market based measure.[5]

Government consumption g_t is given by $g_t = g \exp\{\varepsilon_t^g\}$, where ε_t^g is assumed to follow an exogenous stationary AR(2) process

$$\Delta\varepsilon_t^g = \rho_{g,1} \Delta\varepsilon_{t-1}^g - \rho_{g,2} \left(\varepsilon_{t-1}^g - 1\right) + u_{g,t}, \tag{12}$$

We use an AR(2)-process for government consumption for two reasons. First, to assess the transmission to inflation for a commensurate boost to output as conventional interest rate policy changes and large scale asset purchases. Second, to capture implementation lags associated with conventional fiscal stimulus; i.e. although a spending bill has passed the parliament, it takes some time to fully boost the government consumption level.

On the revenue side, total nominal tax revenues $\mathcal{T}_t$ consist of proportional taxes levied on consumption and labor income and lump sum taxes

$$\mathcal{T}_t = \tau_t^c P_t c_t + \tau_t^n W_t n_t + T_t. \tag{13}$$

Consumption sales taxes are assumed to be constant ($\tau_t^c = \tau^c$), but the labor income tax rate varies gradually around its steady state level τ^n to stabilize the consolidated government debt position GD_t^{con} in the long-run according to

$$\tau_t^n - \tau^n = \psi_\tau \left(\tau_{t-1}^n - \tau^n\right) + \left(1 - \psi_\tau\right) \psi_b (GD_t^{con} - GD^{con}). \tag{14}$$

Setting ψ_τ near unity and ψ_b small ensures government debt sustainability in the long-run with very smooth and gradual adjustment of labor income taxes following the normative analysis in Bohn

[4] In particular, the debt definition in the Maastricht treaty is also based on the face value.

[5] We have studied two alternative measures. First, a market-to-market valuation of debt by defining the numerator of GD_t^{con} as $B_t^f + P_{L,t} B_{L,t}^f$. This measure is subject to near-term revaluation effects. A second measure is similar to our utilized concept in eq. (11) and discounts long-term debt with its steady state price, i.e., $B_t^f + P_L B_{L,t}^f$.

(1990). An additional key advantage of this setup is that short- and medium term debt dynamics is driven by other endogenous forces that we want to highlight.

As the treasury can issue bonds of different maturity, we also need to take a stance on the debt management strategy. To simplify the analysis, the fiscal authority is assumed to keep the composition of outstanding short- and long-term bonds (the latter evaluated at steady state prices) constant, i.e., $B_t^f / B_{L,t}^f = b / b_L^f$. Hence, when the central bank engages in QE and purchases long-term bonds issued by the treasury with central bank short-term assets, it shrinks the duration of outstanding government debt held by private agents.

When discussing the fiscal consequences of shocks and policies, it is instructive to define the fiscal deficit as

$$D_t^f = (R_{t-1} - 1)B_{t-1}^f + B_{L,t-1}^f + P_t g_t - \mathcal{T}_t - \Phi_t^c. \tag{15}$$

The deficit hence is a sum of debt servicing costs, which includes (net) interest payments on short-term bonds and coupon payments on long-term bonds, and of government spending, less tax revenue and central bank profit. Note that, since debt is nominal, its servicing cost is predetermined in nominal terms. Obviously, a deficit must be equal to the net debt issuance by the treasury, which we can show by combining equations eqs. (10) and (15), rewriting them in real terms

$$d_t^f = b_t^f - \frac{b_{t-1}^f}{\pi_t} + P_{L,t}\left(b_{L,t}^f - \kappa \frac{b_{L,t-1}^f}{\pi_t}\right). \tag{16}$$

Recall that our preferred measure of debt (eq. 11) relies on its face value, which in real terms (and before rescaling by steady state output) is $b_t^f + b_{L,t}^f/(1+\kappa)$. Then eq. (16) makes it clear that a change in this measure of fiscal position will be positively affected by fiscal deficits and negatively so by an increase in inflation, the latter eroding the real value of debt. Higher bond prices will also typically contribute negatively to the fiscal position as they imply that the government needs to issue less bonds of a given face value if it can sell them at a higher price.

2.5 Monetary Authority

The monetary authority conducts "conventional" monetary policy according to a Taylor-type feedback rule for the gross nominal policy rate R_t, subject to an effective lower bound (ELB, which we assume to be zero) constraint

$$R_t = \max\left\{1, \tilde{R}_t\right\}, \qquad \frac{\tilde{R}_t}{R_t^*} = \left(\frac{\tilde{R}_{t-1}}{R_{t-1}^*}\right)^{\gamma} \left[\left(\frac{\pi_t^{yoy}}{\pi}\right)^{\gamma_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{\gamma_y}\right]^{1-\gamma} \exp\{\varepsilon_t^r\}. \tag{17}$$

$\tilde{R}_t$ is the unrestricted (shadow) rate that would prevail if monetary policy was not subject to an ELB, in which case $\gamma_r \in (0,1)$ controls the degree of interest rate smoothing, and γ_π and γ_y determine the strength of the long-run response of the policy rate to deviations of (year-over-year) inflation $\pi_t^{yoy} = (P_t/P_{t-4})^{\frac{1}{4}}$ and output growth from their steady state values. Since the model features variations in the effective discount factor in eq. (1) that can be neutralized by suitable adjustments of the short-term policy rate path, the rule (17) allows for a time-varying neutral gross policy rate R_t^*, defined as the steady state nominal gross policy rate adjusted for the expected change in the discount factor shock ε_t^d

$$R_t^* = R\mathbb{E}_t \exp\{\varepsilon_{t+1}^d/\varepsilon_t^d\}. \tag{18}$$

As we explain later, the exact process for the discount factor will be chosen to trigger either a deep and hump-shaped decline in R_t^* below the ELB, or a more shallow and L-shaped one. Finally, the policy rule (17) allows for a standard i.i.d. normally distributed short-term policy rate shock ε_t^r.

The central bank can also be active in the domestic bond market, i.e., it can take a position $B_{L,t}^c$ in long term bonds, financing it entirely by issuing one-period reserves B_t^c that pay interest R_t, and hence which – from the perspective of private agents – are indistinguishable from short-term government bonds. We shall refer to $QE_t \equiv P_{L,t}b_{L,t}^c = -b_t^c$ as the size of LSAP and assume it obeys the following rule

$$QE_t = \left(1 + (1-\varrho)\left(\kappa\frac{P_{L,t}}{P_{L,t-1}} - 1\right)\right) QE_{t-1} + \varepsilon_t^{QE}, \tag{19}$$

where $0 \leq \varrho < 1$ is a parameter controlling the reinvestment strategy.[6] Furthermore, ε_t^c denotes discretionary purchases of long-term assets by the central bank, and is assumed to follow a stationary AR(1) process.

As noted earlier, any profits or losses on the central banks' asset portfolio are fully backed by the government. The holding profits by the central bank – Φ_t^c in eq. (10) – associated with previous central bank asset purchases can be written as

$$\Phi_t^c \equiv R_{t-1}B_{t-1}^c + (1 + \kappa P_{L,t})\, B_{L,t-1}^c. \tag{20}$$

The first term on the right-hand side in eq. (20) is the gross cost of financing a given portfolio of long-term assets, because if there had been no LSAPs, B_{t-1}^c would be nil. The second term is the gross value of the long-term assets the central bank has purchased until period $t-1$, including the current coupon payment. A purchase of long-term assets in period $t-1$ implies that $B_{L,t-1}^c$ is

[6] See Appendix A.2 for detailed derivations and a comprehensive discussion of eq. (19).

positive but that B^c_{t-1} is negative, hence the summation of the negative short- and positive long-positions forms a net profit for the central bank. As these profits are immediately transferred or financed by the treasury, we think about Φ^c_t as the period-by-period profit. Hence, the accumulated central bank profits in period $t+h$ on a QE portfolio purchased in period t is given by

$$CBPROF^{acc}_{t+h} = \Sigma^h_{s=0}\Phi^c_{t+s}. \tag{21}$$

2.6 Market Clearing Conditions

Equilibrium in the goods market requires

$$y_t = \omega_r c^r_t + (1-\omega_r)c^u_t + g_t, \tag{22}$$

and

$$y_t\Delta_t = \exp\{\varepsilon^z_t\}n_t - f, \tag{23}$$

where

$$\Delta_t \equiv \frac{1}{1+\psi}\left(\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{\frac{1}{1-\phi}} di\right)^{-\phi} \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{\frac{\phi}{1-\phi}} di + \frac{\psi}{1+\psi}, \tag{24}$$

captures price dispersion arising on account of staggered price setting in the intermediate goods sector.

Complementing these, we also have market clearing conditions for bonds issued by the home economy's government, including central bank reserves

$$(1-\omega_r)B^u_t = B^f_t - B^c_t, \tag{25}$$

and

$$\omega_r B^r_{L,t} + (1-\omega_r)B^u_{L,t} = B^f_{L,t} - B^c_{L,t}. \tag{26}$$

2.7 Calibration

Broadly speaking, we have two key considerations when calibrating the model. First, we set parameters pertaining primarily to the dynamics of the model to enable it to match the empirical evidence on the transmission of short-term interest rates, QE, and government spending in large economies like the U.S. and the Euro area that we can approximate as closed economies. To this end, we study changes in the policy tools which are implemented by shocks to the short-term interest rate (ε^r_t in eq. 17), central banks asset purchases (ε^{QE}_t in eq. 19), and government consumption (ε^g_t in eq. 12). Second, we follow standard practice and calibrate other parameters to match key steady state and fiscal proportions observed in the data for the U.S., or rely on an extant literature for parameters not pinned down by either dynamics or steady state considerations.

Table 1 shows the adopted parameter values and Table 2 presents the targeted steady state ratios. The time period throughout corresponds to a quarter.

Table 1: Model Parameter Values.

Parameter	Value	Description
		Households
ω_r	0.2	Share of restricted households
σ	1	Inv. elasticity of intertemporal substitution
φ	2	Inv. Frisch elasticity of labor supply
$\varkappa$	0.8	Habit Persistence
β_u	0.99875	Discount factor, unrestricted households
β_r	0.99625	Discount factor, restricted households
m_u	0.95	Cognitive discounting, unrestricted households
m_r	1	Cognitive discounting, restricted households
ϕ_w	0.5	Wage markup
θ_w	0.82	Calvo wage probability
ξ	0.02	Transaction cost on long-term bonds
		Firms
μ	1.15	Gross price markup
ψ	-12	Kimball parameter
θ_p	0.75	Calvo price probability
		Fiscal Policy
τ^c	0.15	Steady state Consumption Sales Tax
τ^n	0.35	Steady state Labor income Tax
ψ_τ	0.98	Tax Smoothing Coeff in eq. (14)
ψ_b	0.01	Gov't Debt Response Coeff in eq. (14)
$\rho_{g,1}$	0.7	First difference coeff in eq. (12)
$\rho_{g,2}$	0.02	Error correction coeff in eq. (12)
D	40	Long-term bond duration
		Monetary Policy
γ	0.9	Interest rate smoothing
γ_π	2	Interest rate response to inflation
γ_y	0.5	Interest rate response to output gap
ϱ	0	Reinvestment strategy
ρ_{QE}	0.4	AR(1) coefficient on QE shock

Notes: D and μ are composite parameters defined as $D = \pi\beta_r^{-1}/(\pi\beta_r^{-1} - \kappa)$ and $\mu = \phi/[(1-\phi)(1+\psi)+\phi]$, so calibrating them means pinning down κ and ϕ, respecitvely.

An important part of our calibration concerns the structure of the bond market. We set the steady state share of sovereign bonds in annual GDP to 0.75, which is close to what was observed in many countries before the Covid-19 pandemic. We also assume that central bank holdings of government bonds were initially zero. We set the duration of long-term bonds to 10 years and their share in total sovereign bond issuance is calibrated at 0.65. These choices are consistent with the approximation of the US debt maturity structure proposed by Barrett and Johns (2024) and imply that the effective duration of outstanding public debt is close to 7 years.

Another key group of parameters determines the degree of bond market segmentation. This is governed by the share of restricted households ω_r, which we set to 0.2, and the sensitivity of transaction costs to changes in bond holdings by unrestricted households ξ, which we calibrate at 0.02. These choices allow us to generate the response of the term premium and output to QE that is consistent with empirical evidence for the U.S. and the Euro area discussed earlier. We use the US average levels of inflation, short-term rates and long-term rates (and hence also the term premiums) to pin down, respectively, the inflation target π at 1.005 (2% annualized), the discount factor of unrestricted households β_u at 0.99875, and that of restricted agents β_r at 0.99625.

Given the focus of our study, the crucial part of calibration concerns parameters governing inflation dynamics, especially in response to monetary policy actions. We allow for a modest degree of cognitive myopia by setting the corresponding discounting parameter of unrestricted households m_u to 0.95. Compared to papers that estimate this parameter within a DSGE framework – for instance Gust, Herbst and Lopez-Salido (2022) or Kolasa, Ravgotra and Zabczyk (2025) – our choice implies a rather small deviation from rational expectations, which, however, turns out to be sufficient to make the potency of forward guidance small when the economy is in a long liquidity trap. To account for state-dependence in the slope of the Phillips curve, we follow Harding, Lindé and Trabandt (2022, 2023) and set the Kimball curvature parameter ψ to -12. The Calvo probability for prices θ_p is set to 0.75 and that for wages θ_w is calibrated at 0.82, consistent with the empirical evidence on average price and wage duration.

Table 2: Targeted Steady State Ratios.

Steady State	Value	Formulae
Government Consumption to GDP	0.2	$\frac{g}{y}$
Government Debt to Annual GDP	0.75	$\frac{b^f}{4y}$
Net inflation (Annualized)	2.0	$400(\pi - 1)$
Nominal Policy Rate (Annualized)	2.5	$400(R - 1)$
Term-premium	1.0	$400(R_L - R)$
Share of Long-term Bonds in Total Bonds	0.65	$\frac{P_L b_L^f}{b^f}$
Central Bank Assets	0	$P_L b_L^c = b^c$

The remaining parameters are relatively well-established in the literature. The steady state government spending is set to 20% of GDP, roughly in line with the long-run averages observed in the data. The elasticity of intertemporal substitution σ, the Frisch elasticity of labor supply φ, and price markups μ are all set to typical values used in New Keynesian models. The monetary policy rule coefficients γ, γ_π and γ_y also reflect typical values found in the DSGE literature.

Given these parameters, Figure 1 show the transmission of the key policy instruments we will study in the paper around the steady state. We size the innovation to each policy instrument – conventional white noise short-term policy rate shocks ε_t^r in eq. (17) , an innovation to large scale asset purchases u_t^{QE} in eq. (19), and government consumption u_t^g in eq. (12) – so that each policy instrument moves output in the upper left panel at peak by the same magnitude. We normalize the output effect around a 100 basis cut in the short-term policy rate.

The figure documents that the effects on output from short-term interest policy cuts (blue solid line) and government spending hikes (red dotted) are well aligned with the empirical evidence. A one percent policy rate cut drives up output by about 0.7 percent after about one year and a half, which is similar to the VAR evidence in the seminal paper by Christiano, Eichenbaum and Evans (2005) and consistent with more recent evidence discussed in detail by Ramey (2016) and Antolin-Diaz and Rubio-Ramirez (2018).

On the fiscal side, our calibration implies an output multiplier of 0.8 on average over the first two years if we assume that government spending follows an AR(2) process that peaks after about 6 quarters. If government spending is more frontloaded and follows an AR(1) process, our model implies an output multiplier around unity. This is in line with the seminal papers by Blanchard and Perotti (2002) and Gali et al. (2007), as well as the more recent studies by Ramey and Zubairy (2018) and Leeper, Traum and Walker (2017), which suggest a fiscal multiplier close to unity in normal times. Even so, while standard monetary and fiscal stimulus provide a similar output boost, its composition is rather different. The bottom right panel shows that higher government spending crowds out private consumption, whereas higher private consumption is the sole driver of the output expansion for a policy rate cut.

The figure also documents that it takes large scale asset purchases by about 13 percent of baseline GDP to generate the same output expansion as a 100 basis points policy rate cut when the short-term rate adjusts in response to QE purchases. This implies a peak output impulse by about 0.05 percent for QE worth 1 percent of baseline GDP. This is a very conservative (i.e. small) estimate, even relative to the empirical evidence surveyed by Fabo et al. (2021) when central bank affiliated papers are excluded, and which imply that 10% of QE leads to a peak output impact of 1.1 percent. Now, the transmission of QE to output will be somewhat larger in a liquidity trap when nominal interest rates do not respond for some time,[7] but since we address the FG puzzle with

[7] More generally, research by Engen, Laubach, and Reifschneider (2016) highlights that QE's impact on unemployment is more pronounced under a more gradual Taylor rule, with central banks adopting commitments to enhance

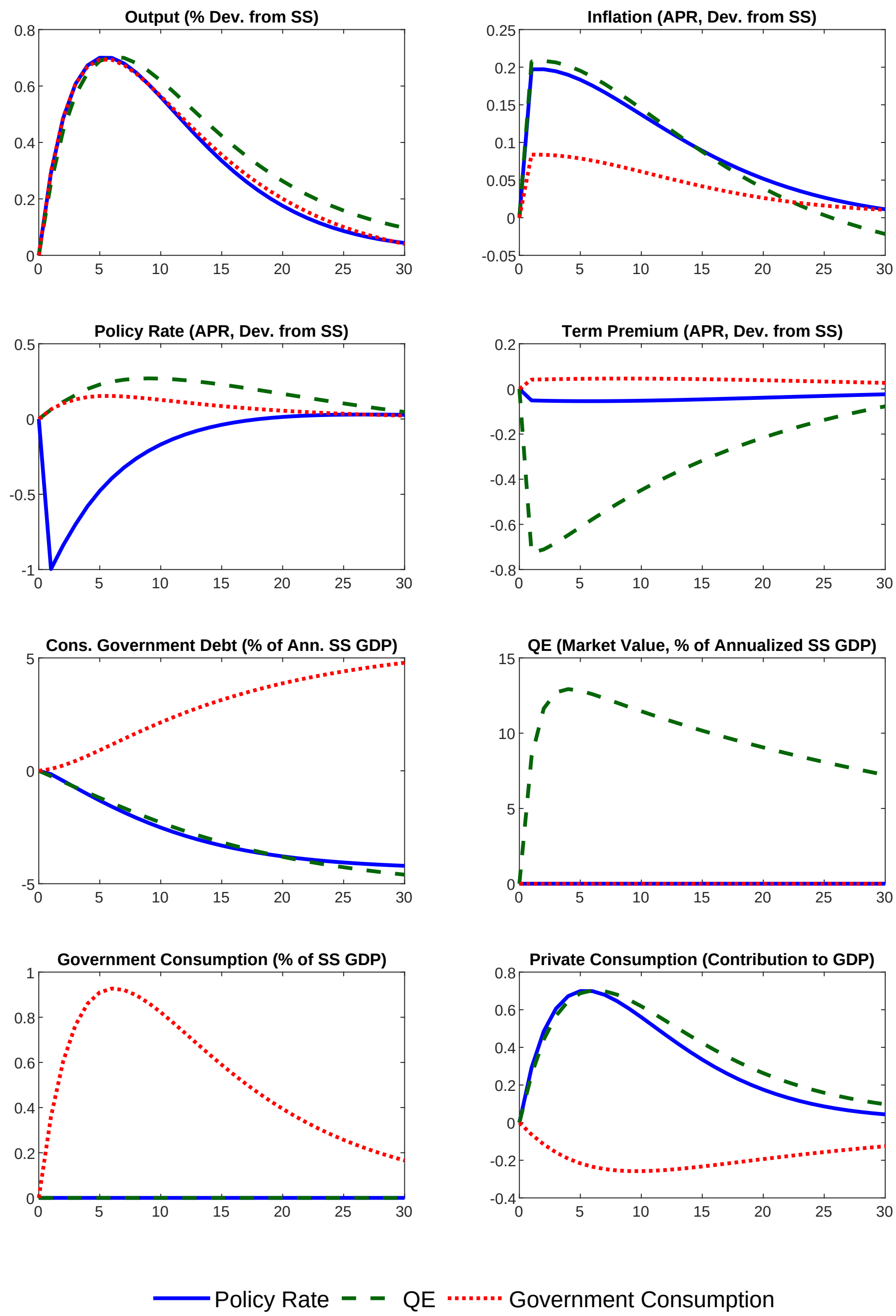

Figure 1: Transmission of Policy Instruments in the Calibrated Model.

cognitive discounting, we err on the conservative side on the potency of QE to stimulate output and raise inflation. By implication, we are cautious in our assessment of QE's favorable impact on

QE's stimulus.

the consolidated fiscal position.

A final observation regards the transmission of the different instruments to inflation. Comparing QE with conventional short-term policy rate cuts, we see that the inflation transmission is very similar. Figure 1 shows slightly larger impact from QE than conventional policy due to the fact that the calibration of the model implies slightly more persistent effects of QE on output. Comparing the two monetary policy instruments with conventional fiscal policy, we find that the monetary policy tools are notably more effective in stimulating inflation for given boost to output. This difference is driven by the fact that monetary and fiscal policy have very distinct differential transmission on labor supply. Higher government spending increases labor supply and reduce real wages which attenuates the upward pressures on output. Put differently, higher government spending drives up potential output and is hence associated with a smaller increase in the output gap than monetary policy when we normalize by the same stimulus to output for the different policy tools.

2.8 Solution

To preserve nonlinearities associated with the Kimball aggregator and the effective lower bound constraint, we solve the nonlinear model using the extended path approach of Fair and Taylor (1983) readily available in Dynare (Juillard, 1996). This solution method is also known as a two-point boundary value or time-stacking algorithm. The Fair-Taylor solution method imposes certainty equivalence on the nonlinear model, and hence does not account for future shock uncertainty. Accordingly, all relevant information is captured by the current state of the economy, including the contemporaneous and future realization of the exogenous shocks that are known by agents.

To deal with behavioral discounting, which is not tractable in a fully non-linear setting, we proceed as follows. We first derive the linearized first-order conditions describing the decisions of behavioral agents. These yield aggregate Euler conditions in which the forward looking terms are multiplied by the cognitive discounting parameter m, with an additional additive term that depends on agents' asset holdings (which, for reasons discussed in Kolasa, Ravgotra and Zabczyk, 2025, is very small). Guided by these considerations, we approximate the relevant first-order conditions in the non-linear model with formulas that, after linearization, yield equations that match the linear derivations, up to the above mentioned quantitatively small term.

3 Transmission of QE in Deep Liquidity Traps

When assessing the effects of QE, it is useful to do it in a liquidity trap generated by economic conditions of varying severity and characteristics. We study two situations in this paper. In this section, we analyze the transmission of QE in a "deep" liquidity trap, where the output gap is substantially negative, inflation is projected to be well below the central banks target for some time, and the short-term policy rate is constrained by the ELB for a prolonged period of time. Roughly speaking, this scenario would be similar to that prevailing in the aftermath of the global financial crisis (GFC), where financial conditions had improved but unemployment was running far above its long-run level. In Section 4, we will analyze the transmission of QE in a "shallow" liquidity trap, in which economic slack is less negative, the inflation undershoot below target is projected to be smaller, and the policy rate is less constrained by the ELB. This is reasonably similar to the situation that a number of advanced economy central banks faced before the pandemic, when inflation seemed stuck well below target even as unemployment moved toward record lows.

3.1 A Baseline Scenario with Slow Recovery

Our first simulation considers QE in a very deep liquidity trap associated with a severe recession in which the output gap is deeply negative and inflation well below target. The blue solid line in Figure 2 presents a baseline simulation in this vein. Starting from an initial position in period 0, when the output gap is closed and inflation is at its 2 percent target, a persistent increase in desired household savings, represented by the discount factor shock ε_t^d, drives the neutral net short-term policy rate ($R_t^* - 1$, see eq. 18) and the nominal net shadow rate $\tilde{R}_t - 1$ in the rule (17) below 0 for a protracted period as shown in the lower left panel in Figure 2.[8] As a result, the short-term policy rate becomes pinned at the ELB for 5 years absent any new shocks, and the undesired positive persistent gap between the actual and neutral policy rate triggers a sharp decline in output by nearly 8 percent. As the discount factor shock leaves potential output unaffected, it also triggers a commensurate negative output gap (not shown) along with significant persistent decline in inflation below the central bank 2 percent target.

Amid this outlook, in which forward guidance in the form of a lower-for-longer policy rate path is ineffective in boosting output and improving the inflation outlook due to the combined impact of behavioral discounting and Kimball asymmetries in price setting, the central bank engages in

[8] When simulating the modal baseline projection in Figure 2, we use a mix of AR(2) and AR(1) processes. The former allows us to generate a U-shaped path of the shadow rate, while the latter ensures that this variable falls below zero already in the first period.

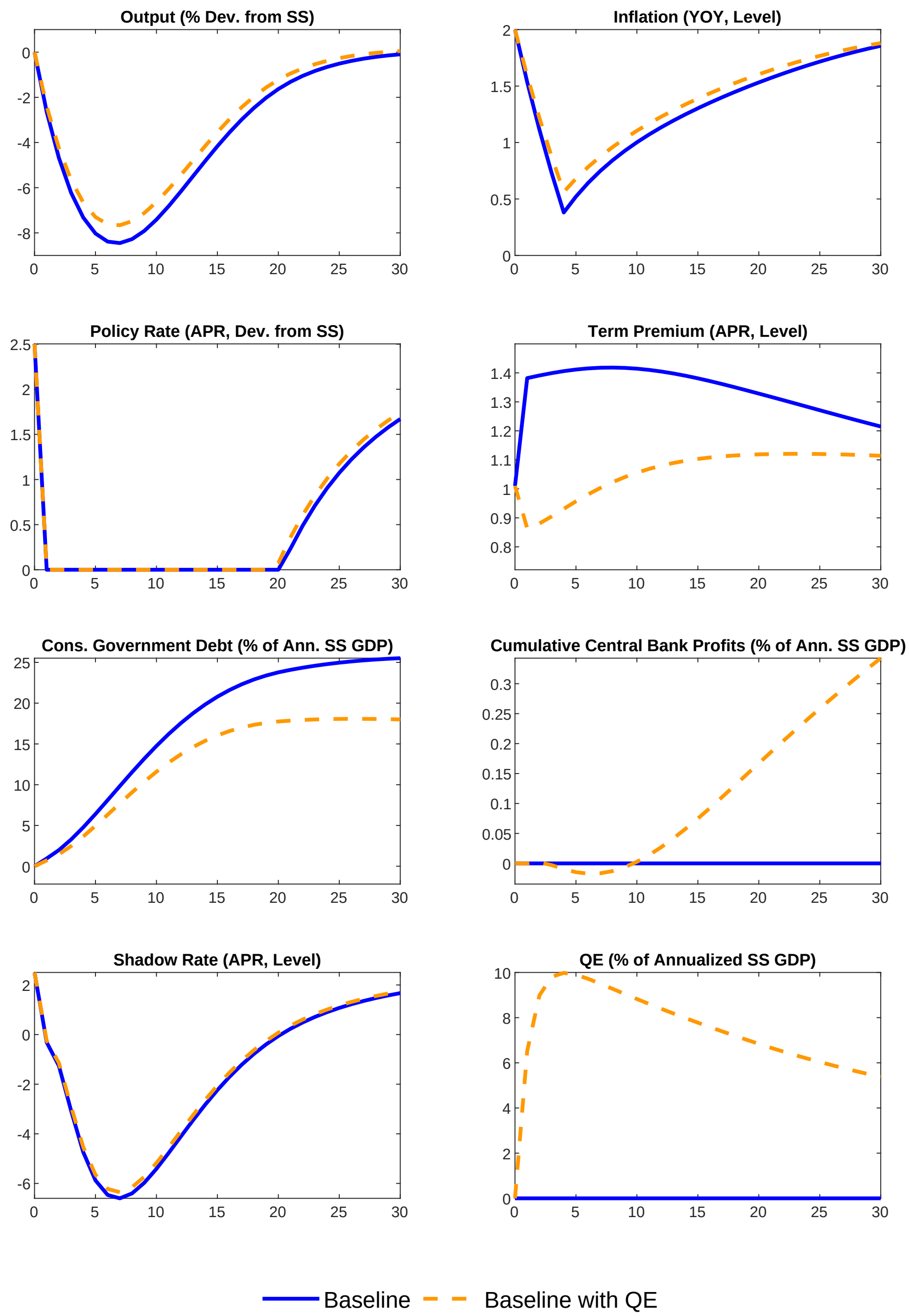

Figure 2: Deep Recession without and with QE.

large scale asset purchases.[9] Our calibration of the process for purchases of long-term assets in eq. (19) implies that QE is assumed to be implemented in an anticipated yet gradual fashion. Given

[9] See Erceg et al. (2024) for a detailed discussion why these two features of our model limit the effectiveness of forward guidance in a prolonged ELB episode.

the calibration of the central banks' reinvestment policy and QE shock inertia, we set the purchase announcement innovation in period 1 such that the stock of assets held by the central bank peaks at 10 percent of baseline GDP after one year as can be seen from the dashed orange line in the lower right panel in Figure 2.

In the deep recession scenario, QE clearly has sizeable macroeconomic benefits. As seen in Figure 2, asset purchases boost output (upper left panel) by about 0.8 percent relative to baseline after six quarters and core inflation (upper right panel) by 0.2 percentage points. This stimulus reflects that markets expect the central bank to progressively expand its balance sheet through asset purchases, so that the term premium declines persistently and initially by about 50 basis points (middle right panel).[10] As the liquidity trap is deep, the macro stimulus provided by QE induces only a slightly steeper liftoff of the policy rate (middle left panel). As this offset is relatively modest, most of the decline in the term premium passes through to long-term yields.

On the fiscal side, the QE-driven stimulus to output boosts the government's primary balance, reduces the real value and cost of servicing past debt as well as the cost of issuing new debt (due to higher bond prices), and hence results in a large reduction in government debt. The central bank also makes profits, with its capital rising close to 0.3 percent of annual GDP after seven years (middle right panel). The central bank profits reflect that long-term yields – while declining substantially – remain well above the policy rate that is pinned at zero for several years and then rises only gradually to its long-run level. As a result, the consolidated fiscal position (middle left panel) improves substantially by about 6 percent of baseline GDP after five years, of which the bulk reflects increased tax revenue (as we discuss in more detail later).[11] In effect, QE more than pays for itself insofar as the macro stimulus is accompanied by falling government debt. In the medium term, this translates into a lower path of labor income taxes that are used to stabilize public debt, and hence a reduction in distortions that these taxes create.

This "holy trinity" of significant macroeconomic benefits, a boost to government revenues, and positive central bank profits seems a reasonable characterization of the central bank experience with QE in the aftermath of the GFC. Moreover, in a deep recession, the macro and fiscal benefits are likely to remain substantial even if there are shocks that occur after the implementation of a QE program that would call for faster policy rate hikes than under normal conditions. In particular,

[10] Following Chen, Curdia, and Ferrero (2012), we define the term premium as the difference between the yield to maturity on long-term bonds and its hypothetical realization in the absence of transaction cost ($\zeta_t = 0$). See also Appendix A.1.

[11] The consolidated position includes central bank profits, which are assumed to be remitted immediately in our model.

given that the central bank would like to set a deeply negative policy rate if constrained by the ELB, modest-sized aggregate demand shocks – such as from fiscal expansion – would not push toward significantly earlier liftoff, and the benefits of QE from a macro and consolidated fiscal perspective would be similar to those in Figure 2.

3.2 A Scenario with Faster Recovery

As suggested by recent experience, large shocks could materially affect the ex post benefits of a given QE program, especially if they induce a rapid recovery and inflation surge that pushes the central bank to exit a stimulative stance much earlier than in the modal outlook. Under these circumstances, the central bank could also face losses as it gets stuck with a large stock of low-yielding assets but has to pay higher interest on reserves (see eq. 20).

To illustrate this, Figure 3 compares the effects of QE in our baseline scenario with a slow projected recovery to a scenario with an unexpectedly faster recovery. The left column shows the effects in the baseline without QE, the modal "slow-recovery" projection with QE, and a third scenario with an unexpected faster recovery. The first two lines were already shown in Figure 2, whereas the green dash-dotted line presents a scenario where a more vigorous recovery precipitates inflation and long-term yields to rise notably faster than under the modal outlook. This scenario features a mix of cost-push impulses for firms (ε_t^p) and stronger consumption demand (ε_t^c) that unexpectedly hit the economy in period 7 as indicated by the vertical black-dashed lines (notice that quarter 0 is the initial period before any shock hits the economy).[12] The right column shows the marginal effects of QE without and with the faster recovery. The impact of QE under the modal outlook without the (surprisingly) faster recovery is simply the difference between the orange-dashed and solid blue lines in Figure 2. The marginal impact of QE with the faster recovery is calculated as the difference between the trajectory with faster recovery in the left column in Figure 3 and a counterfactual simulation with faster recovery but no QE (not shown).

We see from the right column panels for output and inflation that the unexpected faster recovery reduces the ex post macroeconomic benefits of QE. An earlier liftoff of the policy rate dampens the stimulus to output, and the non-linearity in the Phillips curve implies an uptilt in the sensitivity of inflation to asset purchases, which is not desired when inflation is running above the central bank's target. Moreover, as can be seen from the lower right panel, the associated fall in bond

[12] The size of the unexpected shocks is chosen to generate a surge in inflation that is rapid yet plausible given the historical data and stochastic simulations that we present later. Note that the upswing in the US core inflation during the post-COVID period was more than 2 times bigger than we assume here and would have much more dramatic consequences.

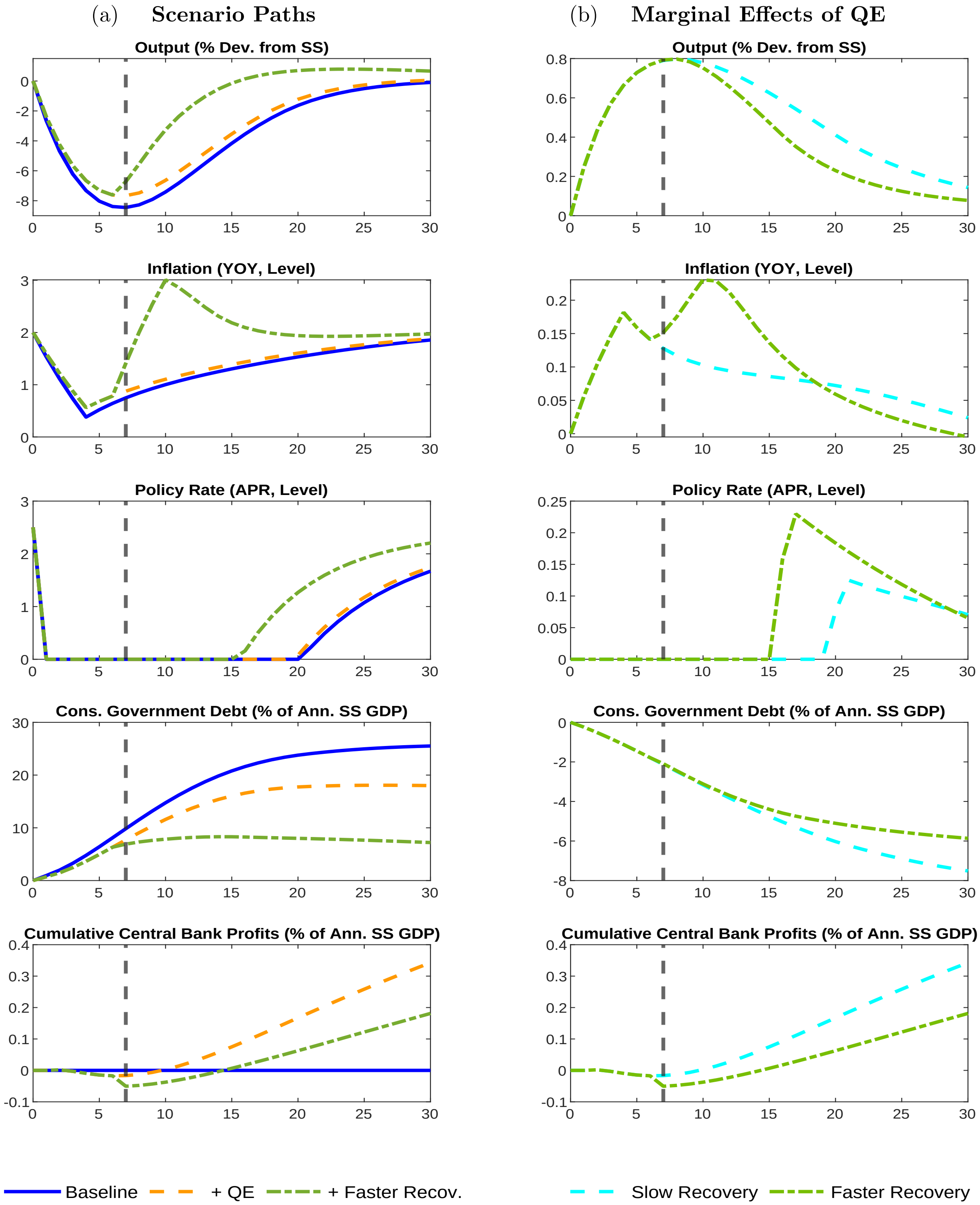

Figure 3: QE in a Deep Recession with Unexpected Faster Recovery.

prices and higher funding costs of the asset purchases implies that the central bank makes some mark-to-market losses on its QE portfolio when the economy bounces back faster than previously envisioned, but these losses are small and are completely erased within two years as bond prices recover.[13] The next to last bottom panel shows that the consolidated fiscal position improves less under the unexpectedly faster recovery, but the gains are still very sizable.

Overall, QE still provides substantial macro benefits, also from this ex post perspective – boosting output and inflation when economic slack is high and the welfare benefits are presumably highest. While a possible overshoot of the inflation target may require a rise in the policy rate earlier than envisioned when QE was undertaken, and hence pare back central bank profits, the consolidated fiscal position still improves considerably. This is because the depth of the liquidity trap prevents an immediate lift-off of the policy rate, which happens only two years after the earlier recovery kicks in. When the policy rate finally increases, it does not need to overshoot its long-run level to contain the inflationary pressure. All of this means that central bank losses are limited and dwarfed by the fiscal benefits resulting from higher tax revenues and lower costs of issuing and servicing public debt. As we discuss later based on stochastic simulations, the risk that QE worsens the overall fiscal position is negligible even if the central bank ends up making significant losses. These results underscore the robustness of QE in a deep trap and the importance of looking at the consolidated fiscal position when assessing its fiscal consequences.

3.3 A Comparison with Conventional Fiscal Stimulus

In this section, we compare QE with conventional fiscal stimulus. The fiscal instrument we consider is an increase in government consumption, for which there is ample empirical evidence in the U.S. and the Euro area as discussed in Section 2.7. We compare both policies by normalizing them to imply the same boost to aggregate output during the coming 7.5 years.[14] Given the same output impulse, we can compare the effects on inflation and the consolidated fiscal position (i.e. government debt). We keep our focus on the case of a deep liquidity trap as this is the most realistic situation where both policies can be meaningfully deployed. The left column in Figure 4 compares the marginal impact of QE and government spending under the modal outlook with a projected slow recovery from the recession.[15] Following the analysis in Figure 3, the right column compares the marginal effects when the economy unexpectedly recover faster than expected from

[13] Quantitatively, the losses are here small because the liquidity trap is deep and the unexpected faster recovery materializes late after asset purchases have ended. We will show later that central bank losses can be much bigger in a shallow liquidity trap.

[14] More precisely, we add to our baseline scenario without QE a sequence of government spending shocks ε_t^g (fully anticipated after announcement), calibrated such that they imply the same path of output over the first 30 quarters as in the baseline scenario with QE.

[15] The marginal impact of QE is the same as in the right column of Figure 3. The marginal impact of higher government spending is calculated analogously.

period 7 onwards (as indicated by the dashed vertical line). In the simulation with the unexpected faster recovery, both QE and fiscal stimulus that was announced and implemented in period 1 are assumed to be fixed and the same as under the modal projection with a slow recovery.

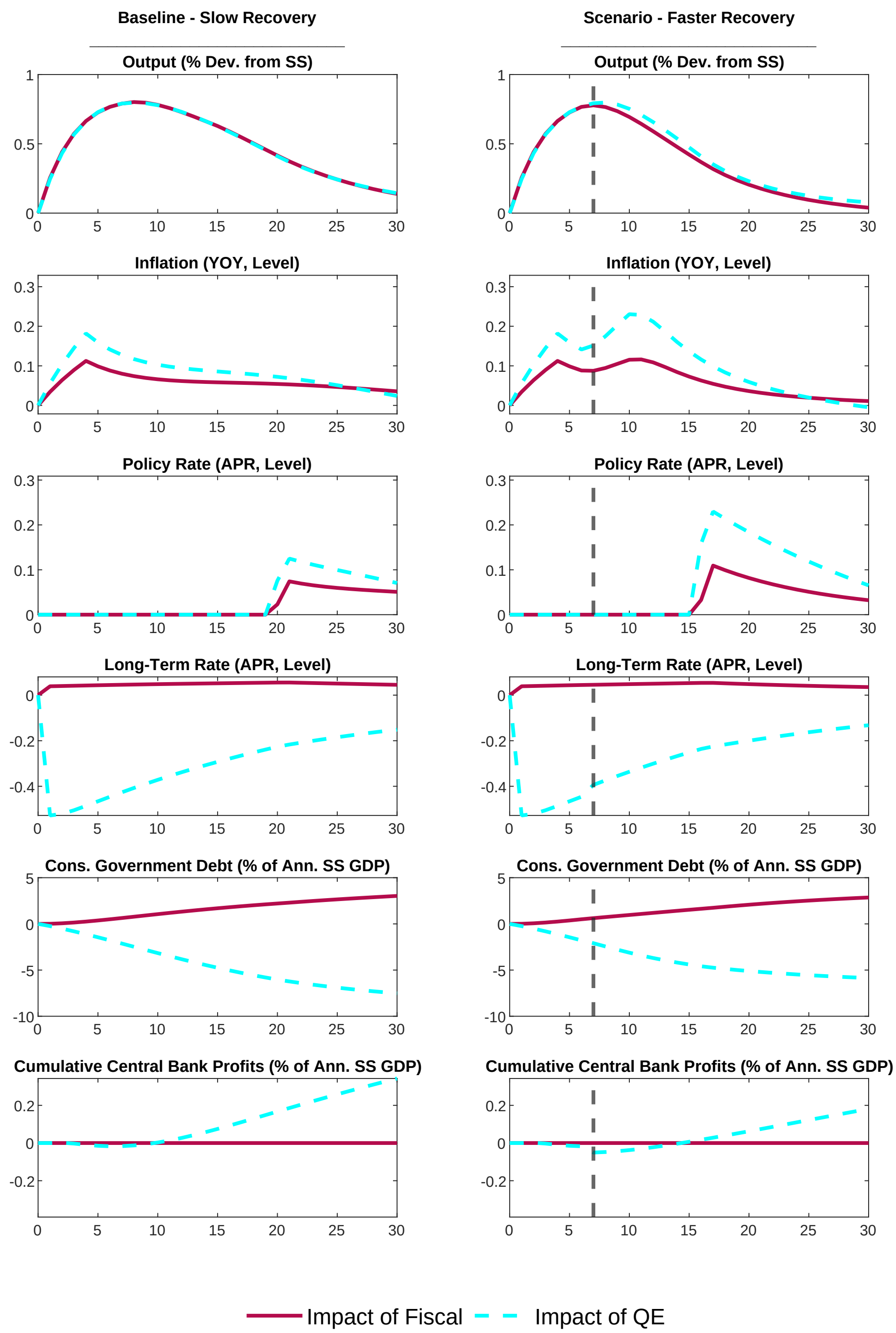

Figure 4: QE versus Fiscal Stimulus in a Deep Trap with Slow and Faster Recovery.

The marginal impact of QE has already been extensively discussed, so in the following we focus on the transmission of conventional fiscal policy. Starting with our baseline results in the left column with a slow recovery, we see that fiscal policy stimulates inflation less than QE for given output boost. This feature was noted when we discussed Figure 1 and is driven by the fact that higher government spending increases potential output in our model, whereas QE leaves it largely unaffected. This implies that fiscal stimulus generates a smaller positive output gap when we normalize both policy interventions on a given sized increase in output, and hence a smaller increase in inflation, although both policies transmit via increasing aggregate demand. Another difference between QE and conventional fiscal stimulus is that the latter will actually nudge the term premium, and hence the long-term rate is a little higher as can be seen from the fourth left panel. The increase in the term-premium is driven by larger issuance of long-term assets as the government debt increases notably under fiscal stimulus via higher government spending. Quantitatively, our model implies that the consolidated government debt position worsens by about 3 percent of steady state GDP after 7.5 years, whereas QE improves the fiscal position by roughly 7 percent.

The right column in Figure 4 presents the results when a mix of cost-push impulses for firms (ε_t^p) and stronger consumption demand (ε_t^c) trigger a faster recovery with stronger output and well above target inflation as considered in Section 3.2. The scenario with a faster recovery means that both policy tools feature notably stronger transmission to inflation, whereas the output stimulus is reduced, especially for QE as the central bank needs to lean against the higher inflationary pressure with tighter policy stance. As we have seen, a faster-than-expected recovery from the recession mutes the improvement in the consolidated fiscal position due to QE notably. The same is true for conventional fiscal stimulus, but the change is very small. Thus, the transmission of conventional fiscal policy is less sensitive to uncertainty than QE. Still, Figure 4 makes it crystal clear that QE in expectation should be associated with notably lower consolidated fiscal costs than conventional fiscal policy, although there is a risk that QE ends up exposing the central bank to some capital losses on its portfolio of long-term bonds, hence making the fiscal benefits potentially smaller if the economy recovers faster than envisaged.

We now seek to understand the drivers behind the consolidated public debt position depicted in Figure 4 for the two alternative means to stimulate the economy in a deep liquidity trap. Accordingly, Figure 5 decomposes the drivers of GD_t^{con} in eq. (11) into the following categories: revenues from consumption and labor income taxes, government consumption expenditures, government debt service costs, central bank profits, and debt deflation and revaluation effects. The red solid lines show the sum of all these drivers and are simply the same as in Figure 4.

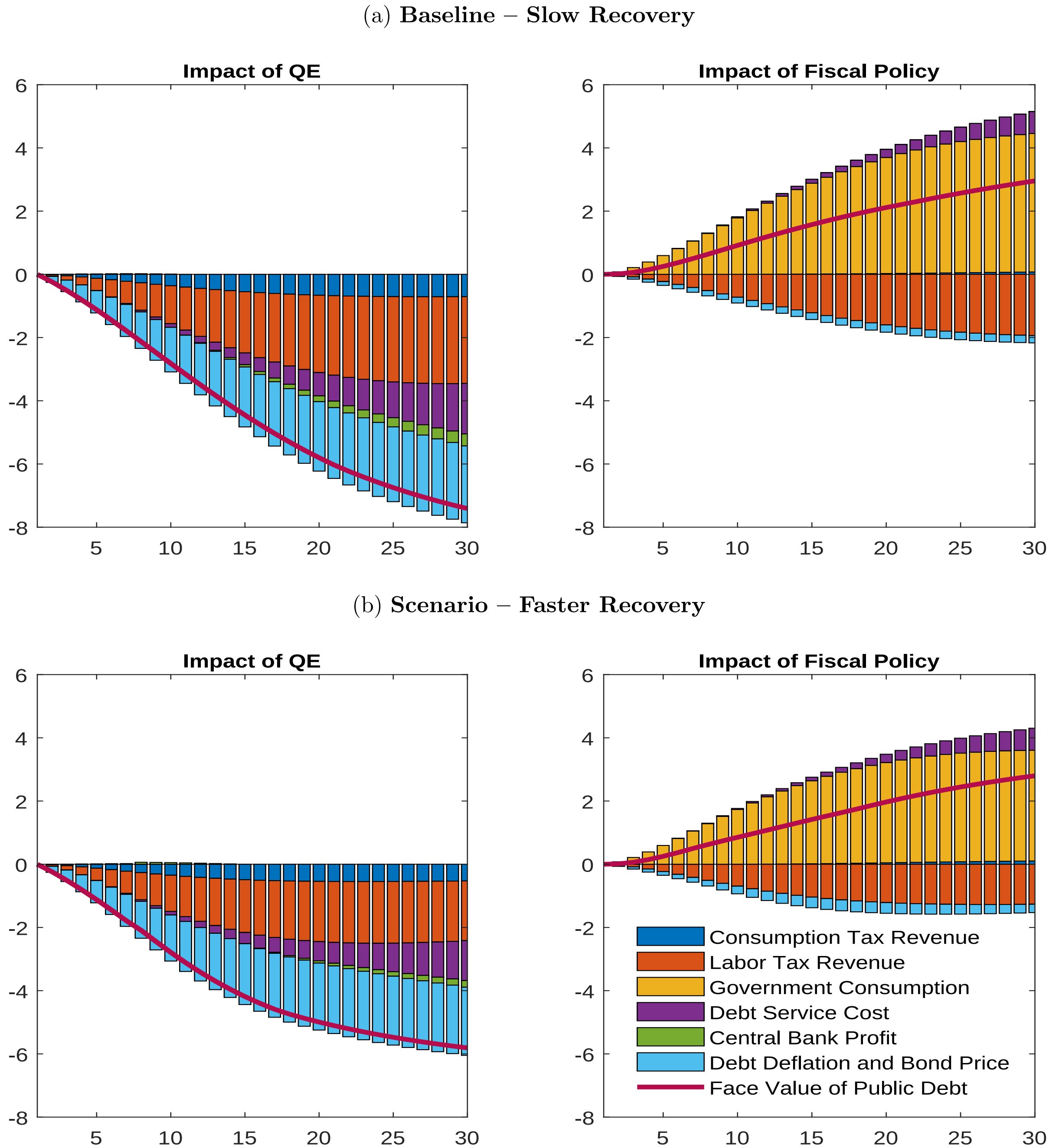

Figure 5: Decomposition of QE and Fiscal Stimulus to Consolidated Government Debt.

Panel (a) in Figure 5 shows the decompositions of government debt for QE and higher government spending in our baseline with slow recovery, i.e. the left column in Figure 4. Starting with QE, we see that increased labor income tax revenues – and to some extent also consumption income taxes – notably improve the fiscal position over time. But also higher inflation, lower debt service costs and gains on the central bank's QE portfolio contribute favorably.

Turning to the stimulus via higher government spending, shown in the upper right panel, we also see improvement in labor income tax revenues, albeit less so than under QE. This difference between QE and conventional fiscal stimulus may at first glance be surprising since the output increase is by construction made identical. As the model does not feature physical capital and technology is the same, the output expansion is completely accounted for by an identical expansion in hours worked. Even so, QE generates notably larger labor income tax revenues as real wages rise less under higher government spending. This is because, unlike QE, an increase in public consumption induces a positive shift in labor supply, which keeps wage pressure lower. Moreover, because higher government spending eventually leads to some crowding out of private consumption, sales tax revenues do not contribute significantly to the change in the fiscal position, in contrast to QE. But the major difference in the consolidated fiscal position with higher government spending relative to QE is the costs of the fiscal stimulus itself: accumulating government purchases over time is a key driver of the deterioration in the fiscal position. On top of this, by driving up government debt, conventional fiscal stimulus also induces higher debt service costs. Finally, when compared to government spending, QE leads to a sizable increase in bond prices and has a much stronger effect on inflation. This means that QE contributes much more to lower consolidated public debt by decreasing the quantity of bonds that need to be issued to finance the deficits and by decreasing the real value of outstanding bonds.

Panel (b) shows the corresponding decompositions for the scenario with a faster recovery, i.e. right column in Figure 4. While the drivers of debt dynamics for conventional fiscal stimulus are very similar to our baseline scenario with slow recovery (albeit quantitatively attenuated), there are some notable differences. In the left chart in Panel (b), we see that less labor income tax revenues is key to smaller improvement in consolidated debt when the economy recovers notably faster than envisioned when QE is implemented. Central bank losses now also contribute less, and are even a source of temporary deterioration in the public debt position. All told, and as indicated before, the favorable debt implications of QE are more affected by uncertainty than for conventional fiscal stimulus.

4 QE in Shallow Liquidity Traps

We now turn to the case of a shallow liquidity trap where economic activity is notably closer to potential than in the deep trap discussed in the previous section, but the central bank finds itself at the ELB to battle persistent below target inflation pressure.

4.1 A Baseline Scenario with Slow and Fast Recovery

Technically, we generate the modal baseline projection in the shallow trap using the same discount factor shock (ε_t^d) as in the deep trap case, but assume that it follows a simple AR(1) process with high persistence. As a result, we get a shadow rate that just slightly falls below the ELB for about three years. Amid this modal projection depicted in the left panels of Figure 6 with solid-blue lines, the orange-dashed lines add identical purchases of long term assets as in Figure 2 (compare QE paths in the bottom right panels in Figures 2 and 6).

QE still appears beneficial provided that the economy evolves reasonably in line with the modal (no-uncertainty) outlook. As illustrated in Figure 6, the baseline without QE has a slightly negative output gap of a little more than 2 percent, and inflation is about 0.8 percentage points below target. A modest-sized QE program is helpful in boosting inflation and in closing the output gap, and after some initial losses on its purchases the central bank experiences eventual improvement in its capital position as the yield curve remains upward sloping (with the policy rate only converging gradually to its long-run level).

However, there are several noteworthy differences between the effects of QE in a shallow liquidity trap compared to deep liquidity trap case considered earlier. First, a given-sized QE program has less "bang for the buck" in reducing long-term yields and hence in boosting output, reflecting that the stimulus from QE tends to cause policy rates to rise more quickly than in a deep liquidity trap. Thus, as can be seen by comparing the blue-dashed lines in the right panels of Figure 6 and Figure 3, the effect on output is about 10 percent smaller if the trap is shallow. In terms of fiscal implications, higher tax revenues and lower debt service costs preserve the favorable impact on the consolidated fiscal position, although the improvement by 4 percent after 5 years is about two-thirds of that in the deep trap in Figure 2.

Second, there is a greater risk that QE can be counterproductive in a shallow liquidity trap if upside inflation risks materialize. Such shocks could significantly affect the benefits of a given QE program, especially if they induce a rapid economic recovery and inflation surge that pushes the central bank to exit a stimulative stance much earlier than in the modal outlook and raise policy

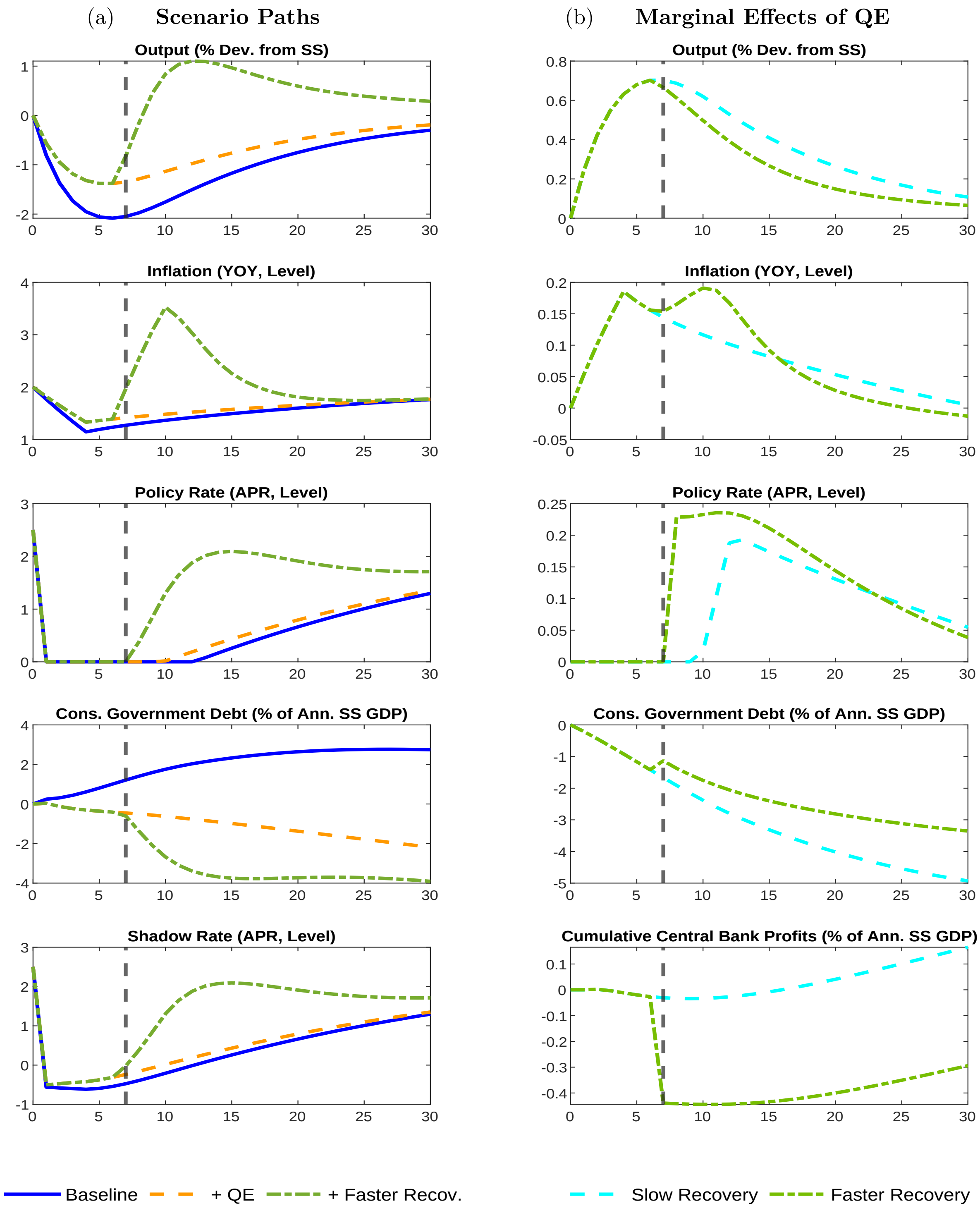

Figure 6: QE in a Shallow Recession with Unexpected Faster Recovery.

rates well above its normal long-run level. Under these circumstances, the central bank could face large losses.

This is illustrated in Figure 6 with green dash-dotted lines, which depict the earlier recovery scenario by using the same mix of shocks that hit the economy in period 7 as in Figure 3 that was describing the deep trap case. This time the unexpected shocks not only drive inflation well above the target but also are sufficient to switch the output gap from negative to positive. As a result, QE turns out to contribute to the overheating. Moreover, since the liquidity trap under modal outlook is shallow, the policy rate lifts off immediately after the unexpected shocks hit and then continues rising steeply to contain the overheating and inflationary pressure. This translates into sizable central bank losses, amounting to about 0.4 percent of annual GDP. While these losses are not sufficient to overturn the favorable impact of QE on the consolidated fiscal position, its improvement is substantially reduced. Overall, while QE implemented in a shallow liquidity trap can still bring sizable macroeconomic and fiscal benefits, it faces a much bigger risk of being counterproductive ex post than under the deep liquidity trap.

4.2 The Role of Initial Financial Conditions and QE Size

Our analysis so far suggests that QE is very likely to pay for itsef, irrespective of whether the liquidity trap is deep or shallow, and even if an earlier recovery scenario materializes. In this section, we highlight two key determinants of the fiscal costs and risk to the central banks balance sheet with QE: the initial level of the term premium and the size of asset purchases. These factors are on top of the assessment of how deeply the unconstrained shadow rate is below the ELB.

Recall that our baseline calibration features a steady state term-premium of 100 basis points. This means that, even though QE drives the premium down, the central bank still can make profits on its holdings of long-term bond as it finances them by issuing short-term liabilities that do not carry a premium. This is exactly what we can observe under the modal outlook presented in Figures 3 and 6, where the central bank profits are positive unless the economy recovers faster than expected. It is however possible that the economy enters a liquidity trap at a time when the term premiums are already compressed, implying central bank losses even under the baseline scenario.[16] Furthermore, we have so far assumed that the expansion in central bank balance sheets is moderate, amounting to 10 percent of annual GDP. A number of countries have implemented much more ambitious programs.[17] As a matter of fact, a 10 percent QE in our shallow trap scenario closes about one-third of the output gap and shrinks the deviation of inflation from target by about

[16] According to the measure developed by Adrian, Crump, and Moench (2013), the 10-year term premium in the US was negative at the time the Covid-related QE program (Q4) was launched.

[17] For example, during the Covid pandemic the balance sheets of the US Fed, European Central Bank, Bank of England and the Bank of Japan expanded by around 20 percent of the respective countries' GDP.

the same proportion, rationalizing a much bigger intervention if one focuses only on the modal outlook.

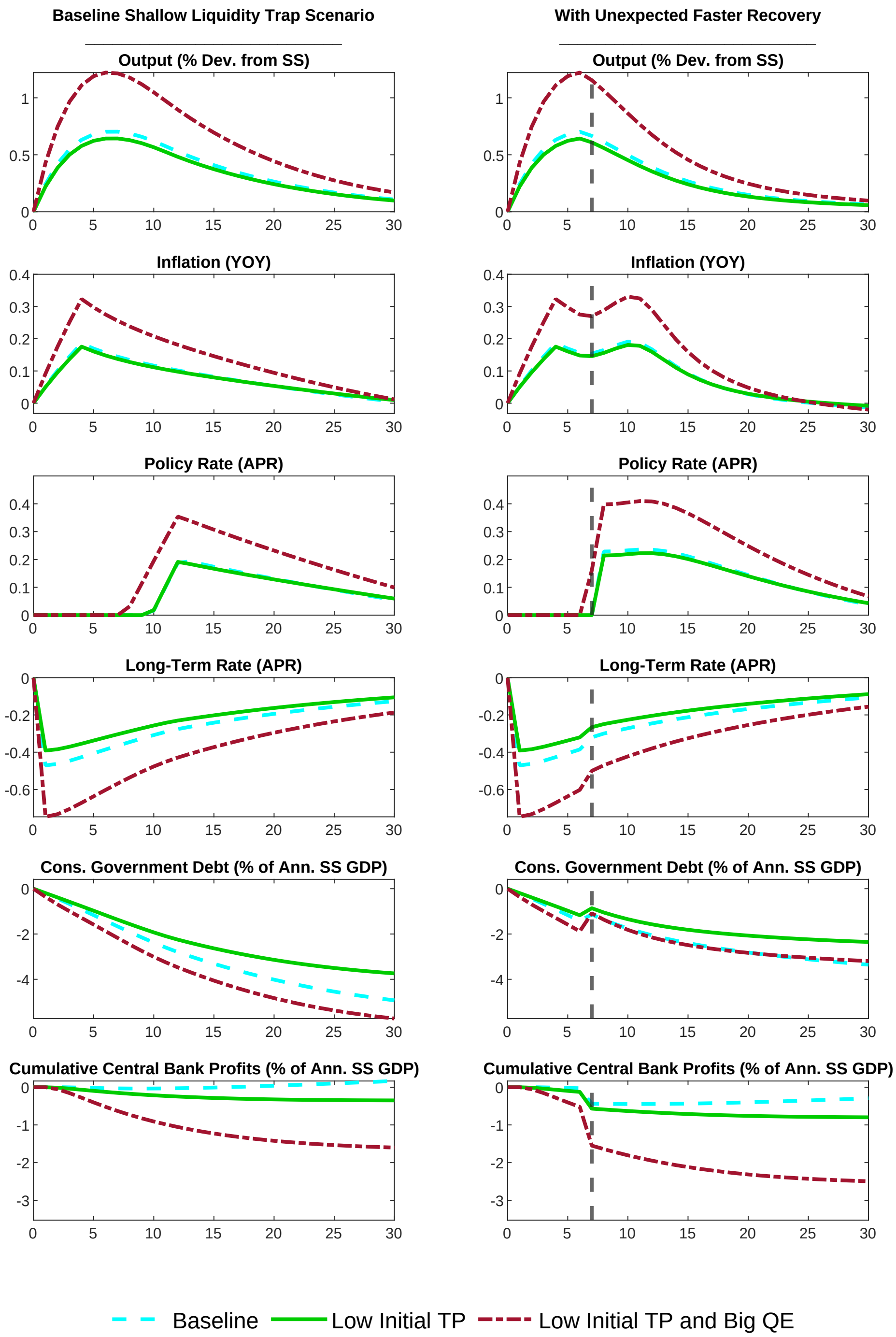

Figure 7: Sensitivity of QE Effects to Steady State Term Premium and QE Size.

Against this backdrop, Figure 7 shows the sensitivity of our results on the marginal effects of QE in the shallow liquidity trap to the initial (steady state) value of the term premium and to the size of asset purchases.[18] We show results for two alternative calibrations – when the term premium is markedly lower (0 basis points) and if additionally the QE is two times bigger (20 percent of GDP) than we assume in our baseline parameterization. The left column shows the marginal impact of QE under the modal outlook, whereas the right column presents the earlier recovery scenario as defined earlier.

As can be seen from the figure by comparing blue-dashed and solid-green lines, the macroeconomic transmission of QE to output, inflation and policy rates is somewhat weaker if the initial term premium is low, but the difference is not very large. However, as the bottom row in Figure 7 shows, the effects on the central bank profits are quite different. If the initial term premium is zero, QE drives it into negative territory, and hence the monetary authority ends up making losses on its asset purchases even under the modal outlook. These central bank losses together with a weaker increase in tax revenue shave off a significant part of gains in the consolidated fiscal position, which after 5 years improves by about 1 percent of annual GDP less if we assume that the term premium is zero rather than 100 basis points. The effects look similarly in the scenario with unexpected faster recovery (right panels of Figure 7), implying that central bank losses are roughly twice larger and the improvement in the consolidated fiscal position after 5 years is merely 2 percent.

The brown dash-dotted lines in Figure 7 show how our results change if, in addition to the low initial term premium, we double the size of the QE intervention from 10 (baseline) to 20 percent of pre-shock GDP. Although the transmission to output and inflation is approximately linearly related to QE size, larger purchases have a significant adverse impact on cumulated central bank profits. This is because larger QE means a larger compression of the term premium, and hence a higher price the central bank needs to pay when purchasing long-term bonds. As the premium is driven very low, the profit made by the central bank on its asset portfolio becomes significantly negative even under the modal outlook, cumulating to about -1.5 percent of GDP. As a result, despite twice bigger QE, the improvement of the consolidated fiscal position is higher only by a half. Additionally, bigger balance sheets expose the central bank to larger risks associated with an earlier recovery. This is illustrated in the right panels of Figure 7, which show that the same sequence of unexpected shocks that we have considered earlier can generate very large central bank losses that cumulate to more than 2 percent of GDP after 5 years. Consequently, the ex post fiscal consequences of this bigger QE program turn out to be roughly the same as those observed under

[18] The conclusions from this part of our analysis are very similar if we conduct it assuming the deep liquidity trap scenario.

our baseline assumptions.

4.3 Commitment Aspects of QE

There are some important arguments why QE can be less beneficial for macrostabilization than accounted for by our analysis so far. If QE embodies a commitment on the short-term policy, it can additionally fuel the overheating and make the central bank less nimble in responding to the upside inflation surprise. As discussed previously, QE can involve guidance about how long it is likely to last, as well as a conditional promise to delay hiking rates until well after QE ends. In effect, the central bank may feel "locked into" keeping policy rates low even when it would otherwise raise them quickly, which can trigger more overheating than shown in Figure 6.

This case is illustrated in Figure 8, which shows a baseline scenario in a shallow trap with QE and one with a faster recovery, defined similarly to Figure 6, and depicted with orange-dashed and green dash-dotted lines as before. These simulations are next compared with an earlier recovery scenario under an additional assumption that the central bank commits to keep the policy rate unchanged for 10 quarters (i.e., period 10 in Figure 6), which coincides with the ELB duration under the modal outlook when QE is implemented. As a result, when unexpected shocks hit in period 7, the policy rate does not lift off but stays flat for another year (see blue-dotted lines). In this case, we see that the commitment path leads to overheating in output and an amplified reaction of inflation as the economy enters a steeper part of the Phillips curve, both making QE even more counterproductive from the ex post perspective. As we show in Appendix A.3, the overheating could be further exacerbated if increased inflation pressure triggers wage indexation mechanisms.

We can also observe that, by delaying the lift-off, commitment slightly reduces central bank losses and hence increases the beneficial effect of the program on the consolidated fiscal position. However, the fiscal implications of QE could be less favorable in the event the central bank felt it was necessary to eventually shift its reaction function and act more forcefully. This would amplify central bank losses and could cause the consolidated fiscal position to deteriorate. Such an outcome would be more likely if the nonlinearities in the Phillips Curve were more pronounced – and lead to more persistent inflation effects – than in our model.

5 QE Effects under Uncertainty

So far we have illustrated how QE can turn out to be counterproductive ex post if the economy recovers from a recession at a faster pace than could be expected when the asset purchase program

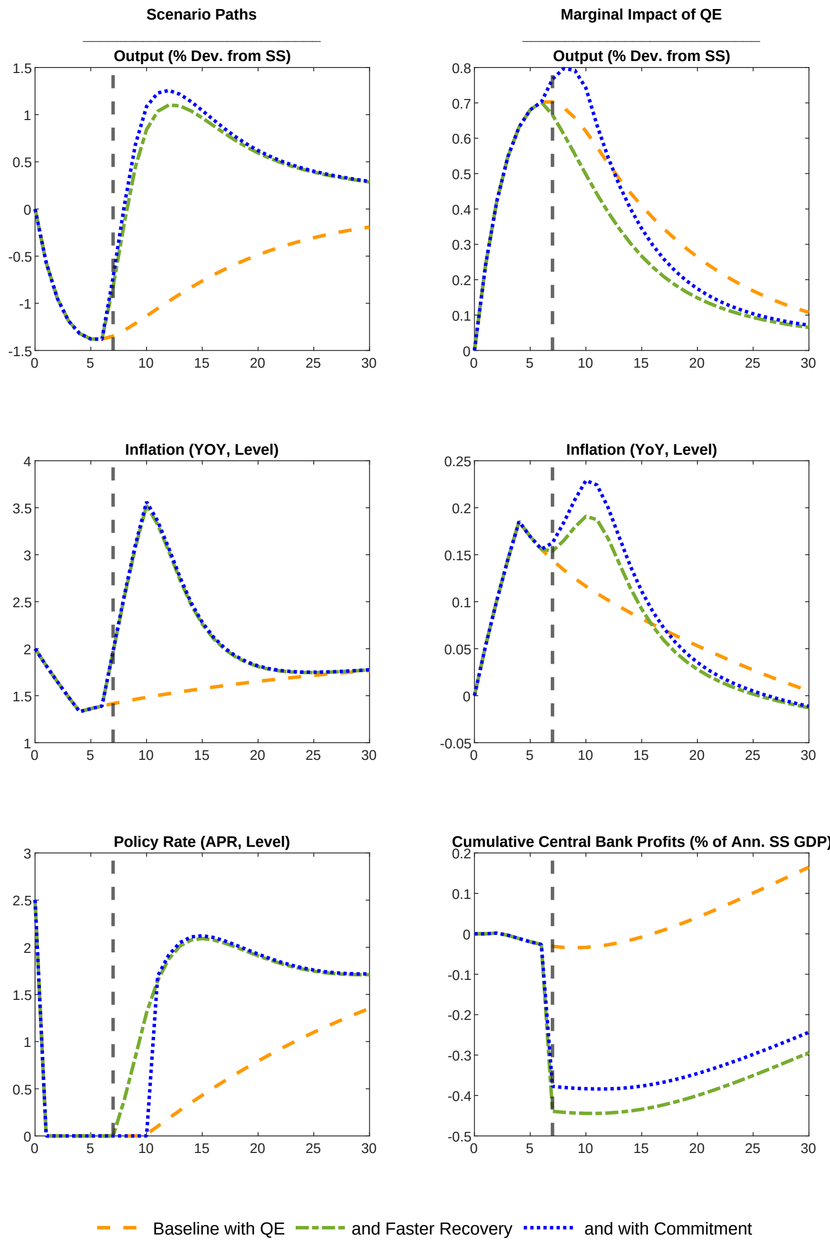

Figure 8: Impact of QE with Faster Recovery and Exit Commitment.

was introduced. We now present a broader account of uncertainty around the modal outlook by using stochastic simulations. This allows us to capture both upside and downside risks in the economic outlook at the time the central bank starts QE.

5.1 Calibration of Stochastic Shocks

For this part of our analysis, we need to parameterize the shock processes. We use a parsimonious set of non-policy shocks, fix their AR(1) coefficients at values typically found in the DSGE literature, and then adopt a simple moments matching procedure to calibrate the standard deviations of the innovations that enables the model to match the unconditional standard deviations of output growth per capita, annualized core PCE inflation, nominal wage growth, and hours worked per capita, as well as the correlation of these variables with output growth per capita. The targeted moments are calculated using the US data for the period 1960-2019. This is a long sample period and, even though it does not cover the Covid-19 recession and its aftermath, it still implies that we include episodes when price and wage inflation, as well as nominal interest rates were volatile.

The AR(1)-shock processes for productivity (ε_t^z), private consumption demand (ε_t^c), cost-push impulses for firms (ε_t^p) and labor unions (ε_t^w) that our simple matching procedure results in are as follows:

$$\begin{aligned}
\varepsilon_t^z &= 0.90\varepsilon_{t-1}^z + u_t^z,\ u_t^z \backsim i.i.d.N\left(0, 0.01\right) \\
\varepsilon_t^c &= 0.90\varepsilon_{t-1}^c + u_t^c,\ u_t^c \backsim i.i.d.N\left(0, 0.035\right) \\
\varepsilon_t^p &= 0.85\varepsilon_{t-1}^p + u_t^p,\ u_t^p \backsim i.i.d.N\left(0, 0.04\right) \\
\varepsilon_t^w &= 0.85\varepsilon_{t-1}^w + u_t^w,\ u_t^w \backsim i.i.d.N\left(0, 0.26\right)
\end{aligned} \tag{27}$$

where the numbers in the $N(.)$ parentheses are mean and standard deviations for each independent and normally distributed shock innovation.

Table 3 reports the selected moments we match in the US data for the period 1960-2019 along with the corresponding model moments. As can be seen, the model fits the data well despite that we only allow for a small set of stochastic supply and demand shocks as underlying drivers of fluctuations in the model. We also cross-check if our procedure implies a reasonable volatility of the nominal policy rate, which we do not use in the matching procedure. It turns out that the volatility of this variable is just slightly lower in the model than in the data as our set of shocks does not include the monetary policy shock (ε_t^r). The reason for this is that we do not want deviations from normal policy behavior to be a source of uncertainty and earlier policy normalization; the latter will hence occur only for fundamental reasons, i.e., through inflation and output developments as implied by the interest rate rule (17).

Notes: The moments in the US data are based on the period 1960Q2-2019Q4. Inflation π_t^{ann} is measured with annualized core PCE inflation. Policy rate R_t^{ann} is measured with the annualized net Federal Funds Rate. Real GDP growth $\Delta \ln y_t$ and non-farm business hours worked are scaled with working age population, and $\hat{n}_t$ is then calculated as $(n_t - n)/n$. Annualized nominal wage is measured with wages in the non-farm business sector. The

Table 3: Targeted Stochastic Moments.

Moment	US Data	Model
$\text{Std}(\Delta \ln y_t)$	0.81	0.85
$\text{Std}(\pi_t^{ann})$	2.17	2.19
$\text{Std}(\pi_t^{w,ann})$	3.45	3.71
$\text{Std}(\hat{n}_t)$	4.99	4.83
$\text{Std}(R_t^{ann})$	3.65	3.12
$\text{Corr}(\Delta \ln y_t, \pi_t^{ann})$	-0.18	-0.23
$\text{Corr}(\Delta \ln y_t, \pi_t^{w,ann})$	-0.12	-0.10
$\text{Corr}(\Delta \ln y_t, \hat{n}_t)$	0.07	0.00

model moments are based on a simulation of a long-sample of 10,000 observations. We match all moments except for $\text{Std}(R_t^{ann})$, which is used to validate our matching procedure.

It is important to note that the parameterization of the various stochastic shocks in eqs. (27) imply that the bulk (88 percent) of the unconditional volatility in output growth per capita is explained by the consumption demand shock, while only explaining a relatively small part (21 percent) of inflation volatility. In line with estimated structural macroeconomic models, for instance the Smets and Wouters (2007) model, fluctuations in inflation are instead mainly explained by the price and wage cost-push innovations (18 and 55 percent, respectively). As a result, both demand and supply shocks contribute significantly to the variation in the nominal policy rate.

5.2 Results of Stochastic Simulations

To highlight the risks to central bank balance sheets and consolidated government debt, we explore uncertainty around a shallow liquidity trap when the initial term premium is low (0 bps) and QE is fairly large (20 percent of annual GDP). To this end, we simulate 500 trajectories for 30 periods, taking as the starting point period 2 of the deterministic simulation.

The left column in Figure 9 shows the modal (no-uncertainty) baseline projection with QE (i.e. the orange-dashed lines), along with the mean and the 68^{th}, 80^{th} and 95^{th} confidence intervals from the distribution generated with the 500 simulations. We see that the uncertainty is sizeable as the percentiles imply that the policy rate may lift-off from the ELB quickly. The rather high probability of an early lift-off from the ELB is primarily driven by two aspects of our model. First, the risks to inflation are asymmetric due to the real rigidities in firms price-setting behavior – the Kimball (1995) aggregator implies that there is more upward than downside inflation risk, which can be seen from the inflation fan chart in the second left panel. Note that the distribution of inflation is positively skewed despite the presence of the ELB, which underscores the importance of accounting for non-linearities in the the Phillips curve to capture the low sensitivity of prices during deep recessions. Second, the size of shocks we introduce in the stochastic simulations are chosen to be large so that they can match the volatility of inflation, output growth and policy rates for a long sample period (1960-2019), i.e. not just the "Great Moderation" but including a number of episodes with volatile and high inflation and policy rates. These two factors imply that the shadow rate, which primarily responds to inflation, can move substantially and long-term yields can rise materially in the near-term. The possible combination of swift repricing of long-term assets and their higher funding costs due to rising short-term rates implies that a central bank can make very sizable losses on its portfolio as shown in the bottom left panel.

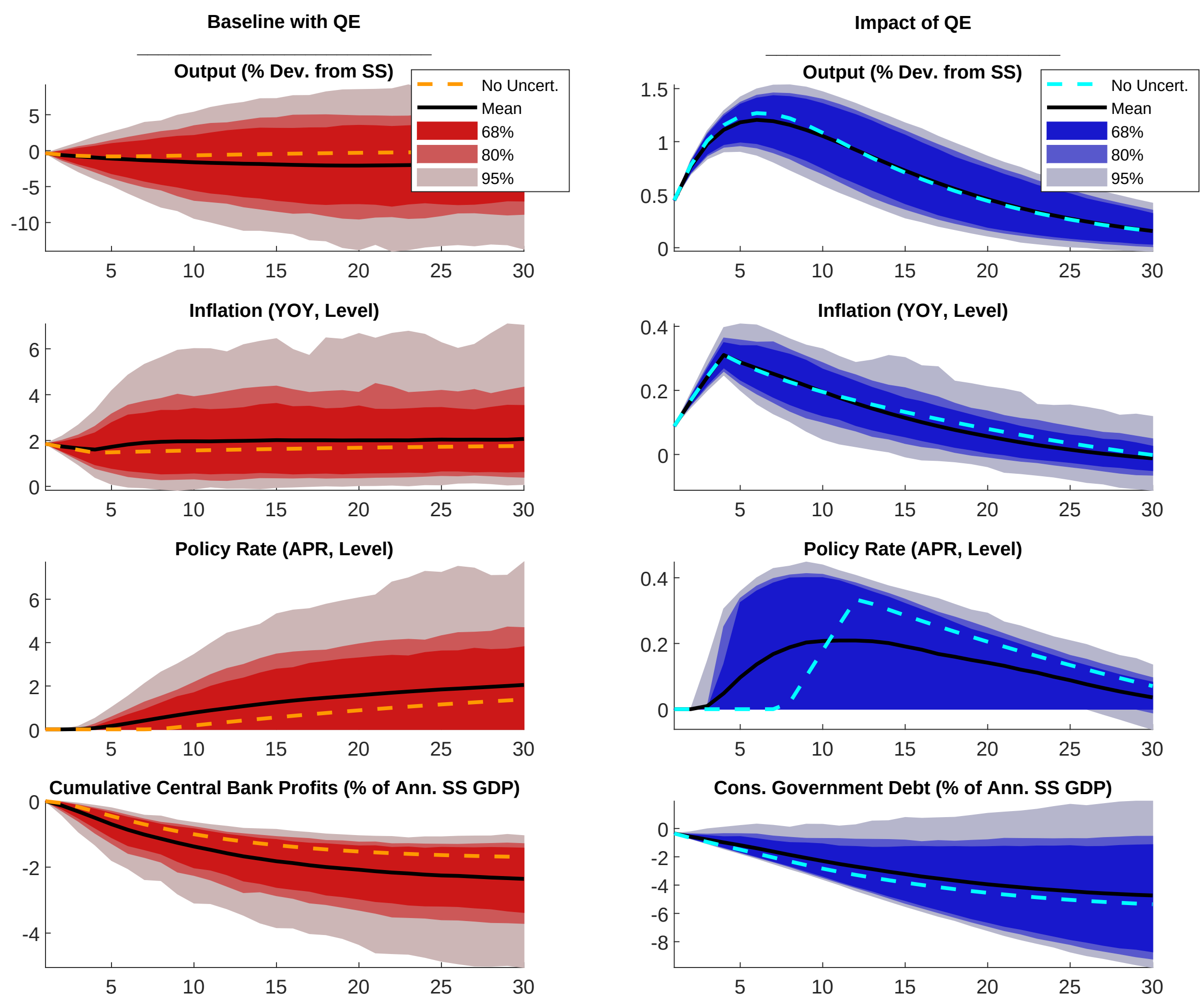

Figure 9: Impact of Uncertainty in a Shallow Trap with Low Initial Term Premium and Big QE.

The right column in Figure 9 shows the marginal impact of QE, i.e. we calculate the difference between the 500 trajectories with QE and the same simulations without QE (not shown). By computing the difference with the trajectories with and without QE, we can parse out a distribution of 500 draws which captures the marginal impact of QE. And in the right column we plot the mean and the 68^{th}, 80^{th} and 95^{th} confidence intervals of this marginal distribution along with the no uncertainty modal path (blue-dashed lines, which coincide with the brown dash-dotted line in the left column of Figure 7, except that they are now plotted starting from period 1).

Allowing for uncertainty does not significantly change the assessment of the impact of QE on the output and inflation trajectories compared to the no-shock modal projection (mean impact of stochastic simulations is very similar to the deterministic simulation). However, the uncertainty bands in the bottom right panel show that the effect of QE on consolidated government debt is positively skewed, meaning that there is a bigger probability of lower fiscal gains from central bank asset purchases than suggested by the modal outlook. There is even some risk that large central bank losses more than offset the positive effects of QE on the fiscal position that works through increased tax revenue and lower costs of financing and issuing debt. Even so, the risk for sizeable consolidated fiscal losses is small. Thus, a striking feature conveyed by Figure 9 is that the adverse impact of QE on the consolidated public debt position is likely very modest although the central bank is at risk of making outsized losses on its portfolio of long-term assets. And it should be borne in mind that we have calibrated sizeable impact of shock uncertainty by forcing the model to match the standard deviation of output growth and inflation for 1960-2019 period, a sample that contains several episodes with inflation surges. Had we reduced shock uncertainty by matching standard deviations of inflation over the sample that starts with the Great Moderation period, the impact of shock uncertainty and scope for consolidated fiscal losses of QE would have been attenuated further.

We finally reemphasize the importance of the macroeconomic conditions during which QE is implemented. As we show in Appendix A.4, the risk of this policy leading to a deterioration in the consolidated fiscal position turns out to be negligible if we repeat the analysis above for the case of a deep liquidity trap. They key reason is that, in such circumstances, QE provides a stronger boost to economic activity (and hence to tax revenue), while a deeply negative shadow rate makes the actual policy rate likely to stay flat for long even if strong inflationary shocks materialize, thus limiting the scope for large central bank losses.

6 Concluding Remarks

This paper aims at providing an assessment of the macroeconomic benefits and fiscal costs of quantitative easing. We emphasize four key points.

The first is that QE policies are likely to have substantial benefits in a deep recession in which policy rates are expected to be constrained by the ELB for a protracted period. QE boosts output and inflation and improves the consolidated fiscal position of the government. Thus, QE is likely to be a very useful tool in the event that the ELB again becomes severely binding.

The second is that – in light of the recent experience of high inflation – more caution is warranted in using QE in a shallow liquidity trap in which the central bank mainly faces below target inflation that does not pose an imminent threat of deanchored inflation expectations. While QE may appear beneficial ex ante, there is considerable risk that it may cause overheating ex post given important nonlinearities in the Phillips Curve, the potential for an outsized easing of financial conditions, and that other inflation-raising shocks may hit after the deployment of QE. Negative, or more deeply negative, short-term interest rates may be preferable in these circumstances.

The third is that the duration risk that central banks take on with QE has the intended outcome of fueling risk-taking, which compresses term premia and eases financial conditions more broadly. But a side effect is to make central banks highly exposed to losses if interest rates rise enough. We argue that the benefits of QE are often significantly positive even when the central bank experiences losses, as can occur if the recovery from recession is unexpectedly fast and the yield curve inverts. Even so, the losses still represent a potentially first order headwind for central bank credibility and may ultimately weaken its independence, at least in some cases.

The fourth is that, relative to conventional fiscal stimulus, QE is likely to be associated with significantly lower fiscal costs to boost the economy in an economic slump. QE lowers debt service costs and boost tax revenues more that conventional fiscal policy for a given stimulus to output. This finding holds up even if the economy rebounds notably faster than envisioned at the time QE is implemented, but a problem for the central bank is that it generates visible financial losses, whereas the gains for the treasury are less palpable.

All told, our analysis suggests that merits of QE should be measured on the basis of its impact on the consolidated government finances, and how it can help stabilize the business cycle and inflation relative to other policy instruments. Doing so is critical to formulate good policy. In the future work, we plan to further explore the normative aspects of QE using formal welfare criteria.

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A Additional Model Details and Simulations

A.1 Term Premium

Typically, the 10Y term premium denotes the difference between the yield on a 10-year bond and the expected yield on a series of short term bonds. In a world with no uncertainty or adjustment costs, there would be no term premium, meaning that the yield on long term bonds would have to equal the expected yield of investing short term. Since the expected yield on the hypothetical long-term bond would equal the expected return on short-term bonds, therefore we can define the term premium as

$$TP_t = R_{L,t} - R_{L,t}^{EH},$$

where $R_{L,t}^{EH}$ is the counterfactual yield to maturity on a longer-term bond in the absence of transaction costs.

A.2 Central Bank Balance Sheet and QE

The CB balance sheet can be written as in Table A.1.

Table A.1: Consolidated Central Bank Balance Sheet.

Assets	Liabilities
$P_{L,t}B_{L,t}^c$	$-B_t^c$

Given the definition of long-term bonds and because $-B_t^c = P_{L,t}B_{L,t}^c$, the holding period profits associated with unconventional monetary policy equal

$$\Phi_t^c \equiv R_{t-1}B_{t-1}^c + (1 + \kappa P_{L,t})\, B_{L,t-1}^c.$$

To keep matters simple, we assume that any QE "carry profits" are fully rebated to the treasury and that losses are rebated lump sum as well.

We now formally define runoff and reinvestment, the first of which describes the mechanical phenomenon of assets maturing and leaving the central bank balance sheet, while the second essentially pins down the baseline investment strategy that we shall analyze deviations from.

In our model, if the central bank purchased $P_{L,t-1}B_{L,t-1}^c$ worth of consols, then at the start of the following period it would have a coupon worth $B_{L,t-1}^c$ and a stock of assets with a market value of $\kappa P_{L,t}B_{L,t-1}^c$. Mechanically, the change in value of long term assets Ψ_t thus equals

$$\Psi_t \equiv \kappa P_{L,t}B_{L,t-1}^c - P_{L,t-1}B_{L,t-1}^c,$$

i.e., it can be written as a combination of runoff and revaluation, as follows

$$\underbrace{\Psi_t}_{\text{“passive” change in portfolio value}} = \underbrace{-B^c_{L,t-1}}_{\text{runoff}} + \underbrace{\left(\kappa P_{L,t} B^c_{L,t-1} - P_{L,t-1} B^c_{L,t-1} + B^c_{L,t-1}\right)}_{\text{revaluation}},$$

where runoff is defined as being negative, as it tends to decrease the, typically positive, value of long term bonds held by the central bank. Exploiting $R_{L,t} \equiv 1/P_{L,t} + \kappa$ and defining $\Pi_{L,t} \equiv P_{L,t}/P_{L,t-1}$, we can then simplify the expression for the revaluation component as

$$\begin{aligned}(1 + \kappa P_{L,t})\, B^c_{L,t-1} - P_{L,t-1} B^c_{L,t-1} &= P_{L,t} \left(\frac{1}{P_{L,t}} + \kappa\right) B^c_{L,t-1} - P_{L,t-1} B^c_{L,t-1} \\ &= (P_{L,t} R_{L,t} - P_{L,t-1})\, B^c_{L,t-1} = (\Pi_{L,t} R_{L,t} - 1)\, P_{L,t-1} B^c_{L,t-1},\end{aligned}$$

which shows that positive inflation and yield to maturity will translate into positive nominal revaluation. Similarly, we can also express run-off in terms of the original value of the long term bond portfolio to arrive at

$$\underbrace{\Psi_t}_{\text{“passive” change in LT portfolio value}} = \left(-\underbrace{\frac{1}{P_{L,t-1}}}_{\text{runoff}} + \underbrace{\Pi_{L,t} R_{L,t} - 1}_{\text{revaluation}} \right) P_{L,t-1} B^c_{L,t-1}.$$

Of course, typically, the central bank will also have a reinvestment strategy in place to counterbalance run-off and revaluation, and it may occasionally wish to deviate from that strategy. To capture such considerations, yet still keep the analysis tractable, we assume that the passive reinvestment strategy is expressed as a share of runoff and revaluation, and that it is governed by parameter ϱ, i.e., that total reinvestment Θ_t is given by

$$\underbrace{\Theta_t}_{\text{total reinvestment}} \equiv \underbrace{\varrho \left(\frac{1}{P_{L,t-1}} - \Pi_{L,t} R_{L,t} + 1 \right) P_{L,t-1} B^c_{L,t-1}}_{\text{passive reinvestment}} + \underbrace{\epsilon^c_t}_{\text{active reinvestment}}.$$

Collecting terms, the expression for the evolution of the value of the central bank's portfolio becomes

$$\begin{aligned} P_{L,t} B^c_{L,t} &= \underbrace{P_{L,t-1} B^c_{L,t-1}}_{\text{previous value}} + \underbrace{\Psi_t}_{\text{mechanical change in value of QE portfolio}} + \underbrace{\Theta_t}_{\text{passive and active reinvestment}} \\ &= \left(1 + (1-\varrho) \left(-\frac{1}{P_{L,t-1}} + \Pi_{L,t} R_{L,t} - 1 \right)\right) P_{L,t-1} B^c_{L,t-1} + \epsilon^c_t, \end{aligned}$$

which confirms that with ϱ set to one, and absent active reinvestment $\epsilon^c_t = 0$, the nominal value of the long term bond portfolio would stay constant. Conversely, with ϱ set to zero, corresponding to no reinvestment, the value of the portfolio would decrease at its fastest possible rate (barring active asset sales).

We conclude by presenting a real equivalent of the above expression, which we obtain by dividing through by P_t and simplifying to arrive at

$$QE_t \equiv \left(1 + (1-\varrho)\left(\kappa \frac{P_{L,t}}{P_{L,t-1}} - 1\right)\right) \frac{QE_{t-1}}{\Pi_t} + \varepsilon_t^{QE}, \tag{A.1}$$

where we defined $QE_t \equiv P_{L,t} b_{L,t}^c$ and $\varepsilon_t^{QE} \equiv \frac{\epsilon_t^c}{P_t}$.

A.3 Impact of Commitment under Wage Indexation

Figure A.1 repeats the analysis presented in Figure 8 under the assumption that the rapid increase in inflation during the faster recovery triggers indexation mechanisms, so that non-reoptimized wages are fully adjusted to the previous period inflation.

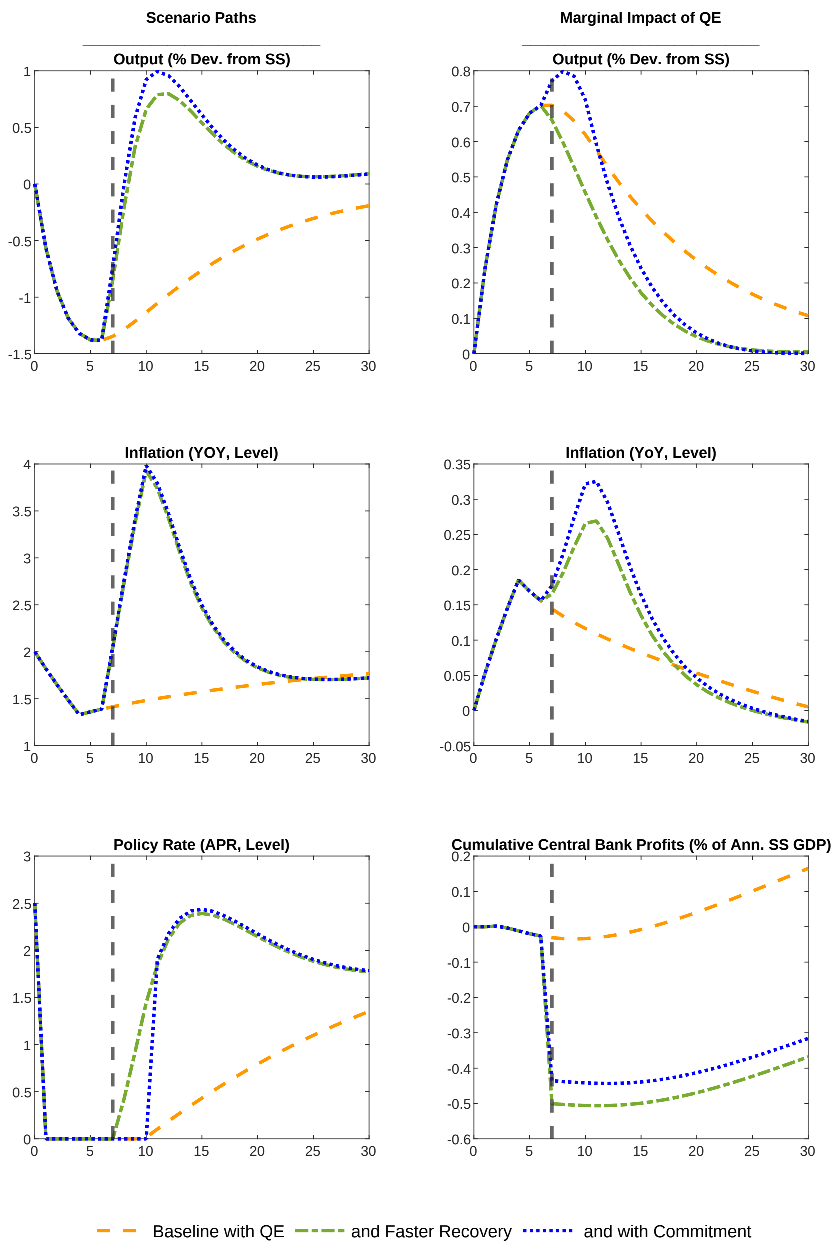

Figure A.1: Impact of QE with Faster Recovery and Exit Commitment under Wage Indexation.

A.4 QE under Uncertainty in a Deep Liquidity Trap

Figure A.2 repeats the analysis presented in Figure 9 for the case of a deep liquidity trap as defined in Section 3.

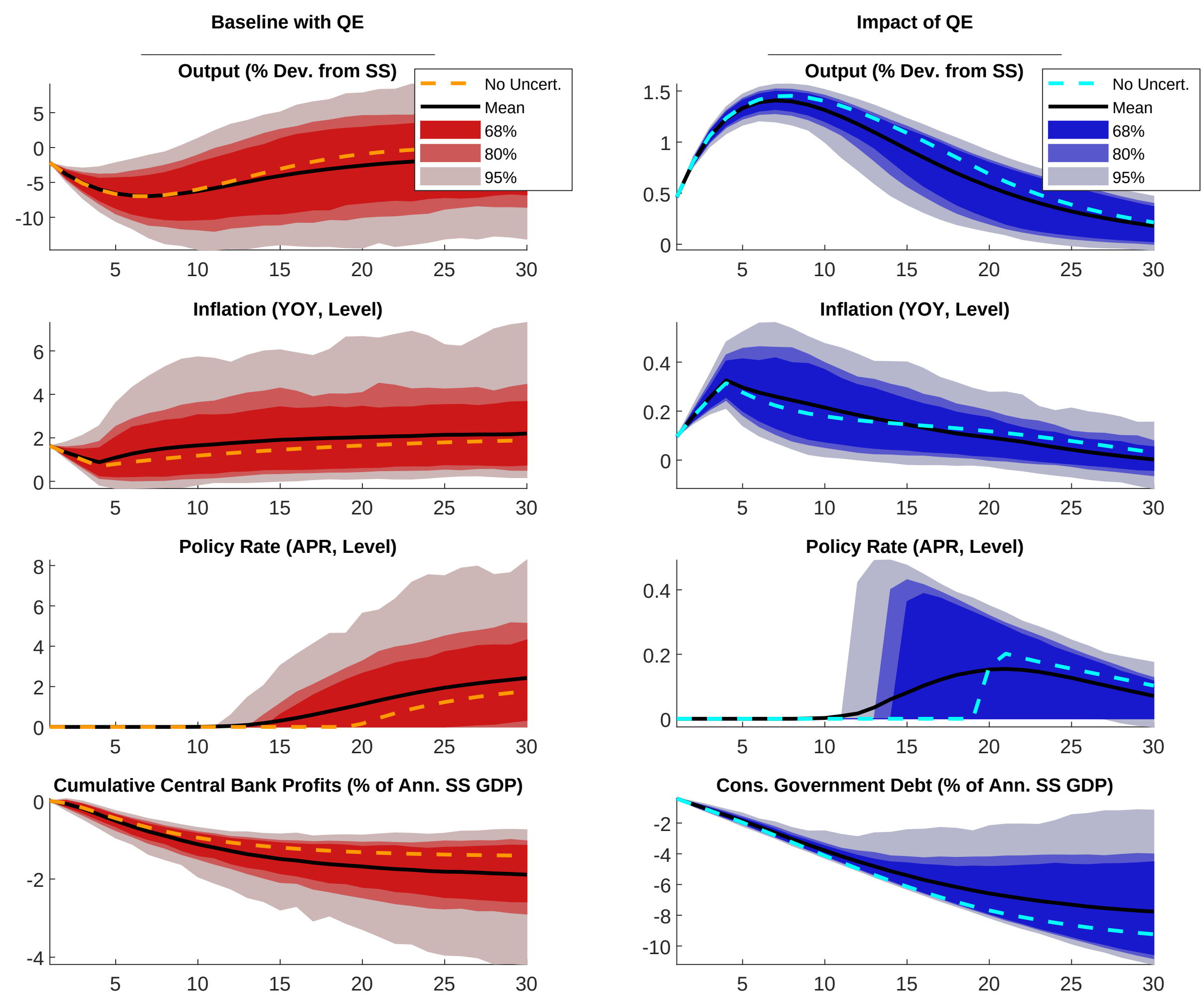

Figure A.2: Impact of Uncertainty in a Deep Trap with Low Initial Term Premium and Big QE.