Macroeconomic and Fiscal Consequences of Quantitative Easing*

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Abstract

Quantitative easing (QE) has been criticized for helping fuel the post-COVID inflation boom and causing large central bank losses. In this paper, we argue that 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 central bank losses can matter to the extent that they may weaken central bank credibility. Using a DSGE model with segmented asset markets, we show how QE can provide a sizeable boost to output and inflation in a deep liquidity trap and can reduce public debt substantially. This contrasts to the rise in public debt that occurs under fiscal expansion and makes QE an attractive tool in a high debt environment. There is more reason 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 is more likely to generate sizeable central bank losses. Some refinements in strategy, including the use of escape clauses, can help mitigate overheating risks.

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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, and Schnabel, 2024).

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 close to record lows. Accordingly, we consider the macroeconomic benefits of QE under these alternative economic conditions.

We also analyze the fiscal consequences of QE – an area which has received relatively little attention in the DSGE literature.[1] Here our main focus is on how QE affects the consolidated fiscal position of the government and central bank, which is the government's overall balance inclusive of interest payments plus central bank profits or losses. This is the natural metric for evaluating fiscal effects in our model where only the consolidated position matters for behavioral choices. Moreover, the consolidated position arguably best captures the potential fiscal costs or benefits of QE from a societal perspective.[2] Even so, we also examine the implications of QE for the central bank balance

[1] Cavallo et al. (2019) examine alternative approaches to quantitative tightening on central bank profits as well as the fiscal position within the context of the Federal Reserve's semi-structural FRB/US model.

[2] Our focus on the consolidated fiscal position (as well as the macroeconomic effects of QE) is consistent with the qualitative argument of English and Kohn (2022). Chien, Cole, and Lustig (2026) also adopt a consolidated approach

sheet, as this may matter in practice for assessing the merits of QE if the central bank views losses as potentially affecting its credibility and independence.[3]

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, Lopez-Salido, and Nelson (2004), Chen, Curdia, and Ferrero (2012), Kiley (2014), and Kolasa and Wesołowski (2020) to allow QE to affect term premiums. We also introduce two key features to give QE an important role in a slump when inflation falls below the central bank's target, and the short-term policy rate becomes constrained by the effective lower bound (ELB). First, our model embeds behavioral (cognitive) discounting as in Gabaix (2020) to mitigate the "forward guidance puzzle," (see Del Negro et al., 2023) so that the central bank can't simply rely on announcements about the future policy rate to achieve its objectives when constrained by a prolonged liquidity trap. 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 aimed at amplifying QE's impact. Our model also allows for an array of nominal and real rigidities – sticky prices, wages, and habit persistence in consumption – to better match empirical evidence on monetary and fiscal transmission. All in all, these features prove helpful in identifying some of the 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 and output are fairly modest from the perspective of the empirical literature. 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. To underscore this, we use our model to compare the effects of QE to an expansion of government spending that is scaled to imply the same path for output. Strikingly, while a 10 percent of GDP central bank asset purchase program reduces the debt-to-

to analyze Japan's low interest rate policies.

[3] Adrian, Khan, and Menand (2024) emphasize the importance of the financial autonomy of a central bank in maintaining its independence, and note that financial autonomy is the characteristic that senior central bankers cited most often as crucial for independence in a broad-based survey they conducted.

GDP ratio about 7 percent after thirty quarters, the government spending hike raises debt by 3 percent – a whopping 10 percent swing. As we show, a rise in government spending not only has a large direct effect in boosting government debt, but also generates considerably smaller revenue (even though the output effects are identical by construction). The smaller revenue effects mainly reflect that the government spending boost tends to raise labor supply, which mutes the effect on real wages and hence on taxable labor earnings, leaves private consumption and hence sales tax revenue largely unchanged, and does not decrease the cost of servicing debt as much as QE given smaller effects on inflation and that it raises interest rates.

These arguments should not be construed as meaning that QE alone should 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.

We next 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, even though 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, posing downside risks to inflation expectations that could undermine the public's confidence in the central bank's ability to achieve its inflation target. As in a deep trap, QE was typically accompanied by forward guidance with 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 raise interest rates 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 potential financial stability risks of eventually unwinding QE through quantitative tightening (Acharya, Rajan, and Steffen, 2023) that are not captured in our model. Even so, moving away from commitment-based forward guidance and hence allowing the policy rate to follow the normal reaction function can help keep overheating risks contained. And the implication that the consolidated fiscal balance improves is robust, even when the central bank experiences large losses. So, while the size of QE should be appropriately calibrated to mitigate overheating risks, 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 and is useful for thinking about the risks of QE going forward in an environment in which supply shocks may be considerably larger than in the Great Moderation period (Gopinath, 2024). While this environment with larger shocks raises the likelihood of early exit from QE and of substantial central bank losses, we find that the probability that reasonably calibrated QE leads to consolidated fiscal losses is small. Overall, this analysis underscores that central bank losses from QE – that are often given substantial prominence in the financial press and in public debates – are a poor metric of the fiscal implications of QE.

Our work contributes to a literature that has studied the impact of credit and quantitative easing in monetary DSGE models, see for example Gertler and Kiyotaki (2010), Gertler and Karadi (2011, 2013), Chen et al. (2012), and Del Negro et al. (2017). These papers – in addition to making seminal contributions to modeling QE and the channels through which it affects the economy – typically found that QE can have sizeable effects on activity and inflation. While building on this work, our paper focuses heavily on the fiscal implications of QE, the effects on central bank balance sheets, and how both the macro and fiscal effects depend on underlying conditions (e.g., the depth of the liquidity trap). Given these objectives, an important advantage of our market segmentation setup is that it gives us flexibility in calibrating the impact of QE on term premiums and, for given reaction of the latter, its impact on economic activity. We also introduce some key innovations on the modeling side, including to address the forward guidance puzzle and overheating risk, while abstracting from other features (such as endogenous risk spreads and capital accumulation) for tractability.

The remainder of the paper is organized as follows. Section 2 presents the quantitative macroeconomic model and discusses how we calibrate it to match empirical evidence on the transmission of QE and conventional fiscal stimulus for the U.S. and Euro area. Section 3 discusses our results for QE in a deep liquidity trap, and compares QE with conventional fiscal stimulus. In Section 4, we consider QE in a shallow trap, highlighting the risks of overheating and central bank losses. Section 5 uses stochastic simulations to evaluate the risks around the modal outlook. Section 6 concludes.

2 Quantitative Model

Our quantitative model builds on a standard DSGE framework with price and wage rigidities, but assumes segmented bond markets similar to Chen et al. (2012). The key feature of this segmentation is that some agents can only trade in long-term bonds, and hence cannot arbitrage away movements in the term premiums using short-term bonds. As a consequence, short- and long-term bonds are imperfect substitutes, and asset purchases by the central bank (quantitative easing, or QE) can depress the term premium and thus have real effects.

We also draw on more recent work by Gabaix (2020) to allow for a moderate degree of cognitive discounting, thus mitigating the "forward guidance puzzle" (see Del Negro et al., 2023). This in turn 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. In addition, our model incorporates strategic complementarities in price setting to allow for a lower sensitivity of inflation to slack in recessions (the "missing deflation puzzle") and higher sensitivity in expansions (see Harding, Lindé and Trabandt, 2022, 2023). This nonlinearity gives rise to significant overheating risk from QE.

It is also worth highlighting two features that are important in accounting for empirically realistic transmission of both monetary policy and fiscal policy shocks, even though both are quite standard in DSGE models. First, external habit formation in consumer preferences helps generate a gradual and hump-shaped peak effect of consumption and output following an easing of the short-term interest rate. Habit formation also 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, sticky wages help the model better account for the behavior of labor income (see Christiano, Eichenbaum and Evans, 2005; Bilbiie and Trabandt, 2023). Both features turn out to be important for appropriately capturing the response of fiscal revenue, which mainly relies on the proportional taxation of consumption and labor income.

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

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

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 for 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 below, 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.[4]

[4] 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.

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, $P_{L-s,t}$, the current price of a long term bond issued s periods ago, 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 a long-term bond, 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 bond markets. These considerations translate into the following flow budget constraint

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

where $\tau_{c,t}$ denotes the sales (VAT) tax rate, $\tau_{n,t}$ is the labor income tax rate, T_t^u stands for lump sum taxes, D_t^u 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

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

with $\xi > 0$. Thus, larger holdings of long-term bonds by unrestricted agents would boost the term premium, while a decrease in their holdings – as would occur with QE – reduces the term premium.

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

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

To understand how central bank asset purchases affect the term premium, it is helpful to consider the first order conditions of the different types of agents for holding long-term bonds. The first order condition of unrestricted agents – abstracting from cognitive discounting, habit, and the preference shocks for simplicity – is given by

$$1=\beta^u \mathbb{E}_t \frac{c_t^u}{c_{t+1}^u}\left\{\frac{P_{L,t+1}}{P_{L,t}}\frac{R_{L,t+1}}{\Pi_{t+1}}\right\}\frac{1}{\zeta_t}, \tag{4}$$

where $\Pi_t = P_t/P_{t-1}$ is (gross) inflation. The first-order condition of restricted agents is similar, with the key difference that they face no transactions costs

$$1=\beta^r \mathbb{E}_t \frac{c_t^r}{c_{t+1}^r}\left\{\frac{P_{L,t+1}}{P_{L,t}}\frac{R_{L,t+1}}{\Pi_{t+1}}\right\}. \tag{5}$$

If there were only unrestricted agents, their intertemporal consumption path would be pinned down by the usual Euler equations involving short-term bond yields, and eq. (4) would only matter for pricing the long-term bond. Accordingly, a central bank asset purchase would depress ζ_t, and the real holding return on a long-term bond (in brackets) would have to fall to compensate – which, given short-term real interest rates are unchanged – is tantamount to a fall in the term premium.[5] But in an environment with restricted agents, who can only smooth consumption intertemporally through long-term bonds, it is evident from eq. (5) that the fall in the holding return on long-term bond stimulates their consumption. Thus, central bank asset purchases shift out aggregate demand, with the magnitude of the shift depending on the share of restricted agents in the economy.[6]

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

$$n_t = \left(\int_0^1 n_t(h)^{\frac{1}{1+\phi_w}}\, dh\right)^{1+\phi_w}, \tag{6}$$

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

[5] See Appendix A.1 for a definition of the term premium in our setup and how it is related to transaction costs.

[6] Our specification can be regarded as capturing – albeit in a stylized way – how different components of aggregate expenditure have varying sensitivities to short- versus longer-term interest rates. Thus, if fixed rate mortgages are prevalent, this would tend to increase the sensitivity of aggregate demand to long-term interest rates, and accordingly to QE. Such differentiation is embedded in large-scale semistructural models such as the Federal Reserve Board's FRB/US model.

preferences.[7] This leads to the following optimization problem

$$\max_{\tilde{W}_t} \ \mathbb{E}_t \sum_{s=0}^{\infty} (\beta\theta_w)^s \left[\Lambda_{t+s} \exp\{\varepsilon^w_{t+s}\} \Pi^s \frac{\tilde{W}_t}{P_{t+s}} - \frac{\exp\{\varepsilon^d_{t+s}\}}{1+\varphi} \left(\frac{\tilde{W}_t}{W_{t+s}} \right)^{\frac{\phi_w}{1-\phi_w}\varphi} n^{\varphi}_{t+s} \right] \left(\frac{\tilde{W}_t}{W_{t+s}} \right)^{\frac{\phi_w}{1-\phi_w}} n_{t+s}, \tag{7}$$

where $\tilde{W}_t$ is the newly set wage and ε^w_t 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 $W_t \bar{n}^j_t$.

2.3 Firms

Perfectly competitive firms combine inputs into final goods according to

$$\int_0^1 G\left(\frac{y_t(i)}{y_t} \right) di = 1, \tag{8}$$

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

$$G(x) \equiv \frac{\phi}{1+\psi} \left[(1+\psi)x - \psi \right]^{\frac{1}{\phi}} - \frac{\phi}{1+\psi} + 1, \tag{9}$$

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

$$y_t(i) = \exp\{\varepsilon^z_t\} n_t(i) - f, \tag{10}$$

where ε^z_t denotes a productivity shock (driven by a stationary AR(1) process) and $f > 0$ is a fixed cost of production.[8] 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^p_t, which follows an exogenous stationary AR(1) process.

[7] 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.

[8] Allowing for decreasing returns to labor would amplify the effects on inflation of the policies considered in this paper, but not in a way that materially alters our main results.

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

$$\max_{\tilde{P}_t} \mathbb{E}_t \sum_{s=0}^{\infty} (\theta_p)^s \frac{\Lambda_{t+s}}{P_{t+s}} \left(\tilde{P}_t \pi^s - \exp\{\varepsilon^p_{t+s} - \varepsilon^z_{t+s}\} W_{t+s} \right) y_{t+s}(i), \tag{11}$$

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

$$B^f_t + P_{L,t} B^f_{L,t} = R_{t-1} B^f_{t-1} + (1 + \kappa P_{L,t}) B^f_{L,t-1} + P_t g_t - \mathcal{T}_t - \Phi^c_t, \tag{12}$$

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

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,[9] 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

$$GD^{con}_t = \frac{B^f_t + \frac{1}{1-\kappa} B^f_{L,t}}{4 P_t Y}. \tag{13}$$

Importantly, our measure of the consolidated fiscal position GD^{con}_t is not mark-to-market, which would be $B^f_t + P_{L,t} B^f_{L,t}$. 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^{con}_t. Even so, we have checked that neither any qualitative nor significant quantitative longer-term aspects (say after 5 years) of the results for GD^{con}_t are notably affected by reasonable alternative definitions, including a mark-to-market based measure.[10]

Government consumption g_t is given by $g_t = g \exp\{\varepsilon^g_t\}$, where ε^g_t is assumed to follow an exogenous stationary process

$$\Delta \varepsilon^g_t = \rho_{g,1} \Delta \varepsilon^g_{t-1} - \rho_{g,2} \left(\varepsilon^g_{t-1} - 1 \right) + u_{g,t}, \tag{14}$$

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

[10] We have studied two alternative measures. First, a market-to-market valuation of debt by defining the numerator of GD^{con}_t as $B^f_t + P_{L,t} B^f_{L,t}$. This measure is subject to near-term revaluation effects. A second measure is similar to our utilized concept in eq. (13) and discounts long-term debt with its steady state price, i.e., $B^f_t + P_L B^f_{L,t}$.

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 decision has been made, it takes some time to fully boost the government consumption level (Ramey, 2011).

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

$$\mathcal{T}_t = \tau_{c,t} P_t c_t + \tau_{n,t} W_t n_t + T_t. \tag{15}$$

Consumption sales taxes are assumed to be constant ($\tau_{c,t} = \tau_c$), 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

$$\tau_{n,t} - \tau_n = \psi_\tau \left(\tau_{n,t-1} - \tau_n\right) + \left(1 - \psi_\tau\right) \psi_b (GD_t^{con} - GD^{con}). \tag{16}$$

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 (1990). An additional key advantage of this setup is that short- and medium term debt dynamics are 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

$$D_t^f = (R_{t-1} - 1) B_{t-1}^f + B_{L,t-1}^f + P_t g_t - \mathcal{T}_t - \Phi_t^c. \tag{17}$$

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. (12) and (17) and rewriting them in real terms

$$d_t^f = b_t^f - \frac{b_{t-1}^f}{\pi_t} + P_{L,t}\left(b_{L,t}^f - \kappa\frac{b_{L,t-1}^f}{\pi_t}\right). \tag{18}$$

Recall that our preferred measure of debt (eq. 13) 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. (18) 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 fewer 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

$$R_t = \max\left\{1, \tilde{R}_t\right\}, \qquad \frac{\tilde{R}_t}{R_t^*} = \left(\frac{\tilde{R}_{t-1}}{R_{t-1}^*}\right)^{\gamma}\left[\left(\frac{\pi_t^{yoy}}{\pi}\right)^{\gamma_\pi}\left(\frac{y_t}{y_{t-1}}\right)^{\gamma_y}\right]^{1-\gamma}\exp\{\varepsilon_t^r\}. \tag{19}$$

$\tilde{R}_t$ 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 (19) 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

$$R_t^* = R\mathbb{E}_t \exp\{\varepsilon_{t+1}^d/\varepsilon_t^d\}. \tag{20}$$

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 (19) 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 $QE_t \equiv P_{L,t} b^c_{L,t} = -b^c_t$ as the size of LSAP and assume it obeys the following rule

$$QE_t = \left(1 + (1-\varrho)\left(\kappa \frac{P_{L,t}}{P_{L,t-1}} - 1\right)\right) QE_{t-1} + \varepsilon^{QE}_t, \tag{21}$$

where $0 \leq \varrho < 1$ is a parameter controlling the reinvestment strategy.[11] Furthermore, ε^c_t 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 bank's asset portfolio are fully backed by the government. The holding profits by the central bank – Φ^c_t in eq. (12) – associated with previous central bank asset purchases can be written as

$$\Phi^c_t \equiv R_{t-1} B^c_{t-1} + (1 + \kappa P_{L,t}) B^c_{L,t-1}. \tag{22}$$

The first term on the right-hand side in eq. (22) is the gross cost of financing a given portfolio of long-term assets, because if there had been no LSAPs, B^c_{t-1} 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 $B^c_{L,t-1}$ is 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

$$CBPROF^{acc}_{t+h} = \Sigma^h_{s=0} \Phi^c_{t+s}. \tag{23}$$

2.6 Market Clearing Conditions

Equilibrium in the goods market requires

$$y_t = \omega_r c^r_t + (1-\omega_r) c^u_t + g_t, \tag{24}$$

and

$$y_t \Delta_t = \exp\{\varepsilon^z_t\} n_t - f, \tag{25}$$

where

$$\Delta_t \equiv \frac{1}{1+\psi} \left(\int_0^1 \left(\frac{P_t(i)}{P_t} \right)^{\frac{1}{1-\phi}} di \right)^{-\phi} \int_0^1 \left(\frac{P_t(i)}{P_t} \right)^{\frac{\phi}{1-\phi}} di + \frac{\psi}{1+\psi}, \tag{26}$$

[11] See Appendix A.2 for detailed derivations and a comprehensive discussion of eq. (21).

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

$$(1-\omega_r)B_t^u = B_t^f - B_t^c, \tag{27}$$

and

$$\omega_r B_{L,t}^r + (1-\omega_r)B_{L,t}^u = B_{L,t}^f - B_{L,t}^c. \tag{28}$$

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_t^r in eq. 19), central banks asset purchases (ε_t^{QE} in eq. 21), and government consumption (ε_t^g in eq. 14). 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 below shows the adopted parameter values and Table 2 presents the targeted steady state ratios. The time period throughout corresponds to a quarter.

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 1, 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

Table 1: Model Parameter Values.

Parameter	Value	Description
		Households
ω_r	0.2	Share of restricted households
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. (16)
ψ_b	0.01	Gov't Debt Response Coeff in eq. (16)
$\rho_{g,1}$	0.7	First difference coeff in eq. (14)
$\rho_{g,2}$	0.02	Error correction coeff in eq. (14)
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 growth
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.

that is consistent with empirical evidence for the U.S. and the Euro area discussed later. 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	1.0	$\frac{b^f}{4y}$
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 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 shows 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. (19) , an innovation to large scale asset purchases u_t^{QE} in eq. (21), and government consumption u_t^g in eq. (14) – 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 rate 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

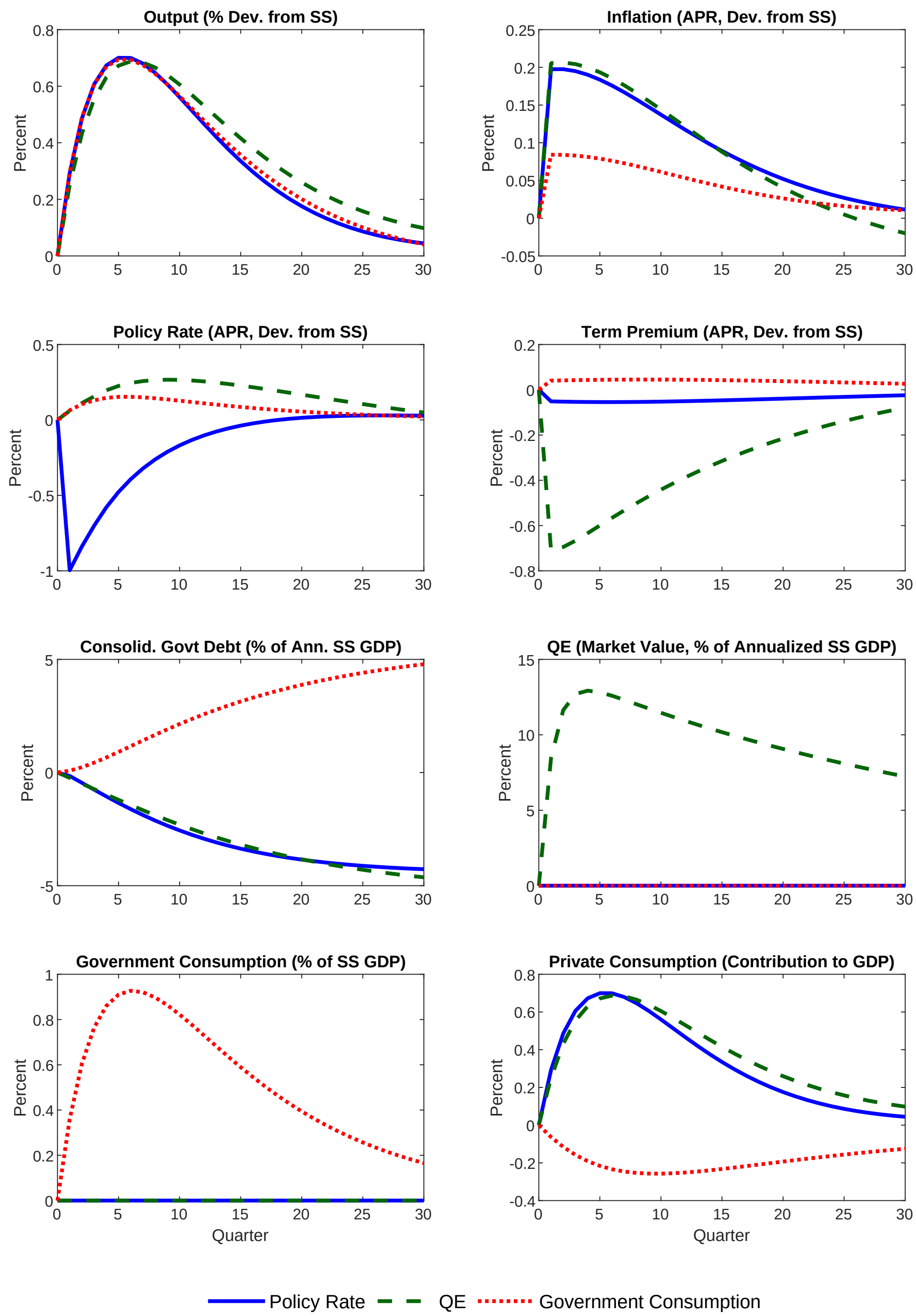

Figure 1: Transmission of Policy Instruments in the Calibrated Model.

6 quarters. If government spending is more frontloaded and follows an AR(1) process, our model implies an output multiplier of around unity. This is in line with the seminal papers by Blanchard and Perotti (2002) and Gali, Lopez-Salido and Valles (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 of about 13 percent of baseline GDP to generate the same output expansion as a 100 basis point policy rate cut when the short-term rate adjusts in response to QE purchases. This implies a peak output impulse of about 0.5 percent for QE of 10 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 GDP of QE leads to a peak output impact of 1.1 percent.[12] 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,[13] but since we address the FG puzzle with 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 the consolidated fiscal position. Our model also generates reasonable effects of QE on the term premium, implying a drop by about 70 basis points for asset purchases of 13 percent of baseline GDP. This is very close to the estimates presented by Ihrig et al. (2018) for Fed's LSAP2 and LSAP3, and by Eser et al. (2023) for ECB's asset purchase program, which suggest an impact of 4-5 basis points per purchases worth 1 percent of GDP. However, our estimate of the effects on the term premium is slightly smaller (i.e., more conservative) than those in the survey evidence of Gagnon (2016).

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 transmission on labor supply.

[12] In a meta-analysis, Fabo et al. (2021) note that the effectiveness of QE is found to be notably smaller by academics than central bank economists.

[13] 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 QE's stimulus.

Higher government spending increases labor supply and reduces real wages which attenuates the upward pressure on inflation from a given-sized output increase. 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) 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

We next use the model to assess the effects of QE in a liquidity trap generated by economic conditions of varying severity. 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 bank's target for some time, and the short-term policy rate is constrained by the ELB for a prolonged period. This scenario is reminiscent of the conditions prevailing in the aftermath of the Global Financial Crisis, 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 much smaller, and the shadow rate is only modestly below 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. As these cases span a wide range, they are also useful for inferring effects in many intermediate cases.

3.1 A Baseline Scenario with Slow Recovery

To assess QE in a deep liquidity trap, we generate a severe recession using a sequence of discount factor shocks ε_t^d that lead to a persistent increase in desired household savings.[14] As shown in Figure 2, these shocks push the nominal (net) shadow rate well below zero for a prolonged period. As a result, the short-term policy rate becomes pinned at the ELB for 20 quarters, and the undesired positive persistent gap between the actual and the shadow policy rate triggers a sharp decline in output of nearly 8 percent. As the discount factor shock leaves potential output unaffected, it also triggers a commensurate negative output gap (not shown) along with a significant persistent decline in inflation below the central bank's 2 percent target.

Against this backdrop – in which forward guidance in the form of a lower-for-longer policy rate path would have little traction in boosting output and inflation given behavioral discounting – we consider the effects of central bank large scale asset purchases. Our calibration of the process for purchases in eq. (21) implies that QE is assumed to be implemented in an anticipated yet gradual fashion. We scale 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 four quarters as can be seen from the dashed orange line in the lower right panel in Figure 2. The persistence of the rise in purchases reflects QE shock inertia and our calibration of the central bank's reinvestment policy.

In this 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. The stabilization gains are substantial. Over the horizon shown in the figure, the cumulative output loss is about 13 percent smaller when quantitative easing is deployed, while a standard discounted quadratic loss measure – which is often used as a proxy for welfare – declines by about 20 percent.[15] Many central

[14] 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.

[15] Following Debortoli et al. (2019), we use the following formulation of the loss function: $\sum_{t=0}^{T} \beta^t [(4\pi_t - 4\pi)^2 + (y_t/y - 1)^2]$, where $\beta = \omega_r \beta_r + (1 - \omega_r)\beta_u$ and $T = 30$.

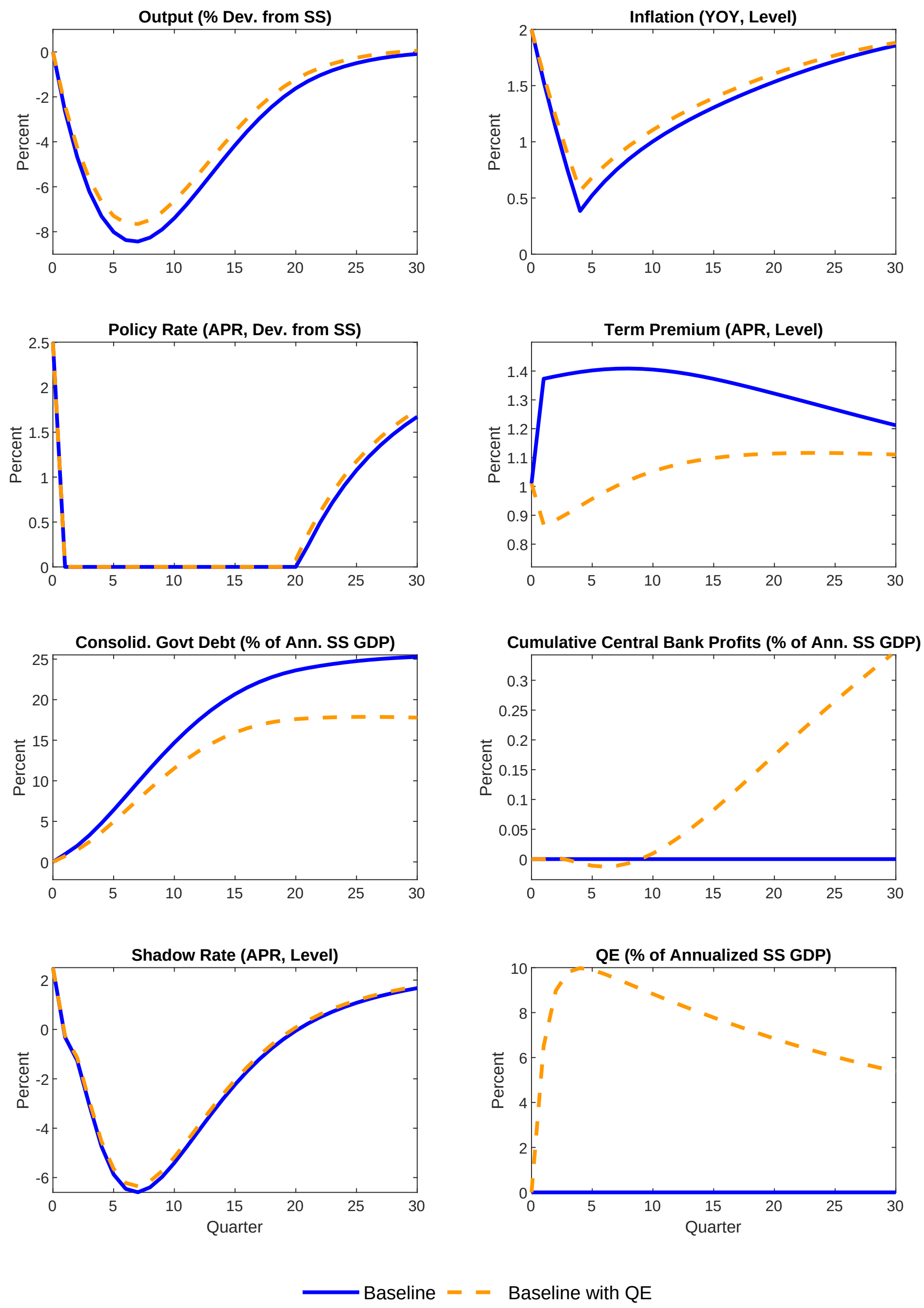

Figure 2: Deep Recession without and with QE.

banks expanded their balance sheets by nearly 20 percent of GDP during the COVID recession. In that case, the decrease in the loss would amount to 37 percent. For comparison, if the central bank instead committed to delaying policy lift-off by one year, the macroeconomic gains would be much smaller, especially in a long-lived trap (see Erceg et al., 2024, for more discussion).

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). 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). This offset is relatively modest, and so most of the decline in the term premium passes through to long-term yields.

On the fiscal side, QE generates a substantial improvement in the government's consolidated fiscal position as the stimulus to output boosts the fiscal primary balance, reduces the real value and cost of servicing past debt, and also pares the cost of issuing new debt. The central bank also makes profits, with its capital rising close to 0.2 percent of annual GDP after five 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 before rising gradually to its long-run level. All told, government debt (middle left panel) falls by about 6 percent of baseline GDP after five years, with increased tax revenue playing a large role (as we discuss in more detail below).

3.2 A Scenario with Faster Recovery

Our scenario showing a "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 Global Financial Crisis. Moreover, it seems plausible given the very low level of the shadow rate that the macro and fiscal benefits would still be likely to remain substantial even if sizeable shocks occurred after the implementation of QE that called for faster policy rate hikes than under the baseline in Figure 2. Given that the central bank would like to set a deeply negative policy rate if unconstrained by the ELB, even fairly sizeable aggregate demand shocks – such as from fiscal expansion – should not push toward significantly earlier liftoff.

To validate this conjecture, the left column of 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 scenario with and without QE that exactly repeats Figure 2, except that we now label the scenario "slow recovery." But Figure 3 also shows their variants under an unexpectedly faster recovery (with the brown dotted and green dash-dotted lines showing the case without QE and with QE, respectively). The latter 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).[16]

Despite the sizeable shocks – which quickly boost inflation above the central bank's target and engender much faster growth – the policy rate still remains tethered to the ELB for more than two years after the shock. As a result, while liftoff is indeed somewhat earlier and faster than under the slow recovery scenario (middle left panel), the stimulus to output from QE turns out to be only slightly smaller. The quantitative effects are most easily seen in the right panel, which shows the marginal effects of QE both in the slow recovery case (orange dashed lines) and faster recovery case. Moreover, while QE induces a faster return of output to baseline, it does not cause any overshoot. Unsurprisingly, given that the faster recovery scenario causes inflation to rise to nearly 3 percent even without QE, deploying this policy induces a bigger inflation overshoot (left panel second from top). But even with some amplification from Phillips Curve nonlinearities, the quantitative effects on inflation are very small (see the marginal effects in the right panel).

Overall, QE continues to provide substantial macro benefits in the faster recovery scenario – boosting output and inflation when economic slack is high and the welfare benefits are presumably largest. Thus, the benefits of QE when initiated in a deep liquidity trap appear quite robust even to sizeable subsequent shocks that would call for faster policy rate adjustment. Moreover, while the policy rate may have to rise earlier than envisioned when QE was undertaken, reducing central bank profits relative to the slow recovery scenario (lower right panel), the consolidated fiscal position still improves almost as much as under the baseline. 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 liquidity trap and the importance of looking at the consolidated fiscal position when assessing the fiscal consequences of this policy.

3.3 A Comparison with Conventional Fiscal Stimulus

In this section, we compare the implications of using QE versus fiscal stimulus in the environment of a deep liquidity trap. The fiscal instrument we consider is an increase in government consumption (for which there is ample empirical evidence about transmission for both the U.S. and the Euro

[16] 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 twice as large as assumed here and would have much more dramatic consequences.

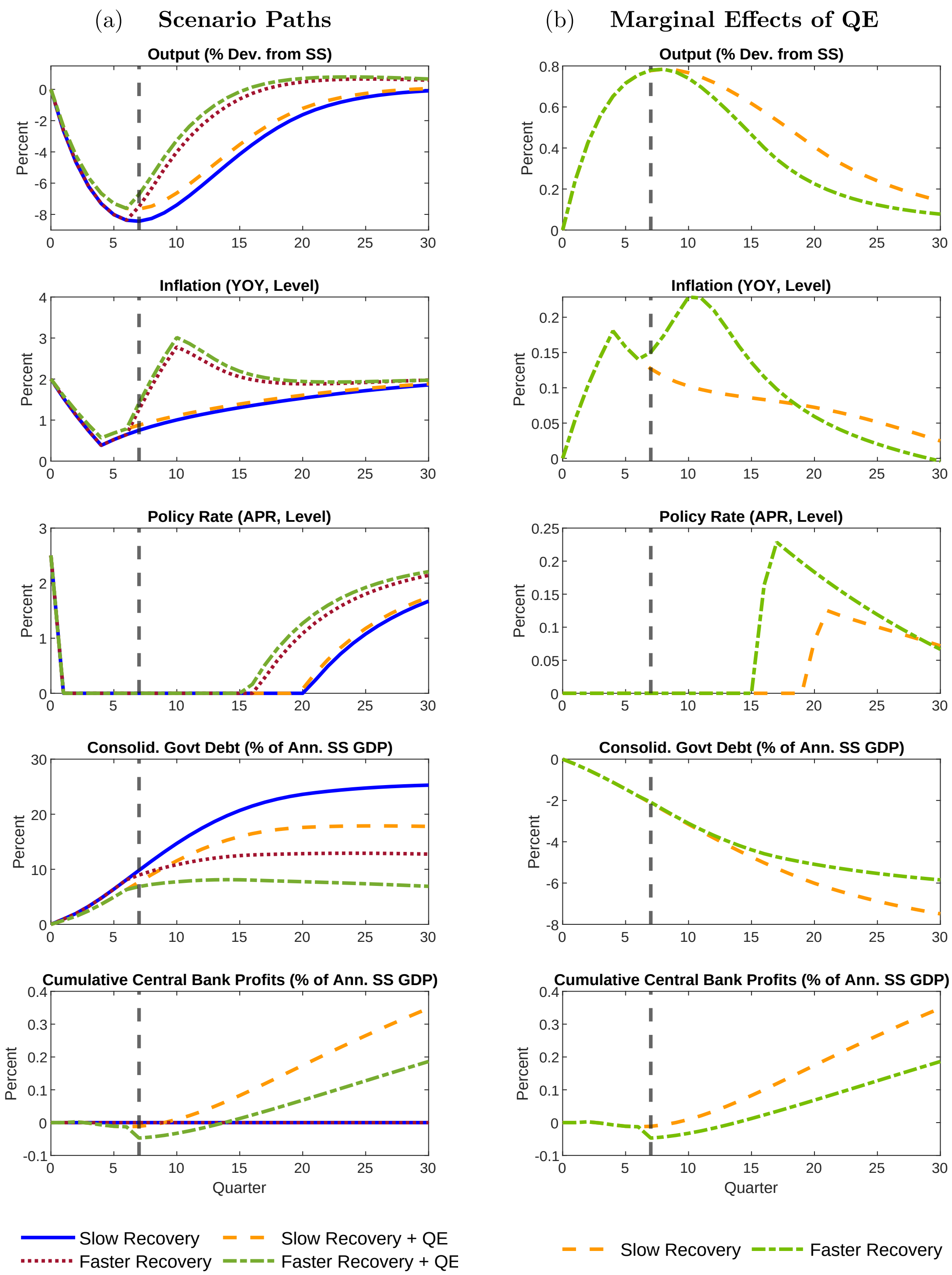

Figure 3: QE in a Deep Recession with Unexpected Faster Recovery.

area as discussed in Section 2.7). After normalizing both policies so that they imply the same boost to aggregate output over the subsequent 30 quarters, we compare the effects on inflation, interest rates, and the consolidated fiscal position (i.e. government debt).[17]

The left column in Figure 4 compares the marginal impact of QE and government spending under the slow recovery baseline, while the right column compares the marginal effects in the faster recovery scenario (thus, the dashed lines showing QE are the same as the "marginal effects of QE" shown in the right column of Figure 3). The paths of QE and fiscal stimulus announced in period 1 are assumed to be implemented subsequently, including in the faster recovery scenario.

Given that we have already discussed the marginal impact of QE, we focus on the transmission of conventional fiscal policy. Starting with our baseline results in the left column with a slow recovery, it is evident that fiscal policy stimulates inflation by considerably less than QE even though the output boost is essentially identical, and reflects that higher government spending increases potential output, whereas QE leaves it nearly unchanged. This implies that fiscal stimulus generates a smaller positive output gap (given that both policy interventions are scaled to generate the same-sized increase in output) and hence a smaller increase in inflation. Another difference between QE and conventional fiscal stimulus is that the latter raises the term premium slightly, reflecting the increased issuance of long-term government debt. Thus, the long-term interest rate rises a bit in Figure 4, in contrast to the sharp decline under QE. Quantitatively, our model implies that the consolidated government debt position worsens by about 3 percent of steady state GDP after 30 quarters, compared to the 7 percent to GDP improvement under QE.

The right column in Figure 4 presents a similar comparison under the same faster recovery scenario considered in Section 3.2. Under these conditions, the output stimulus from each of these tools is reduced as policy tightens more quickly, but the transmission to inflation is somewhat stronger due to the nonlinear Phillips Curve. As we have seen, a faster-than-expected recovery from the recession mutes the improvement in the consolidated fiscal position due to QE. It also deteriorates a bit more in this scenario under the fiscal stimulus, though the change is very small. Even so, Figure 4 makes it clear that QE can be expected to generate a significant improvement in the fiscal position, in sharp contrast to fiscal expansion.

Figure 5 provides a more detailed account of the key factors driving the response of consolidated public debt to QE (left column) and higher government spending (right column). The red solid lines show the overall response of public debt and are identical to Figure 4 for both the slow and faster recovery scenarios. Under the slow recovery scenario, more than half of the overall decline in

[17] 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.

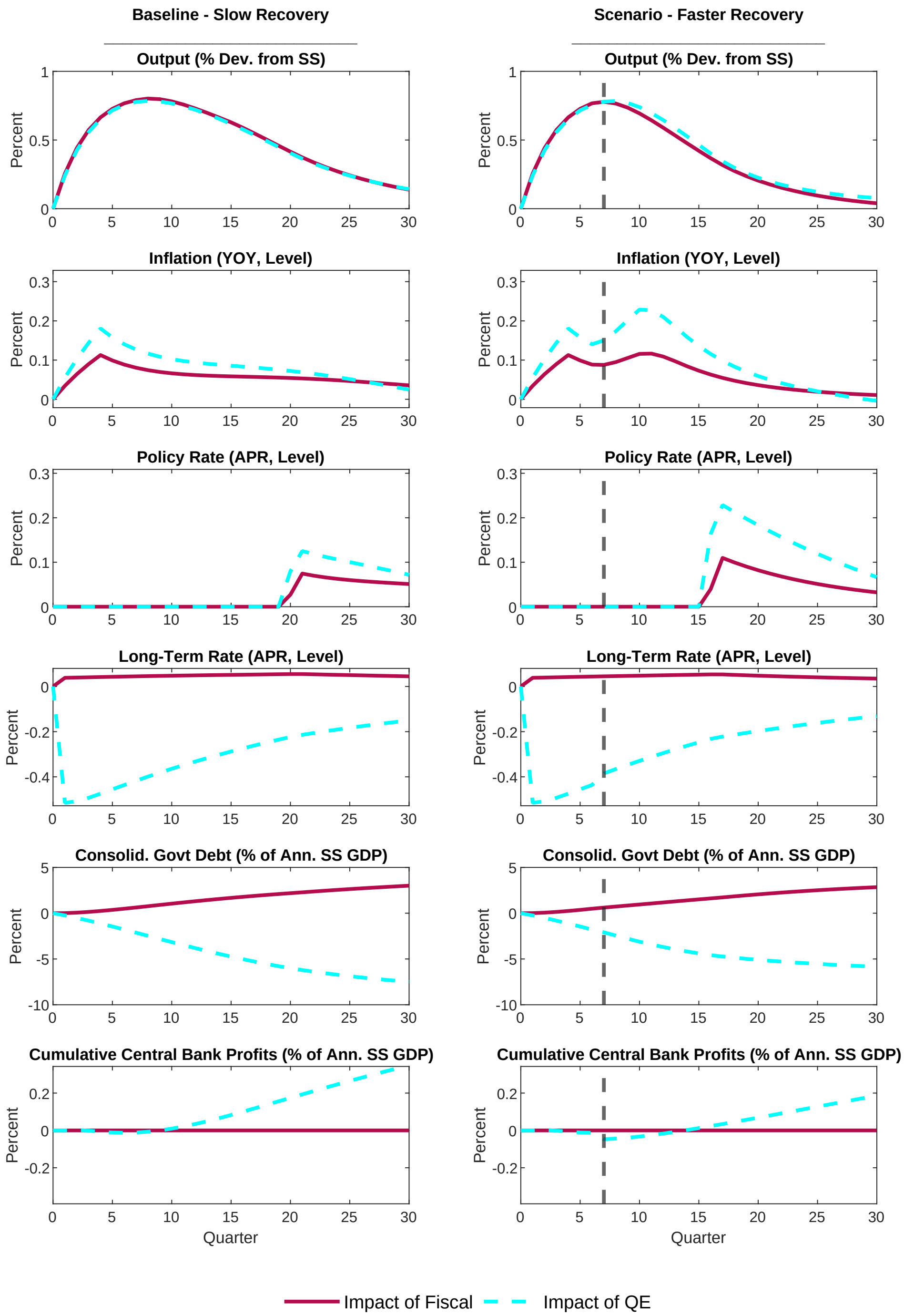

Figure 4: QE versus Fiscal Stimulus in a Deep Trap with Slow and Faster Recovery.

public debt under QE (upper left panel) reflects higher labor income tax revenues and (to a lesser extent) consumption tax revenue. In addition, lower debt service and issuance costs, as well as debt deflation arising from the rising price level reduce debt considerably, with some small added gains from central bank profits.

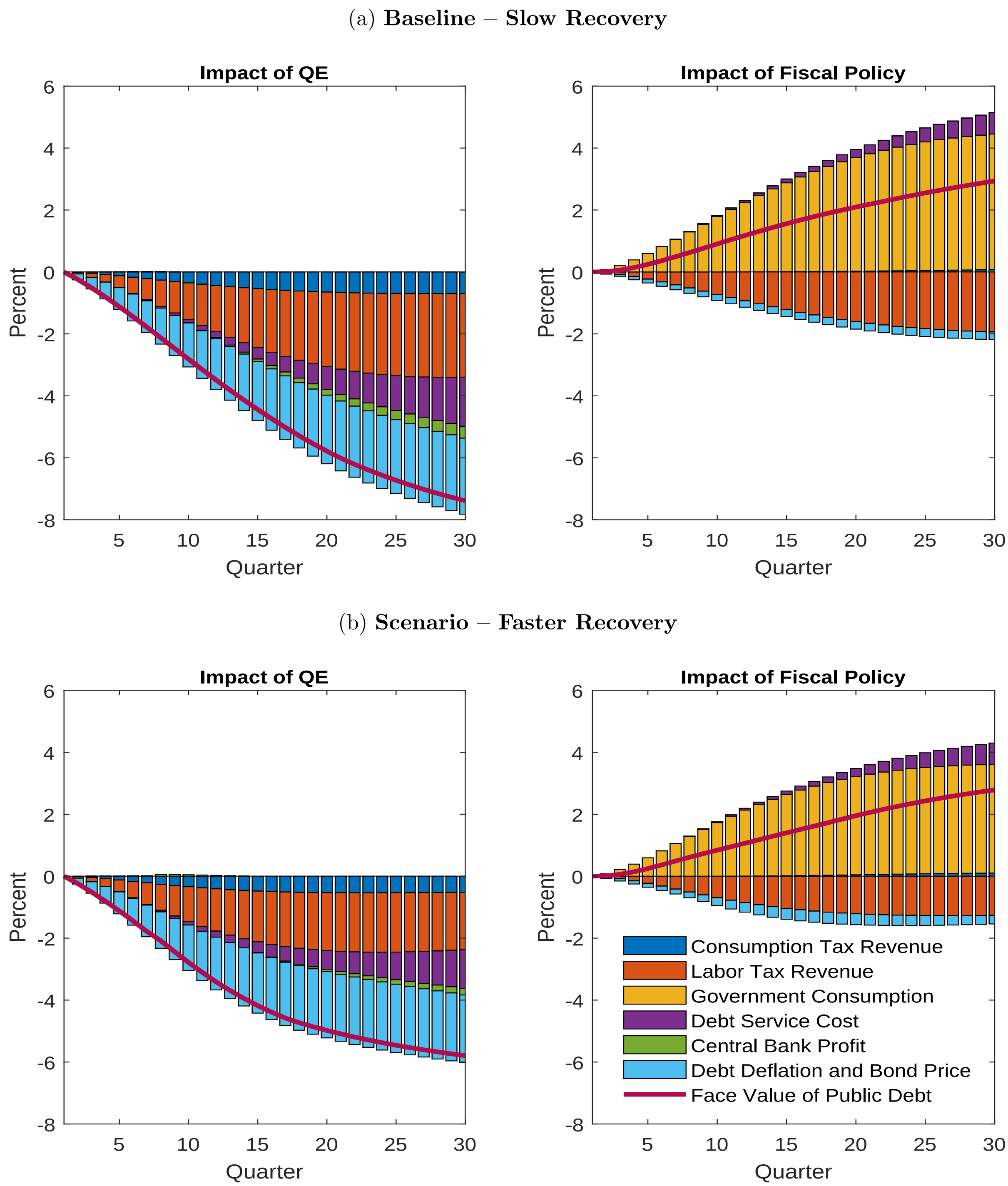

Figure 5: Decomposition of QE and Fiscal Stimulus to Consolidated Government Debt.

As regards the stimulus via higher government spending, shown in the upper right panel, the accumulation of government purchases over time is the key driver of the deterioration in the fiscal position, with some amplification at later horizons from rising debt service costs. While there is some offset from higher tax revenue, the quantitative impact is – somewhat surprisingly – quite a bit smaller than under QE even though the policies are scaled to have essentially identical effects on output (and hours worked, given that total factor productivity is unchanged). The smaller expansion in labor tax revenue under fiscal expansion reflects that the increase in government consumption increases labor supply, which translates into less of a boost in wages and hence real labor earnings. And given that 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. Finally, because fiscal expansion boosts the aggregate price level by less and does not increase bond prices, the debt-deflation and debt issuance cost channels are also weaker.

Turning to the faster recovery scenario in the lower panels of Figure 5, it is clear that the drivers of debt dynamics are quite similar to the slow recovery case. Even so – as noted earlier – the quantitative improvement in the debt-to-GDP ratio under QE is smaller, which mainly reflects noticeably smaller labor income tax revenues.

4 QE in Shallow Liquidity Traps

We now turn to the case of a shallow liquidity trap where economic activity is much closer to potential than in the deep trap discussed in the previous section, but the central bank is still constrained by the ELB from persistent below-target inflation.

4.1 A Baseline Scenario with Slow and Fast Recovery

Here we generate the modal baseline projection 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 illustrated in Figure 6, the baseline without QE has a modestly negative output gap of about 2 percent, and inflation is about 0.8 percentage points below target (labelled "slow recovery," and denoted by solid blue lines). As a result, the shadow rate falls just slightly below the ELB for about three years. Against this backdrop, we assume that the central bank purchases long-term government bonds equal to 10 percent of baseline GDP (as in the deep liquidity trap case considered in Figure 2).

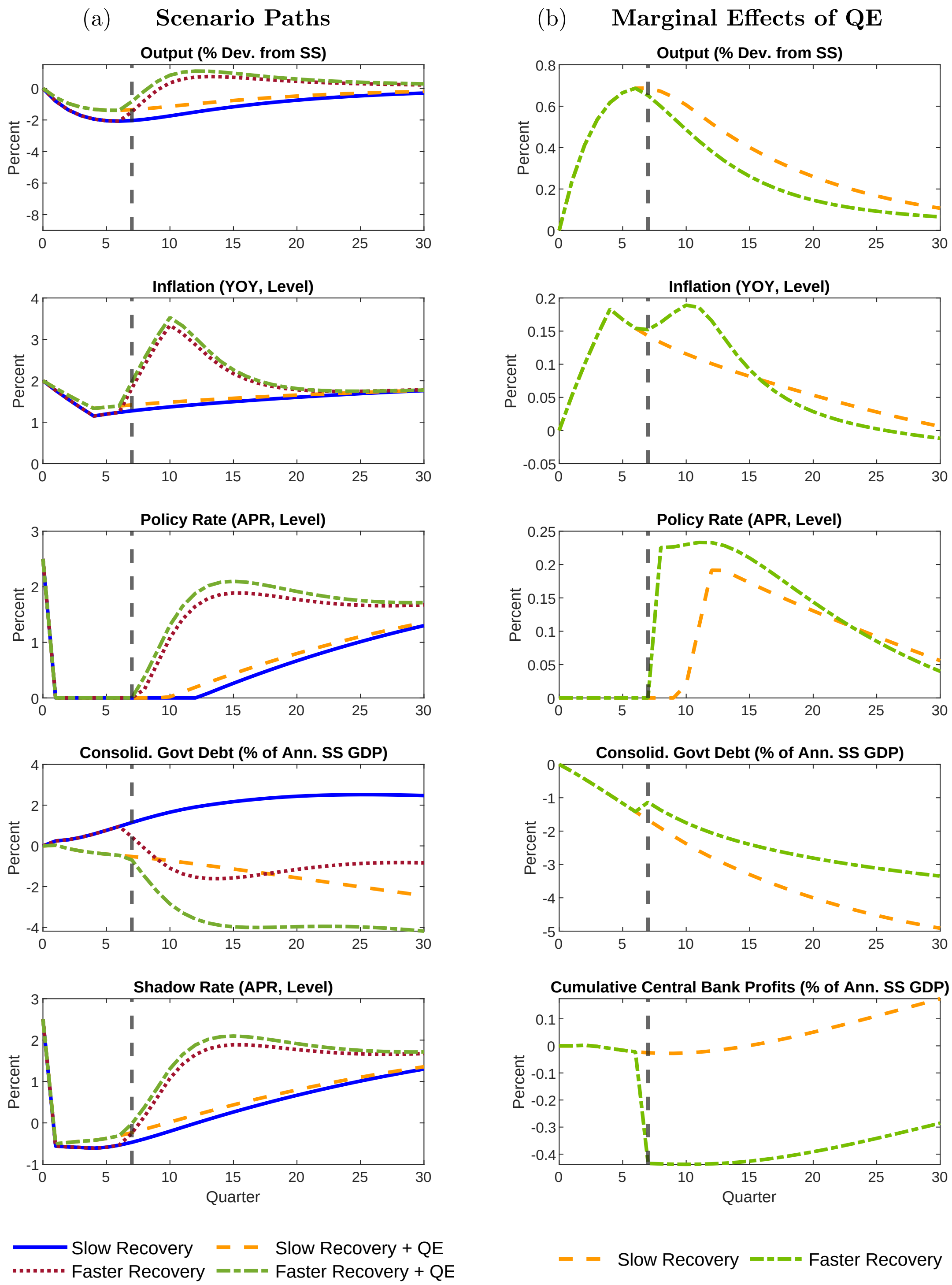

Figure 6: QE in a Shallow Recession with Unexpected Faster Recovery.

QE still appears beneficial provided that the economy evolves reasonably in line with the baseline outlook (orange dashed lines). The 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 the 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, comparing the marginal effects of QE shown by the orange-dashed lines in the right panels of Figure 6 and Figure 3, the peak effect on output is about 0.7 percent in the shallow trap compared with 0.8 in the deep trap, and the stimulus is noticeably less persistent. In terms of fiscal implications, higher tax revenues and lower debt service costs still generate a favorable impact on the consolidated fiscal position, although the improvement of 4 percent of GDP after 20 quarters is only about two-thirds of that achieved in the deep trap in Figure 2.

Second, there is a much greater risk that QE can be counterproductive in a shallow liquidity trap if upside inflation risks materialize than in a deep liquidity trap. 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 under the baseline outlook and to raise policy rates well above their normal long-run level. Under these circumstances, the central bank could face large losses.

This "faster recovery" scenario is illustrated in Figure 6 with green dash-dotted and brown dotted lines. It is generated by using the same mix of demand and supply shocks that was considered earlier in Figure 3 against the backdrop of a deep liquidity trap. 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 (upper left panel). As a result, QE turns out to contribute to the overheating: a standard discounted quadratic loss measure *increases* by 17 percent. 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 (further depressing the marginal effects on output shown in the upper right panel relative to the deep liquidity trap case). 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 Commitment Aspects of QE

While we have assumed that policy rates adjust immediately in the faster recovery scenario, QE may pose significantly greater risks to macroeconomic stability if policy rate adjustment occurs more gradually. This is relevant in practice, as QE typically involves both forward guidance about how long QE will continue, as well as some form of pledge to delay hiking interest rates until well after QE ends.[18] If the central bank feels "locked into" keeping policy rates low even when it would otherwise raise them more quickly, overheating may be amplified considerably relative to what we have considered in Figure 6 (Orphanides, 2023; Eggertsson and Kohn, 2022).

This case is illustrated in Figure 7. We begin by considering the same baseline scenario in a shallow trap with a faster recovery, with the case without QE depicted by the brown-dotted lines, and the case with QE by the green dash-dotted lines, so that they correspond exactly to Figure 6. These simulations are next compared with a scenario which assumes that the central bank commits to delay the lift-off of the policy rate (blue-dashed lines). More precisely, we implement this scenario by assuming that, when the shocks triggering a faster recovery hit in period 7, the interest rate smoothing coefficient γ increases from 0.9 to 0.94 for two years and the central bank keeps the policy rate unchanged for four quarters. These assumptions mean that, despite the earlier recovery, the short-term interest rate is at the ELB for a total of 10 quarters, which coincides with the ELB duration under the slow recovery outlook when QE is first implemented (see Figure 6). 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, with both factors making QE even more counterproductive from the ex post perspective. As we show in Appendix A.3, the overheating could be further exacerbated (and a surge in inflation much stronger) if increased inflation pressure triggers wage indexation mechanisms.

By delaying the lift-off, commitment reduces central bank losses while also boosting revenue and lowering debt-servicing costs. Together, these serve to improve the consolidated fiscal position even more than when interest rates rise immediately. However, it bears emphasizing that 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

[18] This guidance may be indeed the main factor differentiating QE from debt maturity management by the fiscal authority as otherwise both policies can have a similar effect on the portfolio of bonds held by private agents.

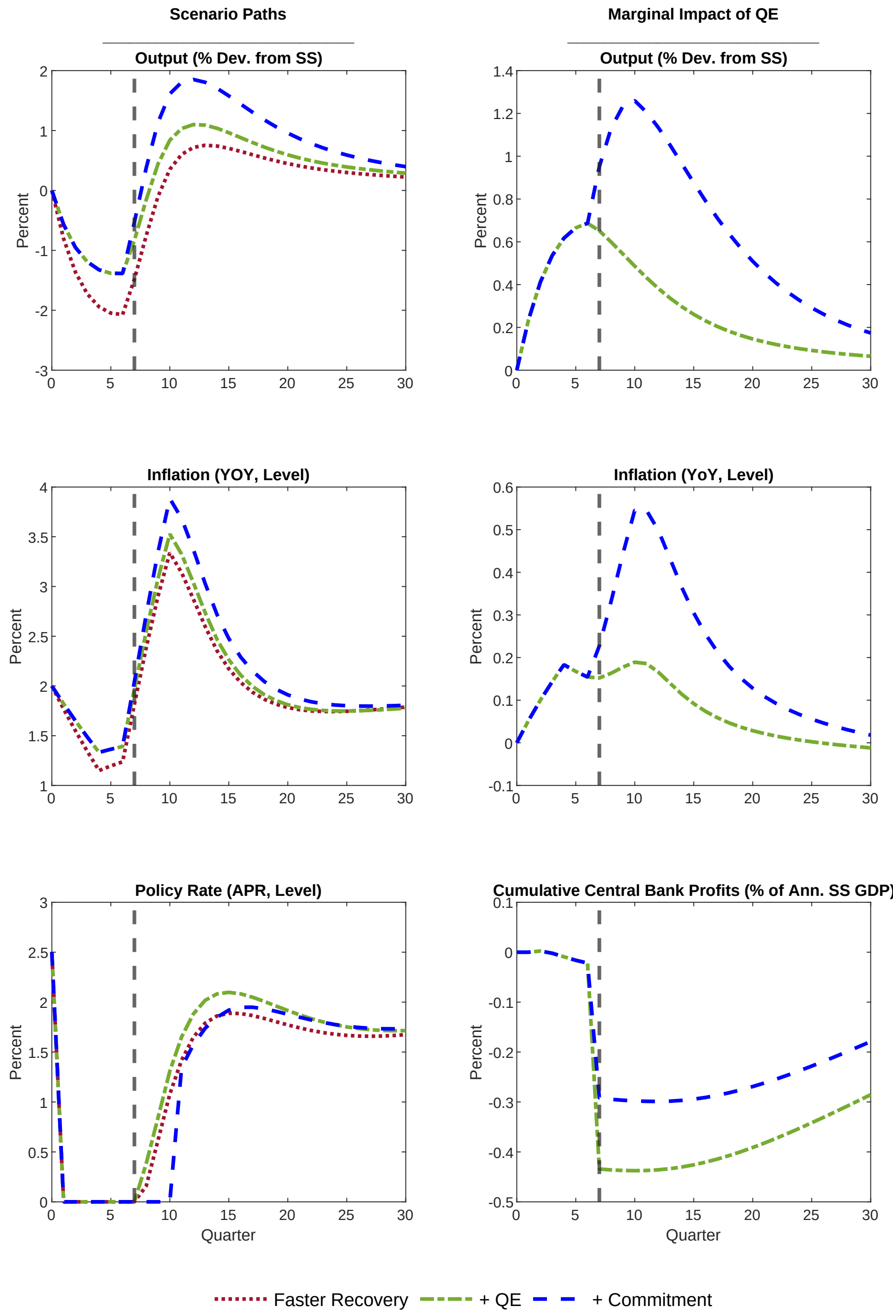

Figure 7: Impact of QE with Faster Recovery and Exit Commitment.

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 led to more persistent inflation effects – than in our model.

Overall, the results presented in this section illustrate that, while guidance on the future policy stance that includes some degree of commitment might be useful to boost the effectiveness of QE, it could be beneficial to complement it with escape clauses. Their goal would be to allow the central bank to mitigate the risk of overheating if the recovery from a shallow liquidity trap turns out to be faster than envisaged at the moment of QE implementation.

4.3 The Role of Initial Financial Conditions and QE Size

Our analysis so far suggests that QE is very likely to improve the consolidated fiscal position, and thus "more than pay for itself," irrespective of whether the liquidity trap is deep or shallow, and even if an earlier recovery scenario materializes. In this section, we further explore the robustness of this result by considering two additional factors beyond the depth of the liquidity trap that could plausibly affect the results: the initial level of the term premium and the size of the asset purchase program.

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 bonds as it finances them by issuing short-term liabilities that do not carry a premium. This is exactly what we can observe under the baseline outlook presented in Figures 3 and 6, where the central bank profits are positive unless the economy recovers more quickly than expected. However, the economy may instead enter a liquidity trap when the term premium is already compressed, potentially leading to considerably bigger central bank losses.[19] Furthermore, while we have assumed that the expansion in central bank balance sheets is 10 percent of GDP, many central banks have implemented considerably bigger programs.[20] In this vein, given that a 10 percent of GDP QE closes only about one-third of the output gap in the shallow liquidity trap case, there could well be grounds for the larger intervention.

Against this backdrop, Figure 8 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. We show results for two alternative calibrations – when the term premium is markedly lower (0 basis points) and if additionally the QE is twice as big (20 percent of GDP) as in our baseline parameterization. The left column shows the marginal impact of QE under the baseline outlook, whereas the right column presents the earlier recovery scenario as defined earlier.

[19] 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 (LSAP4) was launched.

[20] For example, during the COVID-19 pandemic the balance sheets of the US Fed and Bank of England expanded by around 20 percent of the respective countries' GDP, and by more than 30 percent in the case of the European Central Bank and the Bank of Japan.

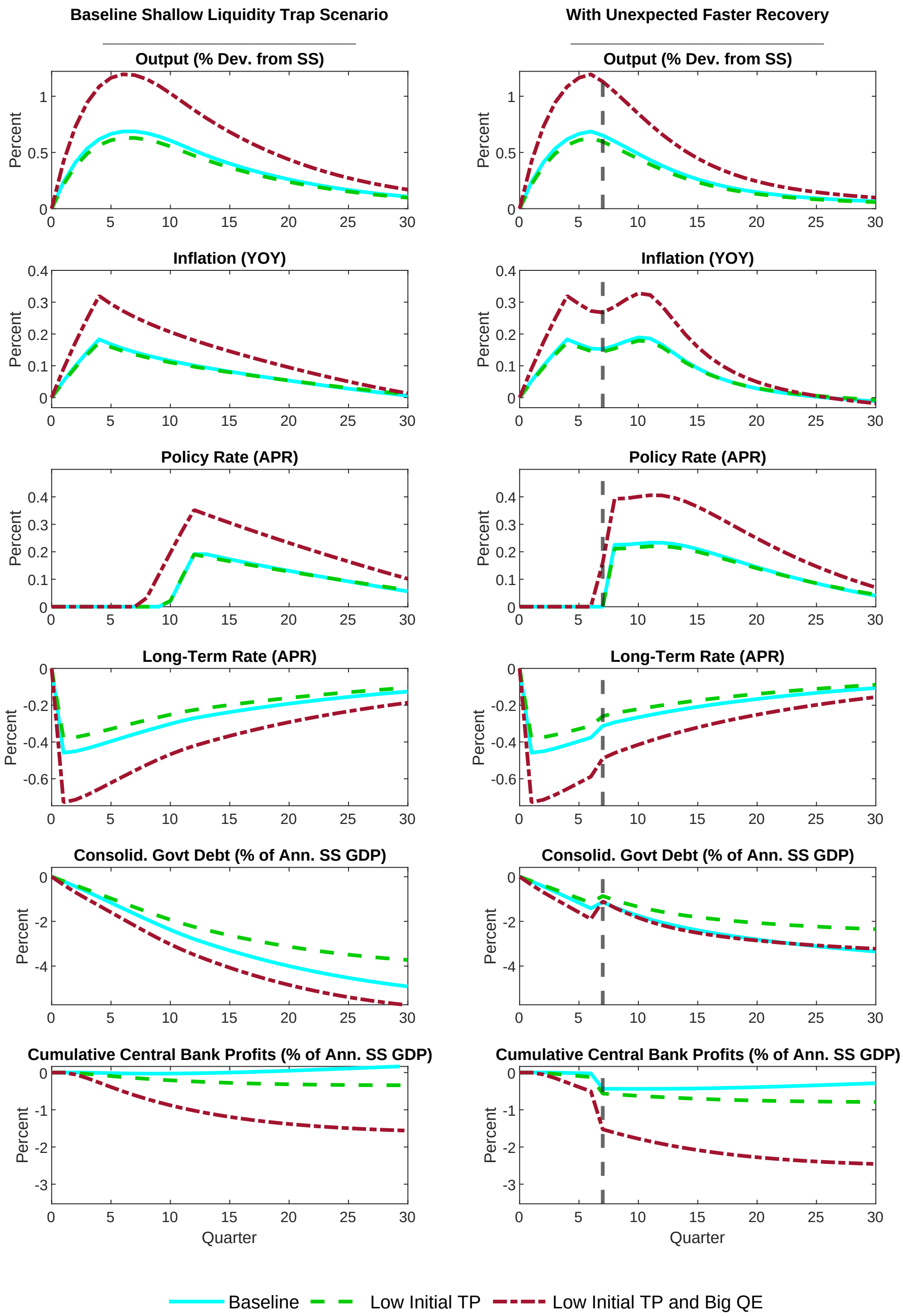

Figure 8: Sensitivity of QE Effects to Steady State Term Premium and QE Size.

As can be seen from the figure by comparing solid-blue and dashed-green lines, while the macroeconomic transmission of QE to output, inflation and policy rates is very similar if the initial term premium is low (just a tad weaker), the effects on 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 about 1 percent of GDP less than if the initial term premium was set to 100 basis points as in our earlier simulations. The effects look similar in the scenario with a faster recovery (right panels of Figure 8). In this case, central bank losses are also about twice as large as in the corresponding case with a higher initial term premium, and the improvement in the consolidated fiscal position after 5 years is merely 2 percent.

The brown dash-dotted lines in Figure 8 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 below zero, 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, while QE is twice as large, the improvement of the consolidated fiscal position is only about 50 percent bigger. 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 8, 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.

4.4 Other Considerations

We also briefly discuss one additional consideration that may be relevant for the deployment of quantitative easing, namely the sensitivity of the term premium to QE. It should be re-emphasized that we have calibrated it quite conservatively, and so the effects of asset purchases are likely to be larger than what we have reported. Moreover, while we have focused on the effects of QE in an environment in which financial conditions are not stressed, the effects on term premiums – and hence on output – would likely be even higher if longer-term Treasury markets were not functioning well as during QE1 in the US and during the “dash for cash” during COVID. Still, there is a possibility that the sensitivity of the term premium to QE may be attenuated in certain circumstances – for example, when yields are already highly compressed and further asset purchases have only limited effects on bond prices.[21] In such an environment, QE provides little stimulus to output and inflation, implying modest macroeconomic benefits. At the same time, it leaves the central bank's balance sheet exposed to the risk of sizable losses if the recovery materializes earlier than anticipated, even though the weaker sensitivity of the term premium tends to support central bank profits under the modal outlook.

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 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. Because this long sample includes periods in which inflation, interest rates, and the real economy were very volatile, it is helpful for "stress testing" some of the risks that could arise from QE, including to the fiscal position and to central bank balance sheets. Such stress-testing seems particularly relevant given that many countries may face a considerably more shock-prone environment than in the period between the start of the Great Moderation in the early 1980s and the recent inflation surge.

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) derived from our simple matching procedure are as

[21] Levin, Lu, and Nelson (2022) argue that the effects of the Federal Reserve's QE easing on the term premium in the aftermath of COVID was very small.

follows:

$$
\begin{aligned}
\varepsilon_t^z &= 0.90\varepsilon_{t-1}^z + u_t^z,\ u_t^z \backsim i.i.d.N\,(0, 0.01) \\
\varepsilon_t^c &= 0.90\varepsilon_{t-1}^c + u_t^c,\ u_t^c \backsim i.i.d.N\,(0, 0.035) \\
\varepsilon_t^p &= 0.85\varepsilon_{t-1}^p + u_t^p,\ u_t^p \backsim i.i.d.N\,(0, 0.04) \\
\varepsilon_t^w &= 0.85\varepsilon_{t-1}^w + u_t^w,\ u_t^w \backsim i.i.d.N\,(0, 0.26)
\end{aligned} \tag{29}
$$

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 even though our set of shocks does not include the monetary policy shock (ε_t^r).[22]

Table 3: Targeted Stochastic Moments.

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

Notes: The moments in the U.S. 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 $\pi_t^{w,ann}$ is measured with wages in the non-farm business sector. The model moments are based on a simulation of a long-sample of 10,000 observations. We match all moments except for 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. (29) imply that the bulk (88 percent) of the unconditional volatility in output growth per capita is explained by the consumption demand shock, while this shock only explains a relatively small part (21 percent) of inflation volatility. In line with estimated structural macroeconomic models, for

[22] We exclude monetary policy innovations because we don't want deviations from normal policy behavior to be a source of uncertainty and earlier policy normalization; hence the latter will only occur for fundamental reasons, i.e., as inflation and output developments affect the interest rate rule (19).

instance the Smets and Wouters (2007) model, fluctuations in inflation are 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 firm price-setting behavior: the Kimball (1995) aggregator implies that there is more upward than downside inflation risk due to Phillips Curve nonlinearities, which can be seen from the inflation fan chart in the second left panel. 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 (1960-2019) that includes the "Great Inflation." 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 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.

The right column in Figure 9 shows the marginal impact of QE. Here we calculate the difference between the 500 trajectories with QE and the same simulations without QE (as in Figures 3 and 6). 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).[23] 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 (i.e., mean impact of stochastic

[23] These coincide with the brown dash-dotted line in the left column of Figure 8 except that they are now plotted starting from period 1.

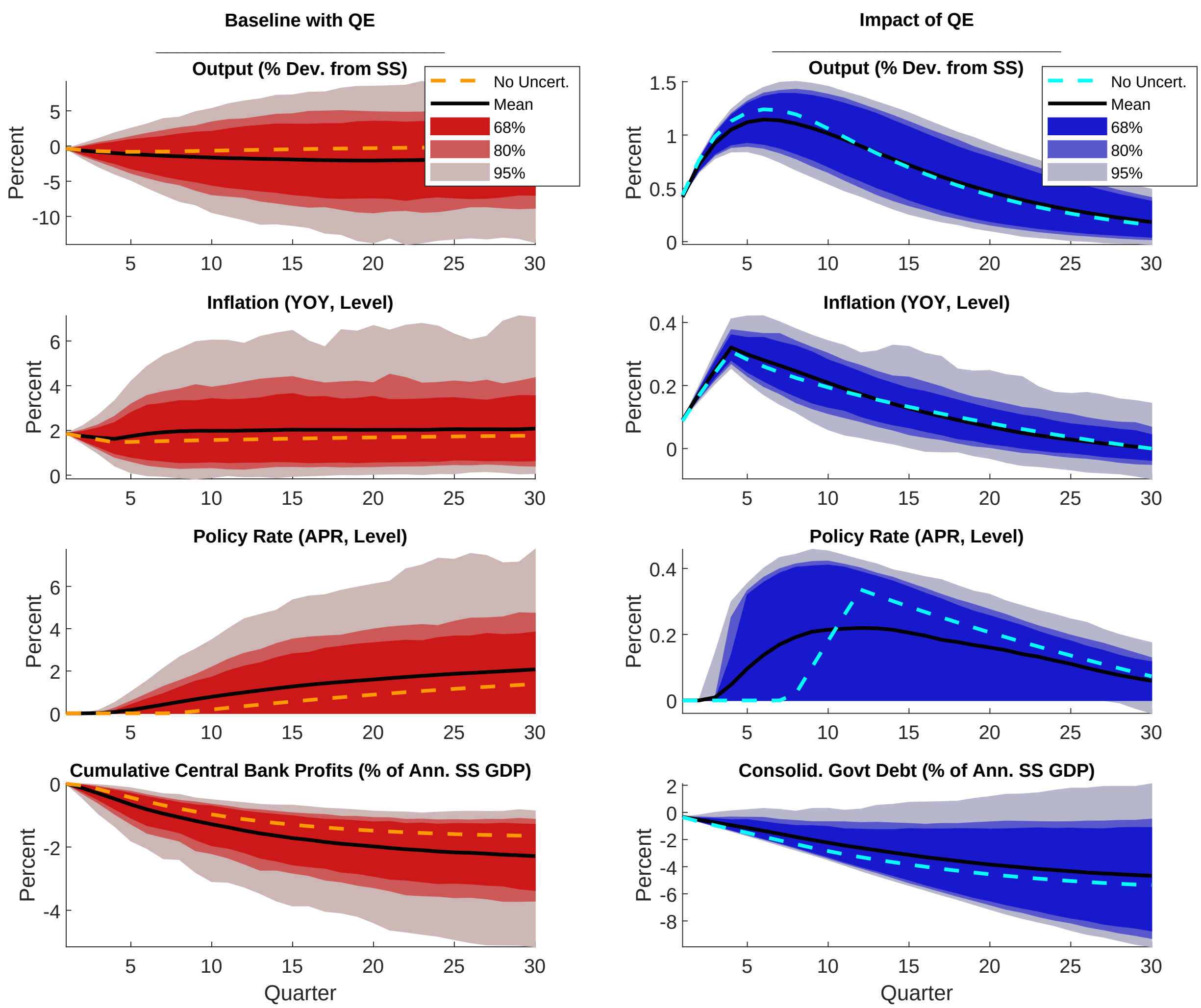

Figure 9: Impact of Uncertainty in a Shallow Trap with Low Initial Term Premium and Big QE.

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 larger 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 arises from increased tax revenue and lower costs of financing and issuing debt. Even so, a striking feature of Figure 9 is that the risk for sizeable consolidated fiscal losses is small even when the central bank faces a large risk of making outsized losses on its portfolio of long-term assets as seen in the lower left panel.[24]

These results underscore the importance of looking beyond central bank losses when considering

[24] The cumulative central bank profits in the left panel are also equivalent to the marginal effects of QE in this simulation.

the fiscal effects of QE. We have also considered sensitivity analysis to the sample period and depth of the liquidity trap, and found that the risk for consolidated fiscal losses from QE would be even smaller if calibrated over a Great Moderation subsample. Similarly, 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 in a deep liquidity trap. Consistent with our earlier analysis, this reflects that QE provides a stronger boost to economic activity and tax revenue, while the deeply negative shadow rate makes the actual policy rate likely to stay flat for long even if strong inflationary shocks materialize, limiting the risk of central bank losses.

6 Concluding Remarks

This paper aims at providing an assessment of the macroeconomic benefits and fiscal costs of quantitative easing. We have shown that QE is likely to have substantial macroeconomic 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 significantly, and these macro benefits are quite robust to scenarios where the economy recovers more quickly than expected. Moreover, QE depresses consolidated government debt significantly, in sharp contrast to fiscal expansion which raises it. This makes QE an attractive tool in an environment of limited fiscal space.

Our analysis does suggest more caution about using QE in a shallow liquidity trap. While QE may appear beneficial ex ante, there is a considerable risk that it may cause overheating given nonlinearities in the Phillips Curve and the potential for inflation-raising shocks to occur after the deployment of QE. Moreover, such faster recovery scenarios can expose the central bank to significant losses that may pose a significant headwind for central bank credibility. Even so, we show how allowing the policy rate to adjust more quickly can help contain these overheating risks, and that the consolidated fiscal position tends to improve. Hence, QE may still be useful to consider, albeit with some refinements such as clearly articulated "escape clauses."

Our paper also highlights the need to look well beyond central bank losses in evaluating the fiscal effects of QE. Asset purchases do pose substantial maturity risk for central banks, and losses can indeed be large – especially if the global environment is considerably more shock-prone than in the Great Moderation period. But both our scenarios and stochastic simulations point to the resilience of QE in improving the consolidated fiscal position, which is what matters for public debt and tax rates.

While our analysis has focused on evaluating QE through the positive lens of its ability to stabilize the business cycle and on its implications for the consolidated fiscal position, it would be desirable in future work to explore the normative aspects of QE using a formal utility-based welfare criteria. In the circumstances we consider, macroeconomic stimulus delivered through quantitative easing is likely to enhance welfare significantly given that it is deployed when the economy is weak and output well below its efficient level. But it would be interesting to assess how QE's effects on the consolidated fiscal position affect welfare by causing adjustments in distortionary taxation. On the modeling side, it would be useful to extend our model of QE to incorporate credit risk and endogenous capital accumulation as in Gertler and Karadi (2013) and to include features that can capture some of the financial stability risks that may accompany the unwinding of QE (through "quantitative tightening"), and that have been highlighted in work by Acharya, Rajan, and Steffen (2023).

Finally, we have noted how central banks may be averse to QE due to concerns about losses and the potential implications for their credibility and independence – raising the possibility that they might not utilize QE even in circumstances in which the macro benefits are considerable and the consolidated fiscal position would be likely to improve. Accordingly, it would seem desirable to consider whether alternative arrangements for sharing central bank profits and losses with the fiscal authority may be able to mitigate these concerns. Adrian et al. (2025) provide some preliminary considerations about potential changes in balance sheet policies.

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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. Chen, Curdia, and Ferrero (2012) show that the thus defined term premium is approximately proportional to a discounted sum of current and future portfolio adjustment 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 $P_{L,t-1}B^c_{L,t-1}$ worth of consols, then at the start of the following period it would have a coupon worth $B^c_{L,t-1}$ and a stock of assets with a market value of $\kappa P_{L,t}B^c_{L,t-1}$. Mechanically, the change in value of long term assets Ψ_t thus equals

$$\Psi_t \equiv \kappa P_{L,t}B^c_{L,t-1} - P_{L,t-1}B^c_{L,t-1},$$

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

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

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 ($\epsilon_t^c = 0$), 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 7 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.

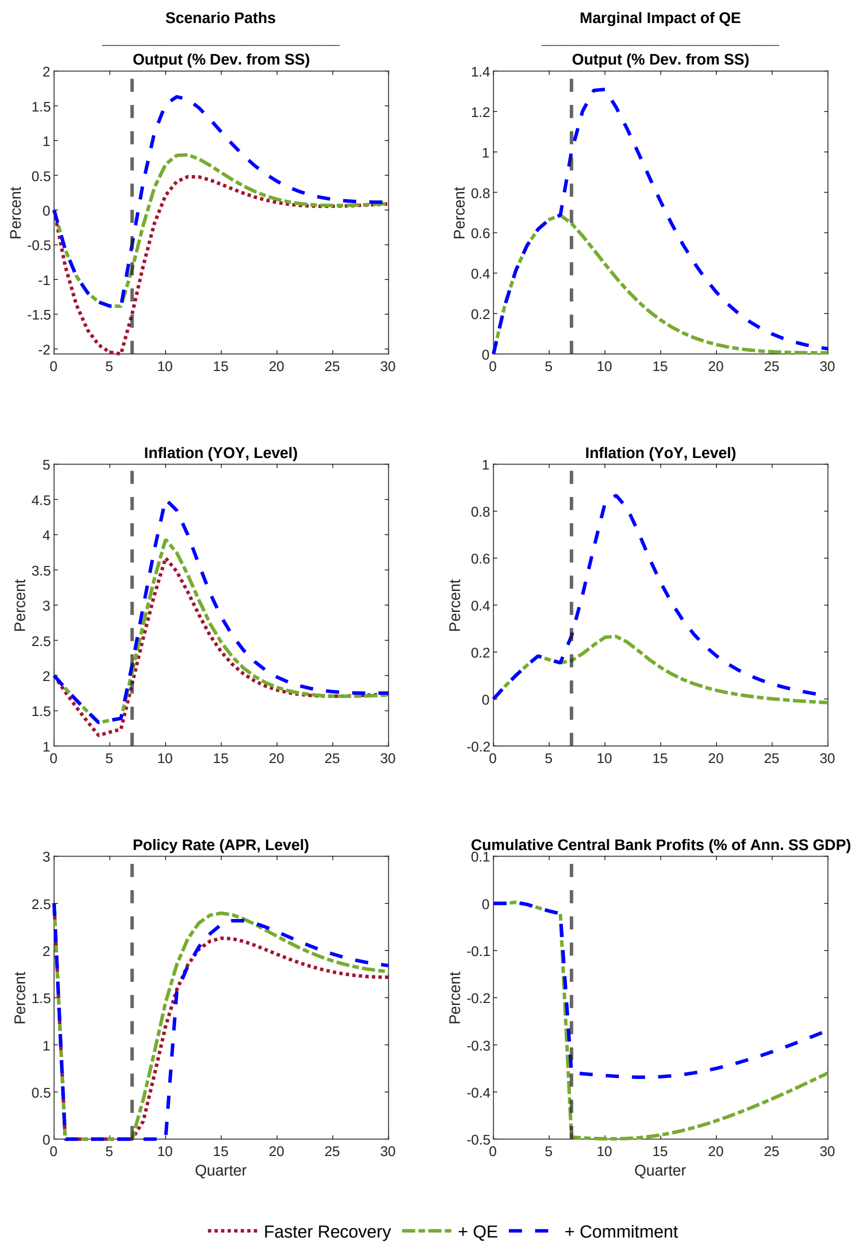

Figure A.1: Impact of QE with Faster Recovery and Exit Commitment under Wage Indexation.

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.

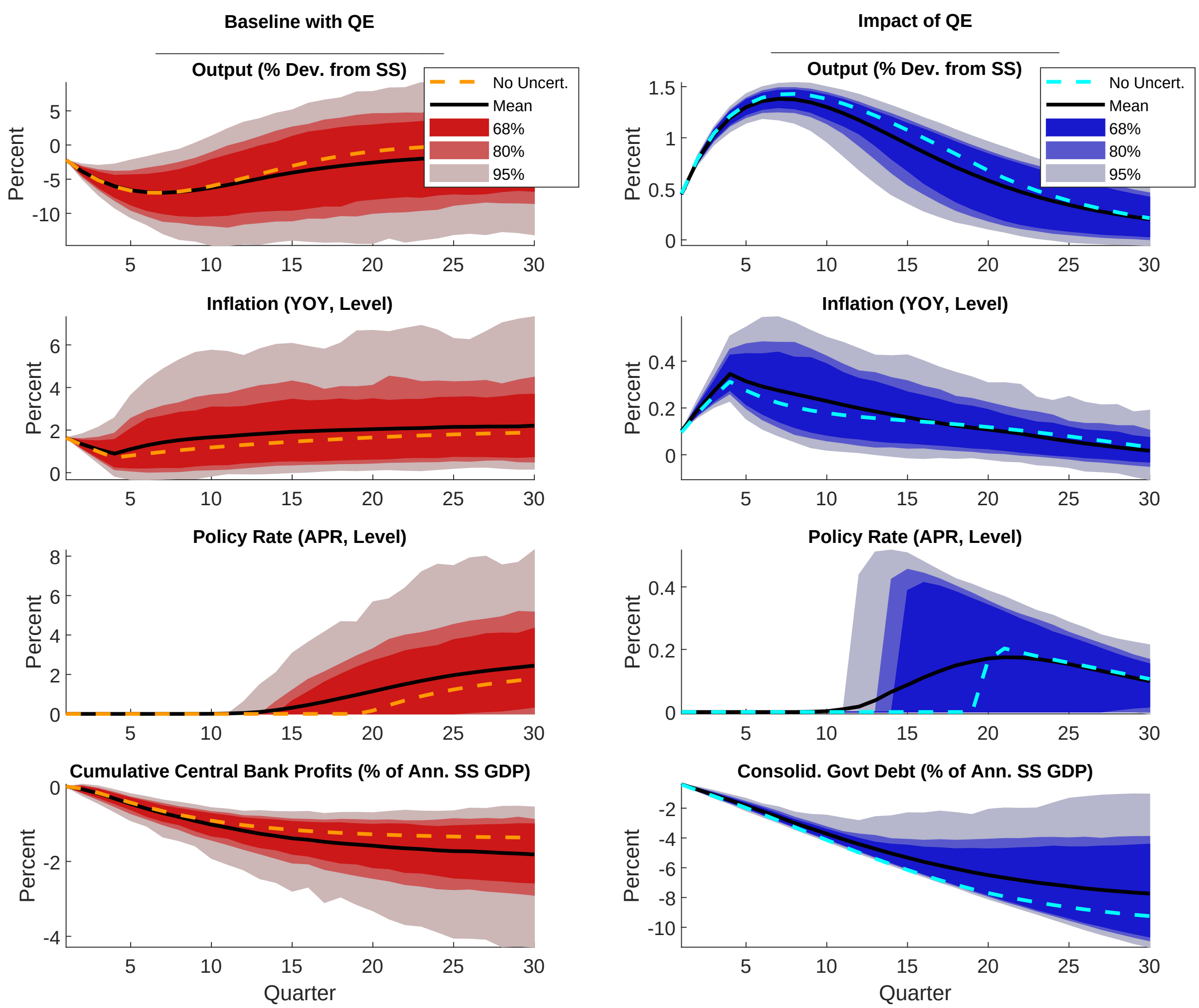

Figure A.2: Impact of Uncertainty in a Deep Trap with Low Initial Term Premium and Big QE.