Can Monetary Policy Create Fiscal Capacity? *

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Abstract

Governments around the world have gone on a massive fiscal expansion in response to the Covid crisis, increasing government debt to levels not seen in 75 years. How will this debt be repaid? What role do conventional and unconventional monetary policy play? We investigate debt sustainability in a New Keynesian model with an intermediary sector, realistic fiscal and monetary policy, endogenous convenience yields, and substantial risk premia. During an economic crisis of the same magnitude as the 2020 Covid recession, increased government spending and lower tax revenue lead to a large rise in government debt and raise the risk of future tax increases. We find that quantitative easing (QE) and a higher inflation target contribute to lowering the debt/GDP ratio and reducing the risk of future tax increases. QE is state- and duration-dependent: while a temporary QE policy deployed in a crisis stimulates aggregate demand, permanent QE crowds out investment and lowers long-run output.

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1 Introduction

The global covid-19 pandemic has resulted in unprecedented contraction in aggregate consumption, investment, and output in nearly every developed economy. For example, U.S. GDP fell 2.75% in 2020. In response to the covid shock, both fiscal and monetary authorities mounted a massive response which mirrored the response after the Great Financial Crisis in magnitude but exceeded it in speed. Government spending increased dramatically, resulting in a primary deficit of 13% of GDP in 2020. Government debt relative to GDP reached 100%, a level not seen in the U.S. since 1947. On the monetary policy front, interest rates were slashed to zero. A large-scale quantitative easing (QE) program was launched, and through forward guidance, the Fed signaled that it would keep interest rates near zero and bond purchases high until the economy had fully recovered. The Fed also announced a new monetary policy framework that would tolerate overshooting the 2% inflation target while the economy was recovering.[1]

In this paper we ask whether these conventional and unconventional monetary and fiscal policy responses have helped the economy recover, and more controversially, whether they can help pay back government debt. We find that they have and that they can. QE, a relaxation of bank capital requirements, and a higher inflation target during the crisis and the early recovery, all contribute towards a smaller increase in the debt/GDP ratio during the crisis and a faster decline in its aftermath. Five years after the start of the crisis, the debt/GDP ratio is 8.5% points lower than it would have been absent the unconventional monetary policies (UMP) put in place, and despite the additional spending. UMP not only lowers the debt/GDP ratio on average, it also limits the tail risk by curtailing the likelihood of future tax increases that become necessary to stabilize the debt once the debt/GDP ratio becomes too high.

We study these questions by building a dynamic stochastic general equilibrium model in the New Keynesian (NK) tradition. Its main new feature is its ability to deliver non-trivial risk and risk premia. To that end, we let the economy undergo both transitory productivity shocks–standard in macro–and permanent productivity shocks–standard in finance– and insist on a high enough market price of risk associated with these shocks to deliver a quantitatively realistic output and equity risk premium. In the presence of non-trivial risk, the NK model

[1] See https://www.federalreserve.gov/newsevents/pressreleases/monetary20200827a.htm.

becomes more difficult to solve and calibrate since the stochastic steady state is far away from the deterministic steady state. We employ state-of-the-art global projection methods to overcome this challenge.

To study QE, we introduce two maturities for government debt and an intermediary sector. The intermediary sector uses its holdings of reserves and firm capital to back deposits, subject to leverage and liquidity constraints. Households invest in deposits, long-term government debt, and firm capital. A QE policy purchases long-term debt from households and issues (short-term) reserves to banks. By providing plentiful high-quality collateral to intermediaries, QE crowds out intermediary demand for firm capital. The reduction in capital demand causes a shift from aggregate investment to consumption, which in the short-run affects the economy like a positive shock to aggregate demand. Due to a large consumption multiplier during the crisis when conventional monetary policy is constrained by the ZLB, QE is an expansionary policy that causes higher output, labor demand, consumption and investment, ultimately resulting in a smaller increase in the debt/GDP ratio in the crisis. Furthermore, the policy lowers long-term interest rates, which combined with short-term policy rates that are lowered to the zero lower bound and a shortening of the maturity of the debt held by the public, substantially and persistently depresses the debt service on government debt.

We contrast a QE policy introduced in response to a crisis to QE policies introduced in normal times, either permanent or transitory in nature. We find that transitory QE policies introduced in normal times are largely ineffective. They provide a temporary consumption and output boost, but the latter is ten times smaller than the same-size QE policy mounted in response to a crisis. As a thought experiment, we also consider a permanent QE program. This program is equivalent to a permanent reduction in the maturity of government debt held by the public. While it boosts consumption temporarily, it lowers the return on household wealth and crowds out banks' investment in firm capital. These two forces lead to a permanently lower capital stock and slightly lower consumption in the long-run. Output falls throughout the transition to the new steady-state with a lower capital stock, so that permanent QE fails to stimulate the economy. At the same time, intermediaries enjoy a greater supply of liquid assets and supply more deposits to households. The benefits from greater liquidity provision to households outweigh the detrimental capital stock effect. Consistent with these findings, lengthening the duration of QE past the end point of the crisis confers little additional benefit in terms of accelerating the recovery.

In contrast to QE, raising the inflation target for longer in response to a crisis has stronger real effects than an inflation target that is just increased for the duration of the crisis. This suggests that the new monetary policy framework laid out by the Fed has provided additional stimulus upon announcement and aided the recovery. It results in higher inflation during the crisis and in a period of inflation overshooting in its immediate aftermath. The new monetary policy framework thus contributes to the high inflation the U.S. economy experienced in 2021.

We assume that fiscal policy does not respond continuously to the debt/GDP ratio, consistent with the post-war U.S. data. Rather, fiscal policy switches from active (stabilizing the macroeconomy) to passive (stabilizing the debt) once the debt/GDP ratio crosses a threshold. In this "austerity region," tax rates increase to bring the debt/GDP ratio back down. The threshold is endogenously determined to guarantee the safety of government debt. Setting the threshold any higher would result in a non-zero probability of default. That is, certain stochastic paths for the economy would require increases in tax rates that no longer generate sufficient tax revenue, given Laffer curve effects, to stabilize the debt. For our calibration, the austerity threshold is a debt/GDP ratio of 112%. If Congress passes the spending bill, under consideration at the time of this writing, the U.S. would cross this threshold in 2022 and would need to raise taxes. Even though the risk-free rate is below the growth rate of the economy in our model ($r^f < g$), fiscal capacity is limited. Interestingly, we find that the policy mix enacted in response to the covid crisis substantially reduced the risk of entering the austerity region, from 29% to 8%.

Related Literature Our paper contributes to the vast literature on macroeconomics in New-Keynesian (NK) models. Our contribution here is three-fold.

First, we consider a rich set of fiscal and monetary policy tools which have not been studied in this combination before. The "conventional" fiscal policies we study feature labor income and corporate profit taxation, transfer spending, and discretionary spending. Crucially, all four policies depend on the state of the economy, producing the counter-cyclicality of spending and pro-cyclicality of tax revenues quantitatively consistent with data. The "unconventional" fiscal policy consists of a switching of regimes whereby the fiscal authority chooses tax rates to target debt reduction once the debt/GDP ratio exceeds an endogenously-determined threshold. Unlike standard models in which tax rates continuously respond to changes in the debt-to-GDP ratio to keep debt bounded (reviewed comprehensively by Leeper and Leith (2016)), our method allows an arguably more realistic fiscal regime that focuses on output stabilization most of the time, and only targets debt stabilization when debt/GDP reaches high values. This non-linear rule necessitates a global solution method. Conventional monetary policy consists of a standard Taylor rule. Unconventional monetary policy arises as a crisis response and includes quantitative easing (QE), a relaxation of intermediary leverage constraints, and a higher inflation target. We find that a tax rule that responds continuously to the debt/GDP ratio leads one to overstate the effectiveness of UMP relative to our benchmark model.

Second, we find a combination of preferences and shocks that generate a realistic amount of risk and risk premia. Standard NK models typically omit permanent shocks, calibrate to low shock volatilities, and standard monetary and fiscal policies remove what little remaining consumption risk households might otherwise face. As a result, the standard NK model generates trivial risk premia. Furthermore, the NK model is typically solved using log-linearization (or low-order perturbation methods) which mostly ignore aggregate risk premia (and their time-variation).[2] The crucial ingredients in our paper that result in meaningful risk and risk premia are: (i) positively correlated transitory and permanent productivity shocks (calibrated to the data), (ii) Epstein-Zin preferences which separate risk aversion from intertemporal substitution motives, (iii) a high enough coefficient of relative risk aversion, and (iv) a global solution method. Meaningful risk premia are not just nice to have, they are necessary to understand the effect of monetary and fiscal policies on debt sustainability (Jiang et al., 2020). We find that lowering risk aversion leads one to understate the effectiveness of UMP relative to our benchmark model. We suspect that having realistic risk and risk premia might make an important difference when evaluating many other policies in NK models.

Our third contribution is to introduce an intermediation sector which is better at providing

[2]De Paoli, Scott, and Weeken (2010) document that nominal rigidities combined with monetary policy following a Taylor rule greatly reduce consumption risk in a standard business cycle model. Gourio and Ngo (2020) generate meaningful risk premia in a globally solved NK model with rare disasters and a ZLB on interest rates. Isoré and Szczerbowicz (2017) adapt Gourio (2012)'s approach to perturbation methods, yet require large disaster probabilities to create non-negligible risk premia. Campbell, Pflueger, and Viceira (2020) and Pflueger and Rinaldi (2021) introduce habit preferences in an NK model to produce realistically time-varying risk premia.

credit to firms than households are, and produces deposits that are valued by households.[3] It is subject to an occasionally-binding leverage constraint (Supplementary Leverage Ratio, SLR) and liquidity regulation (Liquidity Coverage Ratio, LCR), and faces equity issuance costs that make recapitalization during and after a crisis costly. This intermediary sector is important for understanding QE, since QE injects reserves into the banking sector. This affects SLR and LCR constraints and the allocation of assets between banks and households.

In contemporaneous work, Sims and Wu (2021) consider a NK model with credit shocks, financial intermediation, and short-term and long-term government debt to study conventional and unconventional monetary policy. Billi and Walsh (2021) find, as we do, that higher discretionary spending in an economic crisis can decrease the debt/GDP ratio due to a large fiscal multiplier. Andrade et al. (2021) study the effects of a higher inflation target in demand recessions at the ZLB.

Our paper also contributes to the literature evaluating the effectiveness of QE.[4] We find that QE is highly effective when launched in response to a crisis caused by a shortfall in aggregate demand and when it is temporary in nature. Like in the data, QE lowers long-term interest rates in our model and "spills over" to lower the equity risk premium. We highlight three channels through which QE works in our model: a crowding-out channel, a liquidity-creation channel, and a fiscal risk avoidance channel.

A recent literature studies fiscal capacity in a world where the risk-free interest rate is below the growth rate in the economy.[5] The work of Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2019, 2020) emphasizes that, in the presence of realistic permanent output risk and risk premia, keeping government debt risk-free is challenging. It requires making the tax revenue claim safer than the government spending claim ($\beta^T < \beta^G$). This in turn may mean raising taxes at inopportune times. Our model generates this feature. Tax rates are pro-cyclical and government spending is counter-cyclical at business-cycle frequencies, helping households smooth aggregate

[3] Piazzesi, Rogers, and Schneider (2021) study the properties of the NK model in a world with financial intermediaries and ample reserves. Wang (2020) analyzes state-dependent pass-through of monetary policy in an NK model with a financial sector. Elenev (2020) and Faria-e-Castro (2020) develop quantitative NK models with intermediation sectors to evaluate policy responses during the GFC.

[4] See (Woodford, 2012; Vissing-Jorgensen and Krishnamurthy, 2011, 2012, 2013; Vissing-Jorgensen et al., 2018; Bernanke, 2020).

[5] See Blanchard (2019), Jiang et al. (2019, 2020, 2021), Barro (2020), Brunnermeier et al. (2020), Reis (2021), Mankiw and Ball (2021), Cochrane (2019a,b), among others.

risk. However, once the debt/GDP ratio crosses into the austerity region, tax rates increase to stabilize the debt. The model quantitatively replicates the output risk premia in Jiang et al. (2019) as well as the tax and spending betas from Jiang et al. (2020).

Our paper also contributes to the large literature that studies the interaction of fiscal and monetary policy.[6] Bianchi and Melosi (2019) introduce state-dependent policy targets for monetary and fiscal authorities. In an application, Bianchi, Faccini, and Melosi (2020) consider an emergency budget in the wake of the covid-19 pandemic which the monetary authority accommodates by temporarily tolerating higher inflation. Our fiscal rule is also state-dependent but not event-driven. Rather, fiscal policy actively stabilizes aggregate fluctuations until the debt/gdp ratio breaches a bound. Beyond that point, fiscal policy becomes passive. We study the role of (un)conventional monetary policy in this new setting of endogenously-switching fiscal policy regimes.

A literature at the intersection of macro-economics and asset pricing studies how fiscal risk manifests itself in asset prices.[7] It typically works with models where uncertainty about future taxes affects firms incentives to invest in R&D, leading to lower long-run productivity growth through an endogenous growth mechanism. Fiscal policies that stabilize the macro-economy in the short-run are welfare-reducing since they result in tax uncertainty and higher volatility of long-run consumption growth, which hurts welfare when households have Epstein-Zin preferences. Our model does not feature an effect of tax uncertainty on investment and long-run growth since it is not an endogenous growth model, and instead focuses on the effect of tax uncertainty on labor supply rather. We find that additional government spending and unconventional monetary policy (UMP) lower risk premia in a macro-economic crisis, consistent with the stated objective of UMP.

The rest of the paper is organized as follows. Section 2 sets up the model. Section 3 describes the calibration. Section 4 discusses the properties of fiscal variables in normal times. Section 5 contains our main results describing crisis dynamics under various policy scenarios. Section

[6]See Sargent and Wallace (1981); Leeper (1991); Sims (1991); Woodford (1994), Woodford (1995), Woodford (2001); Cochrane (1998), Cochrane (2001); Schmitt-Grohhe and Uribe (2000); Bassetto (2002); Reis (2016); Sims (2016), among many others.

[7]See Croce, Nguyen, and Schmid (2012b); Croce, Kung, Nguyen, and Schmid (2012a); Pastor and Veronesi (2012); Kelly, Pastor, and Veronesi (2015); Croce, Nguyen, Raymond, and Schmid (2019); Liu, Schmid, and Yaron (2020); Corhay, Kind, Kung, and Morales (2021).

6 concludes. The appendix provides detailed model derivations (A), data sources used in the calibration (B), details on the computational method (C), and additional results on QE policies and forward guidance (D).

2 Model

A representative household supplies labor, operates the investment technology, and owns shares in non-financial firms and banks. The household derives utility from holding deposits issued by financial intermediaries. The government issues nominal debt securities to fund its deficits. Government debt has two maturities: short-term debt that matures in the next model period, and long-term debt with duration δ^B. Short-term debt includes both government debt securities with short maturity (T-bills), as well as high-powered money issued by the central bank (reserves).

Intermediaries hold short-term government debt and firm capital as assets and issue deposits and equity to households. Households also invest directly in firm capital and they hold long-term government debt. We assume that only intermediaries hold short-term debt and only households hold long-term debt, broadly in line with the aggregate data (as discussed in the calibration section).

2.1 Production Technology

Productivity. Productivity Z_t has a permanent and a transitory component

$$Z_t = Z_t^p Z_t^r,$$

where

$$\log(Z_t^r) = z_t^r = \rho^z z_{t-1}^r + \varepsilon_t^z, \tag{1}$$

$$\log(Z_t^p) = z_t^p = z_{t-1}^p + g_t. \tag{2}$$

The growth rate of the permanent component evolves according to

$$g_t = (1 - \rho^g)\bar{g} + \rho^g g_{t-1} + \varepsilon_t^g. \tag{3}$$

The innovations to transitory and permanent productivity are jointly normally distributed:

$$(\varepsilon_t^z, \varepsilon_t^g) \sim \text{Normal}(\mu_t, \Sigma_t).$$

Means μ_t are chosen such that $\mathrm{E}[Z_t^r] = 1$ and $\mathrm{E}[g_t] = \bar{g}$. Productivity level and growth shocks are the only two sources of aggregate risk in the model. It will turn out to be very important to allow for a positive correlation between these two shocks.

Final Goods. Production follows the standard New Keynesian framework (Galí (2015)) with price rigidities. The final output good Y_t is a composite of intermediate good varieties $Y_t(i),\ i \in [0,1]$ that are combined by a final-goods producer.

Final output is

$$Y_t = \left(\int_0^1 Y_t(i)^{1-\frac{1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}},$$

where ϵ is the elasticity of substitution. Final goods producers maximize profit by solving

$$\max_{\{Y_t(i)\}} P_t Y_t - \int_0^1 P_t(i) Y_t(i) di,$$

where P_t is the aggregate price index and $P_t(i)$ is the price of input i. This implies the demand functions for all i:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} Y_t.$$

Intermediate Goods. Intermediate goods producers are monopolists for their varieties. They choose price $P_t(i)$ and inputs capital $k_t(i)$ and labor $n_t(i)$ to maximize profit

$$Div_t^P = P_t(i) Y_t(i) - P_t \left(w_t n_t(i) + r_t^K k_t(i) \right) - Z_t^p P_t \Xi^P (P_t(i)/P_{t-1}(i)), \tag{4}$$

where w_t is the real wage and $\Xi^P(P_t(i)/P_{t-1}(i))$ is a convex menu cost for adjusting prices. Profit is paid out in the form of dividends to households. Intermediate output is produced using a standard Cobb-Douglas technology with aggregate productivity Z_t

$$Y_t(i) = (k_t(i))^{1-\alpha}(Z_t n_t(i))^{\alpha}.$$

2.2 Financial Intermediaries

Financial intermediaries are firms that maximize the present value of dividends paid to their shareholders. On the asset side, intermediaries invest in $X_t^{I,K}$ units of capital at real price Q_t and buy $X_t^{I,S}$ short-term government bonds at nominal price p_t^S. On the liability side, they issue deposits D_t^I, modeled as one-period discount bonds, at nominal price p_t^D, and equity to the households. Intermediaries have beginning of period equity capital W_t^I and are expected to pay a fraction τ of equity to their shareholders each period. When they raise new outside equity A_t, they incur a quadratic equity adjustment cost with parameter χ. The total payout to households each period is

$$Div_t^I = \tau W_t^I - A_t. \tag{5}$$

Intermediaries are subject to two regulatory restrictions. First, equity capital regulation requires the following constraint on deposits (bank debt):

$$D_t^I \leq \nu \left(B_t^{I,S} + \nu_K P_t Q_t X_t^{I,K} \right), \tag{6}$$

where ν restricts the total leverage of the intermediary, and ν_K reflects the higher risk weight on capital relative to short-term government bonds. The overall maximum leverage ratio ν reflects the Supplementary Leverage Ratio (SLR) constraint in real world bank capital regulation.

The second regulatory restriction banks face captures the Liquidity Coverage Ratio (LCR) in the real world. Banks incur a liquidity cost per unit of deposits issued:

$$\varrho_t = \varrho_0 \zeta_\varrho \left(\frac{B_t^{I,S}}{\zeta_\varrho D_t^I} \right)^{1-\varrho_1}, \tag{7}$$

where ζ_ϱ is the fraction of deposits a particular bank's depositors can be expected to withdraw per period, and ϱ_0 scales the liquidity cost. We assume that exponent $\varrho_1 > 1$, such that the cost is decreasing in short-term bonds.

In summary, financial intermediaries solve:

$$\max_{X_t^{I,K}, B_t^{I,S}, D_t^I, A_t} \sum_{k=0}^{\infty} \mathcal{M}_{t,t+k} P_{t+k} Div_{t+k}^I$$

subject to the budget constraint:

$$(1-\tau)W_t^I + P_t A_t + (p_t^D - P_t \varrho_t) D_t^I + \text{Rebates}_t^I \geq p_t^S B_t^{I,S} + P_t Q_t X_t^{I,K} + \frac{P_t}{Z_t^p} \frac{\chi}{2} A_t^2,$$

no-shorting constraints $X^{I,j} \geq 0$, for $j \in \{K, S\}$, and the regulatory constraint (6). Intermediaries discount dividend payouts with the household discount factor $\mathcal{M}_{t,t+k}$. Further, they receive liquidity costs as lump-sum rebates, i.e. $\text{Rebates}_t^I = P_t \varrho_t D_t^I$.

The transition law for bank equity W_t^I is given by

$$W_t^I = P_t \left(r_t^K + (1-\delta) Q_t \right) X_{t-1}^{I,K} + B_{t-1}^{I,S} - D_{t-1}^I.$$

2.3 Households

The representative household consumes C_t of the final output good and supplies labor N_t to intermediate goods producers.

Households invest D_t^H in intermediary deposits, which they value for their liquidity services in addition to their pecuniary payoff, giving rise to the intra-period utility function:

$$u(C_t, D_t^H, N_t) = \frac{\left(C_t^{1-\psi} (D_t^H)^{\psi} \right)^{1-\varphi}}{1-\varphi} - (Z_t^p)^{1-\varphi} \omega_0 \frac{N_t^{1+\omega_1}}{1+\omega_1} - (Z_t^p)^{1-\gamma} \bar{u},$$

where $\bar{u} > 0$ is a constant ensuring that $u(C_t, D_t^H, N_t) < 0$.

Households have recursive preferences with subjective time discount factor β, inter-temporal elasticity of substitution $1/\varphi$, and risk aversion parameter γ, such that their value function is:

$$V_t = (1-\beta)u(C_t, D_t^H, N_t) - \beta \mathrm{E}_t \left[(-V_{t+1})^{\frac{1-\gamma}{1-\varphi}}\right]^{\frac{1-\varphi}{1-\gamma}}. \tag{8}$$

In addition to deposits, households purchase $X_t^{H,K}$ units capital at real price Q_t and $X_t^{H,L}$ long-term government bonds at nominal price p_t^L.

Capital and bond purchases are subject to portfolio costs. The long-term bond portfolio cost takes the form

$$\Xi^L(X_t^{H,L}, Y_t) = \frac{\xi_0^L}{\xi_1^L}\left(\frac{B_t^{H,L}}{Y_t}\right)^{\xi_1^L} Y_t, \tag{9}$$

where Y_t is aggregate output. Intuitively, this cost creates a downward-sloping demand curve for long-term debt relative to GDP. The presence of this cost helps the model generate an upward sloping term structure of interest rates, as well as capture the price impact of long-term bond purchases by the central bank (Quantitative Easing). Capital costs take a similar form

$$\Xi^K(X_t^{H,K}, K_t) = \frac{\xi_0^K}{\xi_1^K}\left(\frac{X_t^{H,K}}{K_t}\right)^{\xi_1^K} K_t, \tag{10}$$

where K_t is the aggregate capital stock. Costs associated with capital holdings capture households' comparative disadvantage of lending directly to firms.[8]

Households further operate the economy's investment technology, which creates I_t units of capital from $I_t + \Phi(I_t, K_t)$ units of the consumption good.

In summary, each period households choose consumption, investment, deposits, capital, and long-term bond holdings to maximize (8) subject to the budget constraint:

$$\begin{aligned} P_tC_t + P_t(I_t + \Phi(I_t, K_t)) + p_t^D D_t^H + p_t^L B_t^{H,L} + P_tQ_tX_t^{H,K} + \Xi^L(X_t^{H,L}, Y_t) + \Xi^K(X_t^{H,K}, K_t) \\ \leq W_t^H + P_t(1-\tau_t^w)w_tN_t + P_tQ_tI_t + (1-\tau_t^{div})(Div_t^I + Div_t^P) + \Theta_t + \text{Rebates}_t, \end{aligned} \tag{11}$$

where W_t^H is household financial wealth at the beginning of t. Additional resources for house-

[8] We follow the literature on intermediation (He and Krishnamurthy, 2013) and interpret capital holdings of households as direct, capital-market based finance through equities or bonds. Capital held by intermediaries reflects indirect finance through loans. The cost captures intermediaries' advantage for indirect finance.

holds are labor income $w_t N_t$, which gets taxed at rate τ_t^w (equation (22)), profits of intermediate-goods producers and financial intermediaries, which gets taxed at rate τ_t^{div} (equations (4) and (5)), transfer payments from the government Θ_t (equation (16)), and lump-sum rebates of menu costs from producers, equity issuance costs from banks, and bond portfolio costs:[9]

$$\text{Rebates}_t = Z_t^p P_t \Psi(P_t(i)/P_{t-1}(i)) + \frac{P_t}{Z_t^p}\frac{\chi}{2}A_t^2 + \Xi^L(B_t^{H,L}, Y_t). \tag{12}$$

The transition law for household wealth is:

$$W_t^H = P_t\left(r_t^K + (1-\delta)Q_t\right)X_{t-1}^{H,K} + D_{t-1}^H + (c + 1 - \delta^B + \delta^B p_t^L)B_{t-1}^{H,L}. \tag{13}$$

The payoff to each long-term bond in (13) consists of the coupon c, amortization of old debt $1-\delta^B$, and the market value of remaining debt $\delta^B p_t^L$.

2.4 Government

2.4.1 Fiscal Policy

The fiscal authority follows decision rules for transfers and discretionary spending that depend on the level of output relative to the economy's productivity trend, $\hat{Y}_t = Y_t/Z_t^p$:

$$\theta_t = \theta(\hat{Y}_t), \tag{14}$$

$$\gamma_t = \gamma(\hat{Y}_t), \tag{15}$$

such that total spending is

$$F_t = \underbrace{\gamma_t P_t Y_t}_{\equiv G_t} + \underbrace{\theta_t P_t Y_t}_{\equiv \Theta_t}. \tag{16}$$

Given these spending rules, the government follows either active or passive fiscal policy. When the government follows **active** fiscal policy, then tax rates on wage income and profits depend only on cyclical output $\hat{Y}_t$

$$\tilde{\tau}_t^n = \tilde{\tau}^n(\hat{Y}_t), \tag{17}$$

[9] Capital portfolio costs $\Xi^K(X_t^{H,K}, K_t)$ are not rebated and thus represent resource losses. We view these costs as inefficiencies stemming from suboptimal lending by households.

for $n \in \{w, div\}$. We refer to this fiscal policy as *active*, since the government is only concerned with actively stabilizing the economy by responding to deviations from the stochastic growth trend. With intermediary profits as in equation (5) and intermediate goods producer profits as in equation (4), tax revenue is

$$\tilde{T}_t = P_t \tilde{\tau}_t^w w_t N_t + \tilde{\tau}_t^{div}(Div_t^P + Div_t^I). \tag{18}$$

The combination of tax and spending rules determine the primary surplus $\tilde{S}_t = \tilde{T}_t - F_t$. Denoting the market value of government debt outstanding at the beginning of t by W_t^G, this implies that the government needs to issue new debt $\tilde{W}_t^G$ at the end of the period, where

$$\tilde{W}_t^G = W_t^G - \tilde{S}_t. \tag{19}$$

When the government follows *passive* fiscal policy instead, tax rates are indirectly determined as result of a debt issuance target. We refer to this fiscal policy regime as passive, since its goal is to stabilize the level of government debt once it reaches very high or low levels, rather than insulate taxpayers from aggregate shocks.

In particular, passive fiscal policy specifies a target level $\vec{W}_t^G$ for end-of-period debt as a function of the active issuance $\tilde{W}_t^G$ given in (19). Passive policy occurs when this debt level is either below the **profligacy** threshold $\underline{W}^G$ or above the **austerity** threshold $\overline{W}^G$.

We can summarize the combination of active and passive policy by the target level of debt:

$$\vec{W}_t^G = \begin{cases} (1-v)\underline{W}^G + v\tilde{W}_t^G & \text{if } \tilde{W}_t^G \leq \underline{W}^G \\ \tilde{W}_t^G & \text{if } \overline{W}^G > \tilde{W}_t^G > \underline{W}^G \\ (1-v)\overline{W}^G + v\tilde{W}_t^G & \text{if } \tilde{W}_t^G \geq \overline{W}^G, \end{cases} \tag{20}$$

where $v \in (0, 1)$ parameterizes the degree of fiscal adjustment in the austerity and profligacy regions. The government will then choose tax rates to target a surplus that satisfies:

$$S_t = S(\vec{W}_t^G) = W_t^G - \vec{W}_t^G. \tag{21}$$

To implement this surplus, the government adjusts tax rates by factor $f(\vec{W}_t^G)$, such that tax revenue is:

$$T_t = T(\vec{W}_t^G) = P_t \underbrace{f(\vec{W}_t^G)\tilde{\tau}_t^w}_{\equiv \tau_t^w} w_t N_t + \underbrace{f(\vec{W}_t^G)\tilde{\tau}_t^{div}}_{\equiv \tau_t^{div}} (Div_t^P + Div_t^I) = f(\vec{W}_t^G)\tilde{T}_t. \tag{22}$$

The debt target rule (20) combined with the tax rule (22) implies that the tax adjustment factor $f(\vec{W}_t^G) = 1$ when active debt issuance $\tilde{W}_t^G$ is in the interior region between profligacy and austerity thresholds. In that region, unconstrained active issuance $\tilde{W}_t^G$ is by definition equal to the debt target $\vec{W}_t^G$. However, when active issuance surpasses the austerity threshold, the government will need to raise tax rates by setting $f(\vec{W}_t^G) > 1$ to achieve its target issuance, which by definition is below active (unconstrained) issuance $\tilde{W}_t^G$. Analogously, when active issuance drops below the profligacy threshold, the government can lower tax rates by setting $f(\vec{W}_t^G) < 1$.

To fund the debt $\vec{W}_t^G$, the fiscal authority keeps the maturity composition of newly issued government debt constant in book value terms, with a fraction $\bar{\mu}$ of debt being long-term. As a useful normalization, we assume that coupon c on long-term bonds is always chosen such that the average long-term bond price p_t^L is one (par bond). Then constant issuance in book values requires:

$$\frac{B_t^{G,S}}{B_t^{G,L}} = \frac{1-\bar{\mu}}{\bar{\mu}}.$$

Combined with the requirement that the total issuance target must be met in market value terms, $\vec{W}_t^G = p_t^S B_t^{G,S} + p_t^L B_t^{G,L}$, we obtain:

$$B_t^{G,S} = \frac{(1-\bar{\mu})\vec{W}_t^G}{(1-\bar{\mu})p_t^S + \bar{\mu}p_t^L}, \tag{23}$$

$$B_t^{G,L} = \frac{\bar{\mu}\vec{W}_t^G}{(1-\bar{\mu})p_t^S + \bar{\mu}p_t^L}. \tag{24}$$

2.4.2 Monetary Policy

The central bank chooses the interest rate on short-term government debt $i_t^S = 1/p_t^S$. This is consistent with the central bank directly setting the interest rate on reserves, as in the current policy regime. It is also compatible with a central bank that has a small balance sheet and uses open-market operations to target the rate in the interbank market. In both cases, absence of arbitrage ensures the policy rate set by the central bank coincides with yield on short-term debt and reserves.

We consider a standard monetary policy rule subject to a zero lower bound

$$\frac{1}{p_t^S} = \max\left\{\frac{1}{p_t^*}, 1\right\}, \tag{25}$$

where

$$\frac{1}{p_t^*} = \frac{1}{\bar{p}^S}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi^\pi}\left(\frac{\hat{Y}_t}{\bar{Y}}\right)^{\phi^y}, \tag{26}$$

where we denote gross inflation as $\Pi_t = P_t/P_{t-1}$. The central bank's inflation target is $\bar{\Pi}$ and its target level for cyclical output is $\bar{Y}$. The rule specifies deviations from the average gross interest rate $1/\bar{p}^S$.

We consider the balance sheet of the central bank as an additional policy tool.[10] The central bank can shorten the maturity structure of debt held by the public by buying long-term bonds with reserves, or extend the maturity structure by selling long-term bonds for reserves. Note that these operations do not affect the total face amount of outstanding government liabilities, which are determined by the government budget constraint in (21). Rather, they just change the composition of these liabilities.

In particular, we assume the central bank chooses short- and long-term bond purchases, $B_t^{CB,S}$ and $B_t^{CB,L}$, subject to a revenue neutrality constraint

$$-p_t^l B_t^{CB,L} = p_t^s B_t^{CB,S}, \tag{27}$$

$$B_t^{CB,L} \leq B_t^{G,L}, \tag{28}$$

$$B_t^{CB,S} \leq B_t^{G,S}. \tag{29}$$

Constraint (27) imposes that the central bank swaps government liabilities at market value.

[10]We calibrate the model to the post-2008 Federal Reserve balance sheet with "ample" reserves, such that the interest rate paid on reserves is equal to the Federal Funds rate and the balance sheet is truly a separate policy instrument. A central bank with a small balance sheet and scarce reserves can still pursue large-scale purchases of long-term debt to transition to a regime with plentiful reserves. Piazzesi, Rogers, and Schneider (2021) study a model that nests both regimes as function of the reserve supply.

For example, a purchase of long-term bonds ($B_t^{CB,l} > 0$) needs to be paid for by a sale of short-term bonds ($B_t^{CB,s} < 0$). Sales of short-term bonds are equivalent to new reserve creation. For simplicity, we assume that the central bank can also short-sell long-term bonds to invest in short-term bonds.[11] Constraints (28) and (29) ensure that the central bank cannot purchase more than the total supply of either bond.

The payoff of the central bank's portfolio in $t+1$ is

$$Div_{t+1}^{CB} = B_t^{CB,S} + (c + 1 - \delta^B + \delta^B p_{t+1}^l) B_t^{CB,L}. \tag{30}$$

Since new purchases are revenue-neutral by (27), this is also the profit of the central bank in $t+1$. The central bank remits this profit to the fiscal authority.

2.4.3 Consolidated Government Budget Constraint

Given both fiscal and monetary policy choices, the market value of next period government debt is

$$\begin{aligned} W_{t+1}^G &= B_t^{G,S} + (c + 1 - \delta^B + \delta^B p_{t+1}^L) B_t^{G,L} - Div_{t+1}^{CB} \\ &= B_t^{G,S} - B_t^{CB,S} + (B_t^{G,L} - B_t^{CB,L})(c + 1 - \delta^B + \delta^B p_{t+1}^L). \end{aligned} \tag{31}$$

We view central bank balance sheet operations as overriding the fixed maturity structure $\bar{\mu}$ chosen by the fiscal authority. For example, quantitative easing involves purchasing long-term bonds by issuing short-term bonds, and thereby lowering the fraction of long-term bonds held by the public under a QE policy $\mu^{QE} < \bar{\mu}$.

The evolution equation for the value of government liabilities (31) clarifies that for the accounting of debt claims between the government (central bank and fiscal authority), and the public (banks and households), it suffices to keep track of the consolidated balance sheet of fiscal and monetary authorities. By purchasing $B_t^{CB,S}$ and $B_t^{CB,L}$, respectively, the central bank simply changes the net supply available to the public of both bonds to $B_t^{G,S} - B_t^{CB,S}$ and $B_t^{G,L} - B_t^{CB,L}$.

[11] In reality, the central bank's ability to extend the maturity structure is limited by its holdings of long-term bonds. We do not explore maturity-extending balance sheet policies in this paper.

2.5 Market Clearing

Short-term and long-term government debt, deposit, labor, firm capital, and goods market must clear in equilibrium:

$$
\begin{aligned}
B_t^{G,S} &= B_t^{I,S} + B_t^{CB,S}, \\
B_t^{G,L} &= B_t^{H,L} + B_t^{CB,L}, \\
D_t^I &= D_t^H, \\
N_t &= \int_0^1 n_t(i)di, \\
K_{t-1} &= \int_0^1 k_t(i)di, \\
X_t^{I,K} + X_t^{H,K} &= (1-\delta)K_{t-1} + I_t = K_t, \\
Y_t &= C_t + I_t + G_t + \Phi(I_t/K_{t-1})K_{t-1} + \Xi^K(X_t^{H,K}, K_t).
\end{aligned}
$$

where we have invoked the transition law for the aggregate capital stock.

3 Calibration

The model is solved and calibrated at a quarterly frequency. A subset of model parameters have direct counterparts in the data. The remaining parameters are calibrated to match target moments from the data within the model. To compute model-implied moments, we simulate the model for 120,000 periods (quarters) in total, consisting of 24 simulation runs of 5,000 periods each (with a 3,000 period burn-in). Appendix C provides details on the solution method and simulation approach. While these parameters are chosen simultaneously to match all targeted moments, Tables 1 and 2 list for each parameter the specific moment that is most affected by this parameter.

Table 1: Parameters: Shocks, Firms, Households, and Intermediaries

Par	Description	Value	Source	Data	Model
			Exogenous Shocks		
ρ_g	persistence perm. TFP	0.6	AC(1) real GDP growth (1870-2017, Jorda et al. (2016))	0.25	0.27
σ_g	innovation vol. perm. TFP	1.2	Vol. real consumption growth (1870-2017, Jorda et al. (2016))	1.7%	1.64%
ρ_z	persistence trans. TFP	0.87	AC(1) Ham. filtered TFP (Fernald (2012))	-	-
σ_z	innovation trans. TFP	1.5	Vol. Ham. filtered TFP (Fernald (2012))	-	-
			Production		
ϕ	marginal adjustment cost	10	Vol. investment-to-GDP ratio (53-20)	1.50%	0.77%
δ	capital depreciation rate	0.02	investment-to-GDP ratio (53-20)	17.94%	16.26%
ξ	Rotemberg adjustment cost	140	Vol. inflation (53-20)	0.65%	0.39%
ϵ	Intermediate goods elast.	7	Markup (van Vlokhoven (2020))	-	-
			Preferences and Household Sector		
β	discount rate	0.992	real risk free rate (1870-2017, Jorda et al. (2016))	0.42%	0.42%
γ	risk aversion	20	Unlevered RP on GDP claim	1.00%	0.99%
φ	1/IES	0.7	Vol. consumption-to-GDP ratio (53-20)	0.76%	0.92%
ω_0	disutility of labor	3.12	normalize $\mathrm{E}[Y] = 1$	-	-
ω_1	labor supply power	2	standard value	-	-
ξ_0^L	portfolio cost bonds	0.0017	Term spread (53-20)	0.30%	0.29%
ξ_1^L	portfolio cost bonds, elast.	1.8	Term spread vol. (53-20)	0.26%	0.25%
ξ_0^K	portfolio cost capital	0.003	Household capital share (He and Krishnamurthy (2019))	-	-
ξ_1^K	portfolio cost capital, elast.	2	Quadratic	-	-
			Intermediaries		
ϱ_0	liquidity cost level	0.12	FFR-time deposit spread (94-14)	0.32%	0.46%
ϱ_1	liquidity cost power	$1/(1-\zeta_\varrho)$	normalization	-	-
τ	dividend target	0.08	bank leverage	92%	91.18%
χ	equity issuance cost	25	bank net payout rate	5.7%	7.84%

Aggregate Productivity The aggregate productivity process has permanent and transitory components. The permanent productivity process, Z_t^p, is subject to a growth rate shock, g_t which follows an AR(1) process with persistence $\rho_g = 0.6$ and volatility $\sigma_g = 1.2\%$. The volatility of this process is chosen to match the volatility of real consumption growth for the U.S. for the period 1870-2017, based on the macrofinancial database by Jorda, Schularick, and Taylor (2016). We choose the persistence to match the persistence of real output growth for the same period.[12] The transitory productivity process, Z_t^r, also follows an AR(1) in logs with persistent parameter $\rho_z = 0.87$ and volatility parameter $\sigma_z = 1.5\%$. These parameters are directly taken from Fernald (2012). Since both shocks are persistent, they become state variables. We discretize g_t and Z_t^r into 3-state Markov chains using the Rouwenhorst (1995) method. We further assume that transitory TFP innovations and growth rate shocks are perfectly positively correlated. While our model admits any correlation structure between the two shocks, a strong positive correlation between the shocks is required to match the term structure of risk premia for government debt. Intuitively, the government pursues fiscal stabilization policy through cyclical tax and spending rules to buffer deviations of output from trend. To get the right correlation structure of spending and taxation with consumption growth, permanent and transitory shocks must coincide; Section 4.2 provides an in-depth discussion of the model's ability to match empirical properties of risk premia on government spending and tax claims.

Production Investment adjustment costs are quadratic. We set the marginal cost parameter to $\phi = 10$ to match the observed volatility of (detrended) investment to GDP of 1.5%. Depreciation, δ, is set to 0.02 to match the investment to output ratio of 17.94% observed in the data. We set the parameter α in the Cobb-Douglas production function equal to 0.78 to target the observed labor share of income of 64.16%. The elasticity of substitution for the wholesaler, ϵ, is set to 7 to target a markup of 0.15 from van Vlokhoven (2020). The Rotemberg adjustment cost ξ is set to 140 and targets the observed quarterly volatility of inflation of 0.65%.

Intermediaries Intermediaries are subject to a supplementary leverage ratio (SLR) and equity capital requirements. The SLR constraint is parameterized by $\nu = 0.97$ to reflect real-world

[12] Since our model features persistent shocks to the growth rate of productivity, we use the longest available sample to determine the size of these shocks.

regulation on total leverage. The additional risk weight on capital $\nu_K = 0.959 = \frac{1-\tilde{\nu}_K}{\nu}$, where $\tilde{\nu}_K = 0.07$. Together these parameters determine the maximum leverage ratio and equity requirement for capital.

We choose the equity payout target of banks, $\tau = 0.08$ we to target leverage of the intermediary sector, calculated by Elenev, Landvoigt, and Van Nieuwerburgh (2021) to be 92%.[13] A higher value of τ, in combination with the equity issuance cost, makes equity finance more costly for banks and creates incentives for higher leverage. We further follow Elenev et al. (2021) in calibrating the equity issuance cost to target the net payout ratio of the financial sector, defined as dividends plus share repurchases minus equity issuance divided by book equity. A higher equity issuance cost makes external equity more expensive and raises the net payout ratio. Elenev et al. (2021) construct a time series of dividends, share repurchases, equity issuances, and book equity, aggregating across all publicly traded banks from $1974-2018$. They report an annual net payout ratio of 5.7%, which the model approximately matches with $\chi = 25$.

The liquidity cost per unit of deposits of banks, reflecting real-world liquidity coverage ratio (LCR) regulation, is determined by the parameters ζ_ϱ, ϱ_0, and ϱ_1. ζ_ϱ represents the fraction of deposits a particular bank's depositors can be expected to withdraw per period and is set to 0.05 following BIS (2013). ϱ_0 is set to 0.12 to target the spread between short-term debt and deposits of 0.31% and ϱ_1 is set to $1/(1-\zeta_\varrho)$ for parsimony. The liquidity cost captures the observed disconnect between deposit rates and short-term debt (Lenel et al., 2019).

Households and Preferences The coefficient of risk aversion, γ, is set to 20 and targets the unlevered risk premium on the GDP claim of 1% per quarter. The corresponding Arrow-Pratt measure of relative risk aversion is around 5.[14] We set the elasticity of inter-temporal substitution to 1/0.7 to target the volatility of the consumption to GDP ratio. The subjective discount factor of households $\beta = 0.992$ targets the average quarterly real rate of 0.42%, based on the 1870-2017 sample from Jorda et al. (2016). The coefficient on the disutility of labor, ω_0,

[13]This approach takes a broad view of intermediaries to include depository institutions, government-sponsored enterprises, hedge funds, and some types of insurers.

[14]The Arrow-Pratt measure of relative risk aversion is not equal to γ in a model with Epstein-Zin preferences and leisure in the utility function (Swanson, 2018). We also have the additional complication of the scalar $\bar{u}$ in the period utility function. We compute the coefficient of relative risk aversion to average to 5.4 in a long simulation of the model. Appendix C.2 provides the details of this calculation.

is set to 3.12 to normalize the unconditional mean of output to 1.[15]

The portfolio cost for long-term bonds targets the mean and volatility of the term spread, computed as the difference between the 10-year treasury yield and a weighted average of the yield on 3-month Tbills and the Federal Funds rate. We calculate the weights for the short-term rate based on outstanding market values of Tbills and reserves. This calculation yields and average quarterly term spread of 0.36% with a quarterly volatility of 0.29%. The model matches these targets with marginal cost $\xi_0^L = 0.0017$ and elasticity $\xi_1^L = 1.8$. Without the portfolio cost, the model would generate a slightly negative term spread, a well known feature of models with long-run risk.

The portfolio cost for capital targets the fraction of firm capital held by households. There are several forces in the model that determine the split of firm capital holdings between banks and households. First, absent equity issuance and liquidity costs for intermediaries, firm capital is more valuable to intermediaries than households, since it serves as collateral for issuing deposits that earn a liquidity premium. Therefore, banks would hold all capital in the economy without these costs. Second, firm capital has a relatively high bank equity requirement and, unlike short-term debt and reserves, it does not relax banks' LCR requirement (i.e., at a given balance sheet size, a marginal unit of capital that backs deposits increases banks' marginal liquidity cost). Both regulatory costs reduce bank holdings of capital. Third, households have an inferior technology for screening and monitoring firms, captured by households' capital portfolio cost. Ceteris paribus, this cost increases the bank capital share.

We follow the macro-finance literature on intermediation (e.g. He and Krishnamurthy (2019)) and target an intermediary capital share of 60%, reflecting the broad need of firms and households for intermediation. The model matches this share with $\xi_0^K = 0.003$. For parsimony, we work with a quadratic cost function, $\xi_K = 2$.

Government Parameters Our fiscal policy rules are calibrated to match the unconditional average and cyclical properties of transfer spending, discretionary spending, and tax revenue.

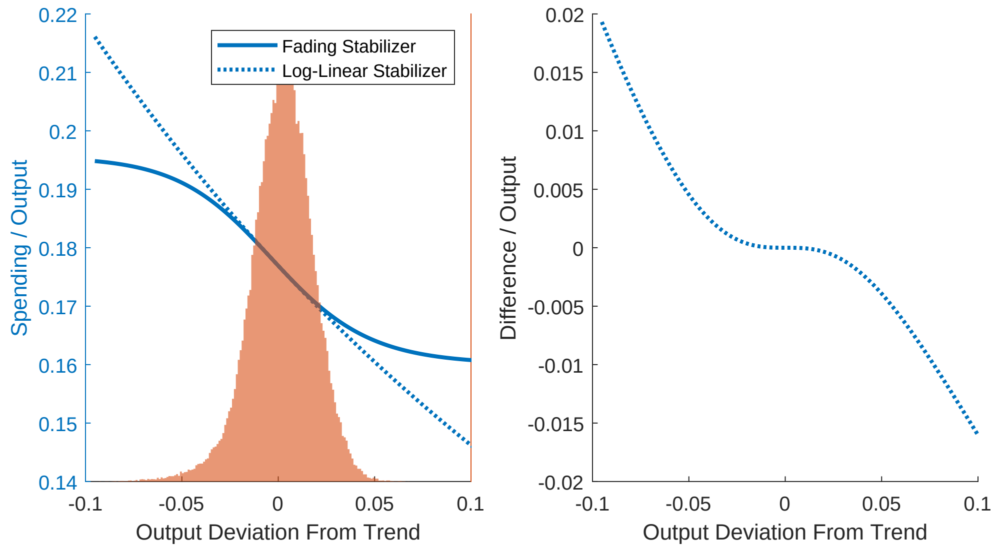
[15]Monetary policy and fiscal rules in the model are parameterized with the implicit assumption that average output is 1. Since the unconditional mean of output in a long-simulation of the nonlinearly solved model is far away from the model's deterministic "steady-state", this normalization leads to a fixed-point: ω_0 needs to be set such that jointly with all other parameters, $\mathrm{E}[Y_t] = 1$ in the stationarized model.

Table 2: Parameters: Government

Par	Description	Value	Source	Data	Model
Government: Fiscal Policy Rules					
τ_0^{π}	base corp. tax rate	21	BEA corp. tax to GDP (53-20)	2.8%	3.33%
τ_0^{w}	base lab. tax rate	25.5	BEA personal tax to GDP (53-20)	16.39%	15.43%
γ_0	average spending/GDP	25.5	BEA govt. spending to GDP (53-20)	16.40%	17.57%
θ_0	average transfers/GDP	3.4	BEA govt. transfers to GDP (53-20)	3.45%	3.35%
b_τ	tax cyclicality	2	regr. slope tax revenue/GDP on GDP growth (53-20)	0.32	0.26
b_γ	spending cyclicality	-2	regr. slope spending/GDP on GDP growth (53-20)	-0.86	-0.54
b_θ	transfer cyclicality	-10	regr. slope transfers/GDP on GDP growth (53-20)	-5.03	-2.75
$\bar{\mu}$	share of long-term debt	0.67	Share of LT treasuries (00-20)	66.82%	68.45%
$\underline{W}^G$	Profligacy threshold	2.4	See Section 4.1	-	-
$\overline{W}^G$	Austerity threshold	4.5	See Section 4.1	-	-
Government: Monetary Policy Rule					
$\bar{\Pi}$	inflation target	1	Fed inflation target (2% p.a.)	-	-
ϕ^{Π}	Weight on inflation	3	standard value	-	-
ϕ^{Y}	weight on output	0.5	standard value	-	-
$\bar{p}^S$	natural interest rate	0.99	normalization	-	-
Government: Financial Regulation					
ν	max. intermediary leverage	0.97	Basel regulation	-	-
ν_K	add. risk weight on capital	0.959	Basel regulation	-	-

The exact functional forms of the fiscal policy rules in equations (41) and (42) for transfers and spending, and algorithm (1) for tax rates, are given in Appendix A.6. These rules are parameterized by a base rate with subscript $_0$ that determines average transfers (discretionary spending, taxes) as fraction of output, and a cyclicality coefficient b_j, $j = \theta, \gamma, \tau$, that governs the correlation with the cyclical component of output. In addition, discretionary spending follows a so-called "fading" rule, meaning that the responsiveness of spending to output fluctuations does not grow proportionally with the deviation of output from its balanced growth path. The solid line in the left panel of Figure 1 plots the resulting cyclical rule for discretionary government spending.[16]

Figure 1: Government Spending Rule



The parameters τ_0^π, τ_0^w and b_τ control the base corporate tax rate, base tax rate on wages, and their cyclicalities, respectively. τ_0^π is set to 21% to target the observed corporate tax revenue of 2.8% of GDP and τ_0^w is set to 25.5% to match the observed tax revenue from wages to GDP of 16.37%. We set $b_\tau = 2$ to match the observed quarterly correlation between log tax revenue and the log of GDP growth of 0.08.

The unconditional averages of spending and transfers are controlled by the parameters γ_0 and θ_0, respectively. We set γ_0 to 17.7% to target the observed average spending to GDP of 16.40%

[16]The gap between the linear and fading spending rules, plotted in the right panel of Figure 1, is calibrated such that the fading aspect has no effects given the cyclical fluctuations caused by productivity shocks. However, the rule disciplines our thinking about the magnitude of extra discretionary spending for our policy experiments in Section 5.1.

and θ_0 to 3.4% to match the observed average transfers to GDP of 3.46%. The cyclicalities of spending and transfers are controlled by $b_\gamma = -2$ and $b_\theta = -10$, respectively. We choose the cyclicality coefficients such that model regressions of the transfer spending, discretionary spending, and tax revenue to GDP ratios, respectively, on GDP growth match the data.[17]

We allow for the government to issue both short-term and long-term debt. The parameter $\bar{\mu} = 0.67$ determines the constant fraction of debt being long-term. This parameter is chosen to reflect the reported maturity distribution of outstanding debt. The average share of long-term debt (greater than one year in maturity) of this series from 2000-2020 is 67.88%. The duration of long-term government debt is 7.76 years, which we match in our model by setting δ^B to 0.92.

The central bank follows a Taylor rule for the interest rate on short-term government debt. The coefficient on inflation, ϕ^π, is set to 3, and the coefficient on output, ϕ^y, is set to 0.5. The values are chosen to match slope coefficients in a regression of short-term interest rates on inflation and output. The inflation target $\bar{\Pi} = 1$ is set to target average inflation of 2% per year.

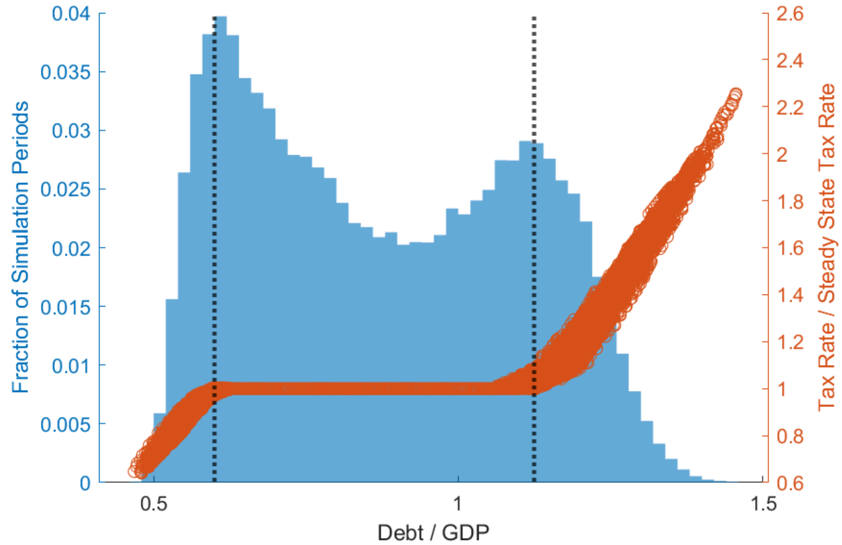
Short-term and Long-term Debt Holdings We assume that households hold all of the long-term debt and the intermediary holds all of the short-term debt in our model. For short-term bonds, this assumption follows Lenel et al. (2019). To assess the assumption on long-term bonds, we look at Treasury holdings from the Financial Accounts of the United States. The broadly defined financial sector (insurance companies, money market funds, mutual funds, and depository institutions) only holds 5.8% of long-term debt on average over the period $1953-2020$.

4 Properties of Fiscal Policy

Before we evaluate whether monetary policy can help alleviate the government's debt burden after economic crises, this section studies fiscal policies during "normal times", i.e., when only productivity shocks to Z_t^p and Z_t^r drive economic dynamics, and only conventional monetary policy is operative. We compare model outcomes from a long simulation to the data.

[17]The model regressions allow for a different slope in profligacy and austerity.

Figure 2: Distribution of Government Debt and Tax Adjustment



4.1 Endogenous Regime-Switching Model of Fiscal Policy

Figure 2 shows a histogram of the government debt/GDP ratio for the full 120,000 simulation periods, overlaid with a scatter plot of the tax adjustment factor $f(\vec{W}_t^G)$. Vertical lines indicate the profligacy and austerity bounds, respectively. The economy spends the majority of time (approximately 70% of all simulation periods) in the interior region between these thresholds. Sequences of shocks may push debt/GDP into either one of the adjustment regions. In that case, as described in Section 2.4, fiscal policy endogenously switches from active to passive, meaning that the fiscal authority now chooses tax rates with the goal of stabilizing debt/GDP.

These tax adjustments are successful in reigning in debt/GDP. However, the figure reveals a clear asymmetry with respect to profligacy (low debt/GDP) and austerity (high debt/GDP). This is caused by the distortionary effect of labor income taxation, resulting in a concave "Laffer" curve of tax revenue generated from tax increases. Thus, consecutive marginal increases in tax rates yield smaller marginal increases in tax revenue in the austerity region. In contrast, consecutive tax rate decreases will yield greater marginal reductions in revenue in the profligacy region.

A direct implication of this Laffer curve effect is that the threshold for entering austerity cannot be arbitrarily large. In particular, the model features an upper bound for the austerity threshold: if the austerity regime only starts for levels of debt/GDP above this bound, then there does not exist a sequence of tax rate increases that can prevent government debt/GDP from exploding for any possible path of exogenous shocks. Put simply, if austerity kicks in "too late" in terms of debt/GDP, then government debt is not guaranteed to remain stationary and is therefore no longer truly risk-free. While we have not systematically characterized this bound, we have verified that for the calibrated model, the simulated time series meets the conditions for stationary. Given all model parameters, the calibrated fiscal rules guarantee that government debt remains well in the interior of the state space for which we have solved the model.[18] Among other factors, the maximum level of the austerity threshold depends on equilibrium bond yields, which determine the government's interest expenses, the labor supply elasticity, which controls the sensitivity of labor supply to higher tax rates, and the monetary policy rule, which dictates how strongly the central bank responds to higher inflation caused by tax increases (tax increases are negative aggregate supply shocks in the model).

Since debt/GDP is in the interior region most of the time, the model generates long time paths with changes in debt/GDP, but no adjustments in tax rates or spending in response. This is a realistic feature of the model: Table 3 demonstrates that in the post-war sample, we do not observe tax increases prompted by higher debt/GDP ratios. Rather, column (1) shows that increases in debt/GDP coincide with decreases in tax revenue to GDP ratio periods. Similarly, debt/GDP growth from $t-1$ to t is associated with decreases in the primary surplus in t in the data. These correlations in the data are likely driven by (1) long-run trends of rising debt/GDP and declining tax revenue since the early 1980s, and (2) the strong cyclicality of government spending and tax revenues: during recessions, spending rises and revenues decline, causing higher debt/GDP going forward. The model matches the data coefficients qualitatively (columns (3) and (4)). As in the data, the cyclical responses of spending and tax revenue drive the correlations in the model (see also Section 4.2 below). Since we have a much longer sample for the model-generated data, we observe visits to profligacy (the indicator variable "Prof" is one if the economy is in the profligacy region, and zero otherwise) and austerity regions (the indicator "Aust."). Columns (5) and (6) verify that profligacy leads to decreases in tax revenue and surpluses, while austerity has the opposite effects. Furthermore, in either austerity or profligacy region an increase of debt/GDP offsets the cyclical effect in tax revenue and surpluses.

[18]We have also verified that significantly increasing the austerity threshold will cause the simulated paths to violate the state space boundaries.

Table 3: Debt/GDP and Surplus Dynamics: Model versus Data

	Dependent variable:					
	Δ Tax Rev.	Δ Pr. Sur.	Δ Tax Rev.	Δ Pr. Sur	Δ Tax. Rev.	Δ Pr. Surp.
	Data	*Data*	*Model*	*Model*	*Model*	*Model*
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Debt/GDP	−0.075***	−0.312***	−0.009**	−0.088***	−0.043***	−0.107***
	(0.012)	(0.032)	(0.004)	(0.003)	(0.001)	(0.001)
Prof.					−0.001***	−0.003***
					(0.0001)	(0.0002)
Aus.					0.001***	0.003***
					(0.0001)	(0.0002)
Δ Debt/GDP × Prof.					0.089***	0.030***
					(0.002)	(0.003)
Δ Debt/GDP × Aus.					0.109***	0.063***
					(0.001)	(0.002)
Observations	272	272	119,976	119,976	119,976	119,976
R^2	0.123	0.258	0.006	0.098	0.166	0.116
Note:						*p<0.1; **p<0.05; ***p<0.01

This table presents the results of regressing changes in tax revenue to GDP and primary surplus to GDP on changes in the debt to GDP ratio. Columns (1) and (2) present the results from observed quarterly data for 1953-2021 for tax revenues and primary surpluses, respectively. Columns (3) and (4) present analogous results using the simulated data. Columns (5) and (6) use the simulated data and include dummy variables to compute the slopes in the austerity and profligacy regions. Columns (2)–(6) are computed using 24 different simulated sample paths of 5,000 quarters each. We include a fixed effect for, and cluster standard errors by, simulation run.

For tax revenue, growth in debt/gdp is associated with an increase in tax revenues, as expected from the alternative fiscal regime in these regions of the state space. Finally, both in model and data, debt/GDP is highly persistent: the (quarterly) auto-correlation coefficient of the data debt/GDP ratio is 0.9946, while in the model it is 0.9950. Therefore, our model demonstrates that lack of responsiveness in fiscal policy to changes in debt/GDP is still consistent with stationary debt dynamics in the long-run. This is because such fiscal adjustments can be triggered by debt/GDP reaching extreme levels, which we have not observed in the modern history of U.S. fiscal policy.

At the same time, our model clarifies that fiscal adjustments cannot be arbitrarily delayed. In particular, if government debt is to remain stationary and riskfree, adjustments to the primary surplus are necessary before debt/GDP becomes unsustainably large. Figure 2 shows that this must begin with debt/GDP ratios of around 112.5%. The U.S. economy in 2021 is dangerously close to this level, and the CBO projects the debt/GDP ratio to rise in the coming decade. The model predicts that delaying tax increases until debt/gdp is higher results in more severe austerity, at a minimum, and in the potential impossibility of debt stabilization (due to ever stronger Laffer curve effects at high debt levels) and eventual default.

4.2 Cyclical Properties of Fiscal Policy

In the short run, fiscal policy provides insurance to taxpayers. When output is below trend, tax rates decline and government discretionary spending rises, as governed by the policy rule coefficients b_τ and b_γ. But to make government debt risk-free, fiscal policy cannot provide this insurance in the long run (Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2020)). To illustrate the this horizon dependence in the simulated model, we regress cumulative fiscal policy growth rates on cumulative GDP growth over increasing horizons. For each fiscal claim $X_t \in \{T_t, F_t\}$, we estimate

$$\log X_{t+h} - \log X_t = \alpha_h^X + \beta_h^X (\log Y_{t+h} - \log Y_t) + \epsilon_{t,h}^X$$

and plot the coefficients β_h^X in the left panels of Figure 3. The bottom-left panel plots coefficients for 400 quarters, while the top-left panel "zooms in" on the first 60 quarters. Contemporaneously, the tax claim has a positive cash flow beta – tax revenues rise more when GDP goes up – and the spending claim has a negative beta. But as the horizon increases, the spending beta rises above tax beta i.e. cumulative spending growth increases in cumulative GDP growth more than tax growth. This reversal is necessary to keep government debt risk-free. At long horizons, fiscal policy must be co-integrated with output through spending and taxation rules in (16) and (18), so both betas converge to 1.

As pointed out by Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2019), the intertemporal government budget constraints implies that investors in government securities hold claims that entitle them to future primary surpluses. This in turn means that we can view bondholders as holding a long position in an asset that pays out tax revenues, and a short position in an asset that pays out government spending. The value of government debt can be expressed as the expected present discounted value of this long-short portfolio, evaluated at the household's SDF $\mathcal{M}_{t,t+h}$, plus a residual term $\mathcal{E}_t$ that arises from incomplete markets between households and intermediaries, as well as frictions associated with holding government debt e.g. liquidity benefits for intermediaries from holding short-term debt and portfolio costs for households from holding long-term debt.

$$\tilde{W}_t^G = \sum_{h=1}^{\infty} \mathcal{M}_{t,t+h} T_{t+h} - \sum_{h=1}^{\infty} \mathcal{M}_{t,t+h} F_{t+h} + \mathcal{E}_t.$$

The cyclicality of fiscal policies provides insurance to taxpayers at business-cycle frequencies and, by the same token, creates risk that must be borne by bondholders. To see how this risk varies by horizon, we compute the risk premium on claims to h-period ahead taxes and spending, or h-strips. We compute prices of these strips recursively. The 0-ahead claim is equal to the cash flow received that period, and the h-period ahead claim is equal to the price of the $h-1$-period ahead claim next period, discounted using the one-period SDF:

$$p_{t,h}^X = \mathrm{E}_t \left[\mathcal{M}_{t,t+1} p_{t+1,h-1}^X \right], \qquad p_{t,0}^X = X_t$$

Risk premia can be computed as expected returns in excess of the risk-free rate $\mathrm{E}_t[\mathcal{M}_{t,t+1}]^{-1}$

i.e.

$$rp^X_{t,h} = \mathrm{E}_t \left[\frac{p^X_{t+1,h-1}}{p^X_{t,h}} \right] - \mathrm{E}_t[\mathcal{M}_{t,t+1}]^{-1}$$

In the right panel of Figure 3, we plot the risk premia for h-quarter ahead tax and spending strips, and plot them along side the risk premium on claims to h-quarter ahead GDP. Since a claim to GDP is like an unlevered claim to firm dividends, GDP strip risk premia are like the risk premia on (unlevered) dividend strips. As the yellow line in the right panel shows, the model generates a high (unlevered) equity risk premium of about 4% per year.

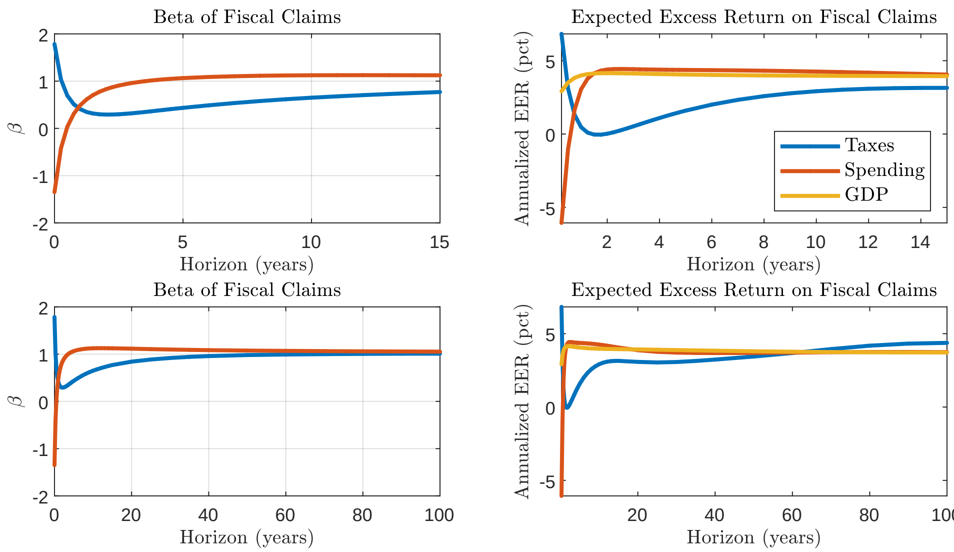
Over short horizons, the bondholder is exposed to a great amount of risk. The risk premium on the tax claim, which the bondholder is long, is high, while the risk premium on the spending claim, which the bondholder is short, is very negative. Put differently, at business cycle frequency, bondholders are providing insurance to taxpayers, who are short the tax claim.

To keep government debt risk-free, these premia must reverse at longer horizons. That is, the return to the long taxes, short spending portfolio must become a hedge at longer horizons. Put differently, taxpayers, who are short the tax revenue claim, face substantial risk at intermediate horizons as shown by the low tax betas in the left panels: $\beta^T < \beta^G$ for intermediate and long horizons. As emphasized by Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2020), keeping the debt safe requires shifting aggregate risk onto the taxpayers.

4.3 Convenience Yields and the Quantity of Debt

Figure 4 shows how convenience yields on government debt fluctuate as a function of the debt-to-output ratio in the simulation of the model. Aggregate convenience yields are computed as the difference between the market value of government debt and the present discounted value (PDV) of future surpluses, both divided by GDP. Absent convenience yields, these values would be identical. In our model, both short-term and long-term debt earn convenience yields that decrease with the supply of total debt. Short-term debt backs bank deposits and thus inherits part of the liquidity premium of deposits; as the supply of deposits increases, the marginal benefit of deposits to households declines and so does the convenience yield on short-term debt. For long-term debt, the portfolio cost in (9) directly introduces an inverse relationship between

Figure 3: Fiscal Risk and Cyclicality of Fiscal Policies



convenience yield and debt supply.

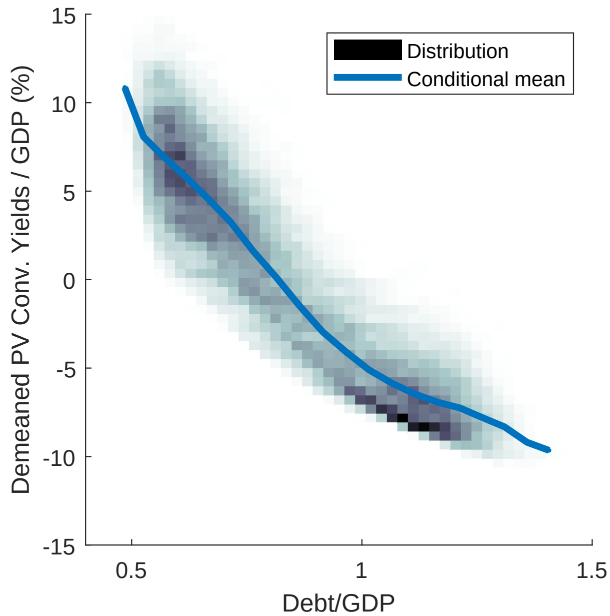
Figure 4 demonstrates that total convenience yields, as a fraction of GDP and centered around their mean, are strongly declining in debt supply. This is consistent with the steep downward slope of convenience yields on treasury securities as a function of debt/GDP in the data, see for example Vissing-Jorgensen and Krishnamurthy (2012).

5 Main Results: Crisis Response

5.1 Fiscal and Monetary Policy in Crises

Our main experiment is an *unanticipated* demand shock that coincides with a negative productivity shock. The productivity shock consists a one-standard deviation drop in the growth rate g_t and a negative transitory TFP shock, with both productivity components following their calibrated law of motions going forward. The additional unanticipated shock has two parts: a demand shock, modeled as an increase in the subjective time discount factor β, and an additional drop in transitory productivity. We choose these two unexpected shock components to match the dynamics of GDP and inflation during the Covid recession. Once the unanticipated shocks to discount factor and productivity hit, agents in the model expect them to mean-revert

Figure 4: Convenience Yields and Debt/GDP



with probability 0.5 each quarter. We study a specific path where the unexpected shock lasts for four quarters before stochastically mean-reverting. Our targets are year-on-year real growth in GDP/capita of -2.75% and year-on-year inflation of 1.3% in Q4 of 2020. The model matches these targets through a discount factor shock of 2% and a total transitory TFP shock of -3.3% (-1.3% as part of the calibrated one-standard deviation negative productivity shock and an additional -2% due to the unanticipated shock). Matching GDP growth and inflation in 2020 requires both negative demand and negative supply shocks. The shocks hit when the debt/GDP ratio is 75%, the value at the end of 2019.

5.1.1 Realistic Policy Combo versus Only Automatic Stabilizers

We match these targets for GDP growth and inflation in a model economy with realistic policy responses to the crisis. First, the central bank's ability to lower the policy rate in response to this shock is limited by a zero lower bound. Second, the government deploys additional transfer spending equivalent to 8% of GDP. We choose this quantity of additional transfer spending to match the the primary deficit of 13.3% of GDP for 2020 in our crisis simulation. Third, the central bank pursues unconventional monetary policy (UMP) in addition to following the Taylor rule. UMP consists of three legs. The first leg is QE, the second leg is an exemption of reserves from banks' Supplemental Leverage Ratio (SLR), and the third leg is a higher inflation target. QE in our model is equivalent to a change in the maturity structure of debt held by the public. We assume that the central bank builds up a portfolio of long-term bonds with total value equal to 32% of GDP, or equivalently 40% of the stock of long-term debt before the policy.[19] Exempting central bank reserves and certain treasury securities from the SLR was a real-world feature of policy, which we capture in our model.[20] The inflation target is raised from 2% to 3% annually. This third leg captures forward guidance. With a Taylor rule, raising the inflation target is akin to keeping the policy rate lower for longer. Fourth, to capture the fact that policymakers keep supporting the economy during the recovery period following the recession, we assume that the increased transfers and UMP policies only mean-revert with probability 0.1 each quarter, such that the policy persists for an additional 10 quarters (in expectation) after the crisis ends. We refer to this long-lasting combination of increased transfers and UMP as the "Long Combo" experiment.

Macro Variables. We assume that this Long Combo policy mix is the data generating process that matches the data targets for GDP growth, inflation, and deficit spending for the chosen combination of demand (β) and supply (productivity) shocks. "Long Combo" is the green line in Figure 5.

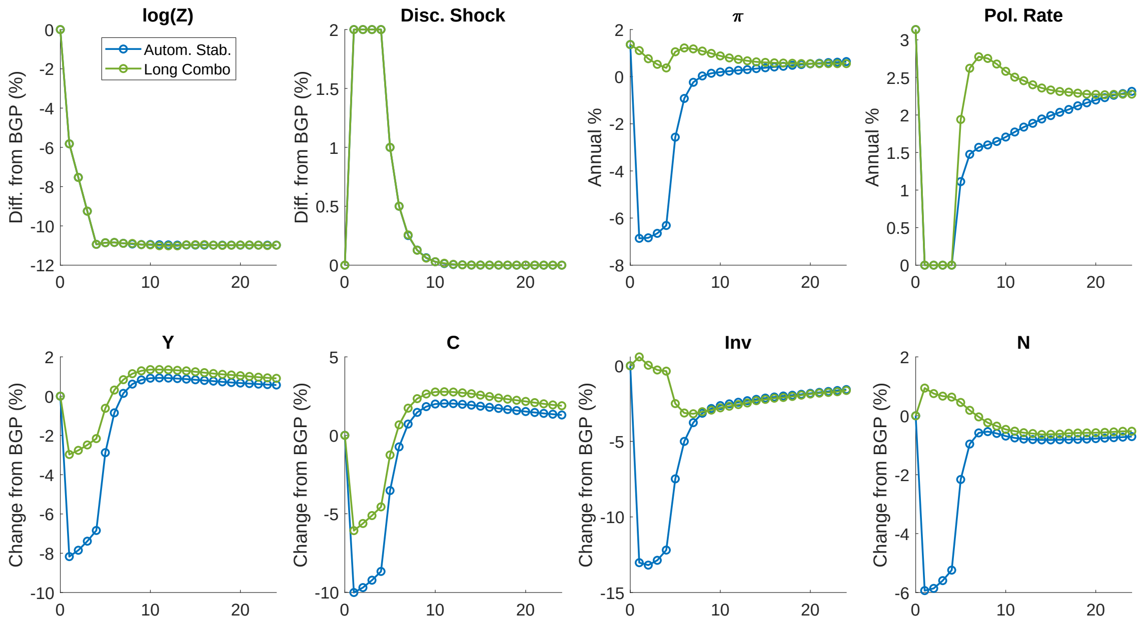
Our main policy counterfactual compares this "Long Combo" path of the economy to a world in which fiscal and monetary authorities only engage in expected policy responses: a Taylor rule governing the conventional monetary response and automatic fiscal stabilizers given by countercyclical spending rules (14)-(15) and procylical tax rule (17) with tax adjustments in the austerity/profligacy region per (22). We label this counterfactual scenario as "Autom. Stab," shown as the blue line in Figure 5.

The two left-most panels in the top row show the exogenous shocks and their persistence (these are the same for all policies). The bottom row shows that the combination of negative supply and demand shocks cause a deep economic crises absent additional policy interventions

[19]As of July 2021, the Fed holds \$8.1 trillion worth of assets, roughly 36% of 2021.Q2 GDP.

[20]The exact policy is that we increase ν in (6) to 1 from 0.97, while keeping the product $\nu\nu_K$ constant. This implies that the equity requirement for capital (bank loans) is unaffected. The SLR exemption for bank reserves was in effect from April 2020 until March 2021; see Federal Reserve System (2020). Regulators are currently considering permanent changes to SLR requirements for safe assets.

Figure 5: Main Policy Experiments: Macro Variables



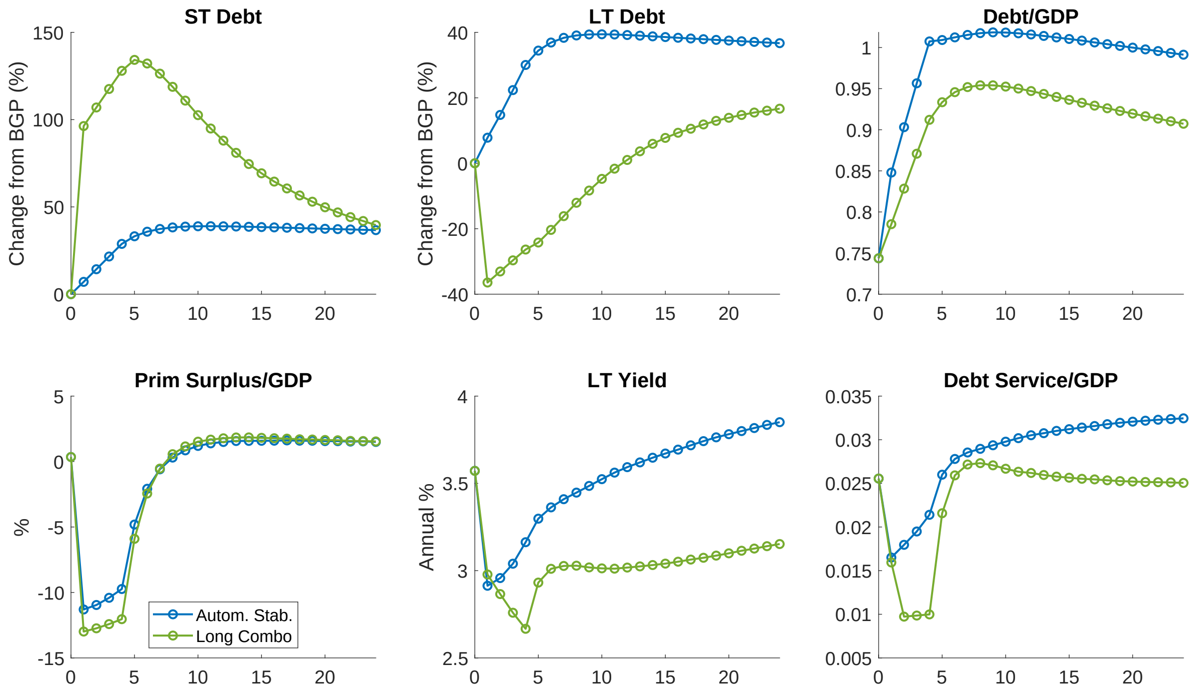
(Autom. Stab.). Output and consumption in Q4 relative to Q0 decline by 6.8% and 8.7%, investment by 12.2% and employment by 5.25%. The recession is highly deflationary (top right), with the inflation rate dropping below -6%. The central bank tries to counter the demand shock as much as possible through lowering the policy rate to zero. The policy rate remains trapped at the ZLB for the duration of the shock (4 quarters).

Comparing the "Autom. Stab." scenario to "Long Combo" reveals how effective the policy response to he crisis was: output drops by 4.6% less in Q4 than without additional policy interventions. Investment and labor input do not decline at all under "Long Combo", inflation remains positive, and consumption only decreases by 4.5% rather than 8.5%.

Fiscal Variables. Figure 6 displays the evolution of debt quantities and long-term bond yields. The (green) "Long Combo" line again shows dynamics under the realistic policy mix, while "Autom. Stab." (blue line) plots the counterfactual scenario where both fiscal and monetary authority follow their conventional policy rules. To implement QE as part of the "Long Combo" mix, the central bank swaps 40% of the fraction of outstanding long-term debt for short-term debt as shown in the left and middle panels on the top row.

The top right panel shows that absent additional policy intervention, debt/GDP increases

Figure 6: Main Policy Experiments: Fiscal Variables



sharply from 75% to above 100%. Under the "Long Combo" scenario, debt/GDP peaks below 95%. The primary surplus, plotted in the bottom left panel, turns sharply negative to -10% of GDP even with spending and taxes only governed by automatic stabilizers, and is only mildly larger under "Long Combo" despite additional transfer spending of 8% of GDP. Yields on long-term government bonds initially decline in both scenarios as the central bank slashes the short rate to zero. Without unconventional monetary policy, long-term bond yields increase during the crisis and recovery as the quantity of debt/GDP rises sharply. The highly persistent increase in yields and quantities of long-term debt feed back on each other, as high bond yields increase the cost of servicing the debt, which in turn requires the government to issue more debt.

The addition of UMP as part of the "Long Combo" policy mix makes a big difference for fiscal dynamics. The reduction in the quantity of long-term debt held by households causes households to move up their demand curve for long-term debt, implying higher long-term bond prices and lower bond yields. The (i) reduction in short-term bond yields, stuck at the ZLB, (ii) the reduction in long-term bond yields, and (iii) the fact that a larger fraction of debt held by the public is short-term with QE, all contribute to lower government interest expenses, plotted in the bottom right corner. The debt service/GDP ratio falls from 2.5% to 1% of GDP during the crisis under "Long Combo." The reduction in debt service in turn leads to a smaller rise in the debt/GDP ratio. Due to the smaller initial rise in debt/GDP and the persistent nature of UMP, long-term bond yields stay persistently lower under "Long Combo" than under "Autom. Stab." These dynamics add up to lower debt servicing costs in the long-run. Combined with the strong positive effects on output in the short-run, discussed above, these dynamics cause a smaller rise and steeper recovery of debt/GDP. The main result of the paper is that UMP creates fiscal space. The debt/GDP ratio is 9% points lower six years after the start of the crisis with long UMP than without it. Debt service/GDP is 0.7% points lower.

To better understand this powerful policy response, we now isolate several of its key ingredients, with a focus on Quantitative Easing.

5.1.2 The Effects of Unconventional Monetary Policy

In this section, we study the effect of UMP relative to the automatic stabilizer scenario, thus separating the benefit of UMP from that of the additional transfer spending that is also part of the "Long Combo" data-generating policy mix. We further want to isolate the impact of long policy duration post-crisis from the immediate effects of UMP during the crisis. Therefore, we study a UMP policy that has the same expected duration as the demand and productivity shock that triggers the crisis: four quarters followed by mean reversion with probability 0.5 each quarter thereafter. Section 5.1.4 below analyzes the additional effects from extending the policy beyond the end of the crisis.

Figure 7 displays the UMP policy (yellow line), alongside the automatic stabilizer scenario (blue line), as well as a combination policy consisting of UMP and transfers, but with shorter duration matching the length of the crisis (purple line, "Combo"). The figure shows that UMP alone accounts for about 50% of the total policy boost on all macro aggregates. The remaining 50% are caused by higher transfer spending. UMP acts like a positive aggregate demand shock would, raising both output and inflation.

Figure 8 performs the same decomposition for fiscal variables. As expected, relative to the "Combo" policy with greatly expanded transfer spending, the primary deficit is lower with

Figure 7: UMP: Fiscal Variables

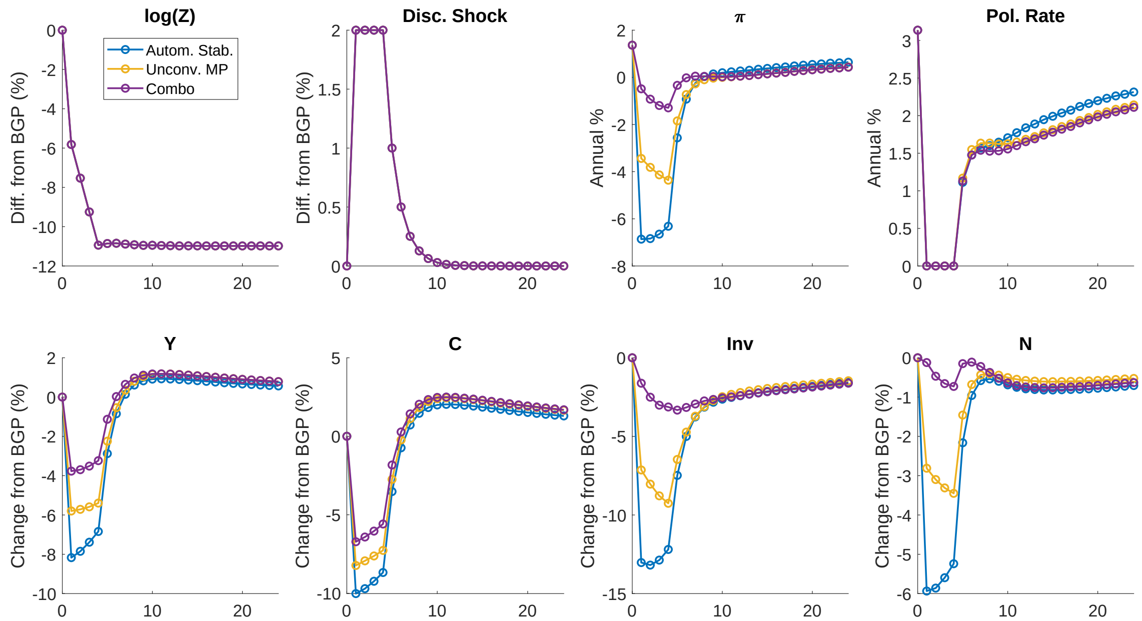


Figure 8: UMP: Fiscal Variables

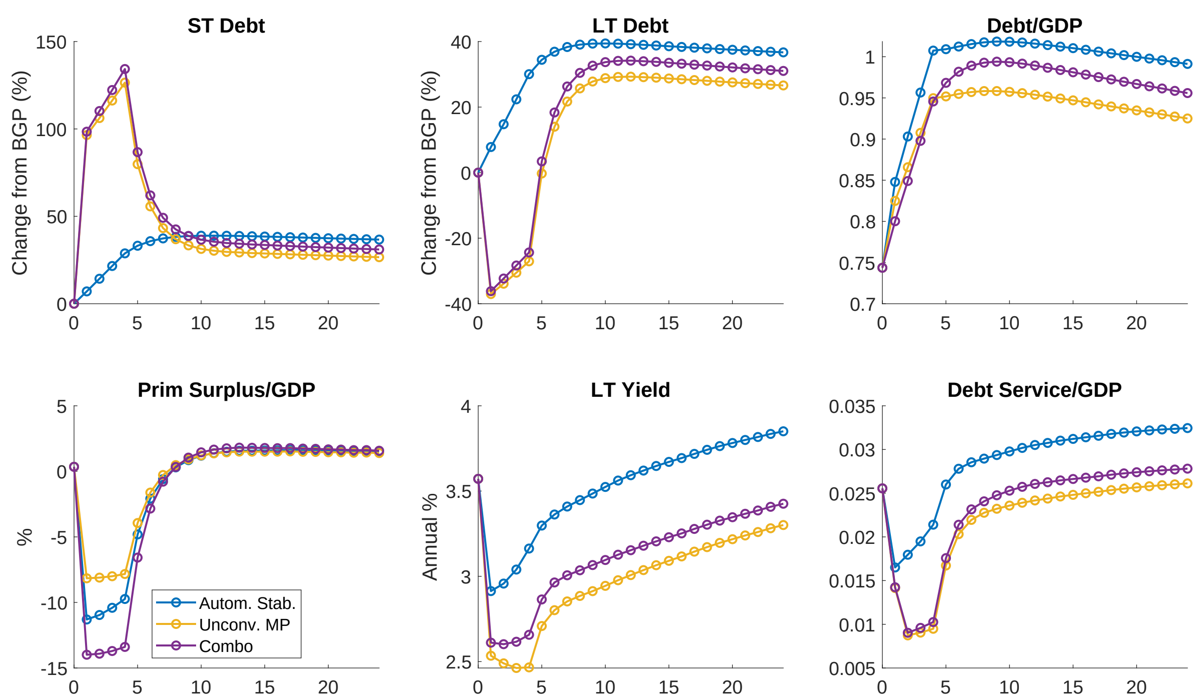
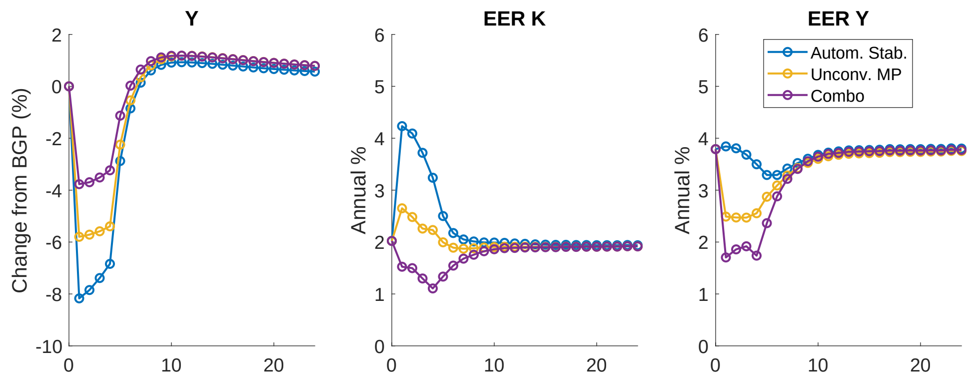


Figure 9: UMP: Risk Premia



UMP only. UMP leads to a deficit reduction relative to the automatic stabilizer baseline. UMP further causes a significant and long-lasting reduction in long-term bond yields, a reduction in debt service/GDP, and a smaller rise in the debt/GDP ratio than the "Autom Stab" policy. Six years after the start of the crisis, the debt/GDP ratio is 6.3% points lower due to transitory UMP.

Figure 9 displays the response of expected excess returns on firm capital claims (middle panel) and on output (right panel) during the crisis. Output changes are repeated in the left panel for convenience. Absent policy interventions ("Autom. Stab."), the capital risk premium spikes sharply by 2% points annually and the output premium by close to 1% point. UMP significantly reduces risk premia on both claims. This demonstrates that UMP reduces required returns on risky assets, a stated objective of the policy.

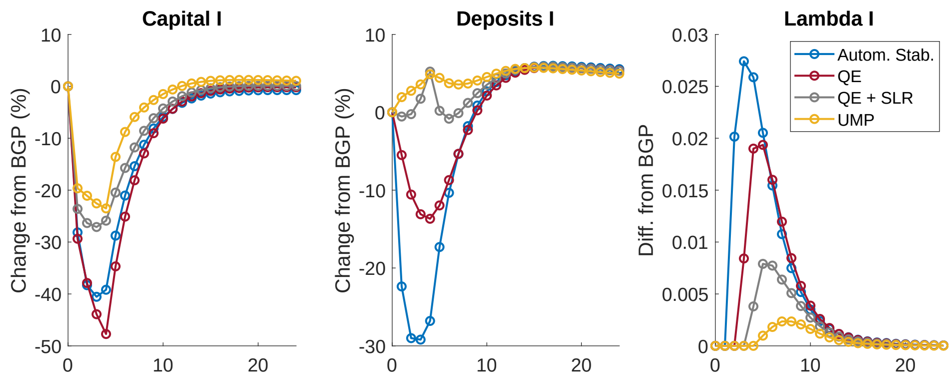
Appendix D.1 discusses the effects of increased transfer spending, by itself, and compares them to the effects of UMP.

5.1.3 Decomposition: Understanding UMP

Intermediary Portfolio. We recall that UMP in Figures 7 and 8 is itself a combination of three policy changes. The first leg is QE, which entails the central bank buying long-term debt from households by issuing reserves to intermediaries. The second component is a relaxation of the SLR constraint for reserves and short-term debt. The third component is an increase in the inflation target from 2% annually to 3%.

Figure 10 shows a decomposition of the effects of these policies for financial intermediary hold-

Figure 10: UMP Decomposition: Intermediary Portfolio



ings of capital, issuance of deposits, and the value of the Lagrange multiplier on the intermediary leverage constraint (6). When policy consists of only automatic stabilizers, intermediaries are forced to shrink their balance sheet as their leverage constraint becomes binding.

QE (maroon line) floods the balance sheet of intermediaries with reserves. This large increase in reserve supply has opposing effects. On the one hand, the liquidity cost of issuing each dollar of deposits is greatly reduced. However, because (and to the extent that) even reserves require scarce equity with the baseline SLR of 0.97, QE induces banks to sell even more of their capital holdings to households.

This capital sale to households is our model's representation of the *crowding-out effect* of QE, documented empirically by Diamond, Jiang, and Ma (2021). Even with this crowding-out effect, QE still causes a smaller net decline in deposit supply than the automatic stabilizer scenario, demonstrating the large *liquidity creation* benefit of QE during the crisis.

The equity squeeze of intermediaries stemming from the flood of reserves is substantially mitigated by eliminating the SLR requirement for reserves (grey line). The Lagrange multiplier on intermediaries' leverage constraint is now much smaller, and intermediaries only sell 30% of their capital to households instead of close to 50%. Overall deposit supply even increases after a few quarters.

Adding a higher inflation target to the policy mix, bringing us back to the UMP policy (yellow line), has little effect on intermediary balance sheet quantities.

Household Portfolio. How does the crowding-out effect of QE on intermediary capital holdings translate into a positive demand shock for the economy that mitigates the severity of the crisis? This can be understood by examining how UMP affects the portfolio composition and return on wealth of the representative household, as we do in Figure 11. QE reduces the supply of long-term debt held by households. Mirroring the effect on intermediary balance sheets, it increases the supply of deposits and of firm capital. Households are worse than banks at intermediating firm capital, due to their capital portfolio costs (equation (10)), resulting in lower returns on capital. Furthermore, as shown in Figure 9, QE lowers the expected excess return on capital. The lower real rate under QE, plotted in the bottom middle panel of Figure 11, combines with the lower risk premium to lower the expected return on capital. All told, households' expected portfolio return falls. The bottom left panel shows that the total return on household wealth declines.

In sum, QE shifts the supply of available assets such that saving becomes less attractive to households, inducing them to consume more. This intertemporal substitution towards higher consumption is reflected in a lower real interest rate and causes an increase in aggregate demand, which boosts employment and output in the New Keynesian model.

5.1.4 Forward Guidance and Announcement Effects at the ZLB

Figure 5 for our main policy experiment compares the realistic "Long Combo" policy mix to the counterfactual automatic stabilizer only scenario. One important feature of "Long Combo" is that the policy outlasts the crisis: the government commits to pursue increased transfers and UMP in expectation for an additional 10 quarters after the end of the crisis. Figure 12 isolates the effect of added policy duration by comparing "Combo" and "Long Combo" policies. It is important to emphasize that the actual policies are identical for the green (Long Combo) and purple (Combo) lines in Figure 12. The only difference during the crisis period is the expected duration of the policy. Yet the figure clearly shows that output, consumption, investment, and employment fall by less with increased policy duration. This comparison demonstrates the presence of a large announcement effect: by committing to longer-lasting fiscal and monetary support for the economy, the government achieves a greater stabilization of the economy upon announcement.

Figure 11: UMP Decomposition: Household Portfolio

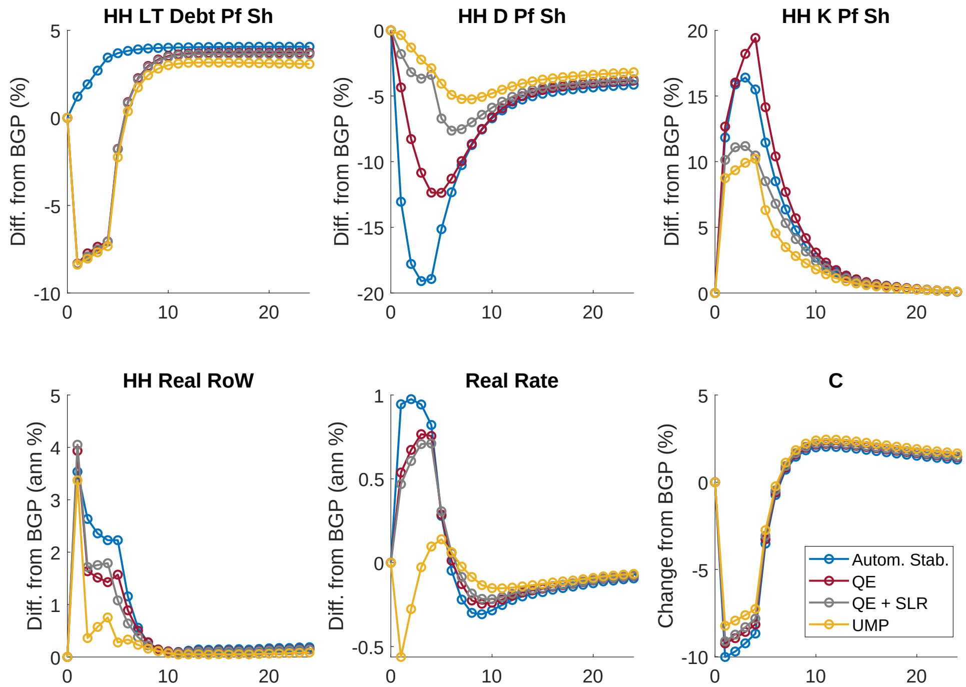


Figure 12: Effect of Policy Duration

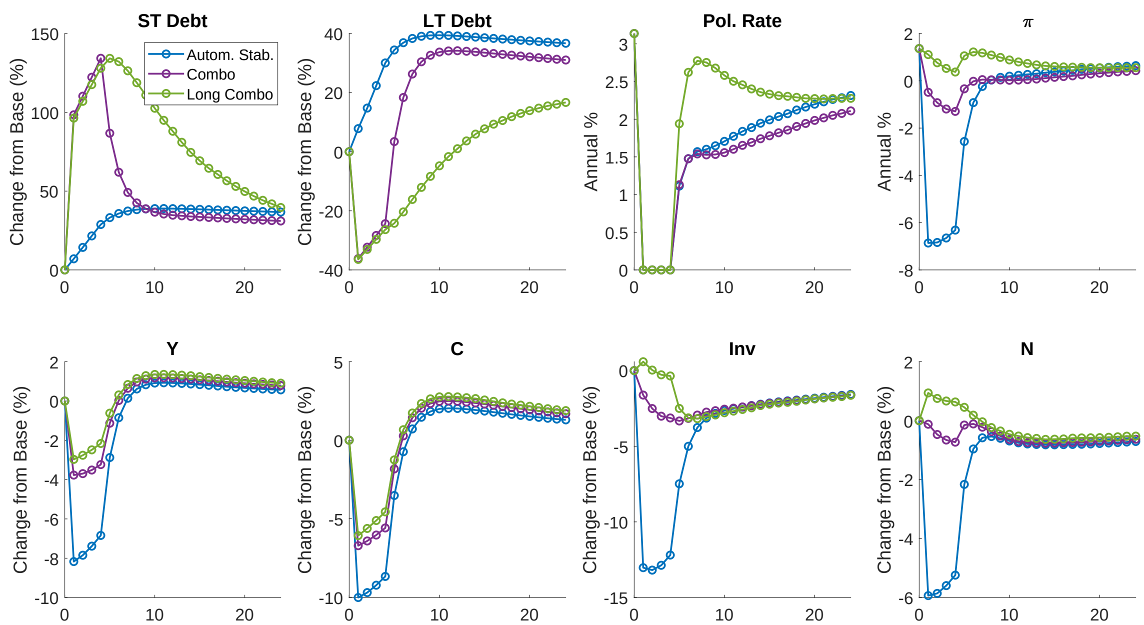
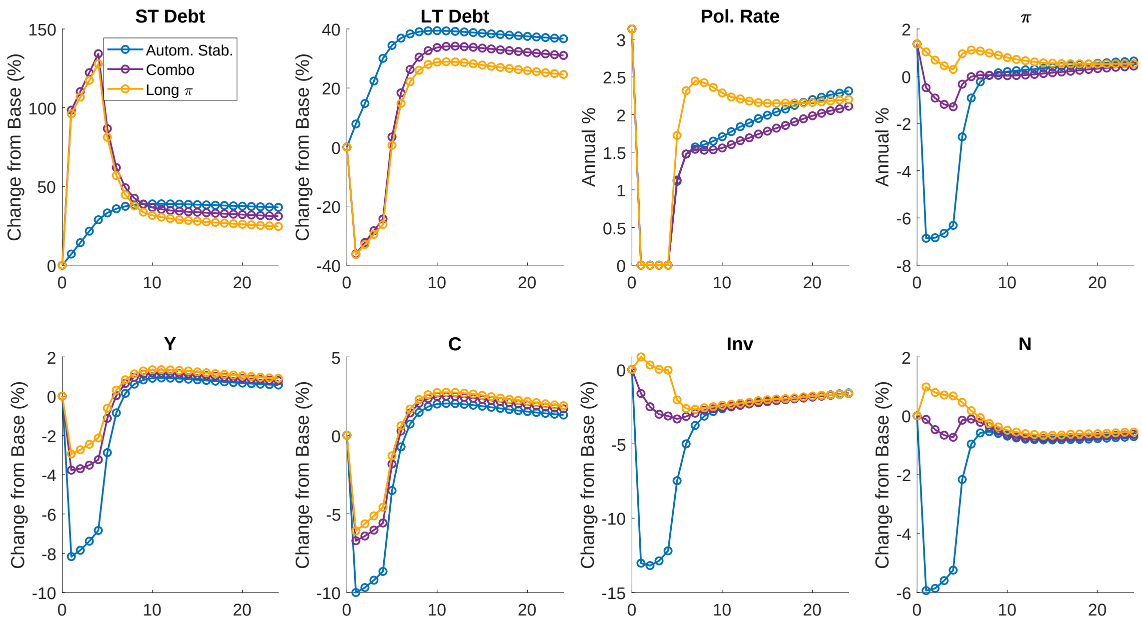


Figure 13: Forward Guidance: Higher Inflation Target



Since the Combo policy in the main experiment is a combination of increased transfer spending and UMP, with UMP in turn consisting of QE, SLR constraint relaxation, and a higher inflation target, the question becomes which of these four policy components is responsible for the large positive announcement effect. To answer this question, we conduct a policy experiment that isolates the duration of the higher inflation target. Specifically, increased transfer spending, QE, and the SLR relaxation all mean-revert with the same probability as the crisis shock itself, just like in the basic "Combo" experiment. Only the higher inflation target outlasts the crisis with the same duration as in the "Long Combo" experiment. Figure 13 reveals that essentially all of the additional benefits of "Long UMP" over "Combo" in Figure 12 are due to the higher inflation target. The experiment clarifies that QE on its own does not benefit from longer policy duration.

The central bank's commitment to a higher inflation target affects the economy by changing expectations of higher future interest rates once the economy recovers and lifts off from the ZLB (Werning, 2011; Basu and Bundick, 2017). In the "Long π" scenario, the central bank credibly promises to keep the inflation target higher at 3% rather than 2% for an additional 10 quarters after the crisis on average. Since the policy rate is stuck at the ZLB during the crisis, this *forward guidance* has no effect on actual interest rates in the crisis period. However, upon announcement the policy has a large positive effect on aggregate demand, causing a relative increase in output by 1% and investment by almost 4%. Our policy experiment highlights the quantitative force of this expectations-driven mechanism, both in terms of how much it can limit the severity of the crisis and affect its long-term fiscal consequences. This suggests that the new monetary policy framework that the Fed put in place in 2020 helped to fight the crisis and accelerate the recovery.

In terms of inflation, the "Long π" experiences about 1.6% points higher inflation during the crisis (the first four quarters) relative to the "Combo" policy. Keeping the inflation target higher for longer results in inflation overshooting during the recovery. The "Long π" economy creates 1% higher inflation in each of the two years following the crisis. If we interpret the four (eight) quarters after the crisis as 2021 (2021 and 2022), the new monetary policy framework accounts for 1% point of the 4% point rise in inflation that the U.S. economy experienced in 2021, and might to lift inflation by 1% point in 2022.

5.2 State and Duration Dependence of QE

Our model is well-suited to study how the effectiveness of QE depends on (i) when the policy is enacted and, (ii) its duration. The results from the previous section already suggested that there is little benefit from keeping the QE policy past the duration of the crisis.

To that end, we study the combination of QE and SLR relaxation when it is implemented in "normal times", i.e. without simultaneous occurrence of negative demand and supply shocks. We first study the economy's transition from the baseline calibration to a world with permanent QE, where the central bank permanently alters the maturity composition of government debt towards short-term debt. The maturity of debt held by the public falls from 5.28 to 3.26 years. We then analyze the differences between this shift to permanent QE and a temporary QE policy shock that occurs independent of other (negative) economic shocks.

As discussed in more detail in Appendix D.2 and visualized in Figures 17 and 18, permanent QE causes a reallocation of capital from intermediaries to households, resulting in an economy with less investment and a permanently smaller capital stock. The reason is the *crowding out effect* discussed before: by providing intermediaries with plentiful reserves, the central bank reduces intermediaries' demand for physical capital as collateral to back deposit issuance. Reserves are a superior collateral asset since they alleviate both equity and liquidity (LCR) requirements of intermediaries. As intermediaries' valuation of capital decreases with greater reserve supply, they sell capital to households, and overall demand for capital declines. During the transition to a smaller capital stock, aggregate consumption rises. Output falls during the transition since declines in investment offset the temporary consumption boom. In the new steady state with permanent QE, consumption is slightly lower then in the initial economy. Intermediaries' balance sheets are larger and they have higher leverage, since their balance sheets are less risky, substantially boosting deposit supply. [21] The economy's behavior during the transition to permanent QE resembles a neoclassical growth model without nominal frictions: since the "QE shock" is permanent, the policy does not trigger any stimulative short-term demand effects.

As discussed in Appendix D.2 and visualized in Figures 19 and 20, the behavior of macro aggregates and fiscal variables is different when the QE policy is temporary, as it is in our main crisis policy experiment. The fundamental mechanism is still that QE temporarily provides plentiful high-quality collateral to intermediaries, causing them to shed physical capital to households. As in the permanent case, households respond to the decreased overall capital demand by temporarily consuming more. However, the transitory nature of the policy activates the New Keynesian elements of the model: QE affects the economy like a standard positive demand shock resulting from e.g. a temporary drop in households' discount factor. The shift from investment to consumption stimulates aggregate demand, causing producers to increase demand for production inputs. Equilibrium hours and real wages rise with higher labor demand, and aggregate output expands. Thus, unlike permanent QE which leads to a slow transition to lower output, the temporary QE policy is expansionary in the short-run and output-neutral in the long-run. Since temporary QE increases both consumption and deposit supply, the policy is welfare-increasing on impact. However, the magnitude of the overall positive effect is small: a replacement of 40% of long-term debt by reserves only leads to a 6 basis point rise in output, a 0.1% rise in consumption, and a 0.01% short-term welfare gain.

[21] Household welfare in consumption-equivalent units is 0.4% greater. The fact that household welfare increases with permanent QE indicates that the benchmark economy suffers from a shortage of liquid assets that causes over-accumulation of physical capital and a shortage of deposits.

The two experiments described above highlight that the effect of QE greatly depends on the timing of the policy. When temporary QE is implemented in response to a crisis (Figure 7), it causes output to rise by roughly 0.7% and the combination of QE and SLR relaxation causes a rise of 1%. However, when implemented during normal times, the same temporary QE policy has output effects that are only one-tenth as large. Furthermore, the ability of QE to stimulate aggregate demand depends on the temporary nature of the policy. QE without end date has permanent effects on the allocation of capital between intermediaries and households, causing a permanent adjustment in the levels of capital and output, akin to a negative supply shock rather than a positive demand shock.

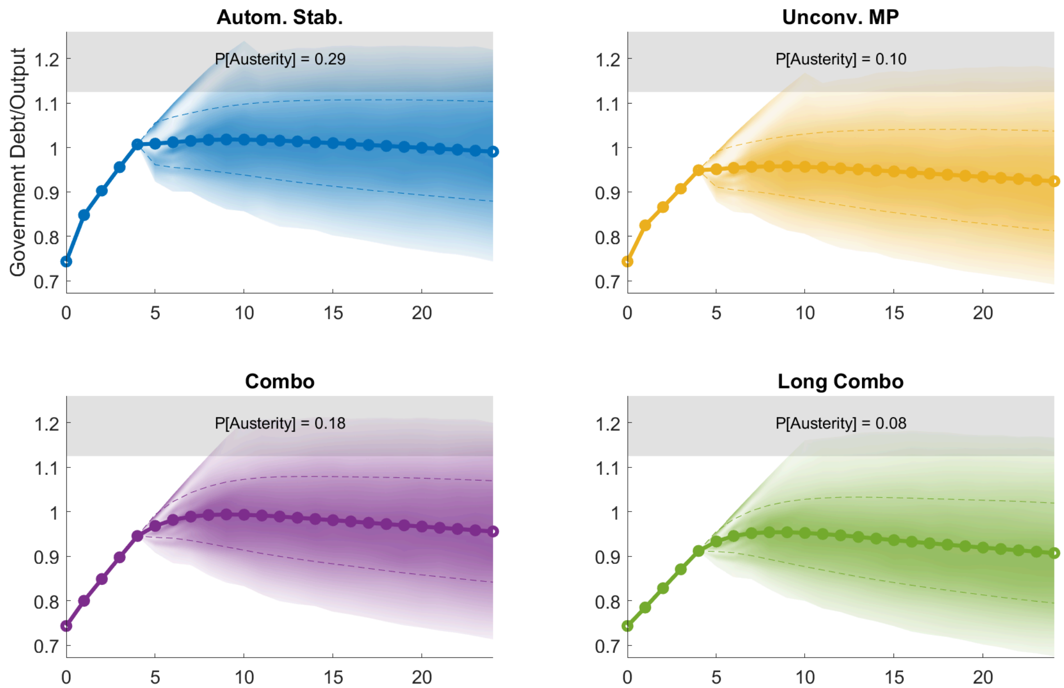
5.3 Fiscal Risk Avoidance and Fiscal Capacity

As result of a smaller rise in debt/GDP, the economy is at lower risk of entering the austerity region. Thus, UMP helps the economy avoid detrimental tax hikes during of in the immediate aftermath of the crisis. We refer to this benefit of UMP as the *fiscal risk avoidance channel*.

We can see this channel at work in Figure 14. It plots the dynamics of debt/GDP for the crisis with only automatic stabilizers, additional UMP, the short duration policy combo, and the data-generating "Long Combo" baseline. The bold lines plot mean paths. In addition, Figure 14 shows standard errors as dashed lines around each mean path. The color intensity around each line indicates the likelihood that the economy's stochastic path will visit the corresponding levels of debt/GDP.[22] At the top of each panel, the austerity region is shaded in grey. We can see that government policies reduce the risk that the economy enters the austerity region. Specifically, UMP alone decreases the probability from 29% to 10%. The Combo policy, which adds the observed amount of transfer spending, still causes an net decline in debt/GDP relative to automatic stabilizers only and therefore reduces the austerity probability to 18%. The long-running combo policy reduces this probability further to only 8%. Not only can monetary policy help the government ease the future debt burden from additional borrowing on average, but it also alleviates fiscal risks by lowering the probability of explosive debt expansion that requires painful fiscal adjustments.

[22]We generate the IRF graphs by simulating 5,000 random paths. For each period of the IRF, we estimate the kernel density of possible paths. Darker shades indicate higher density.

Figure 14: Main Policy Experiments: Government Debt Paths



5.4 Risk Premia, TFP Shock Correlation, and Global Fiscal Rule

Relative to much of the existing literature on monetary and fiscal interactions, our analysis emphasizes the importance of realistically high risk premia, and the need to have a high positive correlation between permanent and transitory TFP shocks to match the observed loading of government spending and taxation on GDP growth. Further, a key innovation of our setup is the global regime switching approach for passive fiscal policy.

Appendix D.3 analyzes how our main results change if we turn off these model features one-by-one. First, we lower the risk aversion coefficient from 20 to 2, which causes risk premia to largely disappear. In this model with counterfactually low risk premia, the same Long Combo policy has significantly smaller effects. Hence, a model that fails to generate realistic risk premia would understate the effectiveness of unconventional monetary policies such as QE.

Second, we study the effect of the Long Combo policy in a model that has a conventional locally passive fiscal rule. In this model, which is standard in models solved with perturbation approaches, small changes in debt/GDP cause smooth adjustments in tax rates. The smooth fiscal rule causes the model to have counterfactual fiscal responses. This model substantially overstates the effect of the Long Combo policy in crises.

Finally, we study the Long Combo policy in a model with uncorrelated transitory and permanent TFP shocks. While this version of the model produces unrealistic cyclical properties of spending and taxation and fails to match the mean and volatility of the term spread, it generates roughly similar effects of the Long Combo policy during the crisis.

6 Conclusion

We study economic crisis dynamics in a New Keynesian model with realistic risk and risk premia. Conventional monetary (Taylor rule) and fiscal policy (automatic stabilizers) are insufficient to stabilize government debt in many states of the world. Keeping government debt risk-free implies a high risk of future austerity, a regime where fiscal policy must abandon stabilizing macro-economic fluctuations and focus on debt reduction instead. We find that unconventional monetary policy can significantly reduce this fiscal risk, and that it leads to a smaller increase in debt/GDP during the crisis and a faster reduction thereafter.

In our model both QE and committing to a higher inflation target are powerful policies in economic crises, when conventional monetary policy is stuck at the ZLB. Temporary QE affects the economy akin to a positive demand shock by shifting macroeconomic activity from investment to consumption. An announcement of permanent QE in response to a crisis acts as a negative supply shock in the long run with little effect on output in the short run. These results highlight that the effectiveness of QE arises from its temporary nature. In contrast, forward guidance about the inflation target in the crisis becomes more powerful as the promised persistence of the policy post recovery increases. This sheds new light on the Fed's new monetary policy strategy, which promises to tolerate higher inflation while the economy is still recovering from a recession.

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A Model Appendix

A.1 Preliminary Definitions

We reformulate the problems of the household, wholesaler, retailer, and intermediary to ensure stationarity. For nominal quantities, define real, stationary variables as

$$\hat{X}_t = \frac{X_t}{Z_t^p P_t}.$$

where Z_t^p is the permanent component of productivity. For real variables, we denote stationary values as

$$\hat{X}_t = \frac{X_t}{Z_t^p}.$$

We define inflation as the gross growth rate on the price level

$$\frac{P_t}{P_{t-1}} = \pi_t,$$

and the growth rate of the permanent component of productivity as

$$\frac{Z_t^p}{Z_{t-1}^p} = \exp(g_t).$$

Finally, we let $\mathcal{S}_t = \{Z_t^r, g_t, K_t, W_t^H, W_t^I, W_t^G\}$ be the vector of aggregate state variables.

A.2 Household

We write the household problem recursively, defining real household wealth using the payoffs to holding capital, deposits, and the long-term bond.

$$\hat{W}_t^H = \exp(-g_t)\left(\left(r_t^K + (1-\delta)Q_t\right)\hat{X}_{t-1}^{H,K} + \frac{\hat{D}_{t-1}^H}{\pi_t} + (c + 1 - \delta^B + \delta^B p_t^B)\frac{\hat{X}_{t-1}^{H,l}}{\pi_t}\right).$$

The value function needs to be divided through by $(Z_t^P)^{1-\gamma}$ to ensure stationarity

$$V^H(\hat{W}_t^H, \mathcal{S}_t) = \max_{\hat{C}_t, N_t, \hat{B}_t^H, \hat{D}_t^H} (1-\beta)u^H(\hat{C}_t, N_t, \hat{D}_t^H) - \beta \mathrm{E}_t\left[\exp((1-\sigma)(g_{t+1}))(-V^H(\hat{W}_{t+1}^H, \mathcal{S}_{t+1}))^{\frac{1-\sigma}{1-\gamma}}\right]^{\frac{1-\gamma}{1-\sigma}}$$

subject to

$$\begin{aligned}\hat{C}_t = {} & \hat{W}_t^H + (1-\tau_t^w)\hat{w}_t N_t + Q_t \hat{I}_t + (1-\tau^{div})(Div_t^I + Div_t^P) + \Theta_t + \text{Rebates}_t \\ & - \hat{I}_t - \Phi(\hat{I}_t/\hat{K}_{t-1}) - \Xi^L(\hat{X}_t^{H,L}, \hat{Y}_t) - p_t^D \hat{D}_t^H - p_t^L \hat{X}_t^{H,L} - Q_t \hat{X}^{H,K} - \Xi^K(\hat{X}_t^{H,K}, \hat{K}_t),\end{aligned}$$

where intra-period utility is

$$u^H(\hat{C}_t, N_t, \hat{D}_t^H) = \frac{\left(\hat{C}_t^{1-\psi}(D_t^H)^\psi\right)^{1-\gamma}}{1-\gamma} - \omega_0 \frac{N_t^{1+\omega_1}}{1+\omega_1} - \bar{u}.$$

Note that the aggregate capital stock is $\hat{K}_{t-1} = K_{t-1}/Z_t^p$, since it is chosen in $t-1$ for production in t.

We define the intra-temporal marginal rate of substitution between deposits and consumption as

$$\text{MRS}_t^D = \frac{u_D}{u_C} = \frac{\psi \hat{C}_t}{(1-\psi)\hat{D}_t^H}.$$

Denote $V(\hat{W}_t, \mathcal{S}_t) \equiv V_t$ and the certainty equivalent.

$$CE_t = -\text{E}_t \left[\exp((1-\sigma)(g_{t+1}))(-V^H(\hat{W}_{t+1}^H, \mathcal{S}_{t+1}))^{\frac{1-\sigma}{1-\gamma}}\right]^{\frac{1-\gamma}{1-\sigma}}.$$

The partial derivative of the certainty equivalent with respect to the value function is then given by

$$\begin{aligned}
\frac{\partial CE_t(V_{t+1}^H)}{\partial V^H t+1} &= \exp\big((1-\sigma)(g_{t+1})\big)(V_{t+1}^H)^{\frac{\gamma-\sigma}{1-\gamma}} \text{E}_t \left[\exp((1-\sigma)g_{t+1})(-V_{t+1})^{\frac{1-\sigma}{1-\gamma}}\right]^{\frac{1-\gamma}{1-\sigma}-1} \\
&= \exp\big((1-\sigma)(g_{t+1})\left(\frac{V_{t+1}^H}{CE_t}\right)^{\frac{\gamma-\sigma}{1-\gamma}}
\end{aligned}$$

We can denote the partial derivatives of the portfolio cost functions as

$$\begin{aligned}
\Xi_{X,t}^K &\equiv \frac{\partial \Xi^L(\hat{X}_t^{H,L}, \hat{Y}_t)}{\partial \hat{X}_t^{H,L}} = \xi_0^L \left(\frac{\hat{X}_t^{H,L}}{\hat{Y}_t}\right)^{\xi_1^L - 1} \\
\Xi_{X,t}^L &\equiv \frac{\partial \Xi^K(\hat{X}_t^{H,K}, \hat{K}_t)}{\partial \hat{X}_t^{H,K}} = \xi_0^K \left(\frac{\hat{X}_t^{H,K}}{\hat{Y}_t}\right)^{\xi_1^K - 1}
\end{aligned}$$

and the partial derivatives of the value function with respect to bond and capital holdings as

$$\begin{aligned}
V_{B,t}^H &\equiv \frac{\partial V_t^H}{\partial \hat{X}_{t-1}^{H,L}} = \frac{\exp(-g_t)}{\pi_t}\left(c + 1 - \delta^B + \delta^B p_t^L\right), \\
V_{K,t}^H &\equiv \frac{\partial V_t^H}{\partial \hat{X}_{t-1}^{H,K}} = \exp(-g_t)\left(r_t^K + (1-\delta)Q_t\right).
\end{aligned}$$

A.2.1 First-order conditions

Stochastic Discount Factor Define the household's intertemporal marginal rate of substitution between time t and $t+1$ as

$$\mathcal{M}_{t,t+1} = \frac{\frac{\partial V_t^H}{\partial C_{t+1}}}{\frac{\partial V_t^H}{\partial C_t}} = \frac{\partial V_t^H}{\partial V_{t+1}^H} \exp(-g_{t+1}) \frac{\partial V_{t+1}^H / \partial C_{t+1}}{\partial V_t^H / \partial C_t}$$

$$= \beta \exp\big(-\sigma g_{t+1}\big) \left(\frac{V_{t+1}}{CE_t}\right)^{\frac{\gamma-\sigma}{1-\gamma}} \frac{\frac{1}{\hat{C}_{t+1}}(1-\beta)(1-\psi)\left(\hat{C}_{t+1}^{1-\psi}\hat{D}_{t+1}^{\psi}\right)^{1-\gamma}}{\frac{1}{\hat{C}_t}(1-\beta)(1-\psi)\left(\hat{C}_t^{1-\psi}\hat{D}_t^{\psi}\right)^{1-\gamma}}$$

Hence, we can define the household stochastic discount factor as

$$\mathcal{M}_{t,t+1} = \beta \text{exp}(-\sigma g_{t+1}) \left(\frac{\hat{C}_{t+1}}{\hat{C}_t}\right)^{-1} \left(\frac{\hat{C}_{t+1}^{1-\psi}\hat{D}_{t+1}^{\psi}}{\hat{C}_t^{1-\psi}\hat{D}_t^{\psi}}\right)^{1-\gamma} \left(\frac{V_{t+1}}{CE_t}\right)^{\frac{\gamma-\sigma}{1-\gamma}}.$$

Consumption Attaching multiplier λ_t to multiplier on the budget constraint, the FOC for consumption is given by

$$\lambda_t = \frac{(1-\beta)(1-\psi)\left(C_t^{1-\psi}D_t^{\psi}\right)^{1-\gamma}}{C_t}.$$

Long-term bonds The FOC for long-term bonds, $\hat{X}_t^{H,L}$ is

$$-\lambda_t p_t^L - \lambda_t \Xi_{X,t}^K + \mathrm{E}_t\left[\beta \frac{\partial V_{t+1}^H}{\partial \hat{X}_t^{H,L}} \frac{\partial CE_t}{\partial V_{t+1}^H}\right] = 0$$

Hence, we can write the FOC for the household's holding of the long-term bond as follows

$$p_t^L = \Xi_{X,t}^K + \mathrm{E}_t\left[\beta \frac{\lambda_{t+1}}{\lambda_t} \exp\big((-\sigma)(g_{t+1})\big) \left(\frac{V_{t+1}^H}{CE_t}\right)^{\frac{\gamma-\sigma}{1-\gamma}} \left(\frac{c+1-\delta^B+\delta^B p_{t+1}^L}{\pi_{t+1}}\right)\right].$$

Simplifying, we get

$$p_t^L = \Xi_{X,t}^K + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\left(\frac{c+1-\delta^B+\delta^B p_{t+1}^L}{\pi_{t+1}}\right)\right] \tag{32}$$

Deposits The FOC for the household's purchases of deposits is given by

$$-\lambda_t p_t^D + \psi(1-\beta)\frac{(\hat{C}_t^{1-\psi}(\hat{D}_t^H)^{\psi})^{1-\gamma}}{\hat{D}_t^H} + \mathrm{E}_t\left[\beta \frac{\partial V_{t+1}^H}{\partial \hat{D}_t} \frac{\partial CE_t}{\partial V_{t+1}}\right] = 0.$$

Then using the definition of the intratemporal marginal rate of substitution between deposits and consumption, and the stochastic discount factor, we have that the FOC for deposits is given by

$$p_t^D = \mathrm{MRS}_t^D + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\frac{1}{\pi_{t,t+1}}\right]. \tag{33}$$

Capital Households operate the economy's investment technology and optimally solve the intratemporal problem of producing I_t unites of capital from $I_t + \Phi(I_t, K_t)$ units of the consumption good. The first order condition is given by

$$Q_t = 1 + \phi\left(\iota_t - \delta\right). \tag{34}$$

Labor The household FOC for labor supply is given by

$$N_t = \left((1-\psi)(\hat{C}_t)^{-1}\left(\hat{C}_t^{1-\psi}(\hat{D}_t^H)^{\psi}\right)^{1-\gamma}\frac{(1-\tau_t^w)w_t}{\omega_0}\right)^{\frac{1}{\omega_1}}. \tag{35}$$

In summary, the household's optimality conditions are given by Equations (32) to (35).

A.3 Banks

The stationarized recursive bank problem is

$$V^I(\hat{W}_t^I, \mathcal{S}_t) = \max_{\hat{X}_t^{I,K}, \hat{X}_t^{I,S}, \hat{D}_t^I \hat{A}_t,} \tau\hat{W}_t^I - \hat{A}_t + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\exp(g_{t+1})V^I(\hat{W}_{t+1}^I, \mathcal{S}_{t+1})\right]$$

subject to

$$(1-\tau)\hat{W}_t^I + \hat{A}_t + (p_t^D - \varrho_t)\hat{D}_t^I + \mathrm{Rebates}_t^I \geq p_t^S\hat{X}_t^{I,S} + Q_t\hat{X}_t^{I,K} + \frac{\chi}{2}\hat{A}_t^2,$$

and

$$\begin{aligned}\hat{D}_t^I &\leq \nu\left(\hat{X}_t^{I,s} + \nu^K Q_t \hat{X}_t^{I,K}\right).\\ \hat{X}_t^{I,S} &\geq 0\\ \hat{X}_t^{I,K} &\geq 0\end{aligned}$$

where the first constraint reflects the regulatory constraint and the final two constraints reflecting no-shorting constraints for short-term bonds and capital. Bank equity evolves according to

$$\hat{W}_{t+1}^I = \exp(-g_{t+1})\left[\left(r_{t+1}^K + (1-\delta_{t+1})Q_{t+1}\right)\hat{X}_t^{I,K} + \frac{\hat{X}_t^{I,S}}{\pi_{t+1}} - \frac{\hat{D}_t^I}{\pi_{t+1}}\right].$$

Bank equity We attach multiplier $\hat{\lambda}_t^I$ to the budget constraint. Then the FOC for raising new equity is given by

$$0 = \hat{\lambda}_t^I(1 - \chi A_t) - 1 \tag{36}$$

Short-term bond First, note that the partial derivative of the liquidity cost with respect to short-term debt is given by

$$\frac{\partial \varrho_t}{\partial \hat{X}_t^{I,S}} = (1-\varrho_1)\varrho_0 \left(\frac{\hat{X}_t^{I,S}}{\zeta_\varrho \hat{D}_t^I}\right)^{-\varrho_1}$$

Attaching multipliers $\hat{\lambda}_t$ and $\hat{\sigma}_t^{I,S}$ to the leverage constraint and non-negativity constraint, respectively, we can we write the first order condition for short-term bonds as

$$0 = -\hat{\lambda}_t^I \left(p_t^S - (1-\varrho_1)\varrho_0\zeta_\varrho \left(\frac{\hat{X}_t^{I,S}}{\hat{D}_t^I}\right)^{-\varrho_1}\right) + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}(V^I)'(\hat{W}_{t+1}^I)\frac{1}{\pi_{t+1}}\right] + \hat{\lambda}_t\nu + \hat{\sigma}_t^{I,S}$$

Deposits Noting that the partial derivative of the liquidity cost with respect to deposits is given by

$$\frac{\partial \varrho_t}{\partial \hat{D}_t^I} = \varrho_0\varrho_1\zeta_\varrho \left(\frac{\hat{X}_t^{I,S}}{\zeta_\varrho \hat{D}_t^I}\right)^{1-\varrho_1},$$

we can write the first order condition for deposits as

$$0 = \hat{\lambda}_t^I \left(p_t^D - \varrho_0\varrho_1\zeta_\varrho \left(\frac{\hat{X}_t^{I,S}}{\zeta_\varrho \hat{D}_t^I}\right)^{1-\varrho_1}\right) - \mathrm{E}_t\left[\mathcal{M}_{t,t+1}(V^I)'(\hat{W}_{t+1}^I)\frac{1}{\pi_{t+1}}\right] - \hat{\lambda}_t.$$

Capital Attach multiplier $\hat{\sigma}_t^{I,K}$ to the non-negativity constraint on capital. Then the FOC for capital is

$$0 = -\hat{\lambda}_t^I Q_t + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}(V^I)'(\hat{W}_{t+1}^I)\left(r_{t+1}^K + (1-\delta_{t+1})Q_{t+1}\right)\right] + \hat{\lambda}_t\nu\nu^K Q_t + \hat{\sigma}_t^{I,K}.$$

Envelope condition To further simplify the bank's first order conditions, we note that the envelope condition is given by

$$(V^I)'(\hat{W}_t^I) = \tau + \hat{\lambda}_t^I(1-\tau).$$

Combining envelope condition and first FOC for new equity, $\hat{\lambda}_t^I = 1/(1-\chi\hat{A}_t)$, we can define the bank stochastic discount factor as

$$\mathcal{M}_{t,t+1}^I = \mathcal{M}_{t,t+1}(1-\chi\hat{A}_t)\left(\tau + \frac{1-\tau}{1-\chi\hat{A}_{t+1}}\right),$$

and the rescaled multipliers as

$$\begin{aligned}\lambda_t &= \hat{\lambda}_t(1-\chi\hat{A}_t),\\ \sigma_t^{I,S} &= \hat{\sigma}_t^{I,S}(1-\chi\hat{A}_t)\\ \sigma_t^{I,K} &= \hat{\sigma}_t^{I,K}(1-\chi\hat{A}_t).\end{aligned}$$

Then the bank FOC can be rewritten as

$$p_t^S = \mathrm{E}_t\left[\mathcal{M}_{t,t+1}^I \frac{1}{\pi_{t+1}}\right] + \lambda_t \nu + (1-\varrho_1)\varrho_0 \left(\frac{\hat{X}_t^{I,S}}{\zeta_\varrho \hat{D}_t^I}\right)^{-\varrho_1} + \sigma_t^{I,S}, \tag{37}$$

$$p_t^D = \mathrm{E}_t\left[\mathcal{M}_{t,t+1}^I \frac{1}{\pi_{t+1}}\right] + \lambda_t + \varrho_0 \varrho_1 \zeta_\varrho \left(\frac{\hat{X}_t^{I,S}}{\zeta_\varrho \hat{D}_t^I}\right)^{1-\varrho_1}, \tag{38}$$

$$Q_t = \mathrm{E}_t\left[\mathcal{M}_{t,t+1}^I \left(r_{t+1}^K + (1-\delta_{t+1})Q_{t+1}\right)\right] + \lambda_t \nu \nu^K \bar{Q}_t + \sigma_t^{I,K}. \tag{39}$$

Note that when the leverage constraint and no-shorting constraint on short-term debt are not binding, the Euler equations for short-term debt and deposits imply that the spread between the two *prices* is a static function of the liquidity coverage ratio:

$$p_t^S - p_t^D = \varrho_0 \left(\frac{\hat{X}_t^{I,s}}{\zeta_\varrho \hat{D}_t^I}\right)^{-\varrho_1} \left(\varrho_1 - 1 - \frac{\hat{X}_t^{I,s}}{\zeta_\varrho \hat{D}_t^I}\zeta_\varrho \varrho_1\right)$$

At 100% LCR, this reduces to $p_t^s - p_t^d = \rho_0(\varrho_1 - 1 - \zeta_\varrho \varrho_1)$. Because $\zeta << 1$, the price spread is increasing in ϱ_1. When ϱ_1 is closer to 1, short-term bonds are cheaper than deposits and have a higher rate. When ϱ_1 is high, short-term bonds are more expensive than deposits and have a lower rate. The prices are exactly equal at 100% LCR if $\varrho_1 = \frac{1}{1-\zeta}$.

A.4 Firms

A.4.1 Retailers

Final output is

$$\hat{Y}_t = \left(\int_0^1 Y_t(i)^{1-\frac{1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}.$$

Retailers maximize profit

$$\max_{\{\hat{Y}_t(i)\}} P_t \hat{Y}_t - \int_0^1 P_t(i)\hat{Y}_t(i)di.$$

This implies the demand functions for all i

$$\hat{Y}_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} \hat{Y}_t.$$

Further, perfect competition and free entry among retailers requires that they make zero profit in equilibrium. This in turn means $P_t\hat{Y}_t = \int_0^1 P_t(i)\hat{Y}_t(i)di$ and

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}.$$

A.4.2 Wholesalers

We simplify notation by dropping i subscripts and writing $p_t = P_t(i)$. Then

$$y(p_t) = \left(\frac{p_t}{P_t}\right)^{-\epsilon} \hat{Y}_t.$$

The stationarized recursive problem of a wholesale firm is in real terms

$$V^W(p_{t-1}, \mathcal{S}_t) = \max_{p_t, n_t, \hat{k}_t} \frac{p_t}{P_t} y(p_t) - (\hat{w}_t n_t + r_t^K \hat{k}_t) - \frac{\xi}{2}\left(\frac{p_t}{\bar{\pi} p_{t-1}} - 1\right)^2 + \mathrm{E}_t\left[\mathcal{M}_{t,t+1} \exp(g_{t+1}) V^W(p_t, \mathcal{S}_{t+1})\right],$$

subject to

$$(Z_t^r n_t)^\alpha \hat{k}_t^{1-\alpha} \geq y(p_t).$$

We first solve the cost minimization problem for given output

$$\min_{n_t, \hat{k}_t} \hat{w}_t n_t + r_t^K \hat{k}_t$$

subject to

$$(Z_t^r n_t)^\alpha \hat{k}_t^{1-\alpha} \geq \bar{y}.$$

We denote the multiplier on the output constraint as m_t. Then the FOC are

$$\begin{aligned}
\hat{w}_t &= m_t (Z_t^r)^\alpha \alpha n_t^{\alpha-1} \hat{k}_t^{1-\alpha}, \\
r_t^K &= m_t (Z_t^r)^\alpha (1-\alpha) n_t^\alpha \hat{k}_t^{-\alpha},
\end{aligned}$$

which implies

$$(1-\alpha)\hat{w}_t n_t = \alpha r_t^K \hat{k}_t,$$

and factor demands

$$\begin{aligned}
n_t &= \frac{\bar{y}}{(Z_t^r)^\alpha} \left(\frac{\alpha}{1-\alpha}\right)^{-\alpha} \left(\frac{\hat{w}_t}{r_t^K}\right)^{-\alpha}, \\
\hat{k}_t &= \frac{\bar{y}}{(Z_t^r)^\alpha} \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} \left(\frac{\hat{w}_t}{r_t^K}\right)^{1-\alpha}.
\end{aligned}$$

Combining these with the binding constraint $(Z_t^r n_t)^\alpha \hat{k}_t^{1-\alpha} = \bar{y}$ gives the following expression for the multiplier, which equals marginal cost

$$m_t = \frac{1}{(Z_t^r)^\alpha} \left(\frac{1}{1-\alpha}\right)^{1-\alpha} \left(\frac{1}{\alpha}\right)^\alpha \hat{w}_t^\alpha (r_t^K)^{1-\alpha}.$$

With this solution in hand, we write the profit maximization problem

$$V^W(p_{t-1}, \mathcal{S}_t) = \max_{p_t} y(p_t)\left(\frac{p_t}{P_t} - m_t\right) - \frac{\xi}{2}\left(\frac{p_t}{\bar{\pi} p_{t-1}} - 1\right)^2 + \mathrm{E}_t\left[\mathcal{M}_{t,t+1} \exp(g_{t+1}) V^W(p_t, \mathcal{S}_{t+1})\right].$$

The FOC for the price is

$$0 = y'(p_t)\left(\frac{p_t}{P_t} - m_t\right) + \frac{y(p_t)}{P_t} - \xi\left(\frac{p_t}{\bar{\pi}p_{t-1}} - 1\right)\frac{1}{\bar{\pi}p_{t-1}} + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\exp(g_{t+1})\frac{\partial V^W(p_t, \mathcal{S}_{t+1})}{\partial p_t}\right].$$

The marginal value of today's price is given by the envelope theorem

$$\frac{\partial V^W(p_{t-1}, \mathcal{S}_t)}{\partial p_{t-1}} = \xi\left(\frac{p_t}{\bar{\pi}p_{t-1}} - 1\right)\frac{p_t}{\bar{\pi}p_{t-1}^2}.$$

In equilibrium, all firms choose the same price and we have $p_t = P_t$. Therefore $y(p_t) = \hat{Y}_t$, and $y'(p_t) = -\epsilon\hat{Y}_t/P_t$.

We can thus write the FOC as

$$\xi\left(\frac{\pi_t}{\bar{\pi}} - 1\right)\frac{\pi_t}{\bar{\pi}} = \hat{Y}_t(1 - \epsilon + \epsilon m_t) + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\exp(g_{t+1})\xi\left(\frac{\pi_{t+1}}{\bar{\pi}} - 1\right)\frac{\pi_{t+1}}{\bar{\pi}}\right], \tag{40}$$

which is the New Keynesian Phillips curve.

A.5 Aggregate Capital Transition

The aggregate capital stock is a state variable of the economy contained in S_t. It is needed to compute adjustment costs, and the aggregate output of intermediate goods. Since $\hat{K}_{t-1} = \frac{K_{t-1}}{Z_t^p}$, the stationarized law of motion for capital is

$$\begin{aligned}\hat{K}_t &= \frac{Z_t^p}{Z_{t+1}^p}\left((1-\delta_t)\hat{K}_{t-1} + \hat{I}_t\right), \\ &= \exp(-g_{t+1})\left((1-\delta_t)\hat{K}_{t-1} + \hat{I}_t\right)\end{aligned}$$

A.6 Government

A.6.1 Fiscal rules

The fiscal rules are parameterized by the following coefficient matrix

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & -b_\gamma^2 \\ 0 & b_\theta & -b_\theta^2 \\ 0 & b_\tau & -b_\tau^2 \end{bmatrix}.$$

We consider two transformations of output for the fiscal rules. The first below, is a modification for the implementation of the fading stabilizing rule described in the main body of the text, and the second is simply the log of detrended output.

$$\begin{aligned}\tilde{y}_t &= m\tanh\left(\frac{b_\gamma \log(\hat{Y}_t)}{m}\right) \\ \hat{y}_t &= \log(\hat{Y}_t)\end{aligned}$$

Then we can consider a vector fiscal variables given by

$$\mathbf{x}_t = \begin{bmatrix} \tilde{y}_t \\ \hat{y}_t \\ \sigma_z^2 \end{bmatrix}.$$

The fiscal authority follows rules for transfers, and discretionary spending characterized by

$$\theta_t = \theta(\hat{Y}_t) = \theta_0 \exp\left((\mathbf{F}\mathbf{x}_t)'\mathbf{e_1}\right) \tag{41}$$

$$\gamma_t = \gamma(\hat{Y}_t) = \gamma_0 \exp\left((\mathbf{F}\mathbf{x}_t)'\mathbf{e_2}\right). \tag{42}$$

where $\mathbf{e}_i$ is the basis vector that selects the *ith* element of a vector. The rule for discretionary spending, equation (42), gives the fading stabilizer rule shown in the main body of the text. Given rules characterized by equations (41) and (42), real total spending is:

$$\hat{F}_t = \gamma_t \hat{Y}_t + \theta_t \hat{Y}_t.$$

Active fiscal policy If the spending and transfer rules imply that the government follow active fiscal policy (i.e. the government actively tries to stabilize the economy by responding to deviations to the stochastic growth trend), the tax rates on wage income and profits depend on cyclical output

$$\tilde{\tau}_t^n = \tilde{\tau}_0^n \exp\left((\mathbf{F}\mathbf{x}_t)'\mathbf{e_3}\right) \tag{43}$$

for $n \in \{w, div\}$. Real tax revenue is given by

$$\hat{\hat{T}}_t = \tilde{\tau}^w w_t \hat{N}_t + \tilde{\tau}_t^{div}(\hat{Div}_t^P + \hat{Div}_t^I).$$

Given taxes and spending, the real primary surplus is given by $\hat{S}_t = \hat{\hat{T}}_t - \hat{F}_t$. Then the government needs to issue new debt, $\hat{\hat{W}}_t$ at the end of the period such that

$$\hat{\hat{W}}_t^G = \hat{W}_t^G - \hat{\hat{S}}_t \tag{44}$$

Passive fiscal policy When the fiscal authority targets the level $\hat{\hat{W}}_t^G$ of end of period debt as a function of the active issuance in Equation (44), we refer to the fiscal regime as passive. In this case, tax rates are determined indirectly as a result of the debt issuance target. Passive policy is characterized by **profligacy** with threshold $\underline{W}^G$ and **austerity** with threshold $\overline{W}^G$.

Combined tax rule The combination of active and passive fiscal policy can best be described as an algorithm.

Algorithm 1. *1. Compute desired primary surplus $\hat{S}_t$ under active fiscal policy using fiscal rules (41) – (43).*

2. Determine desired active debt issuance $\hat{\hat{W}}_t^G$ from (44). Check whether desired issuance *under active policy is within profligacy and austerity bounds:*

$$\tilde{\hat{W}}_t^G = \begin{cases} (1-v)\underline{\hat{W}}^G + v\tilde{\hat{W}}_t^G & \textit{if } \tilde{\hat{W}}_t^G \leq \underline{\hat{W}}^G \\ \tilde{\hat{W}}_t^G & \textit{if } \overline{\hat{W}}^G > \tilde{\hat{W}}_t^G > \underline{\hat{W}}^G \\ (1-v)\overline{\hat{W}}^G + v\tilde{\hat{W}}_t^G & \textit{if } \tilde{\hat{W}}_t^G \geq \overline{\hat{W}}^G. \end{cases} \tag{45}$$

3. *If target issuance equals desired active issuance* $\vec{\hat{W}}_t^G = \tilde{\hat{W}}_t^G$, *tax rates are determined based on active rule* (43). *Otherwise, switch to profligacy or austerity regime, with tax rate determined as implicit function of issuance target* $\vec{\hat{W}}_t^G$ *given by* (45) *(i.e., solve for the tax rate needed to achieve surplus* $\vec{\hat{S}}_t^G$ *that yields the issuance target for debt).*

In the algorithm above, parameter v in (45) regulates the strength of the profligacy or austerity policy. In particular, $v = 1$ implies no responsiveness of fiscal policy to debt/GDP, a case for which the model with active monetary policy does not have a stationary solution since government debt would be non-stationary. $v = 0$ implies the most aggressive austerity or profligacy. If tax rates are bounded below at zero, and taxation is distortionary, such a policy may be infeasible since there is no feasible tax rate to achieve the target surplus. In our calibration, we choose $v = 0.8$, a value that guarantees stationary and implies feasible tax rate adjustments away from the active rule.

The market value of next period government debt, given fiscal and monetary policy choice is then

$$\tilde{W}_{t+1}^G = \frac{\exp(-g_{t+1})}{\pi_{t+1}} \left((\tilde{B}_t^{G,s} - \tilde{B}_t^{CB,s}) + (\tilde{B}_t^{G,l} - \tilde{B}_t^{CB,l})(c + 1 + \delta^B + \delta^B p_{t+1}^L) \right).$$

B Data

Our primary data sources are the NIPA data tables provided by the Bureau of Economic Analysis (BEA) and Financial Accounts of the United States provided by the Federal Reserve Board of Governors (BoG). The table below provides the variables we download via FRED, the associated variable code, and the underlying source of the data.

Table 4: Data from the BEA and BoG

Variable	FRED Code	Data Source	Release table
Government current tax receipts	W054RC1Q027SBEA	BEA	Table 3.1
Gross Domestic Income: Taxes on Production and Imports	GDITAXES	BEA	Table 3.1
Government current tax receipts: Taxes on corporate income	W025RC1Q027SBEA	BEA	Table 3.1
Federal government current tax receipts: Taxes from the ROW	W008RC1Q027SBEA	BEA	Table 3.1
Government current receipts: Contributions for government social insurance	W782RC1Q027SBEA	BEA	Table 3.1
Federal government current receipts: Contributions for government social insurance: From the ROW	W781RC1Q027SBEA	BEA	Table 3.1
Government current receipts: Income receipts on assets: Interest receipts	Y703RC1Q027SBEA	BEA	Table 3.1
Government current transfer receipts	W060RC1Q027SBEA	BEA	Table 3.1
National income: Business current transfer payments (net): to government (net)	W061RC1Q027SBEA	BEA	Table 3.1
Personal current transfer payments: to government	W062RC1Q027SBEA	BEA	Table 3.1
Current surplus of government enterprises	A108RC1Q027SBEA	BEA	Table 3.1
Government consumption expenditures	A955RC1Q027SBEA	BEA	Table 3.1
Government current transfer payments	A084RC1Q027SBEA	BEA	Table 3.1
Federal government current transfer payments: Government social benefits: to the ROW	W016RC1Q027SBEA	BEA	Table 3.1
Federal government current transfer payments: Other current transfer payments to the ROW (net)	W017RC1Q027SBEA	BEA	Table 3.1
Government current expenditures: Interest payments	A180RC1Q027SBEA	BEA	Table 3.1
Government current expenditures: Interest payments: to the rest of the world	Y712RC1Q027SBEA	BEA	Table 3.1
Gross Domestic Income: Subsidies	GDISUBS	BEA	Table 3.1
Private Nonresidential Fixed Investment	PNFI	BEA	Table 1.1.5
Population Level	CNP16OV	BLS	Table A-1
Gross private domestic investment: Fixed investment: Nonresidential (implicit price deflator)	A008RD3Q086SBEA	BEA	Table 1.1.9
Personal Consumption Expenditures: Chain-type Price Index	PCEPI	BEA	Table 2.8.4
Current-Cost Net Stock of Fixed Assets: Private: Nonresidential: Structures	K1NTOTL1ST000	BEA	Table 1.1
Current-Cost Net Stock of Fixed Assets: Private: Nonresidential: Equipment	K1NTOTL1EQ000	BEA	Table 1.1
Current-Cost Net Stock of Fixed Assets: Private: Intellectual property products	K1NTOTL1IP000	BEA	Table 1.1
Current-Cost Net Stock of Consumer Durable Goods	K1CTOTL1CD000	BEA	Table 1.1
Current-Cost Net Stock of Fixed Assets: Residential	K1R53101ES000	BEA	Table 1.1
Personal Consumption Expenditures: Nondurable Goods	PCND	BEA	Table 1.1.5
Personal Consumption Expenditures: Durable Goods	PCDG	BEA	Table 1.1.5
Personal Consumption Expenditures: Services	PCESV	BEA	Table 1.1.5
Private Residential Fixed Investment	PRFI	BEA	Table 1.1.5
Change in Private Inventories	CBI	BEA	Table 1.1.5
Personal consumption expenditures: Nondurable goods (implicit price deflator)	DNDGRD3Q086SBEA	BEA	Table 1.1.9
Personal consumption expenditures: Durable goods (implicit price deflator)	DDURRD3Q086SBEA	BEA	Table 1.1.9
Personal consumption expenditures: Services (implicit price deflator)	DSERRD3Q086SBEA	BEA	Table 1.1.9
Gross private domestic investment: Fixed investment: Residential (implicit price deflator)	A011RD3Q086SBEA	BEA	Table 1.1.9
Government consumption expenditures and gross investment (implicit price deflator)	A822RD3Q086SBEA	BEA	Table 1.1.9
Current-Cost Depreciation of Fixed Assets: Private: Nonresidential: Structures	M1NTOTL1ST000	BEA	Table 1.3
Current-Cost Depreciation of Fixed Assets: Private: Nonresidential: Equipment	M1NTOTL1EQ000	BEA	Table 1.3
Current-Cost Depreciation of Fixed Assets: Private: Intellectual property products	M1NTOTL1IP000	BEA	Table 1.3
Current-Cost Depreciation of Fixed Assets: Residential	M1R53101ES000	BEA	Table 1.3
U.S. National Income	BOGZ1FA086010005Q	BoG	Z.1
Households and Nonprofit Organizations	HNOCERQ027S	BoG	Z.1
Monetary Authority; Total Treasury Securities	BOGZ1LM713061103Q	BoG	Z.1
U.S.-Chartered Depository Institutions; Treasury Securities	BOGZ1LM763061100Q	BoG	Z.1
Property-Casualty Insurance Companies; Treasury Securities	BOGZ1FL513061105Q	BoG	Z.1
Money Market Funds; Treasury Securities; Asset, Level	BOGZ1FL633061105Q	BoG	Z.1
Households and Nonprofit Organizations; Treasury Securities; Asset, Market Value Levels	BOGZ1LM153061105Q	BoG	Z.1
Private Pension Funds; Treasury Securities	BOGZ1LM573061105Q	BoG	Z.1
Rest of the World; Treasury Securities	BOGZ1LM263061105Q	BoG	Z.1
Federal Government; Treasury Bills; Liability, Level	BOGZ1FL313161110Q	BoG	Z.1
Federal Government; Treasury Securities; Liability, Level (FGTSL)	FGTSL	BoG	Z.1

C Computational Methods

C.1 Numerical Solution Method

We solve the model globally using time iteration. We extend the solution method proposed by Elenev, Landvoigt, and Van Nieuwerburgh (2021). Since that model is a real model without monetary policy, the nominal side of the model is new. Methodologically, this paper innovates by solving for a fixed point in key parameter values, in addition to equilibrium prices and quantities. This extension is necessary, since New Keynesian models like ours specify policy rules that characterize the actions taken by the government to stabilize output deviations from trend. With respect to the solution method, this means that the model contains endogenous parameters: trend output along the balanced growth path (i.e, the scale of the economy in the stationarized model) is endogenous, yet the policy rules that are part of the equilibrium system of equations depend on this trend output parameter. In NK models with small shocks that are solved using local methods this problem has a simple solution: trend output is given by the deterministic balanced growth path of the model, which is easy to compute. However, in our model with large risk premia, trend output is only known once we compute the model's solution and simulate its ergodic distribution.

For simplicity, we will use the term "steady state" to refer to deterministic balanced growth path going forward. To see the additional computational challenge, consider the Taylor-style monetary policy rule in our model: the central bank adjusts the interest rate based on deviations of output from trend output. Households in our model have a strong precautionary savings motive. As a result, the average output in a simulation of the stochastic model is approximately 6.8% higher than the steady state value. If we defined conventional monetary policy and fiscal policy rules using the deviation of output from steady state, as is usually done when computing local approximations, these rules would be significantly "off target". The average simulated time path would cause a contractionary policy response because the economy would appear to be significantly above trend. Thus, this dependence of policy rules on average output creates another fixed point: average output in the ergodic distribution of the stochastic model $\mathrm{E}[\hat{Y}_t]$ depends on policy rules, and the policy rules must be centered around $\mathrm{E}[\hat{Y}_t]$. To solve this additional fixed point, we extend the solution algorithm to normalize the average scale of aggregate output to one: $\mathrm{E}[\hat{Y}_t] = 1$. Fiscal and monetary policy rules are all centered around this value.

We can choose the disutility of labor ω_0 to achieve this normalization, while jointly matching all other targets using the other calibrated parameters. Importantly, once we have found the correct value of ω_0, we keep this value fixed across policy experiments.

We proceed as follows:

1. Solve a nonlinear system of equations defining the equilibrium conditions at steady state ($\sigma_g = \sigma_z = 0$) assuming the intermediary leverage constraint binds. The system is augmented by an unknown parameter $\omega_0^{(0)}$ and an additional equation $\bar{Y} = 1$.

2. Implicitly differentiate the system with respect to $\omega_0^{(0)}$ at the solution and solve for $\frac{\partial Y^*}{\partial \omega_0^{(0)}}$.

3. Given the guessed value $\omega_0^{(i)}$, solve the model using transition function iteration as in Elenev et al. (2021). We discretize the exogenous process into $N_e = 3$ states using the Rouwenhorst (1995) method and define rectangular grids for 3 endogenous state variables: log market value of government debt $\log \hat{W}^G$, aggregate capital K, and intermediary wealth share $\frac{W^I}{(MPK+(1-\delta)Q)K+W^G}$. The grid for $\log \hat{W}^G$ is dense in and near profligacy and austerity regions since many equilibrium quantities, particularly labor and inflation, are highly nonlinear around the transitions into those states. We iterate several hundred times to convergence.

4. Simulate the model. We start at the steady state values and simulate N runs of $T_{\text{ini}} + T$ periods each discarding the first T_{ini} to eliminate the effect of initial conditions. Government debt / GDP is highly persistent, so one long simulation may not adequately sample the true ergodic distribution. To obtain robust simulation results, we set $N = 24$, $T_{\text{ini}} = 3,000$ and $T = 5,000$.

5. Compute the error $e = E[\hat{Y}_t] - 1$. If $|e| < \tau$, proceed to the next step. Otherwise, update $\omega_0^{(i+1)} = \omega_0^{(i)} - \frac{e}{\partial Y^* / \partial \omega_0}$ using the derivative computed in Step 2, and repeat steps 3 to 5.

6. Re-solve the model holding ω_0 fixed at the optimized value and augmenting the discretized exogenous states with zero-probability states representing unanticipated shocks and policy responses (e.g. QE).

7. Compute impulse response functions (IRFs) starting from the average exogenous state, a fixed level of government debt, and values of the other two endogenous state variables consistent with the fixed level of government debt in the simulation. We compute generalized nonlinear IRFs by simulating 5,000 paths of 25 quarters from this starting point, and calculating the mean path for each model variable.

C.2 Numerical Risk Aversion Calculation

Proposition 1 in Swanson (2018) derives the Arrow-Pratt measure of risk aversion in models with recursive preferences. Adapting these derivations to our model where $V < 0$, we find that the Arrow-Pratt measure of risk aversion at point x_t in the state space can be written as

$$RRA(x_t) = -\frac{\mathrm{E}_t[-(-V(x_{t+1}))^{-\alpha} V_{WW}(x_{t+1}) + \alpha(-V(x_{t+1}))^{-\alpha-1} V_W^2]}{\mathrm{E}_t[-(V(x_{t+1}))^{-\alpha} V_W(x_{t+1})]} W(x_t)$$

where V is the value function, V_W is the derivative of the value function with respect to wealth (i.e. marginal value of wealth), and V_{WW} is the second derivative (curvature) of the value function. In our model,

$$\begin{aligned} V_W(x_t) &= (1-\beta)C(x_t)^{-\gamma} \\ V_{WW}(x_t) &= -(1-\beta)\gamma C(x_t)^{-\gamma-1} \frac{\partial C}{\partial W}(x_t) \end{aligned}$$

We approximate the marginal propensity to consume out of wealth $\frac{\partial C}{\partial W}(x_t)$ using its steady state value

$$\frac{\partial C}{\partial W}(\bar{x}) = \frac{1 - \beta e^{-(1+\gamma)\bar{g}}}{1 + (1-\tau_0^w)^2 \bar{w}^2 \frac{\gamma \bar{C}_t^{-\gamma-1}}{\omega_0 \omega_1 \bar{N}^{\omega_1 - 1}}}$$

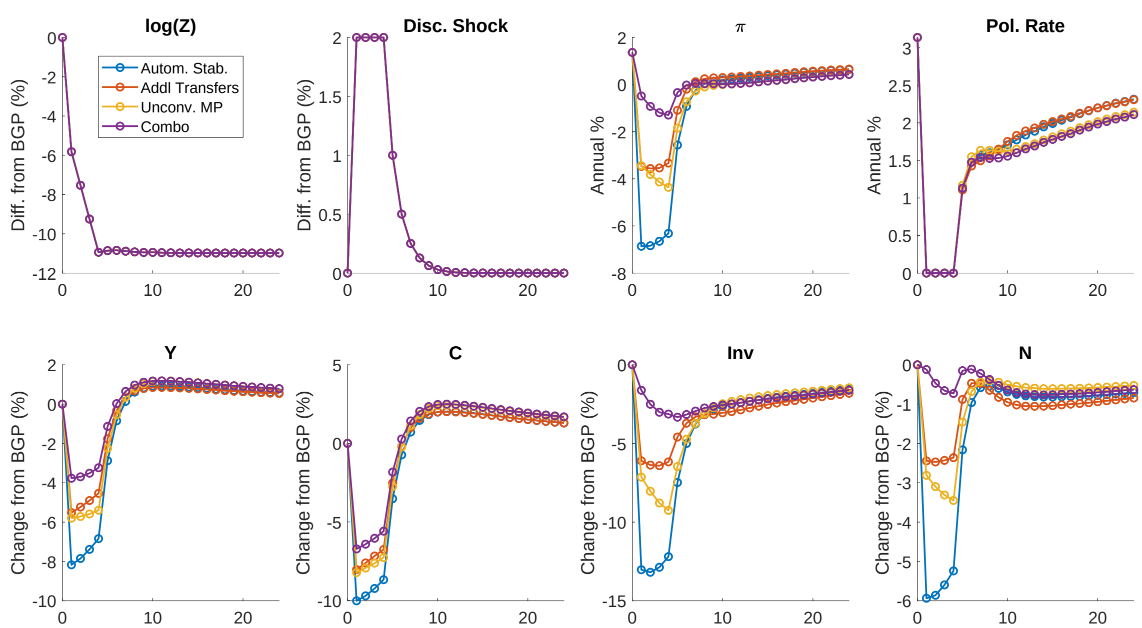
and compute RRA_t at every point in a long simulation using numerical solutions for $C(x), W(x)$ and $V(x)$. We find that relative risk aversion always lies between 4.2 and 6.8, with the average value being 5.4.

D Additional Quantitative Results

D.1 Tranfer Spending

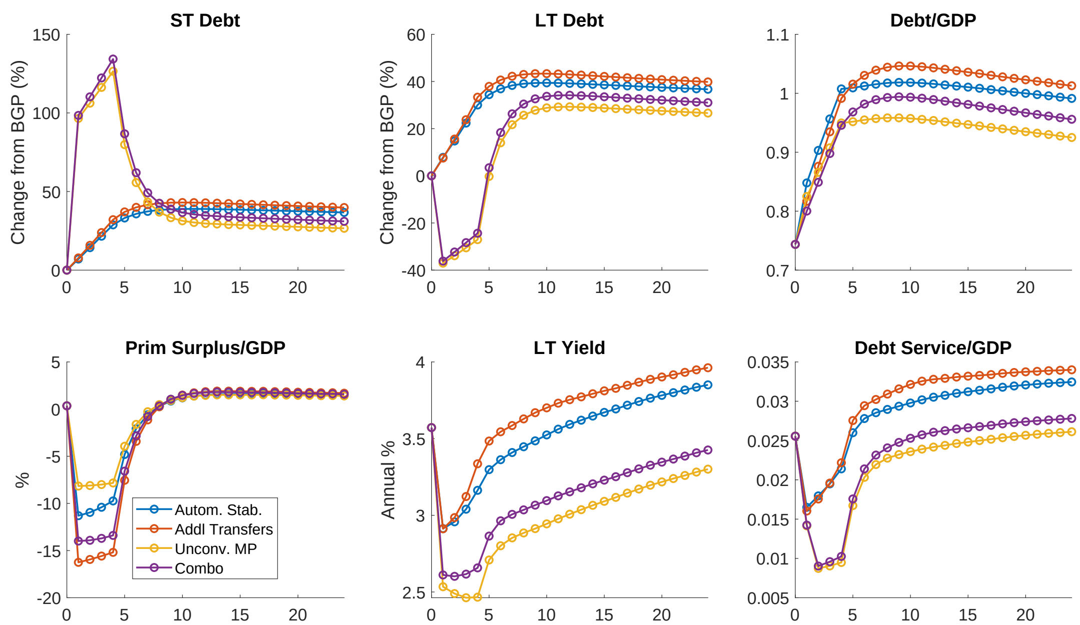
The Combo policies involve a large increase in transfer spending of 8% of GDP, calibrated to match the primary deficit of 2020. Figures 15 and 16 show the decomposition of the Combo policy into the effects of UMP and increased transfer spending for the main macro and fiscal variables. With respect to macroeconomic aggregates, UMP and higher transfers make roughly equally sized contributions: each policy on its own shrinks the drop in GDP by about 2%, with the total Combo policy cutting the 8% decline in GDP in the automatic stabilizer scenario down to 4%. The same division applies to consumption, investment, employment, and inflation. Figure 16, however, clarifies that UMP and increased transfers have substantially different fiscal price tags. Ceteris paribus, implementing UMP leaves the total quantity of debt in book value terms unchanged. Since it stimulates aggregate demand, the positive GE effect of UMP reduces the primary deficit from 11% to 8%. Higher transfer spending, on the other hand, achieves the same GE stimulus to aggregate demand, but causes a increase in the deficit to 16%. In sum, UMP achieves the same level of output stabilization at no fiscal cost, while the output multiplier of transfer spending is below one.

Figure 15: Full Policy Decomposition: Macro Variables



The fact that transfer spending has any positive effect on aggregate demand in our setting is surprising at first. Our model does not feature household heterogeneity, and transfer spending is funded by government borrowing from the same representative household that also receives the transfers. One would therefore expect neutrality of transfer spending in our model. However, given the maturity composition of government debt issuance, a fraction of the new debt is issued to financial intermediaries in the form of reserves. Intermediaries in turn absorb these additional reserves by issuing deposits and equity to households, subject to intermediation frictions. The increased supply of short-term debt to intermediaries resulting from higher transfers has a similar effect as increased reserve supply resulting from QE, thus stimulating aggregate demand in the short run, as discussed in Section 5.1.3. The important difference is that higher transfers cause a net increase in government debt issuance, while UMP does not.

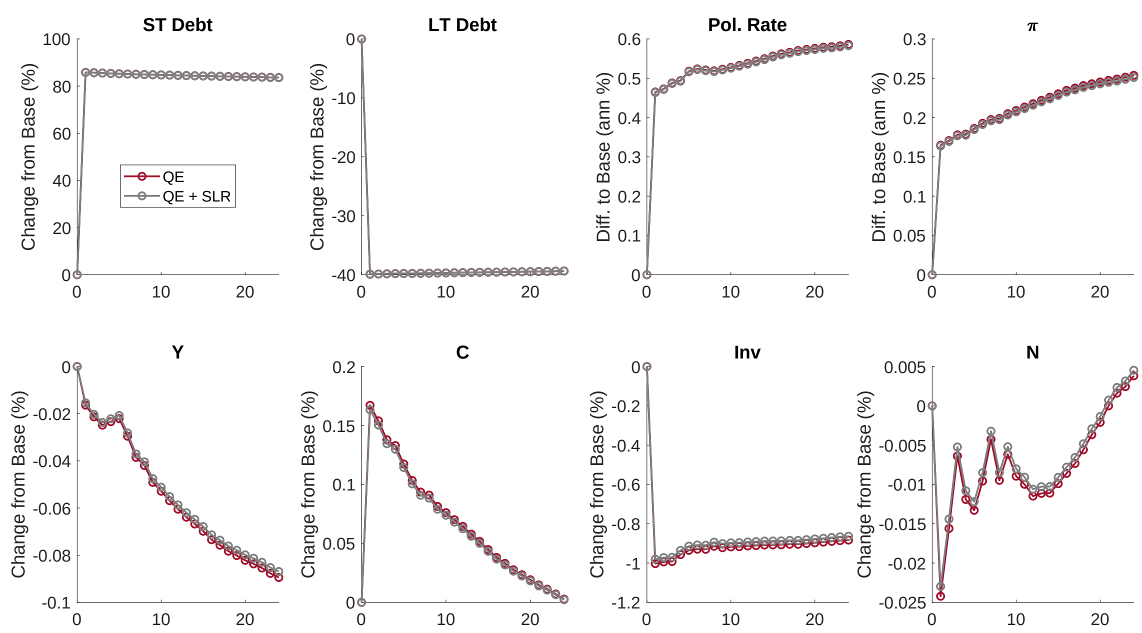
Figure 16: Full Policy Decomposition: Fiscal Variables



D.2 QE in Normal Times

Permanent QE. To understand the mechanism by which QE affects the aggregate economy in our model, we first study the transition from the calibrated baseline model to a world with permanent QE, i.e. an economy in which the central bank permanently expands its balance sheet and shifts the maturity structure of government debt from long- to short-term. We start this transition in a neutral productivity state and without demand shock, in the economy's steady state without a concurrent economic crisis. The policy parameters are the same as for the QE policy in the main experiment: the central bank buys 40% of the stock of outstanding long-term debt and replaces it with reserves. In addition, regulators exempt reserves from the SLR constraint. The only difference is that these policies now last permanently, unlike in the main experiment where the policies mean revert with probability 0.5 each quarter. In this experiment, the average maturity of debt held by the public changes from 5.28 years before the policy change to 3.26 years under permanent QE.

Figure 17: Permanent QE: Macro Variables

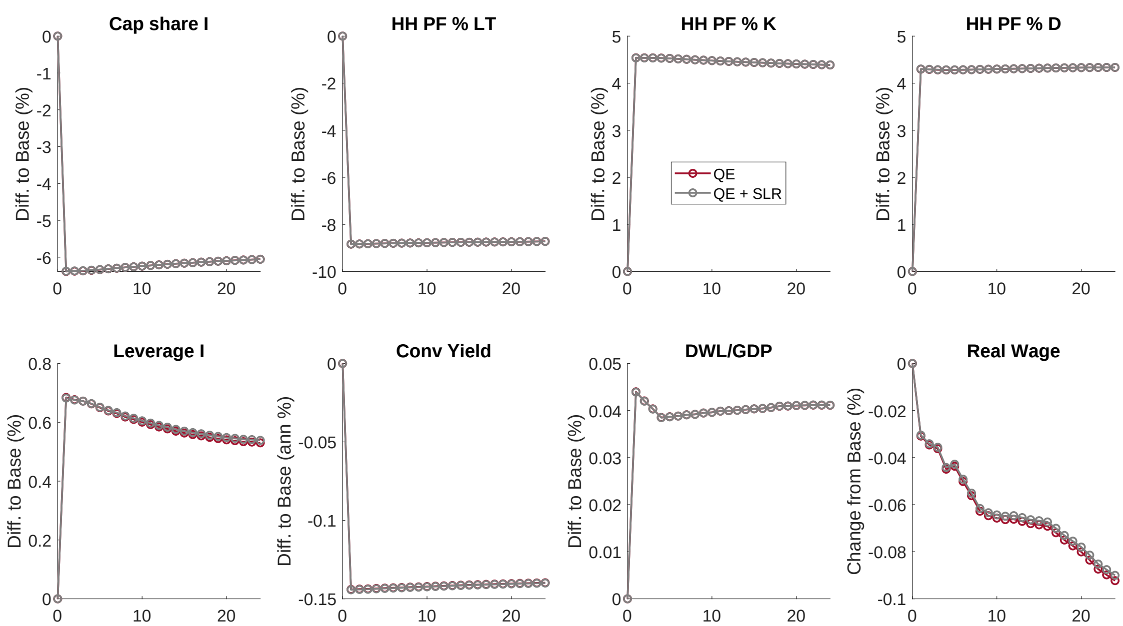


Transition paths from the calibrated baseline to an economy with permanent quantitative easing.

Figure 17 shows the transition paths of important macro variables to the new ergodic state with permanent QE. As is immediately obvious, the SLR exemption of reserves has little to no effect for these transitions (the red line which includes QE and SLR exemption policies almost perfectly covers the blue line, which includes only QE); unlike for the main experiment with QE implemented during a crisis, the SLR constraint is not binding in normal times. Therefore, its relaxation has very little effect. Hence, we can discuss the effects QE and SLR exemption jointly, keeping in mind that these effects are driven exclusively by QE.

The first two panels in the top row show the direct effect of the policy on the supply of short- and long-term debt. In the bottom row of Figure 17 we can see that permanent QE causes a transition to an economy with about 0.1% lower output (relative to trend) with roughly 1% lower investment. This transition to a permanently smaller capital stock leads to a consumption boom along the transition path. The effect on equilibrium labor is minimal. Since QE causes a permanent reduction in aggregate supply, it is an inflationary policy (top right panel). As a result, the central bank sets a higher policy rate.

Figure 18: Permanent QE: Financial Variables



Transition paths from the calibrated baseline to an economy with permanent quantitative easing.

Figure 18 reveals the reasons for this shift to a smaller capital stock. As the central bank floods intermediary balance sheets with reserves (top left panel of Figure 17), intermediaries expand in size and supply a greater quantity of deposits. Due to liquidity costs of deposit production (equation (7)) and a smaller equity requirement, reserves are a superior collateral asset than physical capital for intermediaries. The increase in reserve supply thus leads to a crowding out effect of intermediary capital holdings, with the share of the aggregate capital stock held by intermediaries declining by 6% points (top left panel of Figure 18).

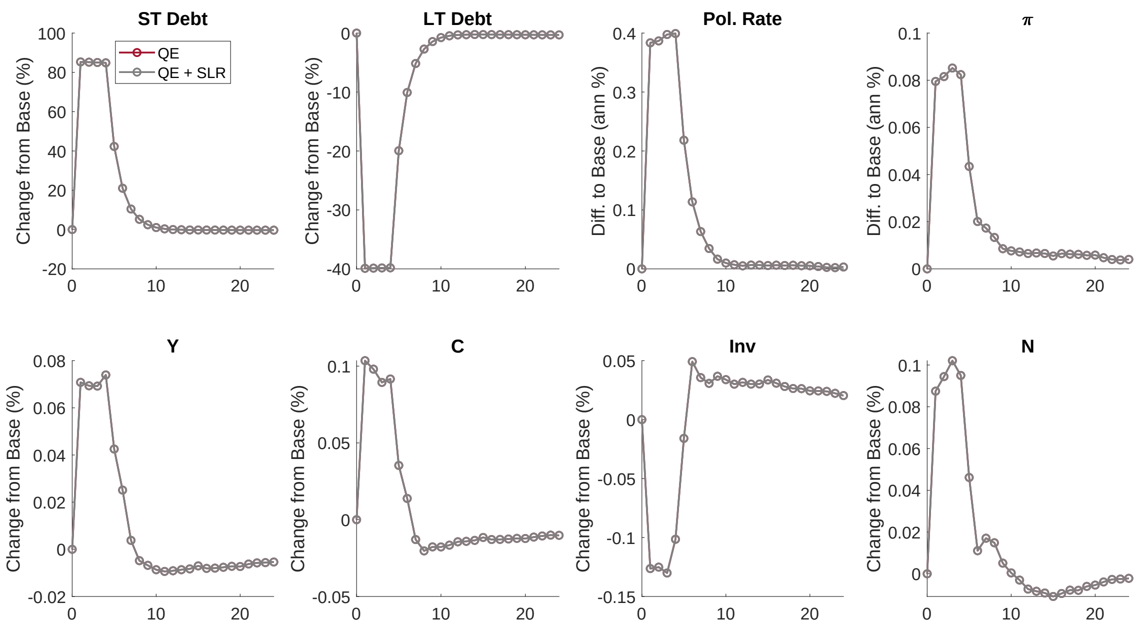
The expansion in deposit supply and reduction in intermediary capital holdings are reflected in household balance sheets: households decrease holdings of long-term debt by selling these to the central bank (QE), and replenish their portfolio with capital purchased from intermediaries and additional deposits in about equal parts (three rightmost panels in the top row). Since intermediaries hold a more liquid and less risky portfolio, they increase leverage by 0.7% points. Deposits are less scarce and thus convenience yields on deposits decline by about 15bp.

As households must absorb extra capital, their holding costs increase, causing slightly higher DWL/GDP. However, aggregate welfare increases by over 0.4% on impact of the policy change, with the positive effects from greater liquidity provision outweighing the negative effects of less efficient capital allocation. Hence the baseline economy, before the switch to permanent QE, suffers from a shortage of liquid assets, which inflates intermediary demand for physical capital as a collateral asset. Relative to the post-QE economy with more ample liquidity, the pre-QE economy over-accumulates capital. Greater permanent liquidity provision by the central bank causes a substantial increase in household utility from greater deposit supply, with a temporary consumption boost and nearly no long-run decline in consumption.

The experiment in Figures 17 and 18 likely underestimates the welfare benefits of permanent QE, since during the implementation of QE, the central bank is assumed to not adjust its long-run output target downward, leading to permanently higher inflation and interest rates. If the central bank accommodated the smaller scale of the economy in its conventional monetary policy rule, the welfare gain would likely be larger.

Temporary QE in normal times. The effects of QE in our main policy experiment differ from those of permanent QE above in two aspects: (1) rather than permanent, the policies in the main experiment are only temporary, either with the same persistence as the economic crisis, or with greater persistence in the "long UMP" scenario, and (2) in our main experiment the policies occur simultaneous with the onset of negative economic shocks that push the economy into the ZLB constraint. We now study the importance of difference (1) by simulating the economy's response to a temporary QE policy shock implemented in normal times. The only difference to the permanent QE case above is the persistence of the policy. Like for the main experiment, the policy now ends with 0.5 probability each quarter, and we study a specific path during which the policy lasts for 4 periods after which it mean reverts stochastically.

Figure 19: Temporary QE: Macro Variables

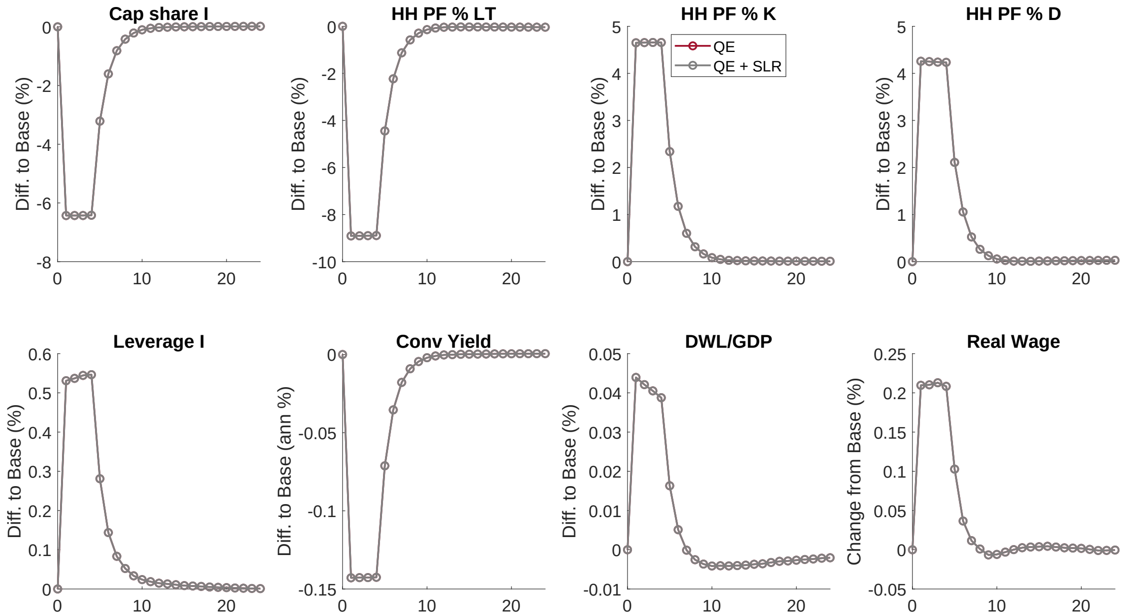


Response of economy to temporary QE in normal times. Policy parameters are identical to main policy experiment.

Figure 19 shows the effects of a temporary QE policy in normal times. The magnitude of the policy in the two leftmost panels in the top row is the same as for the permanent case, yet the duration is shorter. The qualitative effect on consumption and investment in the bottom row is the same as for the permanent transition to QE: consumption increases and investment declines. However, the effects of the temporary policy on GDP and labor are decidedly different. Equilibrium hours worked increase by about 0.1% and output by 7bp for the duration of the policy. The simultaneous rise in inflation, output, consumption and hours reveal that short-run QE triggers a positive aggregate demand shock.

Figure 20 mirrors the effects of the permanent QE transition in Figure 18, just with temporary duration. As the central bank sharply increases reserve supply, intermediaries increase the

Figure 20: Temporary QE: Financial Variables



Response of economy to temporary QE in normal times. Policy parameters are identical to main policy experiment.

supply of deposits and sell capital to households. Households shed long-term debt and replace its value with capital and deposits. Intermediaries increase leverage and convenience yields on deposits decline. As households absorb more capital, their holdings costs increase, leading to higher DWL/GDP.

The key difference to the effects of permanent QE are apparent in the bottom right graph of Figure 20, which shows that real wages rise by 0.2% during temporary QE. This implies that the rise in hours worked is due to higher labor demand from firms, consistent with the aggregate demand shock nature of the economy's response to temporary QE. Intuitively, agents know that the shift to more consumption and less investment is only temporary. Higher consumption demand in the short-term triggers the New Keynesian production sector to raise prices, profits, and demand for both input factors. In summary, temporary QE triggers a small consumption-driven boom.

The difference between the output and consumption effects of permanent and temporary QE are in line with the standard behavior of the New Keynesian model with capital accumulation. Permanent QE affects the economy like a negative supply shock through decreased investment and a lower capital stock. Since the shock is permanent, the New Keynesian model elements play a minor role, and the model essentially behaves like a real neoclassical growth model. However, short-run QE affects the economy like a positive demand shock (e.g., a temporary decrease in the discount factor), thus turning on New Keynesian nominal frictions and demand effects.

D.3 Risk Premia, TFP Shock Correlation, and Global Fiscal Rule

Figures 22 to 24 show the effect of the data-generating "Long Combo" policy for the main macro and fiscal outcome variables for different model parameterizations. For reference, Figure 21 shows the same policy effect for the baseline economy. Each panel shows the difference between the "Long Combo" and "Autom. Stab." scenarios, i.e., the net stabilization effect of the policy combo.

Figure 21: Long Combo versus Automatic Stabilizers in Baseline Economy

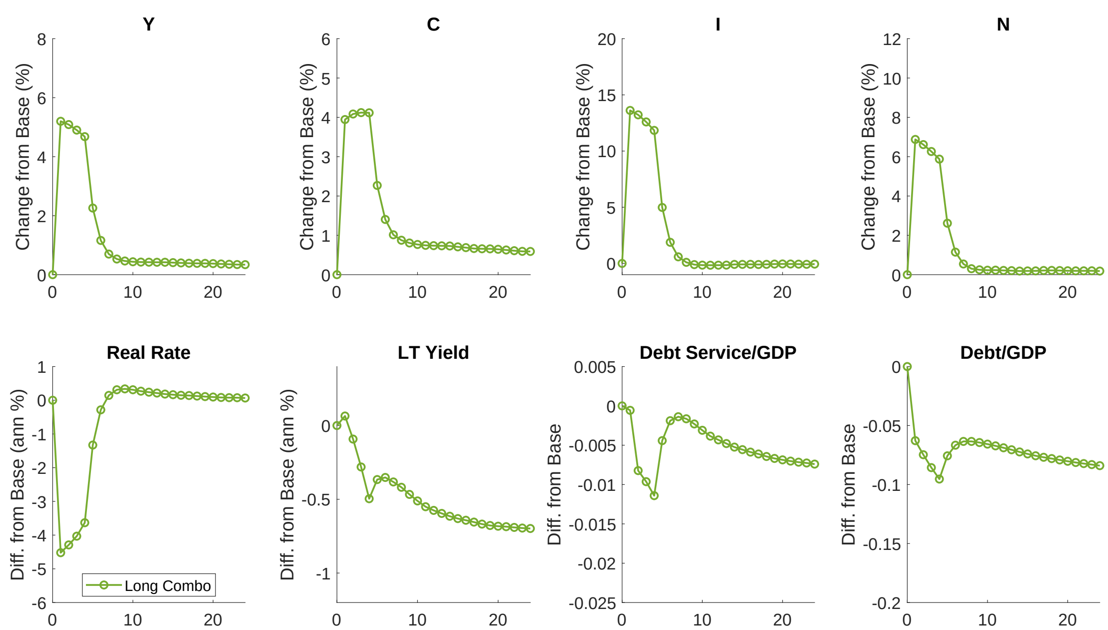
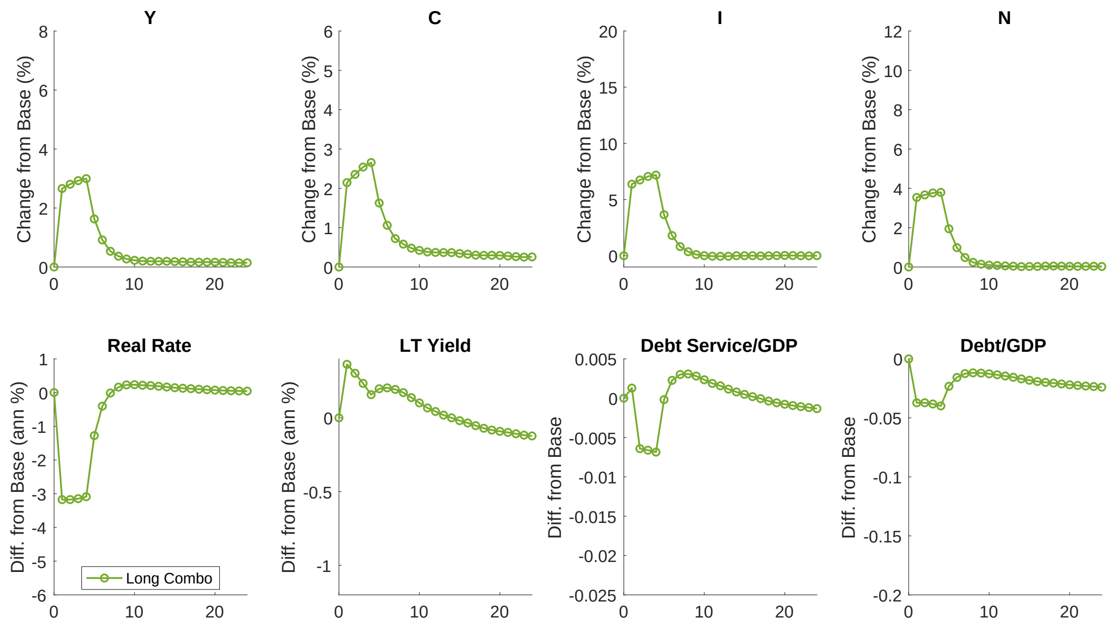


Figure 22 performs this comparison in a model with counterfactually low risk premia, which was calibrated with a risk aversion coefficient of 2 instead of 20 in the baseline calibration. This model substantially underestimates the effectiveness of the Long Combo policy. In the model with low risk premia, the sensitivity of macro aggregates with respect to both shocks and policy

Figure 22: Robustness: Low Risk Aversion



is greatly reduced.

Figure 23 is generated in a model that has a smooth rule for tax adjustments in response to changes in the debt/GDP ratio. Thus, unlike the baseline model that features passive fiscal policy only in the profligacy and austerity regions, this model has locally passive fiscal policy. This model substantially overstates the effectiveness of the Long Combo policy. In the model with the smooth tax rule, the sensitivity of macro aggregates with respect to both shocks and policy is greatly reduced.

Figure 24 shows policy effects in a model with uncorrelated permanent and transitory TFP shocks. Relative to the baseline model that features perfectly correlated shocks, this model has policy effects of similar magnitude. However, it generates unrealistic implications for the yields on long-term debt and the cyclical properties of spending and taxation.

Figure 23: Robustness: Smooth Tax Policy Rule

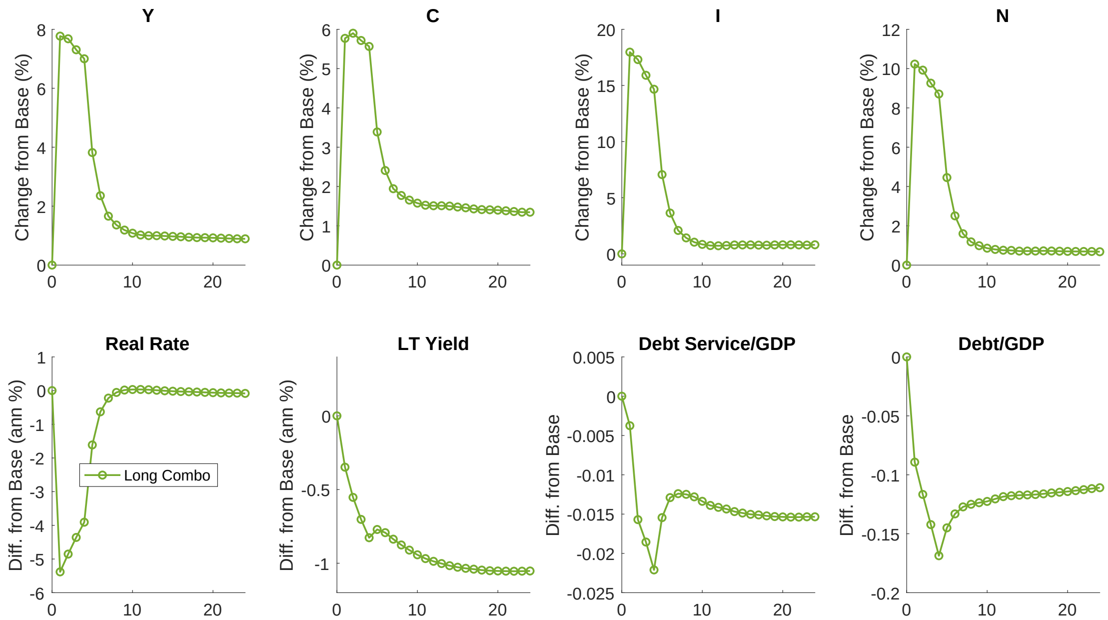


Figure 24: Robustness: Uncorrelated TFP Shocks