Can Monetary Policy Create Fiscal Capacity? [*]

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July 1, 2022

Abstract

Governments around the world embarked on a large fiscal expansion in response to the GFC and COVID-19 crises, increasing government debt to levels not seen in 75 years. We investigate fiscal sustainability in a New Keynesian model with an intermediary sector, realistic fiscal and monetary policy, and substantial risk premia. A temporary unconventional monetary policy (UMP) mounted in response to a crisis stimulates the economy, lowers the long-run debt/GDP ratio, and substantially reduces the risk of future tax increases. UMP's effectiveness decreases in the pre-crisis debt/GDP ratio. In contrast, permanent UMP crowds out investment and lowers long-run output.

JEL: G12, G15, F31.
Keywords: monetary policy, fiscal policy, public debt, quantitative easing, forward guidance, long-run risk

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[*] First draft: May 1, 2021. The authors thank Andrew Abel, Francesco Bianchi, Ester Faia, Zhengyang Jiang, Ralph Koijen, Hanno Lustig, Stavros Panageas, Lubos Pastor, Thomas Sargent, Lukas Schmid, Quentin Vandeweyer, Alessandro Villa, and seminar and conference participants at Wharton, UCSC, Johns Hopkins Carey, Columbia Business School, Carnegie Mellon Tepper, University of Georgia, Chicago Booth, IMF, Bank of Finland, University of Copenhagen, Jackson Hole Finance Group, ECB, Chicago Federal Reserve Bank, UCLA, Stockholm School of Economics, Tepper LAEF Conference, USC Marshall, HKUST, Adam Smith Workshop, FIRS, WFA, and SED.

1 Introduction

The global financial crisis (GFC) and the COVID-19 pandemic each resulted in large contractions in aggregate output, consumption, and investment in nearly every developed economy. In response to these crises, fiscal and monetary authorities mounted a massive response. Government (transfer) spending increased dramatically, resulting in large deficits and a major increase in the debt/GDP ratio. In the U.S., the debt/GDP ratio rose from 35% at the end of 2007 to 105% of GDP at the end of 2020. On the monetary front, policy rates were slashed to zero and large-scale quantitative easing (QE) programs were launched.

In this paper we ask whether these policy responses helped the economy recover from the crisis and how they affect fiscal sustainability in its aftermath. With policy rates stuck at the zero lower bound (ZLB), our focus is on unconventional monetary policy (UMP). We find that UMP stimulates the economy and contributes towards a smaller increase in the debt/GDP ratio during the crisis and in its aftermath. It also lowers the risk of large increases in debt/GDP.

We study these questions by building a dynamic stochastic general equilibrium model in the New Keynesian (NK) tradition. Its first 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 risk premium.

The model's second new feature is 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 macro-economy) 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 austerity threshold is endogenously determined to preserve the safety of government debt. For our calibration, the austerity threshold is a debt/GDP ratio of 115%. Even though the risk-free rate is below the growth rate of the economy in our model ($r^f < g$), fiscal capacity is limited when debt must remain safe (Jiang et al., 2020).

To study UMP, we introduce two maturities for government debt and an intermediary sector, the model's third new feature. The intermediary sector uses its holdings of reserves and firm capital to back deposits, subject to leverage (Supplementary Leverage Ratio, SLR) and liquidity (Liquidity Coverage Ratio, LCR) constraints. It faces equity issuance costs that make recapitalization during and after a crisis costly. Households invest in deposits, long-term government debt, and firm capital. This intermediary sector is important for understanding QE, since in QE the central bank purchases long-term debt from households and issues (short-term) reserves to banks. The injection of reserves into the banking sector affects SLR and LCR constraints and the allocation of assets between banks and households. 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 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 in equilibrium. The positive effect on GDP results in a smaller increase in the debt/GDP ratio in the crisis and its aftermath. Furthermore, QE 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 private sector, substantially and persistently depresses the government debt service costs.

A QE program of the same size as in the GFC lowers the debt/GDP ratio by 5.3% points and the debt service/GDP by 0.6% points five years after the crisis. UMP not only lowers the debt/GDP ratio on the average recovery path, but also the risk of future tax increases necessary to stabilize the debt once the debt/GDP ratio becomes too high. Starting from an initial 85% debt/GDP ratio, QE lowers the risk of austerity from 53% to 34%.

QE is a more potent crisis-fighting tool when the government debt/GDP ratio before the crisis is low. At lower debt/GDP ratios, interest rates tend to be lower and hence closer to the zero lower bound. The same-size crisis then creates a larger aggregate demand shortfall, which QE is able to counter.

We contrast a QE policy introduced in response to a crisis to the same-size QE policy introduced in normal times. We find that a transitory QE policy introduced in normal times is largely ineffective. It creates temporary consumption and output boosts, but the latter are ten times smaller than the QE policy mounted in response to a crisis.

As a thought experiment, we also consider a permanent QE program. This policy is equivalent to a permanent reduction in the maturity of government debt held by the private sector. 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, 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 offset the detrimental capital stock effect. Consistent with these results, lengthening the duration of QE past the end point of the crisis confers little additional benefit in terms of accelerating the recovery.

In addition to unconventional monetary policy, we study fiscal stimulus in response to the crisis. Additional transfer spending stimulates output when the economy is at the ZLB. This is true even in our representative-household economy. Some of the debt issued to finance the extra transfers is held by the intermediary sector. This infusion of liquid, safe assets in the banking sector result in the same crowding out and liquidity creation effects as UMP, and similarly stimulates aggregate demand. Like UMP, the transfers policy is state-dependent. At high pre-crisis levels of debt/GDP, the fiscal multiplier associated with extra transfer spending turns from positive to negative. The spending-induced increase in debt may then trigger a rise in taxes, lowering labor supply and output.

In a final exercise, we explore the ability of *conventional* monetary policy to provide fiscal capacity when the economy is away from the zero lower bound. We envision a situation like 2021 where the economy is saddled with a high debt/GDP ratio and the government raises transfer spending. The additional transfer spending creates substantial inflation, especially when the monetary authority deviates from the Taylor rule by unexpectedly accommodating the high debt/GDP ratio. This surprise inflation erodes the real value of the debt, creating some fiscal capacity relative to a world where the central bank follows the Taylor rule. In contrast, a policy where the private sector rationally expects the central bank to always accommodate high government debt backfires and results in high equilibrium debt/GDP ratios.

Related Literature We contribute to the vast literature in macroeconomics that works with New Keynesian (NK) models in several directions.

We are the first to study UMP in a quantitatively realistic NK model with substantial risk and risk premia. UMP operates via novel capital crowding out and liquidity creation channels, which require the presence of an intermediary sector. Our mechanism for QE naturally delivers duration dependence of the effects of the policy: temporary QE acts as a positive demand shock, while permanent QE crowds out bank lending to firms and acts like a negative supply shock.[1] In order to be effective, QE needs to be followed by QT (quantitative tightening).[2] In the seminal models of Gertler and Karadi (2011, 2013), the government bids up the price of assets held by intermediaries, which relaxes their balance sheet constraints.[3] While the mechanism is different in our model, QE also lowers long-term interest rates and increases firm value (lowers the equity risk premium).

We study the interaction of the UMP policy with a rich set of fiscal policy tools.[4] Labor income and corporate profit taxation, transfer spending, and discretionary spending all depend on the state of the economy, producing the counter-cyclicality of spending and pro-cyclicality of tax revenues quantitatively consistent with data. In contemporaneous work, Billi and Walsh (2021) and Mian, Straub and Sufi (2022) find that higher discretionary spending in an economic crisis can decrease the debt/GDP ratio due to a large fiscal multiplier. The same is true in our model. We find that higher *transfer* spending also has a positive fiscal multiplier when the economy is at or near the ZLB.

The endogenous regime-switching of tax policy between active and passive depending on the level of the debt/GDP ratio is novel to the literature. Unlike standard models in which tax

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[1] Diamond, Jiang and Ma (2021) and Bittner, Rodnyansky, Saidi and Timmer (2021) provide empirical evidence for the crowding out channel.

[2] Important contributions to the literature on the effectiveness of QE include Woodford (2012); Vissing-Jorgensen and Krishnamurthy (2011, 2012, 2013); Bernanke (2020).

[3] Brunnermeier and Koby (2018) emphasize the stealth recapitalization effects of QE. Sims and Wu (2021) extend the Gertler-Karadi model to allow for negative interest rates on reserves. Ray (2019) rationalizes QE policies by integrating a preferred-habitat model of the bond market into a NK model. Other papers viewing QE as operating through segmented bond markets include Chen, Cúrdia and Ferrero (2012), Carlstrom, Fuerst and Paustian (2017), and King (2019).

[4] An extensive literature studies the effects of government spending on output. See, for example Nakamura and Steinsson (2014) and the references therein. Another large literature studies the interaction of fiscal and monetary policy. See Sargent and Wallace (1981); Leeper (1991); Sims (1991); Woodford (1994, 2001); Cochrane (1998), Cochrane (2001); Schmitt-Grohhe and Uribe (2000); Bassetto (2002); Reis (2016); Sims (2016), among many others.

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 empirically more plausible fiscal policy that focuses on output stabilization most of the time, and only targets debt stabilization when debt/GDP reaches high values. Bianchi and Melosi (2019) introduce state-dependent policy targets for monetary and fiscal authorities. 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. Bianchi et al. (2020) consider an emergency budget in the wake of the COVID-19 pandemic which the monetary authority accommodates by temporarily tolerating higher inflation. In the last part of the paper, we consider a similar experiment where conventional monetary policy unexpectedly accommodates the fiscal authority, but after the crisis and from a state of high debt/GDP, resulting in high inflation and debt devaluation.

We introduce an intermediation sector which is better at providing credit to firms than households are, and produces deposits that are valued by households, contributing to the recent literature that introduces intermediation in NK models.[5] Intermediary health interacts in non-linear ways with monetary and fiscal policies.

Our non-linear fiscal rule, the presence of non-trivial risk, the ZLB, and the occasionally-binding leverage constraint for intermediaries make the model non-linear and require a global solution method. The NK model 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. This includes the design of a computationally efficient method to pin down the austerity bound, which allow us to study how different structural parameters such as the labor supply elasticity or the maturity structure of government debt affect fiscal capacity. Alternative models with lower risk aversion and a linear fiscal rule result in dramatically lower effectiveness of UMP, illustrating the importance of our new model features and solution method.[6]

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[5] Piazzesi, Rogers and Schneider (2021) study the properties of the NK model in a world with ample reserves. Wang (2020) analyzes state-dependent pass-through of monetary policy. Elenev (2020) and Faria-e-Castro (2020) evaluate policy responses during the GFC.

[6] Standard NK models typically omit permanent shocks, calibrate 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

We also contribute to a recent literature studies fiscal capacity in a world where the risk-free interest rate is below the growth rate in the economy.[7] Jiang et al. (2019, 2020) emphasize that meaningful risk premia are necessary to understand the effect of fiscal policies on debt sustainability. In the presence of realistic output risk premia, keeping government debt risk-free requires making the tax revenue claim safer than the government spending claim. Tax rates in our model are pro-cyclical and government spending is counter-cyclical at business-cycle frequencies, helping households smooth aggregate risk. However, once the debt/GDP ratio crosses into the austerity region, tax rates increase to stabilize the debt. Since marginal utility is high in the austerity region, the tax claim becomes less risky from the government's perspective. Our 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).

Finally, a literature at the intersection of macro-economics and finance studies how fiscal risk manifests itself in asset prices.[8] 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. Our model focuses on the effect of tax uncertainty on labor supply. We find that UMP and additional government spending lower risk premia in a macro-economic crisis, consistent with the stated objective of UMP, and lower the tail risk in debt/GDP.

The rest of the paper is organized as follows. Section 2 sets up the model. Section 3 describes the calibration. Section 4 contains our main results describing crisis dynamics with unconventional monetary policy. Section 5 studies conventional monetary policy outside crises. Section 6 concludes. The appendix provides details on model derivations (A), calibration (B), data sources (C), computational method (E), and further quantitative results (F).

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time-variation. 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.

[7] See Blanchard (2019), Jiang, Lustig, Van Nieuwerburgh and Xiaolan (2019, 2020), Barro (2020), Brunnermeier et al. (2020), Reis (2021), Mankiw and Ball (2021), Cochrane (2019a,b), Schmid et al. (2021) among others.

[8] 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).

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 short-term and long-term nominal debt securities to fund its deficits. Short-term debt includes both T-bills and reserves, high-powered money issued by the central bank. 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 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 U.S. 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

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

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

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

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 is important to allow for a positive correlation between the two shocks.

Goods production. 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 with elasticity of substitution parameter ϵ. 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

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

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: $Y_t(i) = (k_t(i))^{1-\alpha}(Z_t n_t(i))^{\alpha}$. The details are in Appendix A.

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 $B_t^{I,S}$ 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 D_t^I (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/reserves.

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 $X_t^{I,K} \geq 0$, $B_t^{I,S} \geq 0$, and the regulatory constraint (6). Intermediaries discount dividend payouts with the household discount factor $\mathcal{M}_{t,t+k}$. Liquidity costs are rebated lump-sum: $\text{Rebates}_t^I = P_t \varrho_t D_t^I$.

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

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

with r_t^K the marginal product of capital and δ the capital depreciation rate.

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:

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

Labor supply is endogenous and ω_1 controls the Frisch elasticity.

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:[9]

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

In addition to deposits, households purchase $X_t^{H,K}$ units capital at real price Q_t and $B_t^{H,L}$ 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:

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

Intuitively, this cost creates a downward-sloping demand curve for long-term debt relative to GDP. The presence of this cost (ξ_0^L) 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 (ξ_1^L). Capital costs take a similar form:

$$\Xi^K(X_t^{H,K}, K_t) = \frac{\xi_0^K}{2}\left(\frac{X_t^{H,K}}{K_t}\right)^2 K_t, \tag{10}$$

where K_t is the aggregate capital stock. Costs associated with capital holdings capture households' comparative disadvantage of lending directly to firms.[10]

Households further operate the economy's investment technology, which creates I_t units of

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[9] This definition of the value function requires $\varphi < 1$. A constant may have to be added to intra-period utility to ensure that the value function has the same sign for all feasible choices, see Appendix A. Separable utility over consumption and labor within Epstein-Zin preferences generally implies that γ is not equal to relative risk aversion, see Appendix E.3.

[10] 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.

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:

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

where W_t^H is household financial wealth at the beginning of t. Additional resources for households 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 get 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:[11]

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

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 $\delta^B p_t^L$.

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[11] 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 sub-optimal lending by households.

2.4 Government

2.4.1 Fiscal Policy

The fiscal authority follows decision rules for transfer spending 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

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

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

$$\tilde{\tau}_t^n = \tilde{\tau}^n(\hat{Y}_t), \qquad \text{for } n \in \{w, div\} \tag{17}$$

In this *active* regime, the government is only concerned with actively stabilizing the economy by responding to deviations from the stochastic growth trend rather than with stabilizing the debt. With firm and intermediary profits given by (4) and (5), 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 determines 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:

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

In the **passive** fiscal policy regime, tax rates instead aim to stabilize the level of government debt, rather than insulate taxpayers from aggregate shocks. Tax rates are implied by a debt issuance target. 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) when $\tilde{W}_t^G$ is either below the **profligacy** threshold $\underline{W}^G$ or above the **austerity** threshold $\overline{W}^G$:

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

where $v \in (0,1)$ parameterizes the degree of fiscal adjustment in the austerity and profligacy regions. The government chooses 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 the debt/GDP ratio surpasses the austerity threshold, the government raises 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 debt/GDP drops below the profligacy threshold, the government can lower tax rates by setting $f(\vec{W}_t^G) < 1$. The austerity and profligacy bounds are *endogenously* determined to keep the debt safe (finite) for all simulated paths.[12]

To fund 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. Then

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[12] See Appendix E.2 for details.

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:

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

2.4.2 Monetary Policy

The central bank chooses the interest rate on short-term government debt $i_t^S = 1/p_t^S - 1$. 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 inter-bank 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:

$$\frac{1}{p_t^S} = \max\left\{\frac{1}{p_t^*}, 1\right\}, \tag{24}$$

where monetary policy follows a Taylor rule away from the ZLB:

$$\frac{1}{p_t^*} = \frac{1}{\bar{p}^S}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi^\pi}\left(\frac{\hat{Y}_t}{\bar{Y}}\right)^{\phi^y}, \tag{25}$$

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.[13] The central

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[13] We calibrate the model to the post-2008 Federal Reserve balance sheet with "ample" reserves, such that the interest rate paid on reserves (IOR) is equal to the Federal Funds rate (FFR) and the balance sheet is truly a separate policy instrument. Prior to 2008, the aggregate reserve/deposit ratio was around 1%; since then the ratio was consistently above 10%, which has been sufficient to maintain that IOR=FFR. The central bank in

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 the hands of the private sector.

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

$$-p_t^l B_t^{CB,L} = p_t^s B_t^{CB,S}, \tag{26}$$

$$B_t^{CB,L} \leq B_t^{G,L} \text{ and } B_t^{CB,S} \leq B_t^{G,S}. \tag{27}$$

Constraint (26) imposes that the central bank swaps government liabilities at market value. 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.[14] The constraints in (27) 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:

$$Div_{t+1}^{CB} = B_t^{CB,S} + (c + 1 - \delta^B + \delta^B p_{t+1}^l) B_t^{CB,L}. \tag{28}$$

Since new purchases are revenue-neutral by (26), this is also the profit of the central bank in $t+1$. The central bank remits this profit to the fiscal authority.

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our model can ensure a sufficient supply of reserves by swapping reserves for ST debt. Piazzesi, Rogers and Schneider (2021) study a model that nests both regimes as function of the reserve supply.

[14] For simplicity, we assume that the central bank can also short-sell long-term bonds to invest in short-term bonds. 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.

2.4.3 Consolidated Government Budget Constraint

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

$$\begin{aligned} W_{t+1}^{G} &= B_t^{G,S} + (c + 1 - \delta^B + \delta^B p_{t+1}^L) B_t^{G,L} - Div_{t+1}^{CB} \\ &= B_t^{G,S} - B_t^{CB,S} + (B_t^{G,L} - B_t^{CB,L})(c + 1 - \delta^B + \delta^B p_{t+1}^L). \end{aligned} \tag{29}$$

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 private sector under a QE policy: $\mu^{QE} < \bar{\mu}$. The evolution equation for the value of government liabilities (29) clarifies that for the accounting of debt claims between the branches of government (central bank and fiscal authority) and the private sector (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 private sector of both bonds to $B_t^{G,S} - B_t^{CB,S}$ and $B_t^{G,L} - B_t^{CB,L}$.

2.5 Market Clearing

Short-term and long-term government debt, deposit, labor, firm capital, and goods market must clear in equilibrium. Appendix A contains the market clearing conditions.

3 Calibration

3.1 Parameters

Appendix B contains a detailed discussion of the extensive model calibration work. In the interest of space, the main text discusses the key points. Productivity parameters directly target real consumption growth and moments of the TFP series of Fernald (2012). To get the right correlation structure of spending and taxation with consumption growth and to help the model produce an upward-sloping term structure of interest rates, permanent and transitory shocks are perfectly positively correlated. Production and adjustment cost parameters are standard. The elasticity of substitution for the final good producer matches markups and the Rotemberg adjustment cost targets the volatility of the labor share through its effect on labor demand.

Intermediary parameters match regulatory features such as the maximum leverage ratio (ν in the SLR constraint) and equity requirement for capital (the risk weight ν_K). The equity payout τ targets intermediary leverage and the equity issuance cost χ targets the net payout ratio of the financial sector. The fraction of deposits ζ_ρ a particular bank's depositors can be expected to withdraw per period and is set to 0.05 following BIS (2013). The LCR parameter ρ_1 targets the spread between short-term debt and deposits of 0.31% quarterly.

The coefficient of risk aversion γ targets the risk premium on a claim to GDP of 1% per quarter. The corresponding Arrow-Pratt measure of relative risk aversion is around 3. 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 β targets the average quarterly real rate of 0.42% quarterly. The Frisch elasticity of labor supply is set to 0.5 ($\omega_1 = 2$). Households' utility benefit from deposits ψ targets a quarterly convenience yield in short-term government debt of 0.1%.

The portfolio cost for long-term bonds (ξ_0^L, ξ_1^L) targets the mean and volatility of the term spread of 0.36% and 0.29% quarterly, respectively. Without this 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. Ceteris paribus, this cost increases the bank capital share.[15]

Our fiscal policy rules are calibrated to match the unconditional average and cyclical properties of transfer spending, discretionary spending, and tax revenue. The parameter $\overline{\mu}$ is set

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[15] 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.

to match the observed fraction of debt longer than one year maturity (67%). We set δ^B to match the duration of long-term government debt to 7.76 years. A novel feature of our model is the endogenous regime-switching of fiscal policy based on profligacy and austerity regions specified in the fiscal rule (20). We describe how we choose the thresholds $\underline{W}^G$ and $\overline{W}^G$, and the adjustment coefficient v, in the next section 3.2.

The Taylor rule coefficient on inflation ϕ^π is set to 1.6, targeting the volatility of inflation in the model to the volatility of deviations from the inflation target in the data, using the 2% inflation target and the core PCE price index.[16] The coefficient on output ϕ^y is set to 0.125, which is a standard value in the literature.[17] The inflation target $\bar{\Pi}$ is set to target average inflation of 2% per year.

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.

Appendix E discusses the global non-linear solution method used to solve the model.

3.2 Properties of Fiscal Policy

Before we evaluate whether monetary policy can help alleviate the government's debt burden after economic crises, we first discuss 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.

Figure 1 shows a histogram of the government debt/GDP ratio for a long simulation of the model, overlaid with a scatter plot of the tax adjustment factor $f(\vec{W}_t^G)$. Vertical dashed lines indicate the profligacy and austerity bounds, respectively. The austerity threshold is set at 115% of debt/GDP and the profligacy threshold at 47.5%. Sequences of shocks may push

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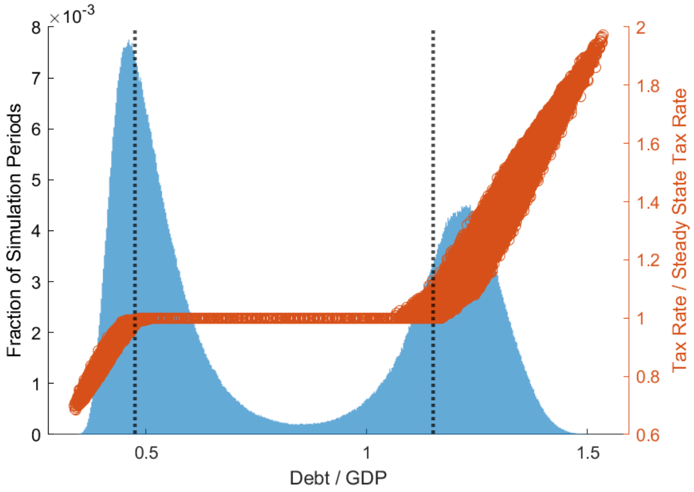
[16] We choose deviations from the inflation target as data measure, since raw inflation volatility in the data is largely driven by low frequency movements in the inflation target, whereas the target is constant in the model.

[17] Qualitatively, results would be unchanged if we set this coefficient to zero.

Figure 1: Distribution of Government Debt and Tax Adjustment



debt/GDP into either one of these 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 in order to stabilize the debt/GDP ratio. The tax adjustment coefficient v is set to 0.85. Given this coefficient, the half-life of a deterministic transition path from austerity or profligacy back to the interior region is 4.25 quarters, a reasonable pace for tax adjustments to take place.[18]

These tax adjustments are successful in reigning in debt/GDP. However, the figure reveals a clear asymmetry with respect to profligacy and austerity. 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 model features an upper bound for the austerity threshold: if the austerity regime only starts 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. In our calibrated model, the implied maximum austerity

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[18] Absent shocks and general equilibrium effects, the law of motion for government debt in the tail regions is an AR(1) process with coefficient v.

threshold is at 115% of debt/GDP.

The austerity bound is a complex function of the structural parameters of the model. We have verified that for the calibrated model, the simulated time series meets the conditions for stationarity. 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.[19] 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). Given the asymmetry of the Laffer curve effect, the model does not imply an analogous minimum profligacy threshold at positive levels of debt/GDP.[20]

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. Appendix D shows that in the post-war sample, we do not observe tax increases prompted by higher debt/GDP ratios. If anything, increases in debt/GDP coincide with decreases in tax revenue/GDP. Our model replicates this behavior. Finally, both in model and data, debt/GDP is highly persistent: the quarterly auto-correlation coefficient of the data debt/GDP ratio is 0.995, while in the model it is 0.988. 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 history of U.S. fiscal policy.

At the same time, our model clarifies that fiscal adjustments cannot be arbitrarily delayed.

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[19] We have also verified that increasing the austerity threshold will cause the simulated paths to violate the state space boundaries. Appendix E.2 contains details.

[20] Setting the profligacy threshold at lower levels than in Figure 1 while recalibrating model parameters to match the same data targets for interest rates and inflation, has little economic effects, other than allowing the model to generate smaller realizations of debt/GDP. However, setting a lower profligacy threshold comes at a high computational cost, as it requires expanding the grid for the government debt state variable. To avoid long computation times while also allowing for a large interior region of debt/GDP, we set the profligacy threshold to 47.5%, which is the average debt/GDP ratio in the postwar sample (1945-2020). A lower threshold does not substantially change the results of our quantitative experiments, which are mainly concerned with interactions of monetary and fiscal policy at high debt/GDP.

If government debt is to remain stationary and risk-free, adjustments to the primary surplus are necessary before debt/GDP becomes unsustainably large. The CBO projects that the U.S. debt/GDP ratio will exceed the austerity threshold of 115% implied by the model in 2034. 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. Also, raising tax rates in the austerity regime is painful since these are high marginal-utility states of the world.[21]

Appendix D also discusses the riskiness of tax and spending claims, making contact with the work by Jiang et al. (2019, 2020), and shows that bond convenience yields decline in the debt/GDP ratio, matching the elasticity estimated in Vissing-Jorgensen and Krishnamurthy (2012).

4 Unconventional Monetary Policy As Crisis Response

4.1 Fiscal and Monetary Policy in Crises

Our main experiment envisions an economy that simultaneously undergoes an *unanticipated* negative demand shock and a negative productivity shock. The productivity shock consists of a one-standard deviation drop in the growth rate g_t and in the transitory TFP component z_t^r, with both components following their calibrated law of motion. The left panel of Figure 2 shows the evolution of the level of TFP during and after the hypothesized crisis, where the level is normalized to 1 before the crisis.

The unanticipated demand shock is modeled as an increase in the subjective time discount factor β, as is standard in the New Keynesian literature. Once the discount factor shock hits, agents expect it to mean-revert with 50% probability each quarter. We study a specific path where the unexpected shock lasts for four quarters before stochastically mean-reverting. Our target is year-on-year inflation of -1.5% in Q3 of 2009. The model matches this target through a discount factor shock of 0.92%.

While we use deflation in 2009 to discipline the size of the demand shock, we do not explicitly

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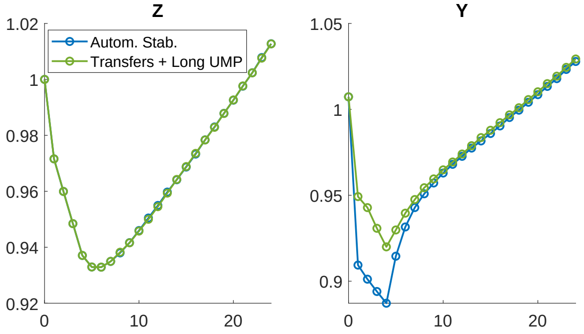
[21] We have verified that GDP is lower and inflation higher in the austerity region.

Figure 2: Main Policy Experiment: GDP Growth



target other aspects of the GFC. The goal of this section is not a realistic replay of the GFC within the model, but rather an analysis of how different policies affect the recovery path if the economy was hit again by a GFC-sized shock. Therefore, we fix the endogenous state variables of the model – capital, intermediary wealth, and government debt/GDP – at their respective ergodic means to illustrate how the shock affects the calibrated economy given the most likely initial conditions. We analyze in Section 4.2 how different initial levels of debt/GDP change the impact of the shock and policy responses.

4.1.1 Realistic Policy Combo versus Only Automatic Stabilizers

As we shall see, the crisis pushes the economy into the zero lower bound, thereby limiting the central bank's ability to stimulate the economy through conventional monetary policy. We study a policy response consisting of additional fiscal stimulus and unconventional monetary policy, capturing the essence of observed crisis responses following the GFC and the COVID-19 crises. First, the government deploys additional transfer spending equivalent to 7.36% of GDP. We choose this quantity of additional transfer spending to match the primary deficit of 10% of GDP for 2009 in our crisis simulation.

Second, and the main point of interest in this paper, the central bank pursues unconventional monetary policy (UMP). UMP consists of large-scale asset purchases (QE) as well as an exemption of bank reserves from the Supplemental Leverage Ratio (SLR) calculation. We assume that the central bank builds up a portfolio of long-term bonds with total value equal to 23.7% of the stock of long-term debt before the policy.[22] Exempting central bank reserves and certain

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[22] This is the amount of long-term Treasuries and Agencies that the Federal Reserve had purchased as a share

treasury securities from the SLR was a real-world feature of policy during the Covid crisis.[23]

To capture policymakers' intentions to keep supporting the economy during the recovery period following the crisis, we assume that the UMP policy only mean-reverts with 10% probability each quarter, so that the policy persists for an additional 10 quarters in expectation after the 4-quarter crisis ends. We refer to this combination of increased transfers and long-lasting UMP as the "Transfers + Long UMP" experiment. We assume that this policy mix is the data generating process. It is for this economy that we size the demand shock to match the data target for inflation (-1.5%) and primary deficit (10% of GDP).

As the right panel of Figure 2 shows, the "Transfers+Long UMP" economy undergoes a sharp drop and slow recovery of GDP, consistent with the observed GDP dynamics during the GFC.

Our main policy counterfactual compares this policy path to a world in which fiscal and monetary authorities only engage in "standard" policy responses: a Taylor rule governing the conventional monetary response (once away from the ZLB) 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 policy path "Autom. Stab." shown as the blue line in Figure 2.

Macro Variables. Figure 3 shows the dynamics of the main macro variables *relative* to the productivity trend. The top left panel shows the decline in that productivity trend itself, relative to the no-shock baseline. The second panel from the left in the top row shows the discount rate shock. The bottom row shows that the combination of negative supply and demand shocks cause a deep economic crises absent additional policy interventions. GDP, consumption, and employment all drop by 6% in Q4 relative to Q0 in the "Autom. Stab" scenario relative to the permanent decline in productivity. Investment declines by 13%. The recession is highly deflationary (third panel on the top row), with inflation dropping to -7%. The central bank tries to counter the demand shock as much as possible by lowering the policy rate to zero. The policy rate remains trapped at the ZLB for the duration of the shock (top right panel).

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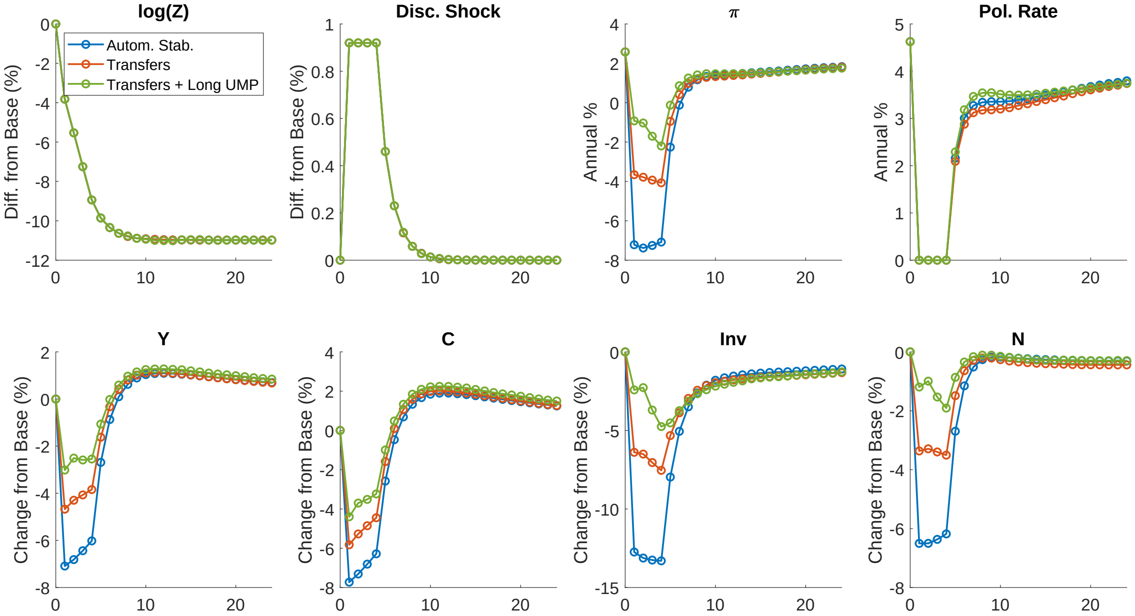
of the outstanding amounts by 2014, the combined result of QE1–QE3 programs.

[23] The exact policy is that we increase ν in equation (6) from 0.97 to 1, 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 considering permanent changes to SLR requirements for safe assets.

Figure 3: Main Policy Experiments: Macro Variables



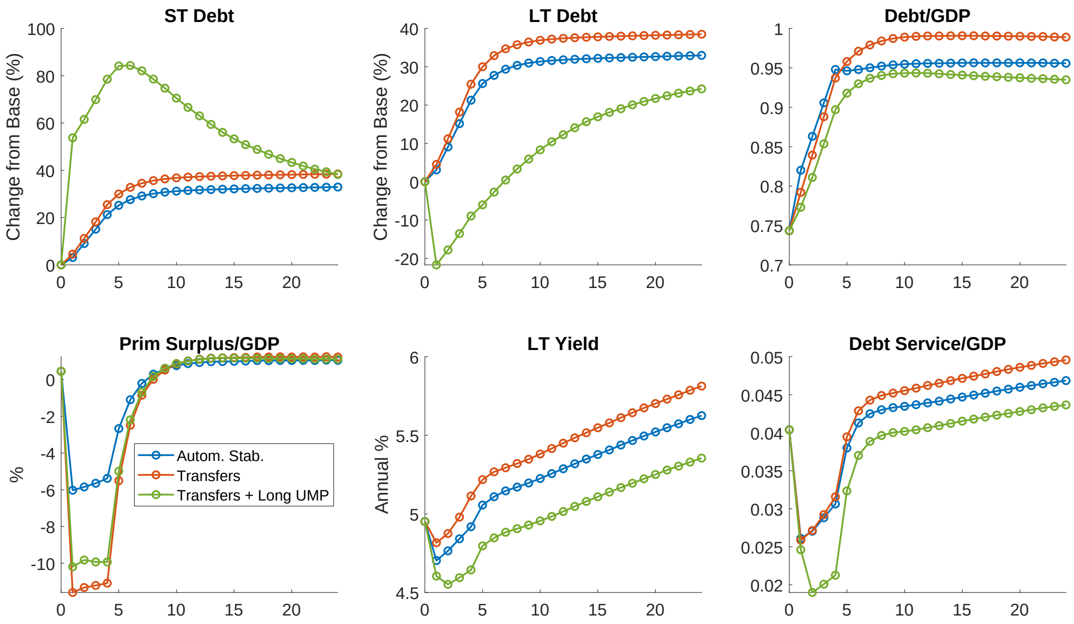
The top left panel plots the productivity level in the crisis (cr) relative to the productivity level in a no-shock simulation (ns): Z^{cr}/Z^{ns}. The second panel from the left in the top row plots the discount rate in the crisis relative to that in a no-shock simulation. The third panel in the top row plots the inflation rate. Cumulative inflation over the first four quarters (i.e. year-on-year) is -1.49%. The top right panel plots the monetary policy rate. The bottom row plots GDP, aggregate consumption, aggregate investment, and aggregate labor supply relative to the productivity trend and relative to a no-shock path: $X^{cr}/Z^{cr} - X^{ns}/Z^{ns}$.

Comparing the "Autom. Stab." scenario to "Transfers + Long UMP" reveals how effective the policy response to the crisis is: output drops by 3.5% points less in Q4 than without additional policy interventions, consumption by 2.5% points, and labor by 4.3% points. Investment declines by only 5% in "Transfers + Long UMP" and inflation never falls below -2.5%. Additional transfers raise GDP by approximately 2.2% points and UMP raises GDP by approximately 1% relative to the "Autom. Stab." counterfactual.

Fiscal Variables. Figure 4 displays the evolution of debt quantities and long-term bond yields for the same experiments. To implement QE as part of the "Transfers + Long UMP" mix, the central bank swaps 23.7% of the fraction of outstanding long-term debt for short-term debt. This leads to a large decline (rise) in the holdings of long-term (short-term) bonds in the hands of the private sector, as shown in the top middle (left) panel.

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

Figure 4: Main Policy Experiments: Fiscal Variables



sharply from 74% to 96%. Under the "Transfers + Long UMP" scenario, the path of debt/GDP is similar to its "Autom. Stab." trajectory. This is despite a government deficit that is twice as large: the primary surplus, plotted in the bottom left panel, turns sharply negative to -6% of GDP even with spending and taxes only governed by automatic stabilizers, and it is -12% under "Transfers + Long UMP" given additional transfer spending of 7.4% of time-0 GDP. The effect of adding UMP to the policy mix can be most clearly seen by comparing the "Transfers + Long UMP" to a world where the government only pursues additional transfer spending, plotted by the red line. In this "Transfers" scenario, debt/GDP peaks at 99%. The difference in the debt/GDP between red and green lines five years after the crisis is 5.3% points. This is the additional fiscal capacity created by UMP.

The addition of UMP in "Transfers + Long UMP" 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 as plotted in the middle panel of the bottom row. 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 private sector 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 3.1% to 2.1% of GDP during Q4 the crisis due to UMP. 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 "Transfers + Long UMP." These dynamics add up to the 0.6% point lower debt servicing costs in the long-run. Combined with the strong positive general equilibrium effects on GDP in the short-run, discussed above, these dynamics cause a smaller rise in debt/GDP.

Appendix F.1 discusses the effects of increased transfer spending, by itself, and compares them to the effects of UMP by itself. 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. However, a fraction of the new debt issued to pay for the transfers is held by intermediaries in the form of reserves. Intermediaries absorb these additional reserves by issuing deposits and equity to households, subject to intermediation frictions. This transfer-induced increase in bank reserves has a similar effect as increased reserve supply resulting from QE, similarly stimulating aggregate demand in the short run, as discussed in the next Section 4.1.2. The important difference is that higher transfers cause a net increase in government debt issuance, while UMP does not.

Appendix F.3.1 shows that the effectiveness of the "UMP+Transfers" policy is understated by a model that has a standard passive fiscal policy rule, where the tax rate increases linearly in the debt/GDP ratio, relative to our benchmark model where fiscal policy only becomes passive in the austerity region. The same is true for a model with a lower risk aversion coefficient, as shown in Appendix F.3.2. In both cases, the effect of policy on the debt (service)/GDP ratio has the opposite sign as in the benchmark. This shows that the two key modeling innovations: realistic risk premia and endogenously-switching fiscal policy have important quantitative implications for the effectiveness of UMP.

4.1.2 Decomposition: Understanding UMP

To better understand this powerful policy response, we now isolate several of its key ingredients, with a focus on QE. We recall that UMP is a combination of QE, the central bank buying long-term debt from households by issuing reserves to intermediaries, and a relaxation of the SLR constraint for reserves and short-term debt. Furthermore, we want to isolate the impact of a 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 shocks that triggers the crisis: four quarters, followed by mean reversion with probability 0.5 each quarter thereafter. The size of the UMP policy is the same as above.

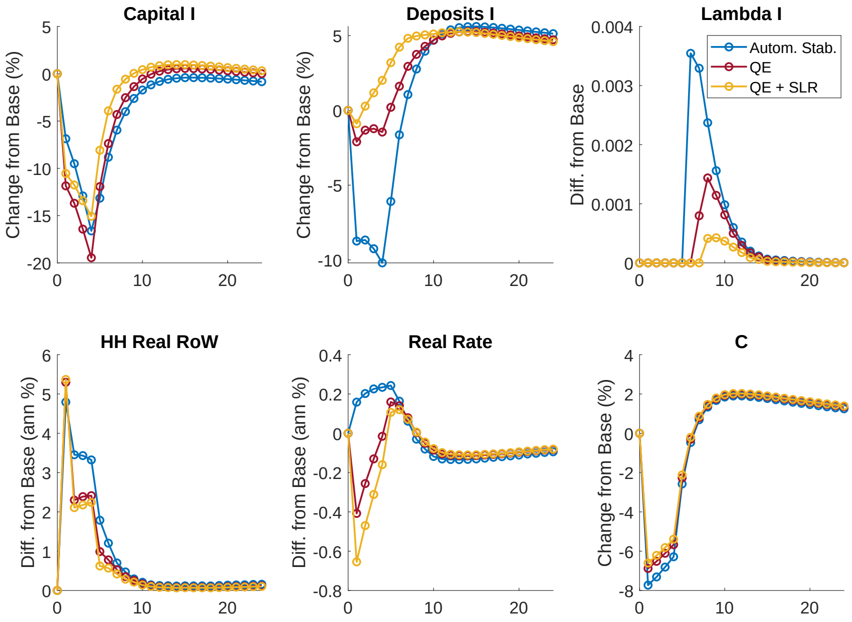
Intermediary Portfolio. The top row of Figure 5 shows a decomposition of the effects of these policies for financial intermediary holdings of capital, issuance of deposits, and the value of the Lagrange multiplier on the intermediary leverage constraint (6). When policy consists of only automatic stabilizers, intermediaries are forced to shrink their balance sheet in the crisis as their leverage constraint becomes binding.

QE (maroon line) floods the balance sheet of intermediaries with reserves. This large increase in reserve supply has two opposing effects. On the one hand, the liquidity cost of issuing each dollar of deposits is greatly reduced since the cost of deposit creation falls in the amount of reserves (recall equation 7). On the other hand, because – and to the extent that – even reserves require the commitment of scarce bank equity capital because of the SLR constraint ($\nu = .97$ in equation (6)), QE induces banks to sell even more of their capital holdings to households, holding constant the size of their balance sheet. The net effect is that intermediaries shrink their capital holdings as much under QE as under the automatic stabilizer scenario, despite a much smaller decline in their deposit issuance. In effect, intermediaries are substituting reserves for capital as collateral asset. The extra risk weight on capital in the bank's leverage constraint makes reserves a superior collateral asset.

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 (yellow line). The Lagrange multiplier on intermediaries' leverage constraint is now much smaller, and intermediaries reduce their capital holdings by less. Deposit supply now increases slightly. The SLR relaxation reduces the

Figure 5: UMP Decomposition: Intermediary and Household Portfolio

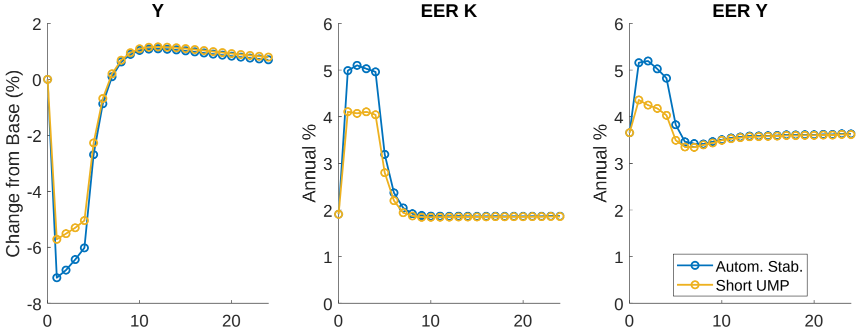


crowding out effect and amplifies the liquidity creation effect of QE.

Risk Premia. Figure 6 displays the response of expected excess returns on a claim to firm capital (middle panel) and to output (right panel) during the crisis. Output changes themselves are repeated in the left panel. Absent policy interventions ("Autom. Stab."), the (unlevered) capital risk premium spikes sharply by 3% points annually and the GDP risk premium by 1.2%. UMP significantly reduces risk premia on both claims ("Short UMP" is the combination of QE+SLR for the duration of the crisis). The capital risk premium in Q4 is 92 basis points lower due to QE. This demonstrates that UMP reduces required returns on risky assets, a stated objective of the policy and consistent with the empirical evidence.

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. QE reduces the supply of long-term government debt held by households. Mirroring the effect on intermediary balance sheets, it increases their holdings of deposits and firm capital. Households are worse than banks at intermediating

Figure 6: UMP: Risk Premia



firm capital due to their capital portfolio costs (equation 10), resulting in lower returns on capital. Furthermore, as shown in Figure 6, QE lowers the risk premium on capital. The lower real rate under QE, plotted in the middle panel of the bottom row of Figure 5, combines with the lower risk premium to lower the expected return on capital. All told, households' expected portfolio return falls; the left bottom panel of Figure 5 shows that the total return on household wealth declines with QE.

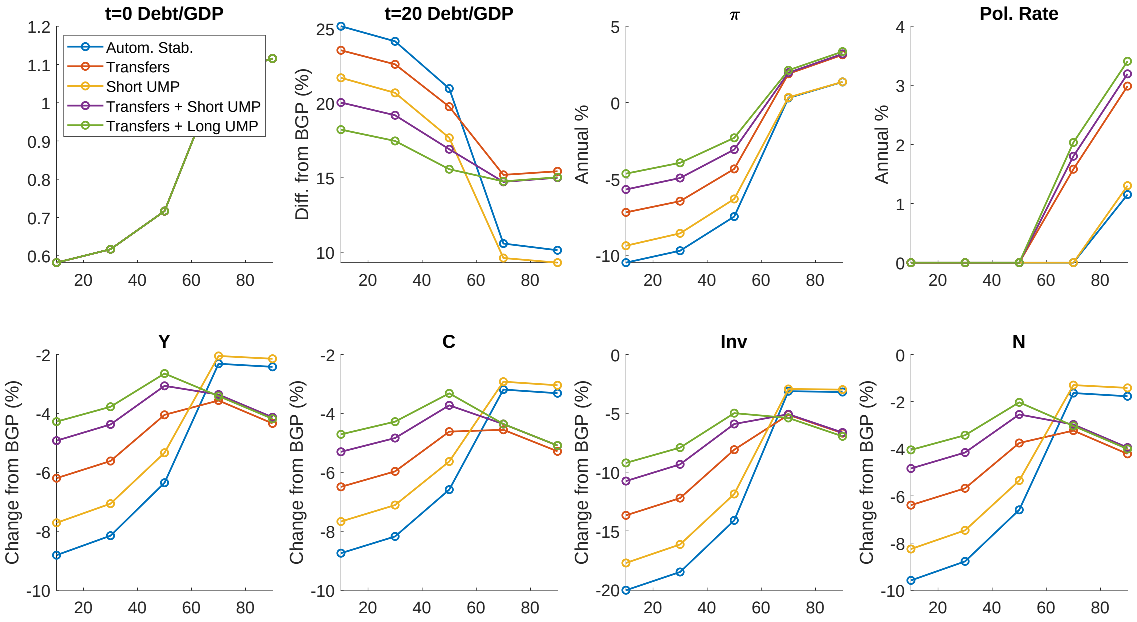
In sum, QE shifts the supply of available assets such that saving becomes less attractive to households, inducing them to consume more as shown in the right bottom panel of Figure 5. This intertemporal substitution towards higher consumption is reflected in a lower real interest rate and causes an increase in aggregate demand, which boosts employment and output in the New Keynesian model. This explains the large output multiplier from unconventional monetary policy.

4.2 State-Contingency of UMP

4.2.1 Role of Initial Debt/GDP Ratios

How do different initial debt/GDP ratios affect both the severity of the crisis and policy effectiveness? To answer this question, we conduct the same crisis simulation described in the previous section from different starting points for the debt/GDP ratio. We hold the other two endogenous state variables, capital and intermediary wealth, fixed at their unconditional ergodic means. Figure 7 plots the same set of variables as Figure 3. On the x-axis are percentiles of the debt/GDP distribution (conditional on the other state variables being at their long-run

Figure 7: Policy Effectiveness by Initial Debt/GDP



means). The top left panel plots the resulting initial debt/GDP ratio. The second panel from the left shows the change in the debt/GDP ratio after 5 years (20 quarters). All other panels plot values of their respective variables in the fourth quarter after the shock hits (Q4).

First, the figure demonstrates that the initial debt/GDP ratio is quantitatively important for the severity of the shock. The blue line shows the effect of the crisis under a bare-bones policy response. Focusing on the bottom left panel, we can see that the decline in GDP is much larger at lower debt/GDP ratios: at the 10th percentile ratio of debt/GDP (a value of 58%), GDP drops by 9% relative to trend, whereas at the 90th percentile ratio (112% debt/GDP), it drops by less than 3%. The difference arises because, at low debt/GDP, interest rates and inflation are much lower to begin with. Therefore, the negative demand shock always causes a binding ZLB (top right) and strong deflation (second from right in top row). At high debt/GDP ratios, equilibrium interest rates are far from the ZLB. The same demand shock is less powerful since it can be partially offset by conventional interest rate cuts.

Second, Figure 7 shows that both UMP and transfer spending are less powerful stabilization policies at higher debt/GDP ratios. UMP becomes a less effective crisis-fighting tool as the pre-crisis debt/GDP ratio increases but retains its positive impact (compare blue and yellow lines).

The UMP-induced reduction in the debt/GDP ratio five years after the crisis is 3.5% points when the initial debt/GDP ratio is low, but less than 1% point when the initial debt/GDP is high. This points to an important state-dependency in the effectiveness of UMP.

Extra transfer spending is powerful medicine at low debt/GDP ratios but becomes counterproductive at high debt/GDP ratios. The latter are likely to push the debt/GDP ratio into the austerity region, forcing the government to enact painful tax increases that lower GDP and increase inflation. For example, when starting at debt/GDP of 110%, the drop in GDP under "Transfers + Short UMP" is almost 2% point *larger* than under "Short UMP" (purple versus yellow lines). The same policies, when deployed at 58% debt/GDP, cause a 2.8% point smaller drop in GDP. The extra transfer spending has minimal repercussions for the long-term debt/GDP ratio at low initial levels of debt/GDP, but reduces fiscal capacity by more than 5% points when done starting from a high debt/GDP situation. The graph also shows that extra transfer spending on top of UMP creates about 2% points of inflation at high debt/GDP ratios.

Finally, a comparison of the green and purple lines shows that a longer policy duration for QE, past the duration of the crisis, amplifies the response of output and creates additional debt capacity, but only at lower levels of debt/GDP.

This exercise highlights that the impacts of both economic shocks and policies crucially depend on the government's fiscal situation at the outset of a crisis. Unconventional monetary policy and additional spending become less powerful as debt/GDP rises. Our globally solved model with realistic fiscal dynamics allows to analyze the full range of initial conditions.

4.2.2 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 are only modest benefits 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 duration of government debt held by the private sector falls from 4.08 to 3.19 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 F.2 and visualized in Figures F.3 and F.4, 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. 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 portfolio is now less risky, substantially boosting deposit supply.[24] 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 F.2 and visualized in Figures F.5 and F.6, 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

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[24] Household welfare is approximately unchanged. The fact that household welfare remains the same with permanent QE indicates that the benchmark economy suffers from a shortage of liquid assets that causes over-accumulation of physical capital and under-provision of deposits.

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 23.7% of long-term debt by reserves only leads to a 9 basis point rise in output and consumption, and a 0.004% short-term welfare gain.

The two experiments described above highlight that the effect of QE greatly depends on the timing of the policy. When temporary UMP is implemented in response to a crisis, it causes output to rise by 1.37% (Figure F.1). However, when implemented during normal times, the same temporary QE policy has output effects that are less than one-tenth as large. Furthermore, the ability of QE to stimulate aggregate demand depends on the temporary nature of the policy: QE has to be followed by a predictable and announced quantitative tightening (QT) to be an effective 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.

4.3 Fiscal Risk Avoidance and Fiscal Capacity

As result of a smaller rise in debt/GDP under UMP, 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 as the *fiscal risk avoidance channel* of UMP.

We can see this channel at work in Figure 8. It plots the dynamics of debt/GDP during and after the crisis under various policies and for many sample paths of productivity shocks during the recovery, starting from 85% debt/GDP. The bold lines plot mean paths, the dashed lines show standard errors around the 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.[25] 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 lowers the probability from 38% to 25%. Additional transfers, not supported by UMP, cause a

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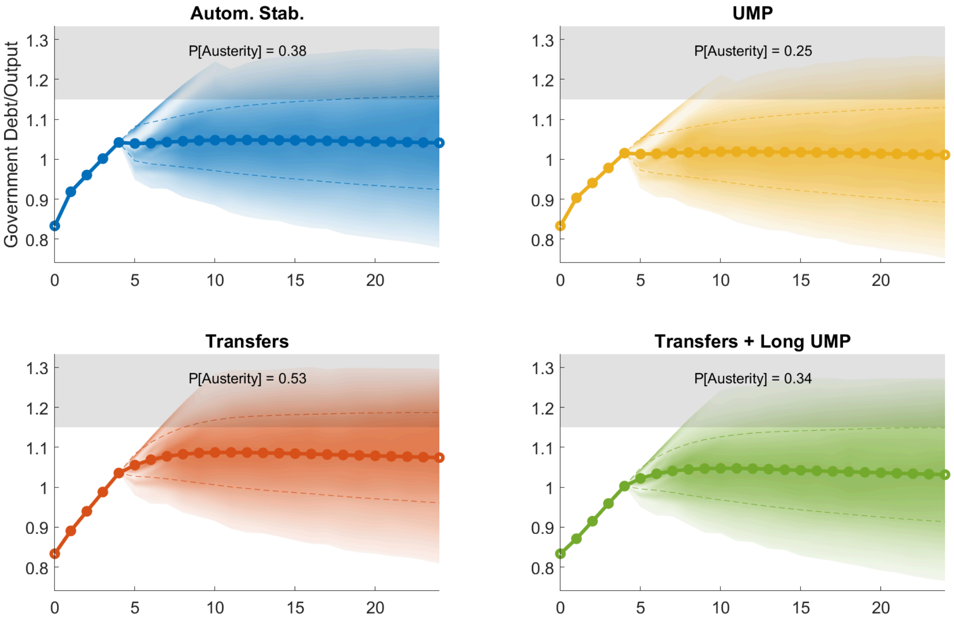
[25] We generate the IRF graphs by simulating 5,000 random paths. For each period of the IRF, we estimate the kernel density of possible paths. Darker shades indicate higher density.

Figure 8: Main Policy Experiments: Government Debt Paths

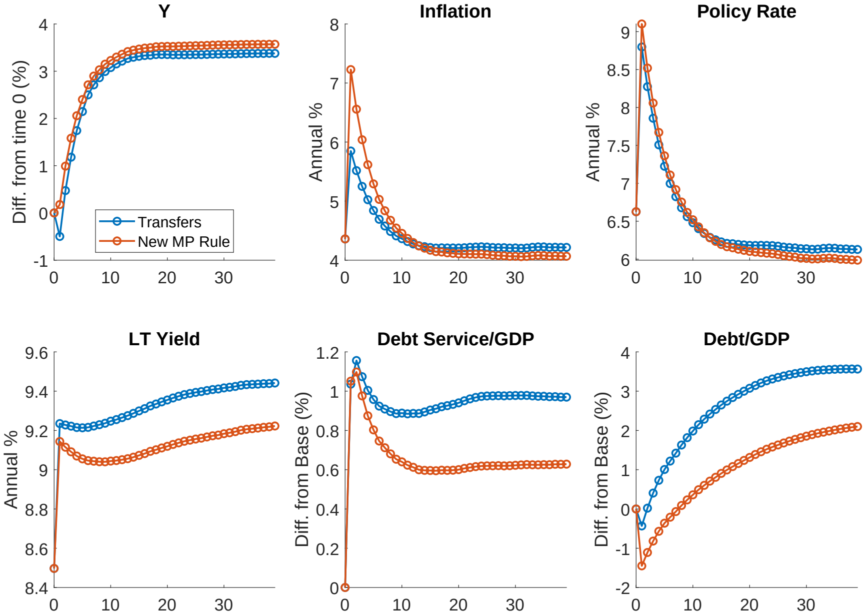


greater rise in debt/GDP relative to automatic stabilizers only and therefore increase the risk of austerity from 38% to 53%. Adding long-running UMP reduces this probability to 34%. This 19% point reduction in austerity probability is a measure of the gain in fiscal capacity due to unconventional monetary policy in our model. UMP not only helps the government ease the future debt burden from additional borrowing on average, but it also alleviates fiscal risks by lowering the probability of debt expansion that requires painful fiscal adjustments.

5 Conventional Monetary Policy Outside of Crises

So far our policy experiments have focused on the role of unconventional monetary policy in economic crises. We finish with a discussion of the extent to which *conventional* monetary policy can create fiscal capacity during post-crisis times with higher-than-normal inflation and a positive output gap. We consider a scenario where the fiscal authority engages in an unexpected increase in transfer spending (5% of GDP), even though the debt/GDP ratio is already high (100% of GDP). The economy is experiencing strong permanent productivity growth of 1% per quarter, driven by the recovery from a crisis. At the same time, transitory TFP is at -1%, possibly reflecting supply constraints. Both transfer and productivity shocks persist with a

Figure 9: Government Spending and Unanticipated Passive Monetary Policy



probability of 75% per quarter. This constellation of circumstances evokes similarities to the state of several developed economies in 2021.

We study the economy's response under two different assumptions on conventional monetary policy. In the first case, the monetary authority follows the regular Taylor rule as calibrated before. This is displayed as the blue lines in Figure 9. In the second case, we consider a central bank that adds a new term to its monetary policy rule:

$$\frac{1}{p_t^*} = \frac{1}{\bar{p}^S}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi^\pi}\left(\frac{\hat{Y}_t}{\bar{Y}}\right)^{\phi^y}\left(\frac{\Delta_t}{\bar{\Delta}}\right)^{\phi^\Delta} \tag{30}$$

The last term builds an interest rate response to deviations of the debt/GDP Δ_t ratio from target $\bar{\Delta}$ into the monetary policy rule. A coefficient $\phi^\Delta < 0$ implies partially "passive" monetary policy that accommodates increases in debt/GDP through rate reductions. We set $\phi^\Delta = -0.08$ and a target debt/GDP level of $\bar{\Delta} = 75\%$, implying a 2% interest rate reduction at 100% debt/GDP, holding constant other terms in the policy rule. This new term is unanticipated by private agents; it is part of the definition of the shock. The response of the economy under this alternative monetary policy rule is plotted in the red lines in Figure 9.

The economy starts at 4.36% inflation before the shock. The extra transfer spending and transitory negative supply shocks cause inflation to rise to 5.85% under standard MP and to 7.23% under the accommodating monetary policy rule. The negative supply shock is inflationary and the transfer spending, undertaken when debt/GDP is already high, increases the likelihood that the economy enters into the austerity region. In austerity, tax rates go up, discouraging labor supply, and increasing prices.

This surprise inflation from the alternative monetary policy rule causes a 0.34% point decrease in the debt service/GDP ratio after five years. The (market value of) debt/GDP ratio falls on impact, despite the expansion in the book value of debt required to finance the extra transfers. The reason is the powerful effect of surprise inflation which erodes the real value of the debt. The debt/GDP ratio falls by 1.4% points on impact under the alternative MP rule, despite the increase in transfers. Because of the rising debt service and the higher book value of debt, the debt/GDP ratio rises, and eventually exceeds the level it started at under the accommodating monetary policy rule. Comparing the red and blue lines in the bottom right panel shows that the central bank created about 1.8% points of GDP worth of fiscal capacity from the alternative MP rule. This exercise demonstrates that unanticipated "passive" monetary policy can lower the real value of government debt. It may help shed light on the high inflation rate in the U.S. in 2021-22 and its potential future evolution.

The key assumption in the previous exercise is that the change in the monetary policy rule is unanticipated and transitory; inflation expectations do not adjust. Our final exercise answers the question whether such an accommodating policy stance can systematically lower debt/GDP ratios. To this end, we solve the model with a new policy rule (30) replacing the standard Taylor rule (25) as part of the rational expectations equilibrium. We set an annualized coefficient $\phi^{\Delta} = -0.01$ and target debt/GDP of $\bar{\Delta} = 82.8\%$. Contrary to the intended effect, the economy in which monetary policy responds systematically to debt/GDP experiences higher debt/GDP ratios on average and spends 42% of simulation periods in austerity, compared to 32% in the baseline. This result suggests that the central bank cannot systematically depress debt/GDP through low rates and high inflation if agents expect such policy responses.

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. Unconventional Monetary Policy is a powerful policy in economic crises, when conventional monetary policy is stuck at the ZLB. It significantly reduces fiscal risk and leads to a smaller increase in the debt/GDP ratio during and after the crisis. UMP effectiveness is higher at lower levels of debt/GDP, and when enacted temporarily in response to an aggregate demand shortfall. Temporary QE affects the economy akin to a positive demand shock by shifting macroeconomic activity from investment to consumption. 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. Unexpectedly accommodating conventional monetary policy can also create fiscal capacity, as long as it does not change inflation expectations.

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Online Appendix

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 for any variable J_t real, stationary values as

$$\hat{J}_t = \frac{J_t}{Z_t^p P_t}.$$

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

$$\hat{J}_t = \frac{J_t}{Z_t^p}.$$

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.

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

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

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

subject to

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

where intra-period utility is

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

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.

In our numerical work, the constant $\bar{u}$ in the utility function may be required to ensure that utility $u^H(\hat{C}_t, N_t, \hat{D}_t^H)$ has the same sign everywhere in the feasible choice set. If $\varphi > 1$, i.e. if the IES < 1, then both utility from consumption and labor disutility are negative, and we can set $\bar{u} = 0$. This low IES case would require to transform the value function as described in Swanson (2018) to maintain a sensible definition of the certainty equivalent. If $\varphi < 1$ such that the IES > 1, which is the relevant case for our numerical experiments, then the consumption term is positive, the labor disutility term is negative, and a $\bar{u} > 0$ may be required to ensure that $u^H(\hat{C}_t, N_t, \hat{D}_t^H)$ is always positive. However, for any of the parameter combinations we consider in the paper this is not necessary. The consumption term dominates in magnitude.

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

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

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

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

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

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

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

$$V_{B,t}^{H} \equiv \frac{\partial V_t^H}{\partial \hat{B}_{t-1}^{H,L}} = \frac{\exp(-g_t)}{\pi_t}\left(c + 1 - \delta^B + \delta^B p_t^L\right),$$

$$V_{K,t}^{H} \equiv \frac{\partial V_t^H}{\partial_{t-1}^{H,K}} = \exp(-g_t)\left(r_t^K + (1-\delta)Q_t\right).$$

A.2.1 First-order conditions

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

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

Envelope Condition The envelope condition is

$$\frac{\partial V_t^H}{\partial \hat{W}_t^H} = \lambda_t = \frac{(1-\beta)(1-\psi)\left(C_t^{1-\psi}(D_t^H)^{\psi}\right)^{1-\varphi}}{C_t},$$

where the last equality uses the FOC for consumption to substitute for λ_t.

Stochastic Discount Factor The household's intertemporal marginal rate of substitution between time t and $t+1$ is given by

$$\begin{aligned}\frac{\frac{\partial V_t^H}{\partial C_{t+1}}}{\frac{\partial V_t^H}{\partial C_t}} &= \frac{\partial V_t^H}{\partial V_{t+1}^H}\exp(-g_{t+1})\frac{\partial V_{t+1}^H/\partial \hat{W}_{t+1}^H}{\partial V_t^H/\partial \hat{W}_t^H}\\ &= \beta\exp\left(-\gamma g_{t+1}\right)\left(\frac{V_{t+1}}{CE_t}\right)^{\frac{\varphi-\gamma}{1-\varphi}}\frac{\frac{1}{\hat{C}_{t+1}}(1-\beta)(1-\psi)\left(\hat{C}_{t+1}^{1-\psi}(\hat{D}_{t+1}^H)^{\psi}\right)^{1-\varphi}}{\frac{1}{\hat{C}_t}(1-\beta)(1-\psi)\left(\hat{C}_t^{1-\psi}(\hat{D}_t^H)^{\psi}\right)^{1-\varphi}},\end{aligned}$$

using the envelope condition. Hence, we can define the household stochastic discount factor (SDF) as

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

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

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

Computing the derivatives and simplifying yields

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

By using the definition of the SDF, we get

$$p_t^L = \Xi_t^L + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\left(\frac{c + 1 - \delta^B + \delta^B p_{t+1}^L}{\pi_{t+1}}\right)\right]. \tag{31}$$

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

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

Then using the definition of the intra-temporal marginal rate of substitution between deposits and consumption, and the SDF, we have that the FOC for deposits becomes

$$p_t^D = \mathrm{MRS}_t^D + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\frac{1}{\pi_{t,t+1}}\right]. \tag{32}$$

Capital The FOC for capital is

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

Again using the definition of the SDF the FOC becomes

$$Q_t = \Xi_t^K + \mathrm{E}_t\left[\mathcal{M}_{t,t+1}\left(r_{t+1}^K + (1-\delta)Q_{t+1}\right)\right]. \tag{33}$$

Investment 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

$$Q_t = 1 + \phi\left(\frac{\hat{I}_t}{\hat{K}_{t-1}} - \delta\right). \tag{34}$$

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 (31) – (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

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

and

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

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

$$\hat{W}^I_{t+1} = \exp(-g_{t+1}) \left[\left(r^K_{t+1} + (1-\delta)Q_{t+1}\right)\hat{X}^{I,K}_t + \frac{\hat{B}^{I,S}_t}{\pi_{t+1}} - \frac{\hat{D}^I_t}{\pi_{t+1}}\right].$$

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

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

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

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

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

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

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

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

we can write the first order condition for deposits as

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

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

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

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

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

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

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

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

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

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

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

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:

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

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 Final Goods Producers

Final output is

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

where ϵ is the elasticity of substitution.

Final goods producers maximize profit by solving

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

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

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

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

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

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

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

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 Appendix A.6.2, and the second is simply the log of detrended output.

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

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, respectively, 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 in Appendix A.6.2. 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

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

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

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

Passive fiscal policy When the fiscal authority targets the level $\hat{\vec{W}}_t^G$ 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 $\hat{\tilde{W}}_t^G$ from (44). Check whether desired issuance under active policy is within profligacy and austerity bounds:*

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

3. *If target issuance equals desired active issuance $\hat{\vec{W}}_t^G = \tilde{\hat{W}}_t^G$, 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 $\hat{\vec{W}}_t^G$ given by (45) (i.e., solve for the tax rate needed to achieve surplus $\hat{\vec{S}}_t^G$ 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 may be no feasible tax rate to achieve the target surplus. In our numerical work, we choose values that guarantee stationarity and imply 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

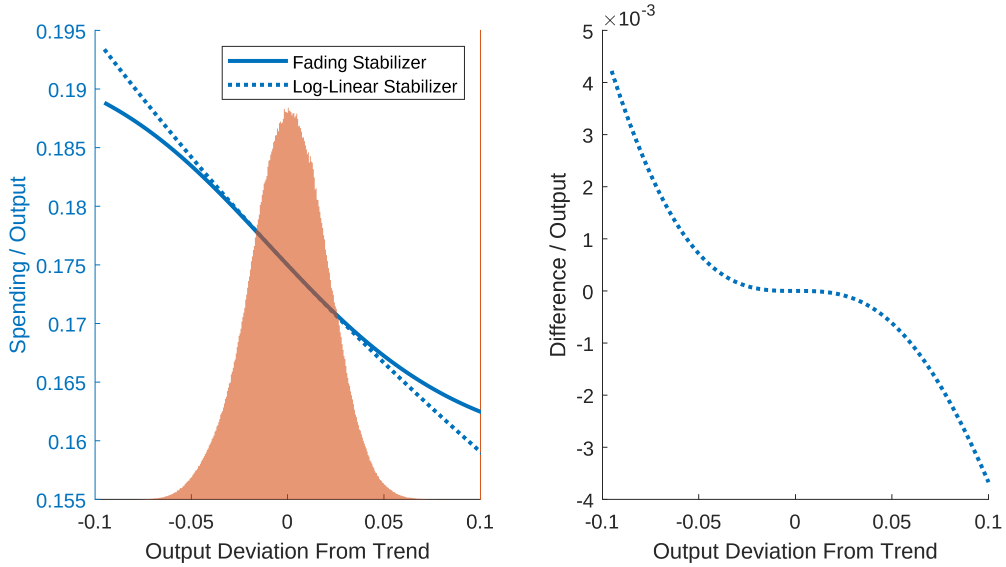
$$\tilde{W}_{t+1}^G = \frac{\exp(-g_{t+1})}{\pi_{t+1}} \left((\tilde{B}_t^{G,S} - \tilde{B}_t^{CB,S}) + (\tilde{B}_t^{G,L} - \tilde{B}_t^{CB,L})(c + 1 + \delta^B + \delta^B p_{t+1}^L) \right).$$

A.6.2 Fading Spending Rule

Figure A.1 illustrates the cyclical rule for discretionary spending. The gap between the linear and fading spending rules in Figure A.1 is calibrated such that the fading aspect has no effects given the cyclical fluctuations caused by productivity shocks.

However, when large shocks such as our main crisis experiment in Section 4.1 occur, the fading rule prevents an unrealistically large rise in discretionary government spending.

Figure A.1: Government Spending Rule



A.7 Market Clearing

The markets for short-term bonds, long-term bonds, deposits, labor, capital, investment goods, and final goods must clear:

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

B 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 4,000,000 periods (quarters) in total, consisting of 400 simulation runs of 10,000 periods each (with a 3,000 period burn-in).[26] While these parameters are chosen simultaneously to match all targeted moments, Tables B.1 and B.2 list for each parameter the specific moment that is most affected by this parameter.

Whenever possible, we compute calibration targets based on aggregate data for the 1953-2020 period, since many NIPA and Flow of Funds data series start becoming available then. For two time series, real consumption growth and the real interest rate, we use a longer sample that starts in 1920. These moments are critical to calibrate the amount of risk and the level of interest rates in the model, which in turn are key parameters for the stationary distribution of government debt.

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 $\sigma_g = 1.2\%$. T The volatility of this process is chosen to match the volatility of real consumption growth for the U.S. for the period 1920-2017, based on the macrofinancial database by Jorda, Schularick and Taylor (2016). 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. We choose the persistence of this process to match the persistence of real output growth for the 1953-2020 period, which is the sample period we use for most aggregate moments. 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 D.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 120 and targets the volatility of the labor share, as the degree of price stickiness governs markups over marginal costs of production.

---

[26] See Appendix E for details on the solution method and simulation approach.

Table B.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 (1953-2020 NIPA)	0.132	0.16
σ_g	innovation vol. perm. TFP	1.2	Vol. real consumption growth (1920-2017, Jorda et al. (2016))	1.51%	1.73%
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%	0.78%
δ	capital depreciation rate	0.02	investment-to-GDP ratio (53-20)	17.94%	15.91%
ξ	Rotemberg adjustment cost	120	Vol. labor share (53-20)	2.10%	1.83%
ϵ	Intermediate goods elast.	7	Marginal cost/Revenue (van Vlokhoven (2020))	0.85	0.85
Preferences and Household Sector					
β	discount rate	0.9915	real risk free rate (1920-2017, Jorda et al. (2016))	0.42%	0.41%
γ	risk aversion	25	Unlevered RP on GDP claim	1.00%	0.97%
φ	1/IES	0.7	Vol. consumption-to-GDP ratio (53-20)	0.76%	0.79%
ψ	liquidity utility	0.032	Liquidity Premium (Van Binsbergen et al. (2021))	0.10%	0.062%
ω_0	disutility of labor	3.051	normalize $\mathrm{E}[Y] = 1$	-	-
ω_1	inverse of Frisch elasticity	2	standard value	-	-
ξ_0^L	portfolio cost bonds	0.0044	Term spread (53-20)	0.36%	0.32%
ξ_1^L	portfolio cost bonds, elast.	1.3	Term spread vol. (53-20)	0.29%	0.29%
ξ_0^K	portfolio cost capital	0.003	Bank capital share (He and Krishnamurthy (2019))	0.60	0.62
Intermediaries					
ϱ_0	liquidity cost level	0.12	FFR-time deposit spread (Drechsler et al. (2017), 94-14)	0.32%	0.44%
ζ_ϱ	deposit run-off rate	0.05	BIS (2013)	-	-
τ	dividend target	0.08	bank leverage	92%	91.18%
χ	equity issuance cost	25	bank net payout rate	5.7%	7.82%

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 regulation on total leverage. The additional risk weight on capital $\nu_K = 0.9588 = \frac{1-\tilde{\nu}_K}{\nu}$, 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%. This takes a broad view of intermediaries to include depository institutions, government-sponsored enterprises, hedge funds, and some types of insurers (see Elenev et al., 2021, for details). 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 25 and targets the unlevered risk premium on the GDP claim of 1% per quarter. The Arrow-Pratt measure of relative risk aversion is not equal to 25 since households supply labor elastically.(Swanson, 2018) The average Arrow-Pratt measure of risk aversion in simulation is 3.1 (see Appendix E.3).

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 $\beta = 0.9915$ targets the average quarterly real rate of 0.42%, based on the 1920-2017 sample from Jorda et al. (2016).

The coefficient on the disutility of labor, ω_0, is set to 3.051 to normalize the unconditional mean of output to 1. 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.

The Frisch elasticity of labor supply is set to 0.5, implying an exponent $\omega_1 = 2$.

Finally, households' utility benefit from holding deposits, ψ is set to 0.032 to target a quarterly convenience yield in short-term government debt of 0.1% following Van Binsbergen, Diamond and Grotteria (2021). In the model, we compute this convenience yield as the difference between the short-term nominal interest rate and the yield on a hypothetical short-term bond that does not confer any liquidity benefits. The price of this asset is simply the inverse expectation of the households SDF, $\mathrm{E}_t[\mathcal{M}_{t,t+1}]^{-1}$.

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 $\xi_0^L = 0.0044$ and elasticity $\xi_1^L = 1.3$. 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 $\xi_0^K = 0.003$.

Government Parameters Our fiscal policy rules are calibrated to match the unconditional average and cyclical properties of transfer spending, discretionary spending, and tax revenue. 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. This rule prevents a counter-factually large increase in discretionary spending in response to large shocks; Appendix A.6.2 contains details.

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 $b_\tau = 0.7$ 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 17.5% to target the observed average spending to GDP of 16.40% 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 $b_\theta = -9$, 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. The model regressions allow for a different slope in profligacy and austerity.

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 0.97. (If y is the target annual yield of the long-term bond, and d is the targeted duration in years, then the duration parameter δ^B is implied by the formula $d = 0.25/(1 - \delta^B \exp(-y/4))$.)

Table B.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%	3.39%
τ_0^w	base lab. tax rate	25.5	BEA personal tax to GDP (53-20)	16.39%	15.86%
γ_0	average spending/GDP	17.5	BEA govt. spending to GDP (53-20)	16.40%	17.51%
θ_0	average transfers/GDP	3.4	BEA govt. transfers to GDP (53-20)	3.45%	3.49%
b_τ	tax cyclicality	0.7	regr. slope tax revenue/GDP on GDP growth (53-20)	0.32	0.26
b_γ	spending cyclicality	-1	regr. slope spending/GDP on GDP growth (53-20)	-0.86	-0.54
b_θ	transfer cyclicality	-9	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%	66.84%
δ^B	duration of long-term debt	0.97	Duration (years) LT treasuries (00-20)	7.76	7.60
c	long-term debt fixed coupon	0.01207	Normalization $\mathrm{E}[p^L] = 1$	–	–
$\underline{W}^G$	Profligacy threshold	1.9	See Section 3.2	-	-
$\overline{W}^G$	Austerity threshold	4.6	See Section 3.2	-	-
v	Tax adjustment coefficient	0.85	See Section 3.2	-	-
			Government: Monetary Policy Rule		
$\bar{\Pi}$	inflation target	1.005	Fed inflation target (2% p.a.)	-	-
ϕ^Π	Weight on inflation	1.6	Vol. of deviations from infl. target (core PCE)	0.34%	0.41%
ϕ^Y	weight on output	0.125	standard value	-	-
$\bar{p}^S$	natural interest rate	0.9918	normalization	-	-
			Government: Financial Regulation		
ν	max. intermediary leverage	0.97	Basel regulation	-	-
ν_K	add. risk weight on capital	0.9588	Basel regulation	-	-

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 1.6, targeting the volatility of inflation in the model to the volatility of deviations from the inflation target in the data, using the 2% inflation target and the core PCE price index. We choose deviations from the inflation target as data measure, since raw inflation volatility in the data is largely driven by low frequency movements in the inflation target, whereas the target is constant in the model. The coefficient on output, ϕ^{y}, is set to 0.125, which is a standard value in the literature. Qualitatively, results would be unchanged if we set this coefficient to zero. The inflation target $\bar{\Pi} = 1.005$ is set to target average inflation of 2% per year.

C 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 C.1: 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

D Fiscal Policy Properties

D.1 Taxes and Debt

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 D.1 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 coefficient for the surplus qualitatively (columns (4), (5), and (6)). As in the data, the cyclical responses of spending and tax revenue drive the correlations in the model (see also Section D.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. For tax revenue, growth in debt/gdp is associated with an increase in tax revenues in the austerity regime, as expected from the alternative fiscal regime in these regions of the state space. 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.

D.2 Cyclical Properties of Fiscal Policy and Fiscal Risk Premia

As pointed out by Jiang et al. (2019), the intertemporal government budget constraints implies that investors who invest in the entire government bond portfolio hold a claim that entitles them to future primary surpluses. 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, in our model, arises from incomplete markets between households and intermediaries, as well as frictions associated with holding government debt such as liquidity benefits for intermediaries from holding short-term debt and portfolio costs for households from holding long-term debt.

$$\tilde{W}_t^G = \sum_{h=1}^{\infty} \mathcal{M}_{t,t+h} T_{t+h} - \sum_{h=1}^{\infty} \mathcal{M}_{t,t+h} F_{t+h} + \mathcal{E}_t. \tag{46}$$

Understanding government fiscal capacity requires understanding the size and the riskiness of tax revenues $\{T\}$ and spending $\{G\}$. In the short run, fiscal policy provides insurance to taxpayers. When output is below trend, tax rates decline and government discretionary and transfer spending rise, as governed by the policy rule coefficients b_τ, b_γ, and b_θ. The cyclicality of fiscal policies provides insurance to taxpayers at business-cycle frequencies and, by the same token, creates risk that must be born by bondholders.

Table D.1: 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	-0.074^{***}	-0.317^{***}	0.028^{***}	-0.066^{***}	-0.024^{***}	-0.104^{***}
	(0.012)	(0.033)	(0.001)	(0.001)	(0.0004)	(0.001)
Prof.					-0.0004^{***}	-0.002^{***}
					(0.00001)	(0.00003)
Aus.					0.001^{***}	0.003^{***}
					(0.00003)	(0.0001)
Δ Debt/GDP × Prof.					0.066^{***}	0.015^{***}
					(0.0004)	(0.001)
Δ Debt/GDP × Aus.					0.083^{***}	0.065^{***}
					(0.0004)	(0.001)
Observations	275	275	3,999,600	3,999,600	3,999,600	3,999,600
R^2	0.118	0.253	0.135	0.146	0.405	0.191

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 240 different simulated sample paths of 10,000 quarters each. We include a fixed effect for, and cluster standard errors by, simulation run.

But to make government debt risk-free, fiscal policy cannot provide this insurance in the long run (Jiang et al., 2020). To illustrate 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 D.1. 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 when GDP goes up – and the spending claim has a negative beta. But as the horizon increases, the spending beta turns positive and 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. The lower GDP-beta of the tax revenue stream at intermediate horizons arises from simulation episodes where the model is in (or close to) the austerity regime, in which taxes rise even when output falls.

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.

To quantify how the risk on tax and spending claims varies by horizon, we compute the risk premium on claims to h-period ahead taxes and spending. 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:

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

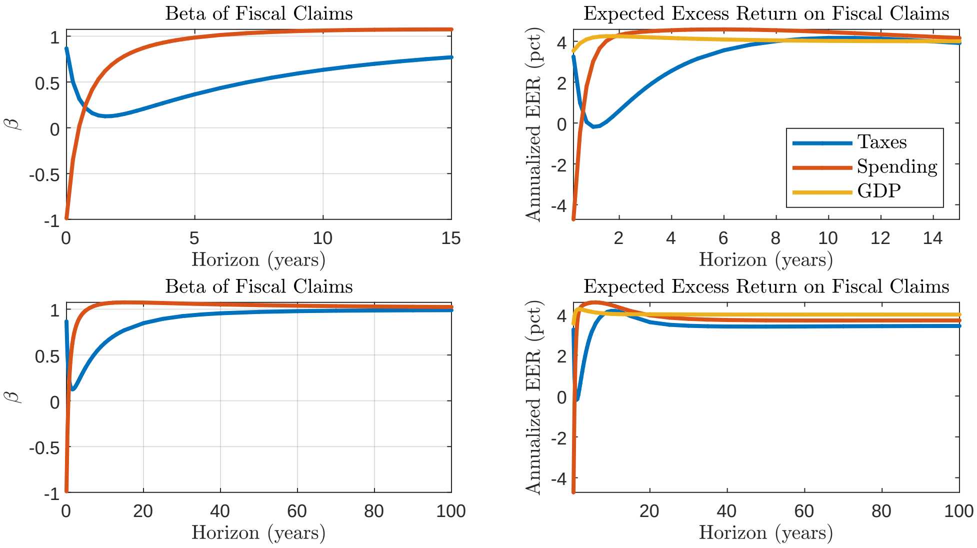
The right panels of Figure D.1 plot the risk premia for h-quarter ahead tax and spending strips, and plot them along side the risk premium on claims to h-quarter ahead GDP.

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 GDP (unlevered equity) risk premium of about 4% per year.

Over short horizons, the surplus claim 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 low. Put differently, at business cycle frequency, bondholders are providing insurance to taxpayers, who are short the tax claim. At very long horizons, tax, spending, and GDP claims are all equally risky by virtue of cointegration.

To keep government debt risk-free, these premia must reverse at intermediate horizons. That is, the return to the long taxes, short spending portfolio must become a hedge at intermediate 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 et al. (2020), keeping the debt safe constrains the amount of taxpayer insurance that can be provided and the horizon over which it can be provided.

Figure D.1: Fiscal Risk and Cyclicality of Fiscal Policies



D.3 Convenience Yields and the Quantity of Debt

The convenience yield is defined as the difference in the yields of a truly risk-free asset and a government bond. For the short-term bond:

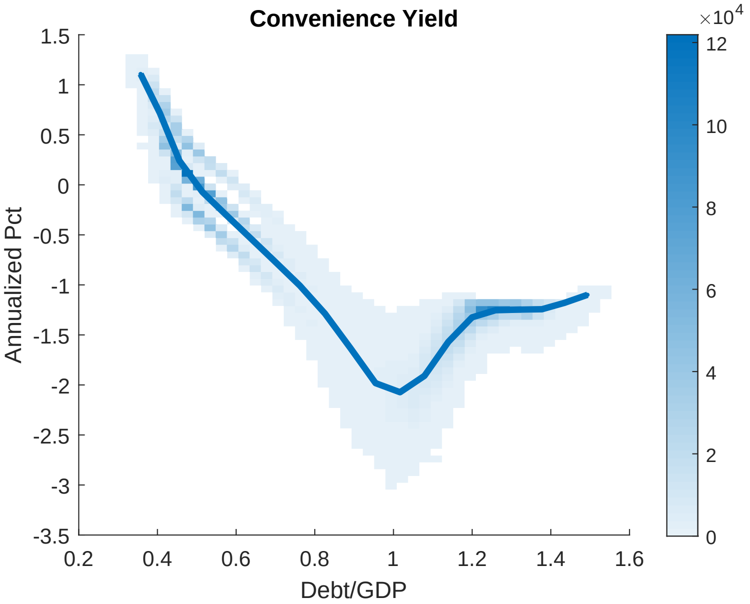
$$CY_t = \mathrm{E}_t[\mathcal{M}_{t,t+1}]^{-1} - (p_t^S)^{-1}$$

For the long-term bond, the convenience yield is the difference between a duration-matched pure discount bond an the yield on the long-term bond $(p_t^L)^{-1}$.

Figure D.2 plots the annual convenience yield on the government debt portfolio, computed as the value-weighted average of the CY of the short- and long-term bonds, against the debt/GDP ratio. It is based on a long simulation of the model. 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 convenience yield and debt supply. We recall that long-term bonds have on average a positive holding cost, which lowers their price, and increases their yield, enabling the model to generate an upward-sloping term structure. This holding cost explains why the convenience yield on long-term bonds is on average negative in the model.

Quantitatively, the model matches the elasticity of the convenience yield to the debt/GDP ratio of -0.017 estimated by Vissing-Jorgensen and Krishnamurthy (2012). The latter implies a 17 basis point reduction in convenience yield for a 10% point increase in the debt/GDP ratio. The elasticity in our model falls in the middle of the [-0.008,-0.025] range of elasticity estimates surveyed by Mian et al. (2021).

Figure D.2: Convenience Yields and Debt/GDP



E Computational Methods

E.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 7.3% 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 our unanticipated policy experiments. We do update ω_0 when computing the Debt/GDP distribution in an alternative economy in which monetary policy responds to Debt/GDP.

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 $N = 400$, $T_{\text{ini}} = 3,000$ and $T = 10,000$.

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. Augment the discretized exogenous states in the model solution with zero-probability states representing unanticipated shocks and policy responses (e.g. QE) and solve policy and transition functions at those states, keeping ω_0 fixed at its final value.

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.

E.2 Finding the Maximum Feasible Austerity Threshold

We define Debt/GDP to be numerically non-stationary if for any upper bound of the Debt/GDP grid there exists at least one period in a series of long simulations in which Debt/GDP transitions to a point at or above the upper bound i.e. violates the grid bounds.

When austerity threshold $\overline{W}^G$ is set to values above the current one, the simulation indeed hits the upper bound of the W^G grid for all feasible levels of the upper bound. To determine $\overline{W}^G$, we hold other parameters fixed and lower $\overline{W}^G$ from a non-stationary level in small increments. For each candidate value of $\overline{W}^G$, we obtain model solutions for many W^G grids differing in the upper bound. We stop this process once at least one solution produces a simulation for which W^G never hits the upper bound of the grid.

This procedure relies on the sample max being a good estimate for the population max. Within a given simulation path, Debt/GDP is highly persistent, so we simulate $N = 400$ such paths with length $T = 10,000$ each. The maximum W^G value of each run gives us an empirical distribution of the maxima. If this entire distribution lies below the upper grid bound, we can conclude with near-one probability that the population max does as well and government debt is therefore "safe" in a stochastic sense.

E.3 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, we find that the Arrow-Pratt measure of risk aversion at point x_t in the state space can be written as

$$RRA(x_t) = -\frac{\mathrm{E}_t[(V(x_{t+1}))^{-\alpha} V_{WW}(x_{t+1}) - \alpha (V(x_{t+1}))^{-\alpha-1} V_W^2]}{\mathrm{E}_t[(V(x_{t+1}))^{-\alpha} V_W(x_{t+1})]} W(x_t) \tag{47}$$

where $\alpha = \frac{\gamma-\varphi}{1-\varphi}$, 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,

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

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

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

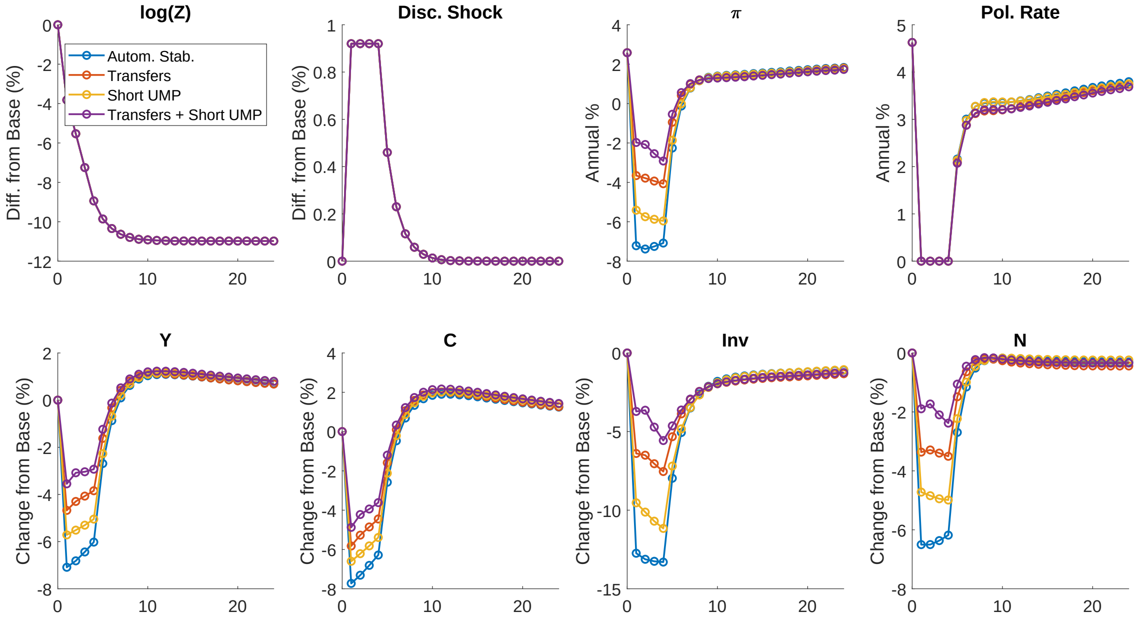
and compute $RRA(x)$ from (47) at every point in a long simulation using numerical solutions for $C(x), W(x)$ and $V(x)$. We find that for $\gamma = 25$, relative risk aversion always lies between 2.5 and 3.8, with the average value being 3.1.

F Additional Quantitative Results

F.1 Decomposition: Transfer Spending and UMP

The "Transfer + Long UMP" combo policy involves a large increase in transfer spending of 7.4% of GDP, calibrated to match the 10% primary deficit in 2009. In this appendix, we discuss the effects of stand-along transfer spending and UMP relative to the automatic stabilizer scenario. Furthermore, we want to isolate the impact of a long policy duration for UMP 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 shocks that triggers the crisis: four quarters, followed by mean reversion with probability 0.5 each quarter thereafter. The size of the UMP policy is the same as in the main experiment. We label this policy "Short UMP".

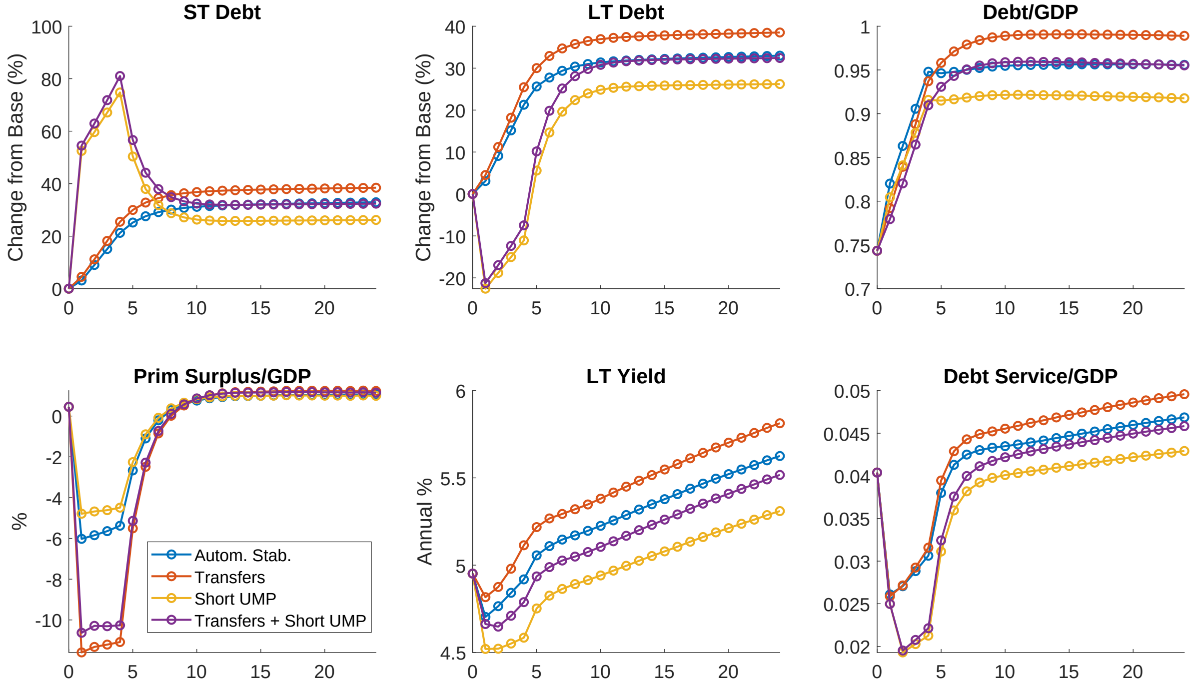
Figure F.1: UMP: Macro Variables



Figures F.1 and F.2 show the effects of Short UMP (yellow) and increased transfer spending (red) on their own, as well as their combination (purple) for the main macro and fiscal variables. With respect to macroeconomic aggregates, higher transfers account for roughly 2/3 of the total effect of the combo "Transfers + Short UMP": it shrinks the drop in GDP by about 2% points, with the combo policy cutting the 6% decline in GDP (4 quarters after the shock) in the automatic stabilizer scenario down to 4%. The same division applies to consumption, investment, employment, and inflation.

Figure F.2, however, clarifies that UMP and increased transfers have substantially different fiscal price tags. Ceteris paribus, implementing UMP leaves the book value of total government debt unchanged. Since it stimulates aggregate demand, the positive general equilibrium effect of UMP *reduces* the primary deficit from 5.8% (automatic stabilizer) to 4.9%. Higher transfer spending, on the other hand, achieves twice the GE stimulus to aggregate demand, but causes a increase in the deficit to over 11%. In sum, UMP achieves output stabilization at no fiscal cost, while the output multiplier of transfer spending is below one. 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

Figure F.2: UMP: Fiscal Variables



than the “Autom Stab” policy. Five years after the start of the crisis, the debt/GDP ratio is 3.7% points lower due to short-lived UMP (purple versus red line).

F.2 QE in Normal Times

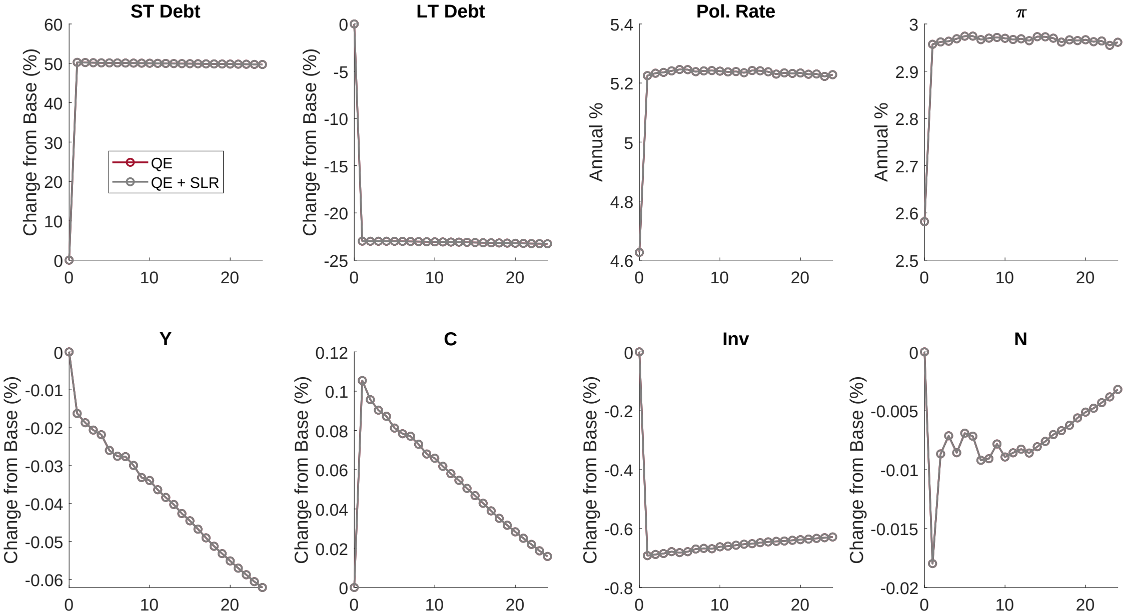
The main text focuses the discussion on QE policies enacted in response to a crisis, a combination of negative demand and productivity shocks. Here, we study QE policies enacted in normal times.

F.2.1 Permanent QE in Normal Times

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 23.7% 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 4.08 years before the policy change to 3.19 years under permanent QE.

Figure F.3 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

Figure F.3: Permanent QE: Macro Variables



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

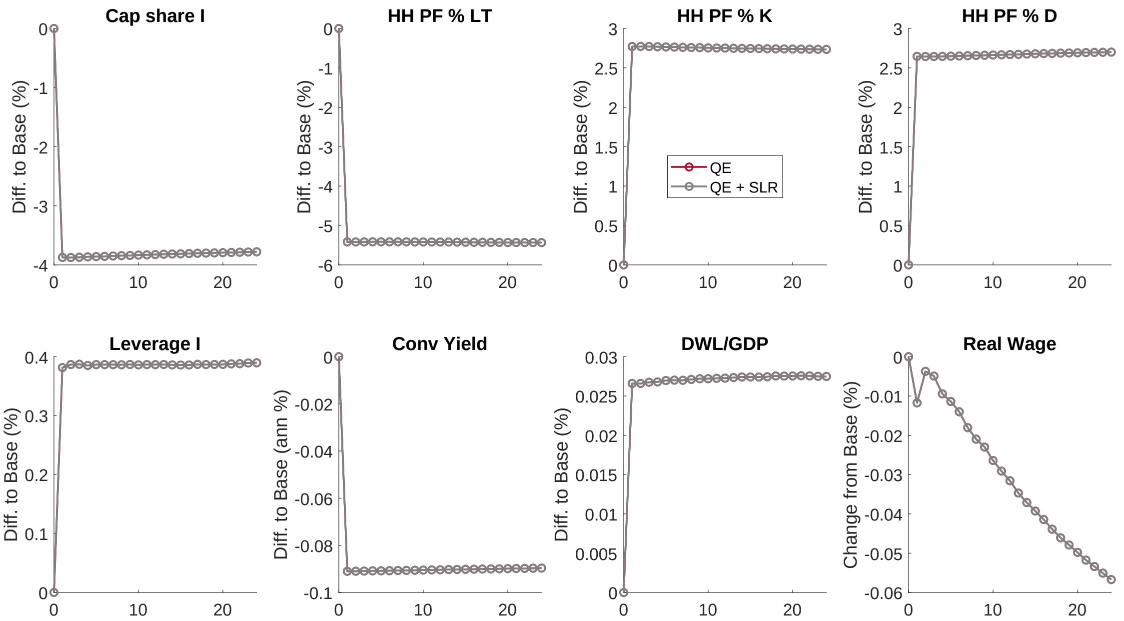
these transitions (the grey line which includes QE and SLR exemption policies almost perfectly covers the maroon line, which includes only QE); unlike for the main experiment with QE implemented during a crisis, the SLR constraint is not binding in normal times. Therefore, its relaxation has very little 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 F.3 we can see that permanent QE causes a transition to an economy with about 0.06% lower output (relative to trend) and investment. This transition to a permanently smaller capital stock leads to a small 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 F.4 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 F.3), 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 nearly 4% points (top left panel of Figure F.4).

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 0.4% points. Deposits are less scarce and thus convenience yields on deposits decline by 9bp. As households must absorb extra capital,

Figure F.4: Permanent QE: Financial Variables



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

their holding costs increase, causing slightly higher DWL/GDP.

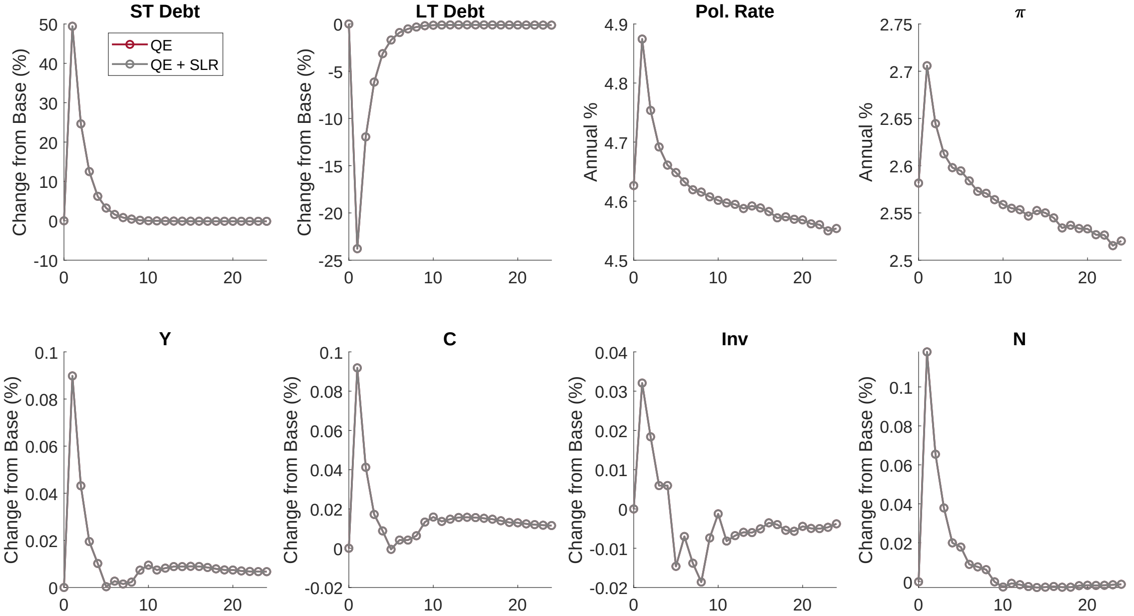
Aggregate welfare on impact of the policy change remains approximately unchanged despite the decline in output. Greater permanent liquidity provision by the central bank causes an increase in household utility from greater deposit supply that compensates for the long-run decline in consumption. Hence the initial maturity structure pre-QE is close to optimal.

F.2.2 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 F.5 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 11bp and output by 9bp. The simultaneous rise in inflation, output, consumption and hours reveal that short-run QE triggers a positive aggregate demand shock.

Figure F.5: Temporary QE: Macro Variables



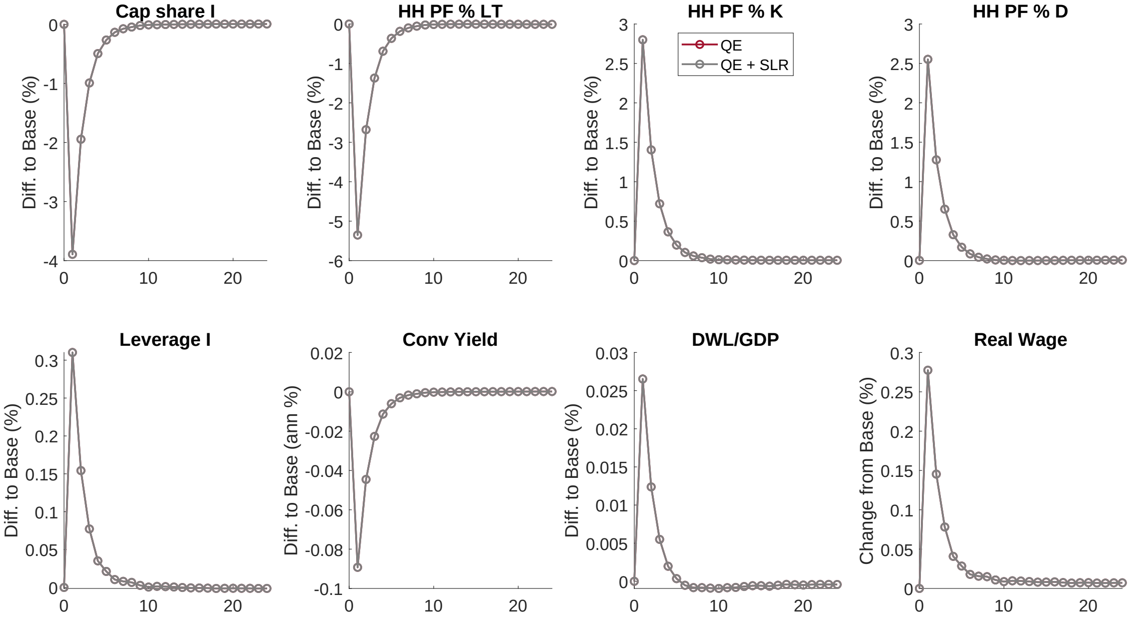
Response of economy to temporary QE in normal times. Policy parameters are identical to main policy experiment.

Figure F.6 mirrors the effects of the permanent QE transition in Figure F.4, just with temporary duration. As the central bank sharply increases reserve supply, intermediaries increase the 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 F.6, which shows that real wages rise by 0.25% 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.

Figure F.6: Temporary QE: Financial Variables



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

F.3 Robustness

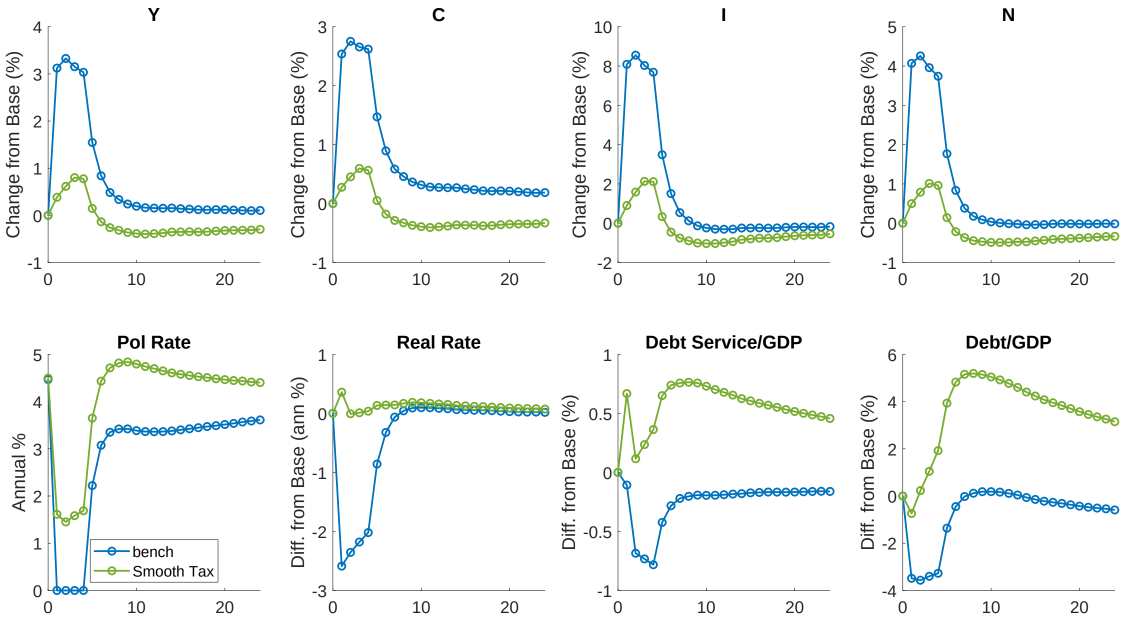
F.3.1 Smooth Tax Rule

A key innovation of our setup relative to the literature is the global regime switching approach for fiscal policy. To illustrate its importance, we study the same policy change from "Autom. Stab" to "Long UMP+Transfers" 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. This is in contrast with our benchmark model, where fiscal policy is only passive in the austerity and profligacy regions.

The blue line in Figure F.7 shows the difference between the "Long UMP+Transfers" and the "Autom. Stab" policies in the benchmark model. The green line shows the same policy difference for the model with the linear tax rule. This "Smooth Tax" economy differs from the benchmark calibration in only two ways: (i) the different tax rule, and (ii) recalibrated parameters for discount factor β and bond holding cost ξ_0^L to match average real rate and term spread given the different tax rule. A comparison of these two lines shows that the smooth-fiscal-rule model substantially understates the effectiveness of the "Transfers+Long UMP" policy on macro aggregates in response to crises (top row). The effect of the policy on fiscal outcomes such as debt/gdp and debt service/gdp is also substantially different across the two models, and even has the wrong sign in the linear tax rule model (bottom row). This is in part due to the much weaker GE effects on output in the linear tax rule model. These results underscore the importance of modeling a more realistic fiscal policy process.

Different policy effectiveness is not the only difference to our baseline model. The smooth-tax economy also generates fundamentally different ergodic distributions of the model's endogenous state variables, which in turn affects most other model outcomes. These differences are shown in Figure F.8;

Figure F.7: Robustness: Smooth Tax Policy Rule



most notably, the top left histogram plot shows that the smooth-tax model produces a much narrower distribution of debt/GDP.

F.3.2 Lower Risk Aversion

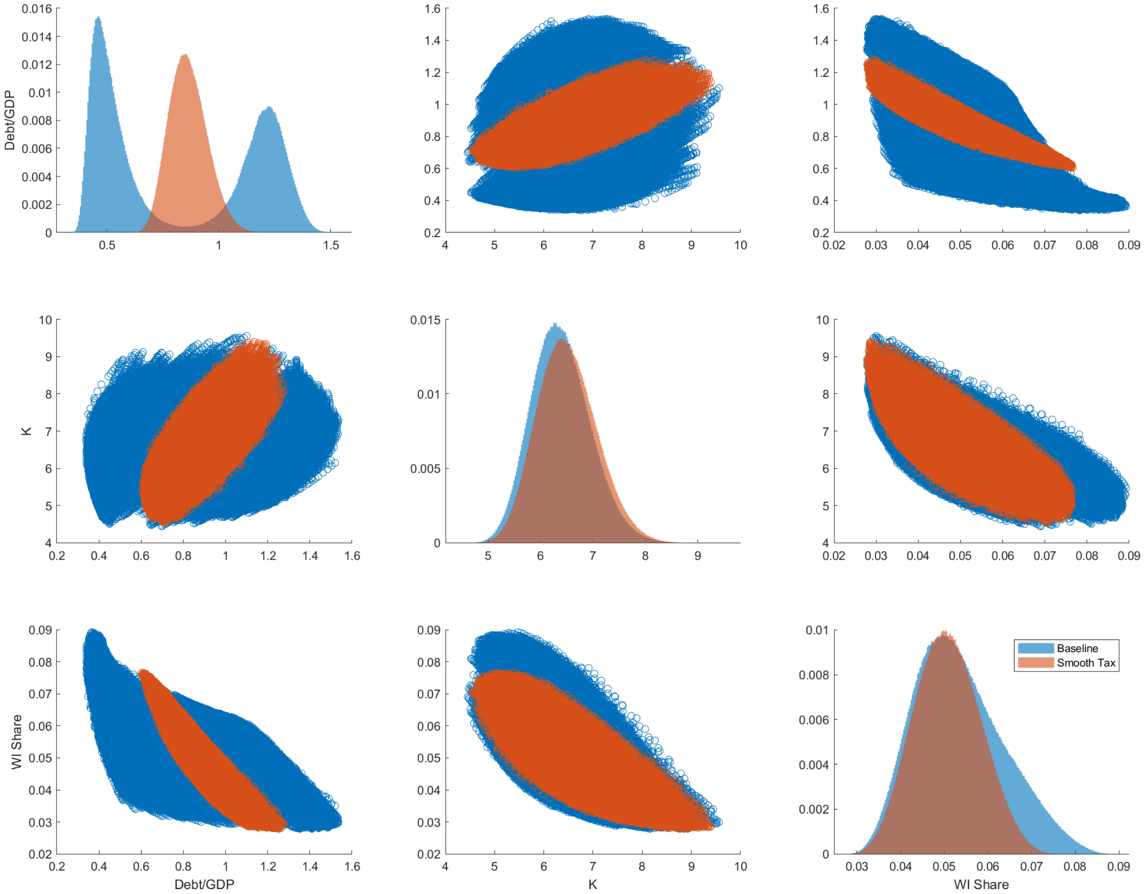
A second key modeling contribution is to generate realistic risk premia in the model. We now show that lowering risk aversion has important implications for the main conclusions regarding the policy effectiveness of the "Long UMP+transfers" in response to a crisis. Specifically, we lower the utility curvature parameter from $\gamma = 25$ to $\gamma = 2$. In the latter model, the output risk premium in excess of the short-term bond yield (in excess of the true risk-free rate) is 0.52% (-0.12%) per year, while in the benchmark economy it is 3.96% (3.70%) per year. As noted in the introduction, low risk premia are a property of the standard New Keynesian model.

To make the models with high and low risk aversion more comparable, we recalibrate the rate of time preference β and the holding cost parameter for long-term bonds ξ_0^L so as to continue matching the observed mean risk-free rate and the mean term spread. All other parameters are kept at their benchmark values.

Even so, the ergodic distributions of the three continuous state variables are quite different in the model with low risk aversion and in the benchmark. Figure F.9 shows the histograms of the state variables on the diagonal, and the bi-variate joint distributions of the various pairs of state variables in the off-diagonal panels. For example, the debt/GDP distribution in the low-γ economy is narrower and shifted to the right from the one in the benchmark model. Since interest rates and the SDF are less volatile in the low-γ economy, interest rates fall by less in high-deficit states. This makes it harder for the government to repay its debt in the low-γ economy.

We then let the low-γ economy undergo the same crisis as the benchmark economy, starting both economies in their respective ergodic means of the state variables. Figure F.10 compares policy

Figure F.8: Ergodic Distribution Of State Variables With Smooth Tax Rule



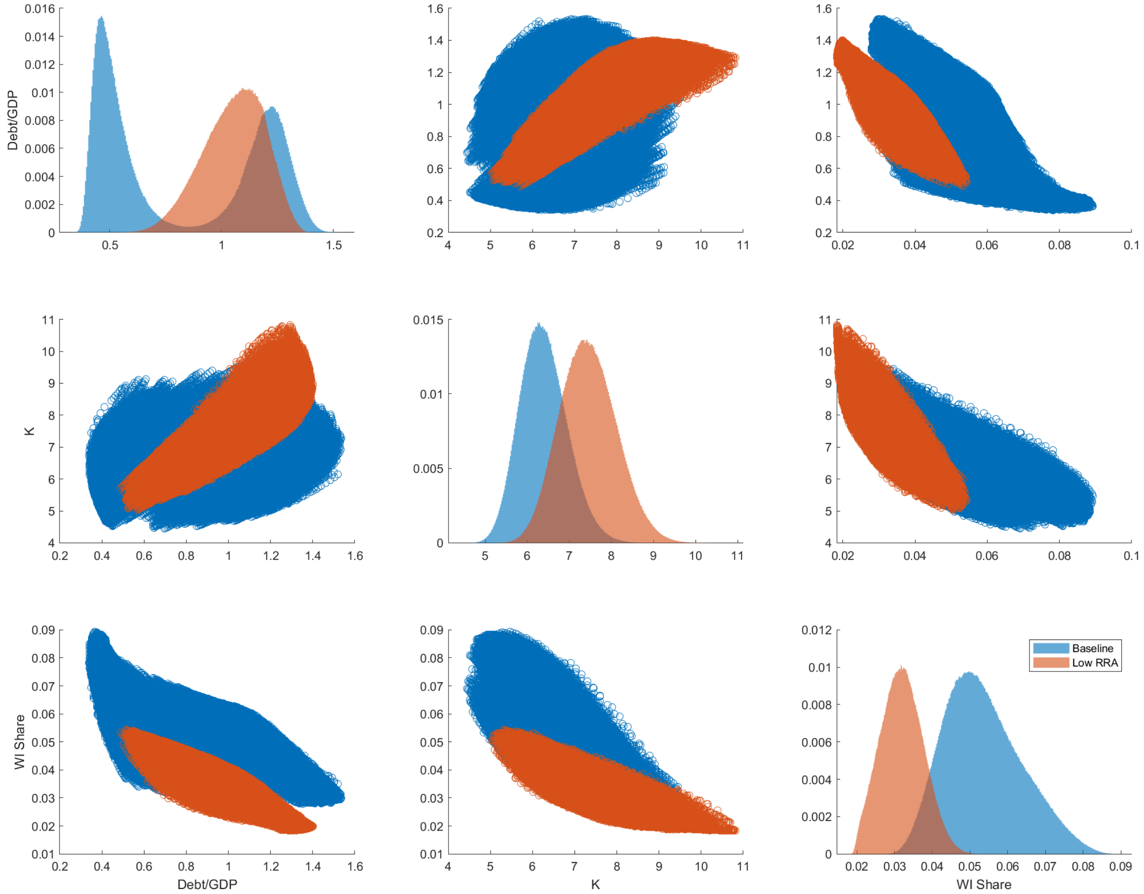
effectiveness in the two economies, where each line is itself the difference between the crisis response under the "Long UMP+Transfers" and the "Autom. Stab." policies.

The policy effectiveness is very different in the low-γ economy than in the benchmark economy. UMP and Transfers are not nearly as effective at stimulating the economy and the effect on the debt/GDP and debt service/GDP ratios has the opposite sign in the low-γ economy as in the benchmark.

One important reason is that in the low-γ economy, the economy is more likely to transition into the austerity region, and in that region of high debt/GDP, policy is less effective, as discussed in the main text. Another important reason is that the GE effects on output are much weaker so that the extra transfer spending ends up adding to the debt without much demand stimulus.

Figure F.11 verifies that if we start off the crisis response from the same triplet of state variable values (at the intersection of their joint distributions plotted in Figure F.9: Debt/GDP of 85%, K of 7, and WI Share of 4%) in the low-γ and in the benchmark economies, the policy effectiveness graph looks very similar to the previous one in Figure F.10. Our conclusions are not driven by a different pre-crisis starting point in the two economies. Furthermore, Figure F.12 compares the distribution of transition paths from this same starting point given the same policies. The paths for the benchmark economy in panel (a) look similar to Figure 8, with only small differences caused by slightly different

Figure F.9: Ergodic Distribution Of State Variables With Low RRA



initial values for capital and intermediary wealth before the onset of the crisis. In the presence of extra transfer spending, UMP reduces the probability of entering into austerity substantially by 21% points. This is not the case in the low-γ model, as shown in panel (b). Transfers more than double austerity risk, and adding UMP only slightly reduces this probability. Like in the benchmark model, UMP crowds out investment. However, unlike in the benchmark model, UMP in the low-γ economy fails to trigger a significant positive aggregate demand response.

In sum, having a realistic output risk premium has quantitatively important effects for the effectiveness of unconventional monetary policy and transfer spending in response to a crisis, and even creates some qualitatively different policy responses.

Figure F.10: Robustness: Low Risk Aversion

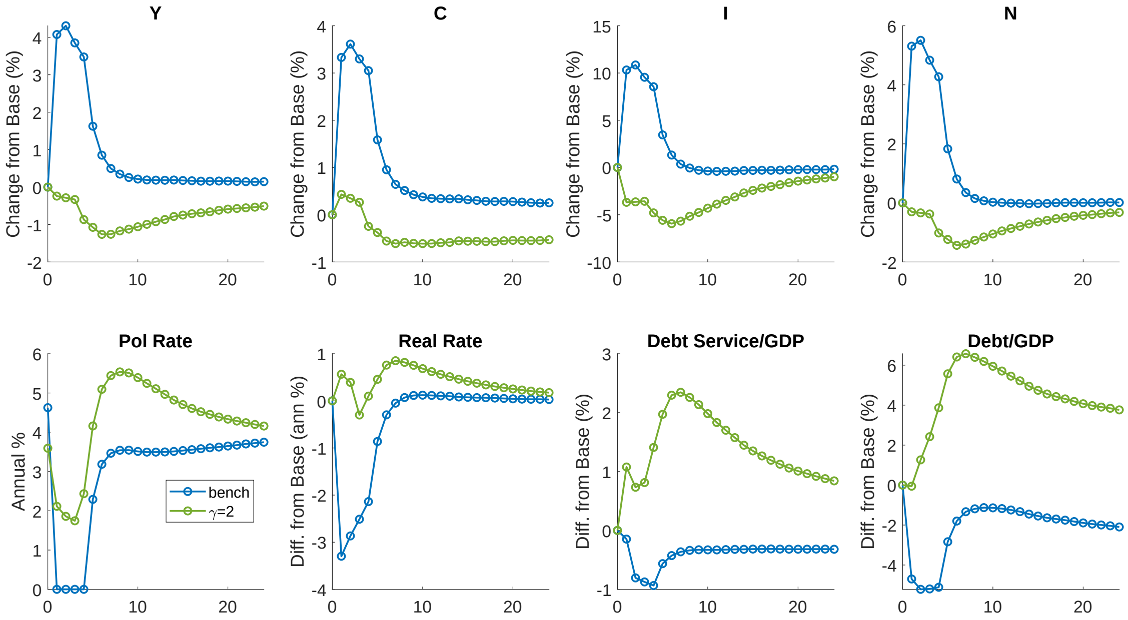


Figure F.11: Robustness: Low Risk Aversion from Same Starting Point

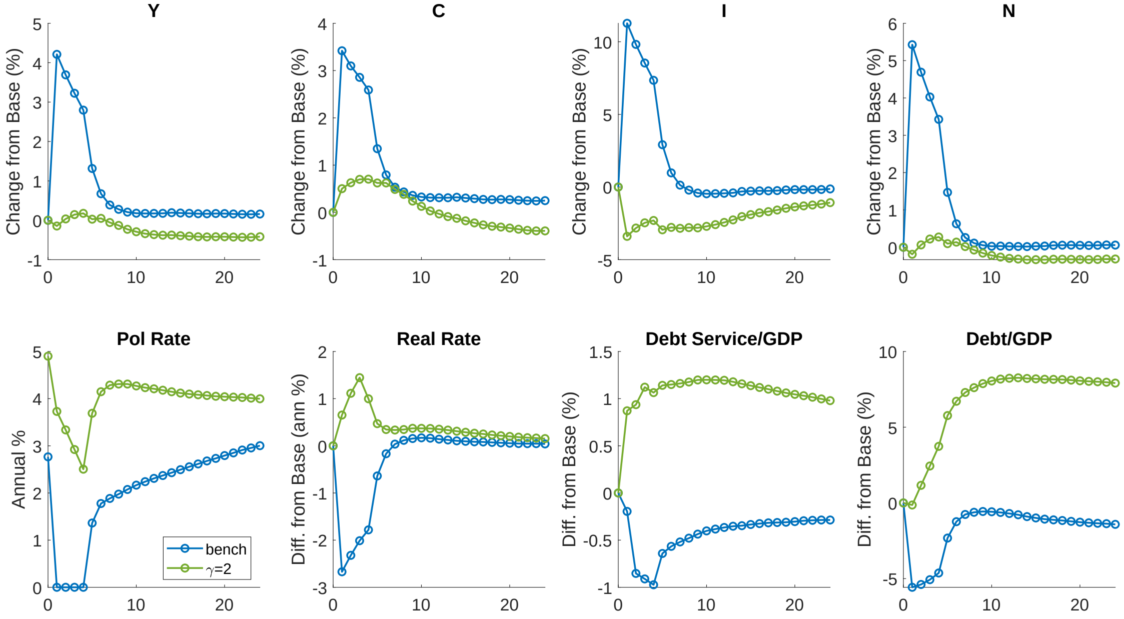
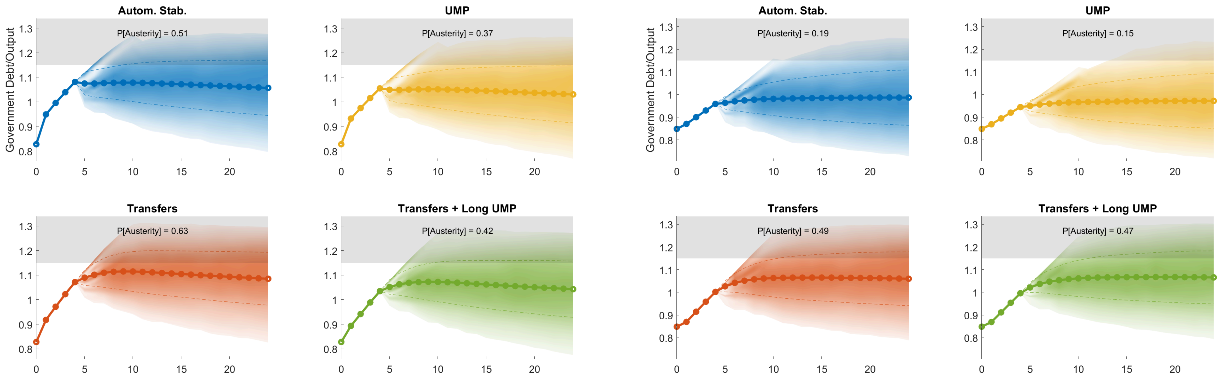


Figure F.12: Austerity Probability from Same Starting Point



(a) Bench

(b) Low Risk Aversion