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Discount Rates, Debt Maturity, and the Fiscal Theory

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ABSTRACT

This paper examines how the transmission of government portfolio risk arising from maturity operations depends on the stance of monetary/fiscal policy. Accounting for risk premia in the fiscal theory allows the government portfolio to affect expected inflation, even in a frictionless economy. The effects of maturity rebalancing on expected inflation in the fiscal theory depend directly on the conditional nominal term premium, giving rise to an optimal debt-maturity policy that is state-dependent. In a calibrated macrofinance model, we demonstrate that maturity operations have sizable effects on expected inflation and output through our novel risk transmission mechanism.

SINCE THE GREAT RECESSION, CENTRAL BANKS around the world have employed large-scale asset purchases as an essential tool in a rapidly evolving policy landscape. With short-term interest rates near an effective lower bound (ELB), traditional methods of expansionary monetary policy were no longer available. Fiscal pressure in the form of deepening deficits and surging govern-

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ment debt during this period also casts doubt on the ability of central banks to target inflation. By resorting to unconventional monetary policy, central banks dramatically increased the size and altered the composition of the government balance sheet. In particular, a large fraction of the central bank announcements following the Great Recession and the global pandemic involved the purchase of long-term government bonds, which reduced the maturity of debt held by the public.

This paper examines how the evolving stance of monetary and fiscal policy influences the transmission of government portfolio risk from debt-maturity operations. We consider a consolidated government budget with nominal liabilities that encompasses the Treasury and the central bank. Two policy environments are examined, labeled the monetary and fiscal regimes. The monetary regime refers to a conventional policy framework whereby the central bank targets inflation through nominal interest rate adjustments and the fiscal authority stabilizes debt through real surplus changes. The fiscal regime represents the fiscal theory, a policy setting whereby the central bank passively responds to inflation and the fiscal authority weakly responds to the debt burden. The fiscal regime arguably characterizes the policy mix in the period since the Great Recession, while the monetary regime is a better representation of the decades preceding it.[1]

The key theoretical result of our paper is that accounting for risk premia in the fiscal theory allows the government portfolio to affect the path of the price level, which constitutes a deviation Wallace (1981) neutrality, even in a frictionless economy. With nominal debt backed by real surpluses, inflation can provide a fiscal cushion for balance sheet shocks. Indeed, without debt stabilization through surplus policy in the fiscal regime, changes in government portfolio risk are absorbed by the inflation path, revaluing nominal debt to ensure that the intertemporal government budget equation holds. For instance, when the nominal term premium is nonzero, shifts in the maturity weights of debt affect the nominal government cost of capital. In the fiscal regime, nominal revaluations offset such changes in government portfolio risk. In contrast, the surplus policy provides fiscal stabilization in the monetary regime, allowing the path of real surpluses to absorb nominal government portfolio risk, thereby insulating the price level.

We first formalize intuition for the risk transmission mechanisms in a simple frictionless model using approximate analytical solutions. The frictionless setting helps identify the distinct economic margins in each regime that offset changes in nominal portfolio risk premia arising from maturity rebalancing. In the fiscal regime, nominal portfolio risk is fully absorbed by the path of inflation while insulating real surpluses from the government portfolio. In the monetary regime, nominal portfolio risk is completely offset by the path of real surpluses, while inflation is independent of the government portfolio. As such, Wallace neutrality holds in the monetary regime in the absence of frictions.

[1] Bianchi and Melosi (2017) provide structural estimation evidence of these policy regimes in the periods before and after the Great Recession.

Our analytical solutions show that the sign and magnitude of the effects of maturity restructuring depend explicitly on the nominal term premium. We also demonstrate in our simple model that the nominal term premium is impacted by portfolio rebalancing in the fiscal regime but not in the monetary regime.

We show that the risk transmission mechanisms can be characterized in terms of expected returns through a government return identity. In particular, when the government issues nominal debt, the intertemporal government budget equation implies that the expected return on the nominal government debt portfolio is equal to expected inflation plus the expected return on a hypothetical claim on all current and future real surpluses. Shocks to the maturity weights affect the expected nominal government portfolio return. For example, when the nominal term premium is positive, shortening debt maturity reduces the expected portfolio return. In the fiscal regime, expected inflation falls to offset the drop in the expected portfolio return, ensuring that the expected intertemporal government budget equation is satisfied. In the monetary regime, in contrast, there is an offsetting change in the expected return on real surpluses, with the present value of real government resources absorbing the disturbance.

We also use the simple model to analyze how the optimal debt-maturity policy is influenced by the novel portfolio risk transmission mechanism featured in the fiscal regime. We assume that the planner trades off minimizing expected inflation fluctuations around a target inflation rate and smoothing debt maturity around a target portfolio weight. We show that the nominal debt revaluation mechanism of the fiscal regime implies that the optimal debt-maturity rule depends on conditional expected inflation and the nominal term premium. For example, suppose there is a deflationary shock that pushes inflation expectations below target. When the nominal term premium is positive, the optimal debt-maturity response is to generate inflationary pressure by extending debt maturity in order to smooth inflation expectations around the target.

The optimal conditional maturity response to deflationary shocks is a direct implication of the nominal risk transmission mechanism of the fiscal regime. When the nominal term premium is positive, extending maturity implies that the government is refinancing at a higher nominal rate. Absent sufficient surplus adjustments in the fiscal regime, expected inflation rises to devalue the nominal debt portfolio, ensuring that the intertemporal government budget equation is satisfied. The inflationary maturity extension provides an opposing force to the deflationary shock, pushing expected inflation back toward the target. The optimal response to inflationary shocks is to shorten maturity when the nominal term premium is positive, implying a negative relation between optimal debt maturity and expected inflation. This relation is positive for a negative term premium, while optimal debt maturity and expected inflation are not related when the term premium is zero. The optimal maturity example illustrates how debt maturity can be used as a dynamic policy tool to stabilize inflation expectations.

To allow portfolio risk transmission mechanisms to affect the real economy, we extend the simple model to a production economy with distortions. Given that the fiscal adjustment margins for portfolio risk are distinct between the two regimes, the type of friction required to generate real effects depends on the regime. For example, nominal rigidities allow the inflation adjustments in the fiscal regime to impact real allocations, while the real surplus adjustments in the monetary regime would require real frictions (e.g., distortionary taxation) to have real effects. As the focus of our paper is to highlight the role of the risk transmission mechanism of the fiscal regime, we feature nominal frictions (i.e., sticky goods prices) in a model with production. To quantify the mechanisms of the simple model, we cast the production model in a New Keynesian framework that includes several distinguishing features. First, the policy mix is subject to changes between fiscal and monetary regimes. Second, the maturity weights on nominal government debt evolve according to a stochastic process. Third, households have recursive preferences that help the model generate a sizable term premium.

The quantitative model is calibrated to match salient features of the term structure of interest rates, debt maturity, and macroeconomic fluctuations. Generating a realistic nominal term premium is particularly important for quantitatively evaluating the transmission of portfolio risk from debt-maturity shocks. In the fiscal regime, a shock calibrated to match the impact of the quantitative easing programs on average debt maturity of −0.73 years lowers both expected inflation and output by around 10 basis points on impact, with persistent effects in the ensuing quarters. As the model is calibrated to match the positive nominal term premium, shortening maturity lowers the expected return on the nominal debt portfolio, requiring that expected inflation falls to satisfy the intertemporal government budget equation. Sticky nominal goods prices imply that the decline in expected inflation is sluggish and, in turn, imply that prices are temporarily too high relative to the flexible price case, generating a contraction in aggregate demand. Shortening maturity also increases the nominal term premium as in the simple model. To the extent that the policy mix in the recent period after the Great Recession was characterized by the fiscal regime, our paper highlights a potential unintended consequence of quantitative easing programs.[2] The sizable negative response of expected inflation attributed to the risk transmission mechanism in the fiscal regime can help explain the weak observed inflation responses following quantitative easing.

The effects of debt-maturity shocks in the monetary regime inherit the properties of the fiscal regime due to rational expectations and policy regime changes. Absent regime changes, debt-maturity shocks would have a neutral effect on inflation and real allocations in the monetary regime, as the path of real surpluses would completely absorb the effects of maturity changes. However, a positive probability of entering into the fiscal regime allows deviations from Wallace neutrality to arise in the monetary regime, propagating

[2] Bianchi and Melosi (2017) identify the period following the Great Recession as a fiscal regime in which the lower bound on the nominal short rate binds.

through agents' expectations. While the responses to debt-maturity shocks in the monetary regime are qualitatively similar to those in the fiscal regime, the magnitudes of the responses are smaller in the monetary regime, with the impact decreasing with a diminishing likelihood of transitioning to a fiscal regime. These results highlight the importance of the current and expected future policy stance for the key effects of large-scale asset purchases.

Our model can also explain key asset pricing and macroeconomic facts conditional on the monetary and fiscal regimes. An informative statistic for the parameterization of the policy regimes and the structural shocks is the ratio of the variance of inflation news to the variance of nominal yield innovations, computed following Duffee (2018). Our model is broadly consistent with patterns in the inflation variance ratio conditional on the policy regime for maturities of one to three quarters. The model explains the higher inflation variance ratio in the fiscal regime compared to the monetary regime as fiscal disturbances (e.g., debt-maturity and surplus shocks) that are primarily absorbed by expected inflation in the fiscal regime but by expected real surpluses in the monetary regime. The presence of sticky prices implies that the additional nominal adjustments in the fiscal regime also produce higher volatility in real variables such as output.

We consider two extensions to the quantitative model. In the first extension, we incorporate an additional regime with a binding ELB that is particularly relevant for the period after the Great Recession. We find that the nominal risk transmission mechanism at the ELB in the fiscal regime redistributes the timing of the inflation response to the nearer term. In the second extension, we consider a debt-maturity rule that depends on expected inflation deviations from target, motivated by the optimal policy from the simple model. We demonstrate how such a state-dependent rule can help smooth macroeconomic fluctuations in the fiscal regime. Overall, the quantitative analysis shows that accounting for the policy stance and differences in risk premia across assets is important when designing policies for large-scale asset purchases.

Our paper is related to prior studies that quantitatively examine risk-based transmission channels for policy interventions in macroeconomic models featuring sizable risk premia, such as Begenau and Landvoigt (2022), Elenev, Landvoigt, and Van Nieuwerburgh (2021), Elenev et al. (2021), Gourio, Kashyap, and Sim (2018), Jiang et al. (2022a, 2022b), Lenel, Piazzesi, and Schneider (2018), and Lenel (2018). We complement this literature by documenting a distinct mechanism through which the intertemporal government budget equation provides a quantitatively significant risk propagation channel for large-scale asset purchases.

Our paper is also related to the broader literature examining the transmission channels associated with government debt. Hamilton and Wu (2012), Krishnamurthy, Nagel, and Vissing-Jorgensen (2018), Greenwood and Vayanos (2014), and Williamson (2016) study debt maturity changes with market segmentation, while Leeper, Leith, and Liu (2021) and Lustig, Sleet, and Yeltekin (2008) consider distortionary taxation. Chernov, Schmid, and Schneider (2020), Reis (2017), and Gomes, Jermann, and Schmid (2016) examine the role of defaultable nominal debt on the maturity structure. We differ from these papers by showing how incorporating nominal term premia in the fiscal theory allows changes in the government portfolio to affect inflation without market segmentation, distortionary taxation, or default risk.

Our quantitative model builds on the Markov-switching dynamic stochastic general equilibrium (DSGE) model of Bianchi and Ilut (2017) and Bianchi and Melosi (2017). We differ in that we focus on how shocks to government portfolio risk affect expected inflation in the fiscal regime through a novel discount rate channel. Moreover, the papers above consider linearized systems, while we use nonlinear approximations to capture endogenous bond risk premia, which is central to our transmission mechanism.

The simple model and optimal maturity policy setup build on insights from Cochrane (2001), who also considers the role of the debt-maturity structure in the context of the fiscal theory in a frictionless economy. Cochrane demonstrates that government debt maturity affects the timing of inflation through face value policies in a risk-neutral framework. By introducing risk premia and an interest rate rule in our model, we show that portfolio rebalancing in the fiscal theory can also affect the path of the price level even in a frictionless economy, constituting a deviation from Wallace neutrality. Our portfolio risk transmission mechanism also gives rise to an optimal maturity policy that is state-dependent.

The linkages between policy uncertainty and risk premia build on the work of Pastor and Veronesi (2012, 2013). Our paper is distinct in that we study interactions between monetary and fiscal policy and introduce policy uncertainty in our quantitative model through stochastic regime shifts in the monetary-fiscal policy mix. We show that policy uncertainty affects the nominal term premium. Like Pástor and Veronesi (2013), we show how the effect of policy changes is influenced by policy uncertainty.

More broadly, our quantitative model relates to general equilibrium models that link the stance of government policy to risk premia. For example, Rudebusch and Swanson (2012), Palomino (2012), Dew-Becker (2014), Campbell, Pflueger, and Viceira (2014), Kung (2015), Gourio and Ngo (2020), and Weber (2015) link asset prices to monetary policy. Croce et al. (2012), Gomes, Michaelides, and Polkovnichenko (2013), Belo, Gala, and Li (2013), and Belo and Yu (2013), and Bretscher, Hsu, and Tamoni (2017) examine fiscal policy and asset prices.

The paper is structured as follows. Section I discusses the key model mechanisms using approximate analytical solutions in the simple model. Section II describes the benchmark model. Section III provides a quantitative assessment of the benchmark model. Section IV considers alternative specifications of the benchmark model. Section V concludes.

I. Simple Model

This section builds a simple partial equilibrium model with an approximate closed-form solution to illustrate how government portfolio risk is transmitted through the intertemporal government budget equation in a frictionless economy. The dependence of the risk transmission mechanism on the policy regime is highlighted. Government portfolio risk is soaked up by expected inflation in the fiscal regime but is instead absorbed by expected surpluses in the monetary regime. We integrate these risk transmission mechanisms into a quantitative general equilibrium framework with frictions in Section II.

A. Pricing Kernel

The log real pricing kernel, $m_{t+1} \equiv \log(M_{t+1})$, is specified as a one-factor model,

$$-m_{t+1} = \delta + z_t + \lambda\varepsilon_{t+1}, \qquad (1)$$
$$z_{t+1} = (1-\varphi)\mu + \varphi z_t + \sigma\varepsilon_{t+1},$$

where z_t is the state variable, ε_t is an identically and independently distributed standard normal, λ is the price of risk parameter, and $\delta = \lambda^2/2$. This specification is a discrete-time version of Vasicek (1977). The real short rate is given by $r_t = z_t$.

B. Government Budget Equation

The government issues one- and two-period nominal zero-coupon bonds that are rolled over each period. The flow budget equation of the government in period t is given by

$$B_{t-1}^{(1)} + Q_t^{(1)}B_{t-1}^{(2)} = P_t s_t + Q_t^{(1)}B_t^{(1)} + Q_t^{(2)}B_t^{(2)}, \qquad (2)$$

where $B_{t-1}^{(j)}$ is the face value of nominal zero-coupon debt issued at time $t-1$ that matures at time $t-1+j$, $Q_t^{(j)}$ is the price of nominal j-period debt, P_t is the price level, and s_t represents real surpluses. Equation (2) consolidates the budget equations of the Treasury and the central bank by using the fact that the residual net earnings of the Fed are remitted to the treasury. Consequently, the outstanding government debt in our model can be interpreted as the amount issued by the treasury net of the holdings of the central bank.

Define $\mathcal{B}_t^{(j)} \equiv Q_t^{(j)}B_t^{(j)}$ as the nominal market value of j-period debt and $\mathcal{B}_t \equiv \mathcal{B}_t^{(1)} + \mathcal{B}_t^{(2)}$ as the total nominal market value of debt. The budget equation can be expressed in terms of market values of debt

$$\frac{1}{P_t}\left(\frac{1}{Q_{t-1}^{(1)}}\frac{\mathcal{B}_{t-1}^{(1)}}{\mathcal{B}_{t-1}} + \frac{Q_t^{(1)}}{Q_{t-1}^{(2)}}\frac{\mathcal{B}_{t-1}^{(2)}}{\mathcal{B}_{t-1}}\right)\mathcal{B}_{t-1} = s_t + \frac{\mathcal{B}_t}{P_t}. \qquad (3)$$

Let $R_t^{(1)} \equiv 1/Q_{t-1}^{(1)}$ be the nominal holding-period return on one-period debt, $R_t^{(2)} \equiv Q_t^{(1)}/Q_{t-1}^{(2)}$ the nominal holding-period return on two-period debt, $\Omega_{t-1} \equiv \mathcal{B}_{t-1}^{(2)}/\mathcal{B}_{t-1}$ the fraction of two-period debt, $R_{g,t} \equiv (1-\Omega_{t-1})R_t^{(1)} + \Omega_{t-1}R_t^{(2)}$ the nominal holding-period return on the government bond portfolio, and $b_t \equiv$

$\mathcal{B}_t/P_t$ the real market value of nominal debt. The budget equation can then be rewritten in terms of the government portfolio return and the real market value of nominal debt,

$$\frac{R_{g,t}}{\Pi_t} b_{t-1} = s_t + b_t, \tag{4}$$

where $\Pi_t = P_t/P_{t-1}$ is inflation.

B.1. Maturity Structure

The fraction of the two-period debt follows an autoregressive process,

$$\Omega_t = (1 - \rho_\Omega)\bar{\Omega} + \rho_\Omega \Omega_{t-1} + \sigma_\Omega \varepsilon_{\Omega,t}, \tag{5}$$

where $\varepsilon_{\Omega,t}$ is an identically and independently distributed standard normal random variable that captures surprise maturity operations. Assume that the two shocks in this model, ε_t and $\varepsilon_{\Omega,t}$, are uncorrelated. Appendix A.F describes how the debt-maturity process characterized in terms of proportional market values can be mapped to an equivalent specification in terms of proportional face values.

B.2. Government Return Identity

This section shows how the government budget equation can be expressed in terms of returns. Start by dividing equation (2) by P_t and rearranging,

$$\frac{1}{\Pi_t}\left(\frac{B^{(1)}_{t-1} + Q^{(1)}_t B^{(2)}_{t-1}}{P_{t-1}}\right) = s_t + \frac{Q^{(1)}_t B^{(1)}_t + Q^{(2)}_t B^{(2)}_t}{P_t}. \tag{6}$$

Substitute out the time t bond prices, $Q^{(1)}_t = \mathrm{E}_t[M_{t+1}/\Pi_{t+1}]$ and $Q^{(2)}_t = \mathrm{E}_t[(M_{t+1}/\Pi_{t+1})Q^{(1)}_{t+1}]$, on the right-hand side of equation (6) to obtain

$$\frac{1}{\Pi_t}\left(\frac{B^{(1)}_{t-1} + Q^{(1)}_t B^{(2)}_{t-1}}{P_{t-1}}\right) = s_t + \mathrm{E}_t\left[M_{t+1}\cdot\frac{1}{\Pi_{t+1}}\left(\frac{B^{(1)}_t + Q^{(1)}_{t+1} B^{(2)}_t}{P_t}\right)\right]. \tag{7}$$

Equation (6) implies that $\frac{1}{\Pi_t}(\frac{B^{(1)}_{t-1}+Q^{(1)}_t B^{(2)}_{t-1}}{P_{t-1}}) = s_t + b_t$, which can be used in equation (7) to arrive at

$$b_t = \mathrm{E}_t\big[M_{t+1}(b_{t+1} + s_{t+1})\big]. \tag{8}$$

Iterating equation (8) forward and imposing the transversality condition yields a fiscal asset pricing equation that equates the real value of the nominal government debt portfolio to the present value of future real surpluses,

$$b_t = \mathrm{E}_t\left[\sum_{j=1}^{\infty} M_{t,t+j} s_{t+j}\right], \tag{9}$$

where $M_{t,t+j}$ is the j-period real pricing kernel. Therefore, the real value of the nominal government debt portfolio is equivalent to the market value of a hypothetical claim that delivers real surpluses as its dividend.

Define the return on real surpluses as $R_{s,t} \equiv (b_t + s_t)/b_{t-1}$. Using this definition of $R_{s,t}$ in equation (4) allows us to rewrite the government budget equation in terms of returns and inflation,

$$\frac{R_{g,t}}{\Pi_t} = R_{s,t}, \tag{10}$$

which we refer to as the government return identity. This identity plays a central role in understanding the risk transmission of government portfolio risk, as discussed in Section I.D.

The government return identity is also equivalent to the intertemporal government budget equation, which can be obtained by substituting equation (9) into equation (4),

$$\frac{R_{g,t} b_{t-1}}{\Pi_t} = \mathrm{E}_t \left[\sum_{j=0}^{\infty} M_{t,t+j} s_{t+j} \right]. \tag{11}$$

Inflation is determined by the intertemporal government budget equation in the fiscal theory. Equation (11) highlights the dependence of inflation on the government portfolio return and the present value of current and future real surpluses.

C. Policy Rules

Monetary policy is characterized by the nominal interest rate rule

$$i_t = i^\star + \rho_\pi (\pi_t - \pi^\star), \tag{12}$$

where i_t is the log nominal short rate, $i^\star$ is the unconditional mean of i_t, π_t is log inflation, $\pi^\star$ is target inflation, and ρ_π reflects the responsiveness of the short rate to inflation deviations from target.

Fiscal policy is characterized by the real surplus rule

$$s_t = s^\star + \delta_b \big(\log(b_{t-1}) - \log(b^\star)\big), \tag{13}$$

where $s^\star$ is the unconditional mean of s_t, $b^\star$ is the real debt target, and δ_b captures the responsiveness of surpluses to debt deviations from target.

The parameter space for ρ_π and δ_b can be partitioned into four distinct regions as in Leeper (1991). We focus on two of the regions, labeled the *monetary* and *fiscal* regimes. The monetary regime is a standard textbook monetary specification described by the parameter restrictions $\rho_\pi > 1$ and $\delta_b > s^\star$. The fiscal regime characterizes the fiscal theory given by the parameter restrictions $\rho_\pi < 1$ and $\delta_b < s^\star$. Sections I.F and I.G illustrate how the risk transmission mechanisms differ between the two policy regimes. Appendix A.E shows how these parameter restrictions are necessary conditions for obtaining bounded solutions in our simple model.

D. Risk Decomposition

This section uses the government return identity to provide a risk decomposition of the sources and uses of government funds. A heuristic interpretation of the transmission channels for government portfolio risk is discussed through the lens of a risk decomposition. We then formalize the risk transmission mechanisms and how they depend on each policy regime ahead of providing our approximate analytical solutions.

Taking logs of equation (10), iterating forward one period, and taking conditional expectations at time t yields the *expected government return identity*

$$\mathrm{E}_t[r_{g,t+1}] = \mathrm{E}_t[\pi_{t+1}] + \mathrm{E}_t[r_{s,t+1}]. \tag{14}$$

This equation shows that changes in the expected return of the nominal government portfolio need to be offset by either expected inflation or the expected return on real surpluses.

In a log-normal no-arbitrage framework like our simple model, equation (14) can be expressed in terms of the risk premium and variance of the nominal government return and the real return on surplus using the corresponding Euler equations for the returns,

$$\begin{aligned}\mathrm{cov}_t\left(m^{\$}_{t+1}, r_{g,t+1}\right) + \frac{1}{2}\mathrm{var}_t\left(r_{g,t+1}\right) = i_t - r_t - \mathrm{E}_t[\pi_{t+1}]\\ + \mathrm{cov}_t\left(m_{t+1}, r_{s,t+1}\right) + \frac{1}{2}\mathrm{var}_t\left(r_{s,t+1}\right),\end{aligned} \tag{15}$$

where r_t is the log real short rate and i_t is the log nominal short rate. The right-hand side of equation (15) decomposes possible transmission channels for government portfolio risk in terms of conditional risk premium terms and short rates.

When expected bond returns differ across maturities, portfolio rebalancing directly impacts the conditional risk premium and variance of the nominal bond portfolio, organized on the left-hand side of equation (15). We show in our simple model below that the nominal short rate does not respond contemporaneously to portfolio rebalancing and that the real rate is independent of the government portfolio. Therefore, the only variables on the right-hand side of equation (15) that can absorb changes in government portfolio risk are expected inflation, the conditional risk premium on real surpluses, or the conditional variance on real surpluses.

Sections I.F and I.G show that the policy regimes feature distinct risk transmission channels. In the fiscal regime, only expected inflation absorbs fluctuations in government bond portfolio risk. In the monetary regime, only the conditional risk premium and variance on the real surplus claim offset changes in government portfolio risk. The key theoretical result of our paper is that the presence of bond risk premia in the fiscal regime allows changes in the maturity weights of the government portfolio to impact the expected path of the price level, constituting a deviation from Wallace neutrality, even in a frictionless economy. An approximate analytical solution is used to illustrate the model mechanisms.

E. Return Approximations

To derive closed-form solutions for the monetary and fiscal regimes in our simple model, the log return on real surpluses is approximated in a similar way as Campbell and Shiller (1988), but modified to approximate around the level of surplus as in Cochrane (2022). The approximation around the level of surplus rather than the log surplus allows for deficits. The second-order approximation of the government portfolio return follows Campbell and Viceira (2001). A second-order approximation for the portfolio return is used to accurately capture the nonlinear impact of portfolio weight shocks on the expected government bond return.[3]

The approximation for the log return on real surpluses is given by

$$r_{s,t+1} = \kappa_0 + \kappa_1 \log(b_{t+1}) + \kappa_2 s_{t+1} - \log(b_t), \tag{16}$$

where the coefficients of the approximation (κ_i) depend on average real surpluses and the log real value of debt.

The log excess return on the government bond portfolio is approximated with the second-order approximation

$$r_{g,t+1} - i_t = \Omega_t \left(r^{(2)}_{t+1} - i_t \right) + \frac{1}{2}\Omega_t (1 - \Omega_t) \operatorname{var}_t \left(r^{(2)}_{t+1} \right), \tag{17}$$

where $r^{(2)}_{t+1} \equiv \log(R^{(2)}_{t+1})$ is the log holding-period return on the two-period nominal bond, and the log holding-period return on the one-period nominal bond is equal to the log nominal short rate $r^{(1)}_{t+1} = i_t$.

Additional details on the return approximations are provided in Appendix A.A. The next two sections use these return approximations to solve for inflation and debt in each regime. The policy regimes are assumed to be fixed in the simple model. The quantitative model in Section II allows for stochastic regime changes.

F. Fiscal Regime

The fiscal regime is the policy specification that characterizes the fiscal theory. Monetary policy does not stabilize inflation because the nominal interest

[3] The second-order approximation allows for internal consistency when computing the conditional nominal risk premium of the government bond portfolio using the Euler equation (i.e., covariance with the pricing kernel) or by taking conditional expectations of the future excess return. We verify the accuracy of our approximate analytical solution using a third-order perturbation method with Dynare.

rate rule responds passively to inflation deviations from the target ($\rho_\pi < 1$). Fiscal policy weakly responds to debt deviations from the target ($\delta_b < s^\star$). Given that surplus adjustments are insufficient to offset fiscal disturbances, inflation in this regime adjusts to ensure that the intertemporal government budget equation holds.

This section uses the return approximations described above to obtain the solution to inflation and debt in the fiscal regime. We show that expected inflation offsets changes in portfolio risk arising from the maturity shocks while the return on surplus is insulated. The sign and magnitude of the effect of the maturity shocks on expected inflation depend on the conditional nominal term premium.

F.1. Debt Solution

The real value of debt is solved forward in the fiscal regime using the Euler equation on the surplus return together with the surplus rule. The Euler equation for the real surplus return is

$$1 = \mathrm{E}_t\big[\exp(m_{t+1} + r_{s,t+1})\big]. \tag{18}$$

Plugging the surplus rule (equation (13)) into the approximation for the return on surplus yields

$$r_{s,t+1} = \bar{r}_s + \kappa_1 \log(b_{t+1}) + \theta_s \log(b_t), \tag{19}$$

where $\bar{r}_s \equiv \kappa_0 + \kappa_2(s^\star - \delta_b \log(b^\star))$ and $\theta_s \equiv (\kappa_2\delta_b - 1)$. Substituting equation (19) into the Euler equation yields

$$1 = \mathrm{E}_t\big[\exp(m_{t+1} + \bar{r}_s + \kappa_1 \log(b_{t+1}) + \theta_s \log(b_t))\big]. \tag{20}$$

As the log real pricing kernel is specified exogenously as an affine model that depends on a single-state variable z_t, solving for the real value of debt using equation (20) implies that the real value of nominal debt depends only on this state variable. We guess that the solution for the log real value of debt is affine in z_t,

$$\log(b_t) = A_0 + A_1 z_t, \tag{21}$$

where A_0 and A_1 are undetermined coefficients. We use the guess in the Euler equation above to obtain the coefficients, which are provided in Appendix A.B along with the derivations. Equation (21) illustrates that the real value of nominal debt is independent of the debt-maturity process, Ω_t, in this regime.

Real surpluses are insulated from Ω_t since real surpluses depend only on the lagged real value of debt through the fiscal rule, implying that the return on surplus is also independent of Ω_t. Indeed, the solution for the log return on surplus depends only on the contemporaneous and lagged values of the state variable of the real pricing kernel,

$$r_{s,t+1} = \zeta_0 + \zeta_1 z_{t+1} + \zeta_2 z_t, \tag{22}$$

which is obtained by substituting the debt solution into equation (19). The coefficients ζ_j are contained in Appendix A.B.

From the perspective of the risk decomposition given in equation (15), the conditional risk premium of the real surplus claim is not affected by maturity shocks. Consequently, expected inflation needs to offset changes in the risk premium of the nominal bond portfolio from maturity shocks to ensure that the expected intertemporal government budget equation is satisfied. We next describe the mechanics of inflation and how it reacts to debt maturity changes in the fiscal regime.

F.2. Inflation Solution

Log inflation is determined jointly with the solution to debt using the intertemporal government budget equation expressed in log returns,

$$\pi_{t+1} = r_{g,t+1} - r_{s,t+1}. \tag{23}$$

The approximate analytical solution is computed in two steps. We first solve for the inflation innovation. We then solve for expected inflation.

We start by rewriting equation (23) in terms of log innovations,

$$(\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}]) = \left(r_{g,t+1} - \mathrm{E}_t[r_{g,t+1}]\right) - \left(r_{s,t+1} - \mathrm{E}_t[r_{s,t+1}]\right). \tag{24}$$

Recall from the section above that the return on real surpluses is determined independent of inflation and the nominal return on the government bond portfolio. Consequently, the expected return on surplus and the corresponding innovation component can be computed using the solution presented in equation (22).

The innovation to the log return on the nominal government bond portfolio can be expressed in terms of the inflation innovation by substituting the interest rate rule into the two-period nominal bond return and utilizing the return approximation given by equation (17), allowing us to back out the log inflation innovation using equation (24),

$$\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}] = -\frac{1}{1+\rho_\pi \Omega_t}\kappa_1 A_1 \sigma \varepsilon_{t+1}. \tag{25}$$

Details of the derivation are provided in Appendix A.B. The innovation to the log return on the nominal government bond portfolio is subsequently pinned down by the inflation innovation.

Given the log innovation to the return on the nominal government bond portfolio, the expected return can be calculated using the pricing equation,

$$\mathrm{E}_t[r_{g,t+1}] = i_t - \mathrm{cov}_t\left(m^{\$}_{t+1}, r_{g,t+1}\right) - \frac{1}{2}\mathrm{var}_t\left(r_{g,t+1}\right). \tag{26}$$

Using the solutions for the expected return on the government bond portfolio and the return on real surpluses described above, expected log inflation can be obtained using the expected return identity by taking conditional expectations of equation (23). As inflation depends only on lagged maturity, the nominal short rate does not respond contemporaneously to maturity changes. Only the conditional covariance and variance terms are affected by maturity, implying that maturity shocks only impact expected bond portfolio returns. In the section below, we show that changes in the expected portfolio return are offset by expected inflation in the fiscal regime.

Combining the solutions to the log inflation innovation and expected log inflation yields

$$\pi_{t+1} = \rho_\pi \pi_t + f_1(\Omega_t) + f_2(\Omega_t) z_{t+1} + f_3(\Omega_t) z_t, \tag{27}$$

where the $f_j(\Omega_t)$ coefficients depend explicitly on the lagged portfolio weight. The exact expressions for the coefficients are provided in Appendix A.B. The parameter restriction on monetary policy ($\rho_\pi < 1$) in this regime is required to solve equation (27) backward.

The dependence of inflation on the lagged portfolio weight in equation (27) rather than on the contemporaneous weight implies that changes in portfolio weights impact expected inflation but not realized inflation. The section below discusses how changes in portfolio risk are transmitted to expected inflation. Equation (27) also highlights the role of the coefficient ρ_π from the interest rate rule for the response of the intertemporal distribution of the price level to shocks to the pricing kernel z_{t+1}. In Appendix A.B, we show that the coefficient $f_2(\Omega_{t-1}) = -\zeta_1/(1 + \rho_\pi \Omega_{t-1})$ is decreasing with respect to ρ_π as $\zeta_1 < 0$. Therefore, as ρ_π increases in the fiscal regime, the response is distributed more to expected inflation relative to realized inflation.

Note that the presence of nominal government debt is required to determine inflation in the fiscal regime through the intertemporal government budget equation, expressed equivalently as a return identity in equation (23). Indeed, if the government only issued real debt rather than nominal, the government budget equation would be entirely real, with inflation dropping out of the return identity, leading to indeterminacy in this regime.

F.3. Portfolio Risk Transmission

This section illustrates how expected inflation absorbs changes in government bond portfolio risk arising from maturity shocks in the fiscal regime. As the real surplus claim is independent of debt maturity, changes in the expected bond portfolio return need to be completely offset by expected inflation to ensure that the expected intertemporal government budget equation (14) holds, implying that

$$\frac{\partial \mathrm{E}_t[\pi_{t+1}]}{\partial \Omega_t} = \frac{\partial \mathrm{E}_t[r_{g,t+1}]}{\partial \Omega_t}. \tag{28}$$

From the perspective of the risk decomposition presented in equation (15), expected inflation adjusts to exactly offset the change in the conditional risk premium and the conditional variance of the government portfolio return from portfolio rebalancing.

The conditional nominal term premium on the two-period nominal bond, $TP_t^{(2)} \equiv \mathrm{E}_t[r_{t+1}^{(2)} - i_t] + (1/2)\,\mathrm{var}_t(r_{t+1}^{(2)})$, depends on debt maturity Ω_t in the fiscal regime,

$$TP_t^{(2)} = \rho_\pi \left(\lambda - \frac{\zeta_1 \sigma}{1 + \rho_\pi \Omega_t} \right) \frac{\zeta_1 \sigma}{1 + \rho_\pi \Omega_t}. \tag{29}$$

Appendix B.4 describes how the sign of the derivative of the conditional nominal term premium with respect to debt maturity relates to the sign and magnitude of the nominal term premium itself. For example, a positive nominal term premium is required for a maturity shortening to increase the nominal term premium. These results show that in the fiscal regime, the government portfolio can affect the nominal term premium and bond yields even in a frictionless environment. The sign of the nominal term premium also plays an important role in determining the effect of maturity shocks on expected inflation, as we discuss next.

The solution for expected inflation can be expressed in terms of the nominal term premium,

$$\mathrm{E}_t[\pi_{t+1}] = \xi_\pi + \rho_\pi \pi_t - z_t + \Omega_t \cdot TP_t^{(2)} - \frac{1}{2}\,\mathrm{var}_t\left(r_{g,t+1}\right), \tag{30}$$

where ξ_π is a constant and the conditional variance $\mathrm{var}_t(r_{g,t+1})$ depends on Ω_t. The last two terms of equation (30) characterize how expected inflation soaks up changes in government portfolio risk.

The transmission of government portfolio risk to expected inflation can be decomposed into three terms,

$$\frac{\partial \mathrm{E}_t[\pi_{t+1}]}{\partial \Omega_t} = TP_t^{(2)} + \Omega_t \frac{\partial TP_t^{(2)}}{\partial \Omega_t} - \frac{1}{2} \frac{\partial\, \mathrm{var}_t\left(r_{g,t+1}\right)}{\partial \Omega_t}. \tag{31}$$

The first term reflects the "direct" effect of portfolio rebalancing on the conditional risk premium of the government portfolio, which depends only on the nominal term premium. The second term captures the impact of the endogenous nominal term premium response. The third term characterizes the nonlinear effect of portfolio rebalancing on expected returns. The last two terms capture the influence of endogenous bond price responses on the portfolio risk transmission mechanism. The direct portfolio rebalancing effect dominates the other terms so that the sign of the conditional nominal term premium signs the derivative above. To see this, equation (31) can be rewritten more compactly as

$$\frac{\partial \mathrm{E}_t[\pi_{t+1}]}{\partial \Omega_t} = \left(\frac{1}{1 + \rho_\pi \Omega_t} \right) TP_t^{(2)}, \tag{32}$$

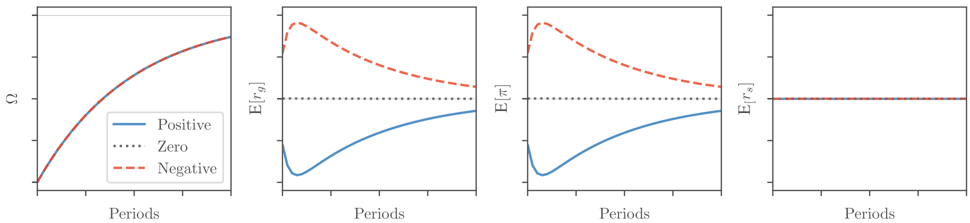

Figure 1. Maturity shocks in the fiscal regime. This figure plots the impulse response functions to a negative government debt-maturity shock ($\varepsilon_\Omega < 0$) in the fiscal regime of the simple model for parameterizations in which the nominal term premium is positive (solid blue line), zero (dotted black line), and negative (dashed red line) for average debt maturity Ω, expected return on the nominal government bond portfolio E[r_g], expected inflation E[π], and expected return on real surpluses E[r_s]. (Color figure can be viewed at wileyonlinelibrary.com)

where $1/(1 + \rho_\pi \Omega_t) > 0$ and the details of the derivations are contained in Appendix A.B.[4] Equation (32) shows that when the conditional nominal term premium is positive (negative), a maturity extension increases (decreases) expected inflation; when the nominal term premium is zero, the maturity extension has no effect on expected inflation. The endogenous bond price responses dampen the "direct effect" of the maturity change when $\rho_\pi > 0$ and $\Omega_t > 0$, implying that the coefficient $1/(1 + \rho_\pi \Omega_t)$ is less than one. The direct effect dominates, however, as the coefficient is always positive. Indeed, given the restriction on monetary policy in this regime ($\rho_\pi < 1$), in a realistic scenario where Ω_t is bounded between zero and one, the lower bound on $1/(1 + \rho_\pi \Omega_t)$ is one-half.

Figure 1 plots impulse response functions in the fiscal regime to a negative maturity shock ($\varepsilon_{\Omega,t} < 0$) to the debt-maturity process specified in equation (5). Three cases are considered: a positive nominal term premium (solid blue line), zero nominal term premium (dotted black line), and negative nominal term premium (dashed red line). As a qualitative illustration, we set the policy parameters to $\rho_\pi = 0.5$ and $\delta_b = 0.5$, and the price of risk parameter, λ, is calibrated separately to obtain the different term premia. In the case of a positive term premium, a surprise decline in the portfolio weight on the two-period bond lowers the expected return on the nominal government bond portfolio. The decrease in government portfolio risk is completely offset by a decrease in expected inflation while insulating the expected return on surplus from the shock. The effects of the maturity shock have the opposite sign when the nominal term premium is negative. When the nominal term premium is zero, portfolio rebalancing does not affect the cost of government financing, leading to a neutral effect on expected inflation. A quantitative examination of this regime is explored in the general equilibrium model presented in Section II.

The risk transmission mechanism described above shows how accounting for risk premia in the fiscal regime allows the composition of the government

[4] As $0 < \rho_\pi < 1$ in the fiscal regime, the condition $1/(1 + \rho_\pi \Omega_t) > 0$ also requires that $\Omega_t > -1$.

portfolio to impact the expected path of the price level, constituting a deviation from Wallace (1981) neutrality, even in a frictionless economy. The monetary regime features a different risk transmission channel that insulates the path of the price level from changes to the government portfolio, which we discuss next.

G. Monetary Regime

The monetary regime is the standard textbook policy specification (e.g., Woodford (2003) and Galí (2015)). Monetary policy satisfies the Taylor principle with the nominal short rate responding more than one-for-one with inflation ($\rho_\pi > 1$). Fiscal policy adjusts real surpluses sufficiently ($\delta_b > s^\star$) to absorb fiscal disturbances, ensuring that the intertemporal budget equation holds. As a consequence, inflation is independent of fiscal disturbances in this regime.

The return approximations from Section I.E are used to solve for inflation and debt. The government portfolio risk transmission mechanism in the monetary regime operates through the risk premium on the real surplus claim, distinguishing it from the expected inflation adjustments in the fiscal regime.

G.1. Inflation Solution

Inflation is solved forward in the monetary regime using the Euler equation for the one-period nominal bond together with the interest rate rule. The Euler equation written in terms of log variables is

$$-i_t = \log\left(\mathrm{E}_t\left[\exp(m_{t+1} - \pi_{t+1})\right]\right), \tag{33}$$

where we use $\log(Q_t^{(1)}) = -i_t$. Substitute the interest rate rule into the Euler equation to obtain

$$-i^\star - \rho_\pi(\pi_t - \pi^\star) = \log\left(\mathrm{E}_t\left[\exp\left(m_{t+1} - \pi_{t+1}\right)\right]\right). \tag{34}$$

The parameter restriction on monetary policy ($\rho_\pi > 1$) is required to solve log inflation forward using equation (34). As the log real pricing kernel is specified exogenously as an affine model that depends on a single-state variable z_t, solving for inflation using equation (34) implies that inflation depends only on this state variable. We guess that the solution for log inflation is affine in z_t,

$$\pi_t = H_0 + H_1 z_t, \tag{35}$$

where H_0 and H_1 are undetermined coefficients. Use the guess for inflation in the Euler equation above to solve for the coefficients. Inflation is independent of the debt-maturity process Ω_t, ensuring that Wallace neutrality holds in the monetary regime. Changes to the conditional risk premium of the nominal government bond portfolio arising from maturity shocks are offset by adjustments in the conditional risk premium on the real surplus claim.

The inflation solution and the process for the real pricing kernel specified in equation (1) pin down the nominal bond prices. As inflation is independent of debt maturity in this regime, so too are the solutions for bond prices and the term premium, which are contained in Appendix A.C. The term premium is also constant in the monetary regime. Substituting the nominal bond prices into the return approximation presented in equation (17) determines the log return nominal government bond portfolio,

$$r_{g,t+1} = \varrho_0 + \varrho_1 z_t + \varrho_2 \Omega_t + \varrho_3 \Omega_t^2 + \varrho_4 \Omega_t z_t + \varrho_5 \Omega_t z_{t+1}, \tag{36}$$

where the coefficients ϱ_j are contained in Appendix A.C. Given that the portfolio return depends only on the lagged portfolio weight, maturity shocks affect only the expected portfolio return.

G.2. Debt Solution

This section presents the solution for the real value of the nominal debt portfolio. We start by plugging the solution for log inflation and the log return of the nominal government bond portfolio into the intertemporal government budget equation, expressed as the log return identity, $r_{s,t+1} = r_{g,t+1} - \pi_{t+1}$, which pins down the return on real surpluses,

$$r_{s,t+1} = \varrho_0 - H_0 - H_1 z_{t+1} + \varrho_1 z_t + \varrho_2 \Omega_t + \varrho_3 \Omega_t^2 + \varrho_4 \Omega_t z_t + \varrho_5 \Omega_t z_{t+1}. \tag{37}$$

The return on surplus depends on the lagged portfolio weight in this regime, while the return on surplus is independent of the portfolio weight in the fiscal regime. In particular, changes in government bond portfolio risk are absorbed by adjustments in the expected return on real surpluses in the monetary regime.

Given the solution for the return on surplus, the log real value of debt is determined by substituting the surplus rule into the approximation for the log return on real surpluses presented in equation (16),

$$\log(b_{t+1}) = \psi_0 + \psi_1 \log(b_t) + \frac{1}{\kappa_1} r_{s,t+1}. \tag{38}$$

Appendix A.C shows that the parameter restriction on fiscal policy, $\delta_b > s^\star$, implies that $\psi_1 < 1$, which is required to solve equation (38) backward for debt in the monetary regime. As the return on surplus depends on debt maturity, so too does the solution for the real value of debt.

G.3. Portfolio Risk Transmission

This section illustrates how changes in government bond portfolio risk are transmitted to the expected return on the surplus claim in the monetary regime. As inflation is shielded from debt maturity in this regime, changes in the expected return on the nominal government bond portfolio are required to be completely offset by the expected return to real surpluses for the expected government return identity to hold, implying that,

$$\frac{\partial \mathrm{E}_t[r_{s,t+1}]}{\partial \Omega_t} = \frac{\partial \mathrm{E}_t[r_{g,t+1}]}{\partial \Omega_t}. \tag{39}$$

In contrast, recall that fluctuations in portfolio risk are offset by expected inflation adjustments in the fiscal regime. In relation to the risk decomposition provided in equation (15), the risk absorption mechanism in this regime works through the conditional risk premium and conditional variance of the real surplus claim that exactly offsets the change in the conditional risk premium and conditional variance of the government portfolio return from portfolio rebalancing.

Using the model solution, the expected surplus return can be expressed in terms of the nominal term premium and conditional variance of the government portfolio return by taking conditional expectations of the return solution presented in equation (37),

$$\mathrm{E}_t[r_{s,t+1}] = \xi_s + z_t + \Omega_t \cdot TP^{(2)} - \frac{1}{2}\,\mathrm{var}(r_{g,t+1}), \tag{40}$$

where the nominal term premium in the monetary regime, $TP_t^{(2)} = TP^{(2)} \equiv (-\lambda - H_1\sigma)\rho_\pi H_1\sigma$, is insulated from portfolio rebalancing and the expression for the conditional variance and constant terms are provided in Appendix A.C. The last two terms of equation (40) characterize how the expected return on real surpluses absorbs changes in government portfolio risk.

The transmission mechanism of government portfolio risk to the expected surplus return can be decomposed into two terms,

$$\frac{\partial \mathrm{E}_t[r_{s,t+1}]}{\partial \Omega_t} = TP^{(2)} - \frac{1}{2}\frac{\partial\, \mathrm{var}_t(r_{g,t+1})}{\partial \Omega_t}. \tag{41}$$

The first term reflects the "direct" portfolio rebalancing effect on the conditional risk premium of the government portfolio, which depends only on the nominal term premium. The second term captures the nonlinear effect of portfolio rebalancing on the expected return. Note that there is no endogenous feedback effect from the term premium since nominal bond prices are insulated from debt maturity in the monetary regime.

Figure 2 plots the impulse response functions to a negative maturity shock ($\varepsilon_{\Omega,t} < 0$) to the debt-maturity process specified in equation (5). Three cases are considered: a positive nominal term premium (solid blue line), zero nominal term premium (dotted black line), and negative nominal term premium (dashed red line). As a qualitative illustration, the policy parameters are $\rho_\pi = 1.5$ and $\delta_b = 1.5$, and the price of risk parameter λ is calibrated separately to obtain the different term premiums. In the case of a positive nominal term premium, a surprise decline in the portfolio weight on the two-period bond reduces the expected return on the nominal government bond portfolio. The decrease in government portfolio risk is offset completely by a decrease in the expected return on real surpluses while insulating expected inflation. The

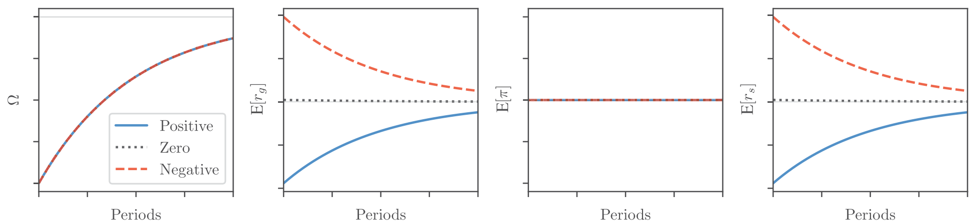

Figure 2. Maturity shock in the monetary regime. This figure plots the impulse response functions to a negative government debt-maturity shock ($\varepsilon_{\Omega,t} < 0$) in the monetary regime of the simple model for parameterizations in which the nominal term premium is positive (solid blue line), zero (dotted black line), and negative (dashed red line) for average debt maturity Ω_t, expected return on the nominal government bond portfolio $\mathrm{E}_t[r_{g,t+1}]$, expected inflation $\mathrm{E}_t[\pi_{t+1}]$, and expected return on real surpluses $\mathrm{E}_t[r_{s,t+1}]$. (Color figure can be viewed at wileyonlinelibrary.com)

effects are reversed when the term premium is negative and neutral when the term premium is zero.[5] A quantitative examination of this regime is explored in the general equilibrium model presented in Section II.

The risk transmission mechanism in the monetary regime operates through the real surplus claim, insulating the path of the price level from the government portfolio, which ensures that Wallace neutrality holds. In contrast, Wallace neutrality is violated in the fiscal regime in the presence of risk premia, as expected inflation absorbs changes in portfolio risk while the real surplus claim is insulated.

Overall, the policy regime dictates the precise risk transmission channel (i.e., expected inflation or the expected return on surplus), while the nominal term premium determines the sign of the effect. The key theoretical result of this paper is that the presence of bond risk premia in the fiscal theory allows government bond portfolio rebalancing to directly impact expected inflation, even in a frictionless economy. Portfolio rebalancing in the fiscal regime generates real effects (another type of deviation from Wallace neutrality) when the simple model is extended to a production economy with nominal frictions, which we consider in Section II.

H. Optimal Maturity Policy

This section shows how the portfolio risk transmission mechanism in the fiscal regime can influence the optimal management of debt maturity in the context of the simple model outlined above. We solve for the optimal conditional maturity policy when the social planner considers a trade-off between minimizing expected inflation and debt-maturity fluctuations around their respective target values, in a similar spirit to Cochrane (2001) and Sims (2013). The analysis here focuses on the fiscal regime because the path of inflation is

[5] Note that there is a small effect on the expected return to surplus and the expected government portfolio return when the nominal term premium is zero arising from the convexity term in equation (41).

independent of the government portfolio in the monetary regime. We show that the optimal conditional debt-maturity response to inflationary shocks depends on the conditional nominal term premium, giving rise to a state-dependent maturity rebalancing policy.

The objective of the planner is to minimize expected squared log inflation deviations from target inflation $\pi^\star$ and squared deviations of debt maturity from the target $\Omega^\star$ by choosing the optimal maturity policy $\widehat{\Omega}_t$,

$$\widehat{\Omega}_t = \arg\min_{\Omega_t} \mathrm{E}_t\Big[\big(\pi_{t+1} - \pi^\star\big)^2 + \omega\big(\Omega_t - \Omega^\star\big)^2\Big], \tag{42}$$

given that log inflation is generated by the solution presented in equation (34) and the law of motion for the state variable of the real pricing kernel z_t follows equation (1). The parameter $\omega > 0$ captures the relative importance of smoothing maturity deviations relative to inflation deviations. As maturity changes only impact expected inflation in the fiscal regime, the objective is specified in terms of expected inflation rather than realized inflation. In the general equilibrium model presented in Section II, expected inflation fluctuations impact welfare due to sticky prices. The quadratic portfolio adjustment term in the objective can be interpreted as a reduced-form way of capturing a trade-off between investors deriving monetary services from short-term debt, balanced against the refinancing risk faced by the government from rolling over short-term debt, as considered in Greenwood, Hanson, and Stein (2015). This portfolio adjustment term ensures an interior solution for the optimization problem.

The optimal debt-maturity policy $\widehat{\Omega}_t$ is characterized by the first-order condition

$$-\frac{\rho_\pi(\zeta_1\sigma)^2}{(1+\rho_\pi\widehat{\Omega}_t)^3} + \omega\big(\widehat{\Omega}_t - \Omega^\star\big) + \frac{\mathrm{E}_t[\pi_{t+1} - \pi^\star] \times TP_t^{(2)}}{(1+\rho_\pi\widehat{\Omega}_t)} = 0. \tag{43}$$

The derivation and details on the solution method are presented in Appendix A.D. Equation (43) highlights three effects of changing debt maturity. The first term on the left-hand side captures the impact of changing debt maturity on the conditional variance of log inflation. This term leads to an upward bias in optimal debt maturity because lengthening maturity dampens the response of the inflation innovations to shocks to z_{t+1} by redistributing the response of the price path to future periods. The second term reflects the penalty of debt maturity deviating from the target. These first two terms impact the average level of the optimal maturity policy but not the dynamics.

The final term in equation (43) depends on the state of the economy and captures the influence of the novel portfolio risk transmission mechanism in the fiscal theory on optimal debt maturity. This term generates a motive for dynamic portfolio rebalancing as a tool to smooth inflation expectations around the target. Suppose that there is an inflationary shock (i.e., a positive shock to z_t) that pushes expected inflation above the target. When the nominal term premium is positive, this last term implies that the optimal response is to reduce debt maturity, creating an opposing deflationary force against

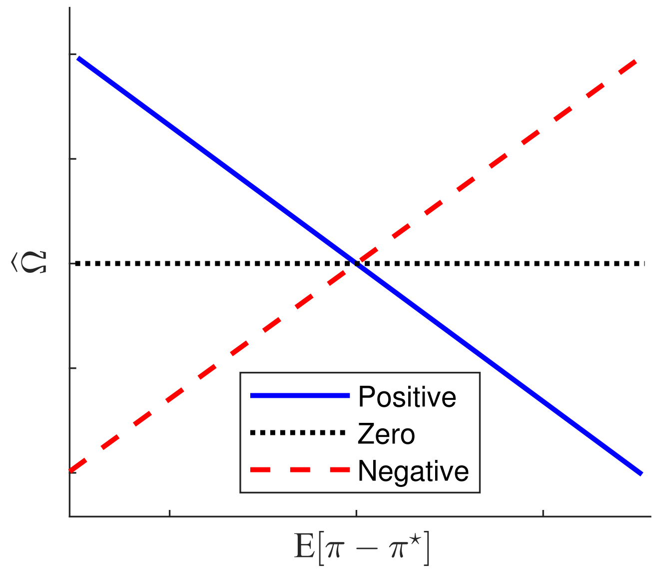

Figure 3. Optimal maturity in the fiscal regime. This figure plots the relation between the expected inflation deviation from target $\mathrm{E}[\pi - \pi^{\star}]$ and the optimal debt maturity $\widehat{\Omega}$ for parameterizations in which the nominal term premium is positive (solid blue line), zero (dotted black line), and negative (dashed red line). The plots are obtained by evaluating the policy functions for optimal debt maturity and expected inflation deviations from target across different values of the exogenous state variable z_t. Policy functions are centered around the steady state. (Color figure can be viewed at wileyonlinelibrary.com)

the inflationary shock to smooth expected inflation around the target. The intuition is that when expected bond returns are increasing by maturity, shortening maturity lowers the expected return on the nominal government bond portfolio, requiring an offsetting decline in inflation expectations to satisfy the intertemporal government budget equation. If, instead, a negative shock to z_t pushes expected inflation below target when expected bond returns are increasing by maturity, the optimal response is to increase maturity. Therefore, the optimal maturity policy is negatively related to expected inflation when the nominal term premium is positive.

Using similar logic as above, the relation between optimal maturity and expected inflation is positive when the nominal term premium is negative. The last term in equation (43) is zero when the nominal term premium is zero, implying a constant-maturity policy. The presence of nominal term premia in the fiscal regime allows the government portfolio to be a state-dependent tool for smoothing expected inflation deviations around the target. Figure 3 shows how the optimal conditional maturity policy depends on the nominal term premium and the state of the economy. We plot the relation between the expected log inflation deviations and the optimal maturity across different values of the exogenous state variable z_t that drives the stochastic fluctuations in this framework. For illustration purposes, the figure employs parameter values $\Omega^\star = 0.5$ and $\omega = 0.05$. The remaining parameter values are the same as in the numerical example of the fiscal regime in Section I.F.

II. Quantitative Model

This section integrates and quantifies the insights of the simple model in a New Keynesian model with several departures. First, the representative household has recursive preferences, which allows the model to generate sizeable bond risk premia endogenously. Second, we allow the monetary and fiscal policy mix to vary stochastically between monetary and fiscal regimes. Third, the government varies the supply of nominal debt across different maturities according to a stochastic process. Section IV.B extends the model to consider a state-dependent maturity rule. Differences in expected nominal bond returns across maturities in the presence of a fiscal regime imply that government portfolio rebalancing across maturities impacts expected inflation.

A. Households

The representative household has Epstein-Zin preferences defined over streams of consumption, C_t, and labor, L_t,

$$U_t = (1-\beta)\varrho_t u\big(C_t, L_t\big) + \beta \mathrm{E}_t \left[U_{t+1}^{\theta}\right]^{\frac{1}{\theta}}, \tag{44}$$

where γ is the coefficient of risk aversion, ψ is the elasticity of intertemporal substitution, and $\theta \equiv \frac{1-\gamma}{1-1/\psi}$ is a parameter defined for notational convenience. The time preference shocks are specified as in Albuquerque et al. (2016) with the log growth rate $x_{\varrho,t} \equiv \log(\varrho_{t+1}/\varrho_t)$ evolving as an autoregressive process, $x_{\varrho,t} = \rho_\varrho x_{\varrho,t-1} + \sigma_\varrho \varepsilon_{\varrho,t}$, where $\varepsilon_{\varrho,t}$ is a standard normal shock. The utility kernel is additively separable in consumption and leisure,

$$u\big(C_t, L_t\big) = C_t^{1-1/\psi}/(1-1/\psi) + \chi_0 N_t^{1-1/\psi}\big(\bar{L} - L_t\big)^{1-\chi}/(1-\chi), \tag{45}$$

where χ captures the Frisch elasticity of labor ε^F, $\chi_0 > 0$ is a scaling parameter, and $\bar{L}$ is the total time endowment. The component that captures the utility over leisure is scaled by the exogenous trend component in productivity, N_t, to ensure that this component does not become trivially small along the balanced growth path.

The objective of the household is to choose the sequences of C_t, L_t, and $\mathcal{B}_t$ that maximize lifetime utility subject to the budget constraint, $P_t C_t + \mathcal{B}_t = P_t D_t + W_t L_t + R_t^g \mathcal{B}_{t-1} - T_t$, where P_t is the aggregate price level, $\mathcal{B}_t$ is the market value of the portfolio of nominal government bonds, D_t represents the aggregate payout received from firms, R_t^g is the gross nominal interest rate on the bond portfolio, W_t is the nominal competitive wage, and T_t is the nominal lump-sum tax raised by the government.

B. Firms

Production in our economy consists of a final goods and an intermediate goods sector.

B.1. Final Goods

A representative firm produces final consumption goods, Y_t, in a perfectly competitive market. The firm uses a continuum of differentiated intermediate goods, X_{it}, as input in a constant elasticity of substitution (CES) production technology, $Y_t = (\int_0^1 X_{it}^{(\nu-1)/\nu} di)^{\nu/(\nu-1)}$, where ν is the elasticity of substitution between intermediate goods. The profit maximization problem of the final goods firm yields an isoelastic demand schedule, $X_{it} = Y_t(P_{it}/P_t)^{-\nu}$, where P_{it} is the nominal price of the intermediate goods i.

B.2. Intermediate Goods

The intermediate goods sector is characterized by a continuum of monopolistic firms. Each intermediate goods firm produces intermediate goods, X_{it}, using labor, L_{it}, with production technology $X_{it} = Z_t L_{it}$, where $\log(Z_t) = a_t + n_t$ represents log measured total factor productivity (TFP). The transitory component follows an autoregressive process, $a_t = \rho_a a_{t-1} + \sigma_a \varepsilon_{at}$. The trend component n_t contains a low-frequency growth component as in Croce (2014) and Kung and Schmid (2015),

$$\Delta n_t = \mu + x_{t-1}, \tag{46}$$

where $x_t = \rho_x x_{t-1} + \sigma_x \varepsilon_{xt}$. The shocks ε_{at} and ε_{xt} are correlated standard normal shocks with a contemporaneous correlation equal to ρ_{ax}, and μ is the unconditional mean of productivity growth.

The intermediate firms face a cost of adjusting their nominal price. Following Rotemberg (1982), the cost is assumed to be quadratic, $\frac{\phi_R}{2}(P_{it}/(\Pi^\star P_{it-1}) - 1)^2 Y_t$, where $\Pi^\star \geq 1$ is the gross risk-adjusted target inflation rate and ϕ_R dictates the magnitude of the costs. A firm's source-of-funds constraint is

$$D_{it} = (P_{it}/P_t)X_{it} - (W_t/P_t)L_{it} - (\phi_R/2)(P_{it}/(\Pi^\star P_{it-1}) - 1)^2 Y_t, \tag{47}$$

where D_{it} represents real firm payouts.

The objective of the firm is to choose a sequence of intermediate goods prices, P_{it}, and labor, L_{it}, to maximize the value of the firm, subject to the inverse demand for its product and the source-of-funds constraint. Taking the pricing kernel, M_t, as given and denoting the vector of aggregate state variables by $\Upsilon_t = (P_t, Z_t, Y_t)$, the firm's problem in recursive form is given by

$$V(P_{it-1}; \Upsilon_t) = \max_{P_{it}, L_{it}} \{D_{it} + \mathrm{E}_t[M_{t+1} V(P_{it}; \Upsilon_{t+1})]\} \tag{48}$$

subject to the demand schedule and source-of-funds constraint.

C. Government and Bond Supply

The government issues both short-term and long-term nominal bonds. The short-term bonds have a maturity of one period and promise payment of \$1 at maturity. The total nominal face value of short-term bonds outstanding at time t is given by $B_t^{(1)}$. The long-term bond has infinite maturity and pays coupons every period at a geometrically declining rate; that is, the coupon payment in period $t+1+j$ is $\$(1-\lambda)\lambda^j$, for $j = 0, \dots, \infty$. We denote the total nominal face value of the long-term bonds outstanding at time t by $B_t^{(L)}$. The prices of the short-term and long-term government bonds are determined by the equilibrium conditions $Q_t^{(1)} = \mathrm{E}_t[M_{t+1}^{\$}]$ and $Q_t^{(L)} = \mathrm{E}_t[M_{t+1}^{\$}(1-\lambda+\lambda Q_{t+1}^{(L)})]$, respectively, where $M_{t,t+j}^{\$} \equiv M_{t,t+j}/\Pi_{t,t+j}$ is the j-period nominal stochastic discount factor.

For parsimony, we abstract from government expenditures. Therefore, primary surpluses are equal to household lump-sum taxes. The flow consolidated budget equation of the government at time t that merges the sources and funds of the treasury and the central bank is

$$B_{t-1}^{(1)} + \left(1-\lambda+\lambda Q_t^{(L)}\right) B_{t-1}^{(L)} = S_t + Q_t^{(1)} B_t^{(1)} + Q_t^{(L)} B_t^{(L)}. \tag{49}$$

In each period, the government retires outstanding debt through surpluses and issues new liabilities to obtain a target maturity structure, which boils down to determining the fraction of debt financed by long-term bonds, $\Omega_t \equiv \mathcal{B}_t^{(L)}/(\mathcal{B}_t^{(1)} + \mathcal{B}_t^{(L)})$, where $\mathcal{B}_t^{(n)} \equiv Q_t^{(n)} B_t^{(n)}$ is the nominal market value of government bonds, for $n \in \{1, L\}$. The target maturity structure follows the autoregressive process

$$\Omega_t = (1-\rho_\Omega)\overline{\Omega} + \rho_\Omega \Omega_{t-1} + \sigma_\Omega \varepsilon_{\Omega,t}, \tag{50}$$

where $\varepsilon_{\Omega,t}$ is a standard normal shock and $\overline{\Omega}$ is the average of the maturity structure process.

D. Monetary and Fiscal Rules

This section describes the policy rules followed by the monetary and fiscal authorities. In contrast to the fixed coefficients in the simple model, the policy rules are allowed to vary over time by adding an index ζ_t to the parameters that determine the policy mix at time t.

The monetary authority sets the log nominal short rate, i_t, according to a Taylor rule that depends on inflation,

$$i_t - i^\star = \rho_i(i_{t-1} - i^\star) + (1-\rho_i)\rho_{\pi,\zeta_t}\left(\pi_t - \pi^\star\right) + \epsilon_{it}, \tag{51}$$

where $\pi^\star$ is a risk-adjusted log inflation target, $i^\star$ is the unconditional average of i_t, $\epsilon_{it} = \varphi_i \epsilon_{it-1} + \sigma_i e_{it}$ captures surprises to monetary policy, e_{it} is a standard normal shock, and the variables without time subscripts denote values in the deterministic steady state.

The fiscal authority adjusts the real primary surplus-to-output ratio, $s_t \equiv S_t/(P_tY_t)$, according to a rule that depends on lagged debt and inflation, similar to the specification from Cochrane (2020),

$$s_t - s^\star = \delta_{b,\zeta_t}\left(\tilde{b}_{t-1} - \tilde{b}^\star\right) + \delta_\pi\left(\pi_t - \pi^\star\right) + u_{ct} + u_{pt}, \tag{52}$$

where $s^\star$ is the unconditional mean of s_t, $\tilde{b}_t \equiv \log((\mathcal{B}_t^{(1)} + \mathcal{B}_t^{(L)})/P_tY_t)$ is the log of the debt-to-GDP ratio, $\tilde{b}^\star$ is the log of the debt-to-GDP target, and u_{ct} and u_{pt} are the surplus innovations.

We specify the surplus innovations to have an "S-shaped" moving-average representation following Cochrane (2001, 2020). The cyclical component, u_{ct}, is the business cycle shock to surpluses that follows the autoregressive process, $u_{ct} = \rho_c u_{ct-1} + \sigma_c \epsilon_{ct}$, where $\epsilon_{ct} \sim N(0,1)$. The persistent component, u_{pt}, follows an autoregressive process, $u_{pt} = \rho_p u_{pt-1} + \sigma_p \epsilon_{pt}$, where $\rho_p \gg \rho_c$ and the residual ϵ_{pt} is assumed to be negatively correlated with cyclical innovations ϵ_{ct} to deliver the S-shaped surplus dynamics (i.e., $\epsilon_{pt} = -\epsilon_{ct}$).[6] These surplus dynamics capture the observation that the government typically finances deficits in bad times by issuing new debt backed by promises of higher future surpluses.

The policy parameters ρ_{π,ζ_t} and δ_{b,ζ_t} determine the policy regime as described in the simple model. We assume that the policy mix alternates between monetary and fiscal regimes according to a two-state Markov chain following Bianchi and Ilut (2017) with the transition matrix

$$\mathcal{M} = \begin{pmatrix} p_{MM} & 1 - p_{FF} \\ 1 - p_{MM} & p_{FF} \end{pmatrix}, \tag{53}$$

where $p_{ij} \equiv \Pr(\zeta_{t+1} = i | \zeta_t = j)$ and M and F denote the monetary and fiscal regimes, respectively.

The full set of equilibrium conditions is listed in Appendix B.

III. Quantitative Analysis

This section quantifies the effects of the novel risk transmission mechanism for maturity shocks in the fiscal theory using the model presented in Section II. The model is calibrated to match key features in macroeconomic and bond pricing data. We also provide empirical support for the monetary and fiscal regimes by explaining key empirical moments in each regime. The model is solved using third-order Markov-switching perturbation methods, described in Appendix C.

[6] Cochrane (2001) shows that this surplus shock structure can be obtained endogenously from an optimal policy problem in which the government takes as given the cyclical shock and endogenously chooses the trend component ϵ_{pt} (jointly with debt maturity and the level of debt) to minimize inflation variance.

A. Data

This section describes the sources and construction of the data series used in the empirical evaluation of the model.

A.1. Debt-Maturity Structure

Data on all outstanding U.S. government bonds are obtained from the Center of Research in Security Prices (CRSP) historical bond database. Each month, CRSP reports the face value outstanding for every government bond issued with the associated bond characteristics, such as the issue date, coupon rate, and maturity. When the face value outstanding is missing in a given month, that observation is filled in with the face value outstanding at the end of the previous month.

A government bond is a portfolio of promised payments occurring at various dates in the future. Coupons are typically paid twice a year and the face value is paid at maturity. To account for the underlying maturity structure of payments, each of these payments is assigned to their due dates following Doepke and Schneider (2006). The maturity structure of government debt is constructed at a given date by aggregating cash flows across all individual bonds. In particular, the total nominal debt payment promised k years from time t is

$$\hat{B}_t^{(k)} = \sum_i CP_{it}^{(k)} + \sum_i FV_{it}^{(k)}, \tag{54}$$

where the first term on the right-hand side is the sum of all coupon payments due in k years and the second term is the sum of all face value outstanding expiring in k years.

CRSP also reports the quantity of marketable debt held by the public but these data are often incomplete or missing. As a result, we follow Hamilton and Wu (2012) and net out the Federal Reserve System Open Market Account (SOMA) Holdings from the maturity structure of face value outstanding. In particular, we obtain monthly FED holdings of Treasuries by maturity bin (less than 15 days, 16 to 90 days, 91 days to 1 year, 1 to 5 years, 5 to 10 years, and over 10 years) from the H41 release reports and evenly allocate these holdings across each monthly maturity falling within a broader maturity bin.[7] After subtracting Federal Reserve holdings from the total face value outstanding, we obtain our series on the monthly maturity structure of publicly held

[7] The data are available in table 2 of the H41 report, available at https://www.federalreserve.gov/releases/H41/default.htm. Data prior to 1990 are obtained from Kuttner (2006) and are available at https://www.sugarsync.com/pf/D64142_75919_698028. Data from 1990 to 2010 are obtained from Hamilton and Wu (2012) and are available at https://drive.google.com/open?id=1zFwtKmkPDVh2_Q6ivj9PiF-dpqmFXuTf. Note that we pool holdings of Treasuries with a maturity of less than 15 days and holdings of 16 to 90 days when allocating to the monthly maturity structure. In addition, we exclude Treasury Inflation-Protected Securities (TIPS) by assuming that the Fed holdings of TIPS as a fraction of the Fed's total holdings of notes and bonds are the same across all maturity categories as in Hamilton and Wu (2012).

nominal U.S. government bonds. When calculating the maturity structure of government debt, excess reserve balances with Federal Reserve banks are included as an obligation with zero maturity. Reserve balances are included in the maturity structure since they are backed by total government resources in the consolidated government budget equation (e.g., Reis (2019)). Moreover, the Fed started to pay interest on reserves starting on October 2008, making them similar to short-term government debt.[8]

Our empirical proxy for the average maturity structure (AMS) of government debt in market value is calculated as

$$AMS_t = \sum_{0\leq k\leq 40} \frac{Q_t^{(k)}\hat{B}_t^{(k)}}{\sum_{0\leq k\leq 40} Q_t^{(k)}\hat{B}_t^{(k)}} \times k, \tag{55}$$

where $Q_t^{(k)}$ is the price at time t of a \$1 zero-coupon bond with a maturity of k.

The monthly zero-coupon yield curve is obtained as follows. Prior to 1970, the term structure of one-period forward rates is used following the Waggoner (1997) cubic spline method as in Hall and Sargent (2011). For the post-1970 period, the nominal yield curves are computed following Gürkaynak, Sack, and Wright (2007). We supplement the yield curve for maturities of less than one year using the one- and three-month yields from the CRSP risk-free file and use linear interpolation to complete the monthly yield curve. Missing observations are filled in with the yield that has the closest maturity.

A.2. Other Macroeconomic and Asset Price Variables

Quarterly data for consumption and output are obtained from the Bureau of Economic Analysis (BEA). Consumption is measured as services plus nondurable goods consumption. Output is measured as real gross domestic product. Inflation is computed by taking the log return of the Consumer Price Index for All Urban Consumers. TFP comes from the utilization-adjusted series constructed in Fernald (2014). Monthly yield data are from CRSP. Nominal yield data for maturities of 1, 2, 4, 8, 12, 16, and 20 quarters are from the CRSP Fama-Bliss discount bond file and the Board of Governors of the Federal Reserve System. Inflation expectations are from the Survey of Professional Forecasters (SPF) available from the Federal Reserve Bank of Philadelphia.

A.3. Regime Periods

The unconditional data moments are computed over the period 1957Q1 to 2020Q4. To compute statistics conditional on the monetary and fiscal regimes, we use the regime periods identified in Bianchi and Ilut (2017) using structural

[8] Indeed, Cochrane (2014) points out that when reserves pay interest, there is no difference between interest-paying reserves and short-term Treasury bills held directly by the public because banks can always use short-term Treasuries to create excess reserves.

Table I
Calibration

This table reports the parameter values used in the quarterly calibration of the quantitative model and described in Section III.B. The table is divided into four categories of parameters: Preferences, Production, Policy, and Bond Supply.

Parameter	Value	Parameter	Value
Panel A: Preferences			
β	0.998	γ	10
ρ_ϱ	0.95	ε^F	0.25
σ_ϱ	0.04%	$L/\bar{L}$	1/3
ψ	1.23		
Panel B: Production			
ν	4	σ_a	0.80%
ϕ_R	30	ρ_x	0.99
μ	0.28%	σ_x	0.005%
ρ_a	0.90	ρ_{ax}	0.95
Panel C: Policy			
$\pi^\star$	3.60%/4	$\delta_b(M/F)$	0.07/0
$\rho_\pi(M/F)$	1.80/0.85	p	0.99
ρ_i	0.66	ρ_c	0.65
σ_i	0.41%	σ_c	1.67%
φ_i	0.11	ρ_p	0.94
δ_π	1.30	σ_p	0.20%
Panel D: Bond Supply			
$\bar{b}/4$	0.57	ρ_Ω	0.95
λ	0.96	σ_Ω	0.05
$\bar{\Omega}$	0.79		

estimation on the post-World War II period. The fiscal regime spans the period 1957Q1 to 1979Q3. The monetary regime covers the period 1981Q4 to 2008Q2. Bianchi and Melosi (2017) identify the period after 2008Q3 as a distinct fiscal regime in which the ELB binds. In Section IV.A, we examine this type of regime in a model extension that incorporates an ELB constraint. The 1979Q4 to 1981Q3 period is identified as a regime of conflict between the monetary and fiscal authorities that is not analyzed separately because it is outside of the regimes considered in our model.

B. Calibration

Table I presents the quarterly calibration. Panel A reports the values for the parameters related to preferences. The elasticity of intertemporal substitution (ψ) is set to 1.23 and the coefficient of relative risk aversion (γ) is set to 10, both of which are within the range of standard values in the long-run risks literature (e.g., Bansal and Yaron (2004)). The time discount factor (β) is calibrated to be consistent with the level of the real short rate. The persistence of the preference shock (ρ_ϱ) is used to match the first autocorrelation of the real rate, and the volatility of the preference shock (σ_ϱ) is set to generate a positive real term premium (e.g., Albuquerque et al. (2016)). The parameters χ and χ_0 are calibrated such that the labor supply is one-third of the household's time endowment and imply a Frisch elasticity consistent with estimates from the microeconomics literature (e.g., Pistaferri (2003)).

Panel B reports the calibration of the parameters related to production and price-setting. The price elasticity of demand (ν) is set to four, implying a price markup in the steady state of 33%, in line with the evidence in De Loecker, Eeckhout, and Unger (2020). The price-adjustment cost parameter (ϕ_R) is calibrated to be within the range of values used in the literature (Kung (2015)). The mean growth productivity rate (μ) is set to match the average TFP growth in the data. The parameters dictating the cyclical dynamics of productivity (ρ_a and σ_a) are set to be in a ballpark range of the standard deviation and persistence of realized consumption growth. The parameters governing the dynamics of the trend component of productivity (ρ_x and σ_x) are calibrated to be consistent with the expected consumption growth dynamics from Bansal and Yaron (2004). The correlation parameter between the cyclical and trend shocks (ρ_{ax}) is set to 0.95 to match the endogenous relation generated in the innovation-based growth models of Kung (2015) and Kung and Schmid (2015).[9]

Panel C describes the calibration of the policy rule parameters. Target inflation ($\pi^\star$) is chosen to match average inflation. The inflation coefficient of the interest rate rule (ρ_π) in the monetary regime is calibrated to a value consistent with the estimates from Bianchi and Melosi (2017), while we set the inflation coefficient in the fiscal regime to a similar value as in Cochrane (2020). The debt coefficient on the surplus rule (δ_b) is calibrated to be consistent with the estimates from Bianchi and Ilut (2017). The persistence and volatility parameters associated with the interest rate rule (ρ_i and σ_i) are calibrated to values from Kung (2015). The persistence of the monetary policy shock φ_i is set within the range of estimates from Smets and Wouters (2007). Following Bianchi and Ilut (2017), the transition matrix governing the dynamics of the policy mix is assumed to be symmetric, $p_{MM} = p_{FF} \equiv p$, and is equal to 0.99. The inflation coefficient of the surplus rule is set to be consistent with the conditional inflation volatility across the policy regimes.

The surplus innovations are calibrated to match the unconditional surplus and inflation dynamics. The cyclical surplus shock parameters (ρ_c and σ_c) are set to explain the first autocorrelation and standard deviation of surplus changes, while the persistent surplus shock parameters (ρ_p and σ_p) are calibrated to match the first autocorrelation and standard deviation of infla-

[9] A strong positive correlation between trend and cycle components of TFP help generate sizable inflation risk premia, as discussed in Kung (2015). We find that the results for the yield curve hold for a range of parameter values for ρ_{ax} between 0.85 and 1.

Table II

Summary Statistics

This table presents summary statistics for key variables in the model as well as corresponding moments in the data. Panel A reports unconditional means. Panel B reports unconditional standard deviations. The reported statistics are annualized. The sample period for data moments is 1957Q1 to 2020Q4.

	Data	Model
Panel A. First Moments		
E(term premium)	1.30%	1.39%
E(inflation)	3.51%	3.55%
E(TFP growth)	1.08%	1.08%
E(AMS) (in years)	3.49	3.63
Panel B. Second Moments		
σ(term premium)	2.38%	0.91%
σ(consumption growth)	2.11%	2.16%
σ(inflation)	1.59%	1.54%
σ(change in surplus-to-GDP)	3.66%	3.65%
σ(TFP growth)	1.61%	1.63%
σ(output growth)	2.27%	2.22%
σ(labor hours growth)/σ(output growth)	0.65	0.85
σ(AMS) (in years)	0.68	0.73
$AC1$(inflation)	0.60	0.56
$AC1$(change in surplus-to-GDP)	−0.23	−0.21

tion. The surplus dynamics are transmitted to inflation with the presence of the fiscal regime. The negative correlation between the cyclical and persistent components described in Section II.D produces the S-shaped surplus dynamics highlighted in Cochrane (2001, 2020). These dynamics help explain surplus and inflation volatility jointly. The cyclical component hedges the persistent component of surpluses to stabilize the present value of surpluses, thereby smoothing inflation dynamics in the fiscal regime.

Panel D reports the calibration for the supply of bonds. We set the target steady-state debt-to-GDP ratio using the parameter $\bar{b} \equiv \exp(\tilde{b}^{\star})$ to be consistent with the empirical average. The dynamics of the bond portfolio weight are calibrated to target salient features of the empirical bond duration measure defined in equation (55). The parameter $\overline{\Omega}$ is used to match the average duration of the government bond portfolio. The value for the coupon decay rate (λ) implies that the average duration of the long-term bond is around five years. The parameters ρ_{Ω} and σ_{Ω} are calibrated to explain the persistence and volatility of bond duration.

Overall, the model produces realistic macroeconomic dynamics and bond risk premia, as evidenced in the summary statistics reported in Table II.

C. Term Structure of Interest Rates

The term structure of interest rates dictates the transmission of maturity operations in the fiscal theory. As we show in the simple model above, the effect of debt maturity changes on expected inflation depends explicitly on the nominal term premium in the fiscal regime. Therefore, to discipline the quantitative effects of maturity shocks (considered in Section III.D), it is important that our model generates a realistic term structure of interest rates. The first part of this section presents the unconditional term structure results to illustrate the key mechanisms for generating a sizable nominal term premium. We then demonstrate how our model is consistent with term structure facts conditional on the monetary and fiscal policy regimes.

C.1. Unconditional Analysis

Table II shows that the unconditional mean of the five-year nominal term premium is in line with the analogous empirical moment over the entire sample. The nominal term premium in the data is computed by first regressing the excess five-year minus one-year bond return on the Cochrane and Piazzesi (2005) factor. The fitted values from this regression are then used as our measure of the nominal term premium. Term premia variation in the model is driven mainly by the policy regime changes, which explains around 40% of the observed variability in the data. Extending the model with stochastic volatility in the structural shocks can help explain the dynamics of the term premia more closely. Panel A of Table III reports the unconditional mean, standard deviation, and first autocorrelation of nominal yields for maturities of one quarter to five years in both the model and the data. The model can explain the mean and volatility of the five-year minus one-quarter nominal yield spread, reported in the final column.

The sizable nominal term premium and average yield spread arise through supply- and demand-based mechanisms. The positive relation between the stationary and trend productivity shocks contributes to a positive inflation risk premium. A good technology shock simultaneously increases expected consumption growth through the trend component and increases the marginal product of labor through the stationary component. The increase in the marginal product of labor is large enough to offset the higher real wages induced by the wealth effect from the higher trend component so that real marginal costs decline. Since equilibrium inflation is related to the present value of current and future marginal costs (at the first order), lower marginal costs imply lower inflation. In sum, the technology shock structure produces a negative relation between inflation and expected consumption growth. When the agent prefers early resolution of uncertainty ($\gamma > 1/\psi$), low expected growth states are associated with high marginal utility. Also, persistently higher inflation erodes the real payoff of long nominal bonds more than short nominal bonds, implying that long nominal bonds are riskier than short ones.

Table III

Term Structure of Interest Rates

This table reports unconditional term structure statistics in the model and the data. Panel A presents the mean, standard deviation, and first autocorrelation of the one-quarter and one-, two-, three-, four-, and five-year yields as well as the five-year minus one-quarter spread for nominal yields. Panel B presents the slope coefficient, standard error, and R^2 for inflation forecasts of one-, four-, and eight-quarter horizons using the five-year nominal yield spread. The n-quarter regressions, $\frac{1}{n}(x_{t,t+1} + \cdots + x_{t+n-1,t+n}) = \alpha + \beta(y_t^{(5)} - y_t^{(1Q)}) + \varepsilon_{t+1}$, are estimated using overlapping quarterly data, and Newey-West standard errors are used to correct for heteroskedasticity. All moments are annualized. The sample period for data moments is 1957Q1 to 2020Q4.

Panel A: Unconditional Moments

	Maturity						
Nominal Yields	1Q	1Y	2Y	3Y	4Y	5Y	5Y−1Q
Mean (Model) (in %)	4.77	4.96	5.23	5.44	5.62	5.76	0.98
Mean (Data) (in %)	4.35	4.82	5.01	5.19	5.35	5.45	1.10
Std (Model) (in %)	2.44	2.16	1.91	1.71	1.54	1.39	1.25
Std (Data) (in %)	3.10	3.24	3.21	3.14	3.08	3.01	1.01
AC1 (Model)	0.90	0.93	0.94	0.94	0.95	0.95	0.79
AC1 (Data)	0.95	0.96	0.97	0.97	0.98	0.98	0.73

Panel B: Inflation Forecasts

	Data			Model		
	Horizon (in Quarters)					
	1	4	8	1	4	8
β	−1.04	−0.81	−0.53	−0.63	−0.72	−0.63
S.E.	0.23	0.32	0.31	0.16	0.18	0.18
R^2	0.11	0.09	0.05	0.08	0.16	0.17

The persistent time preference shocks contribute positively to the real term premium and the inflation risk premium. A negative time preference shock makes households more impatient to consume today, reducing the wealth-to-consumption ratio and the return on the consumption claim. When the agent prefers an early resolution of uncertainty, a lower return on consumption raises marginal utility. Higher impatience also drives up the real rate persistently, eroding the value of long real bonds more than short real bonds in high-marginal-utility states. In contrast, the productivity growth shocks generate negative comovement between marginal utility and the real rate, making long real bonds a better hedge asset against long-run risks. The preference shocks are calibrated to be large enough to offset the hedging effects of long real bonds, ensuring a positive real term premium. The negative time preference shock also increases aggregate demand, creating higher inflation. As such, the time preference shocks also generate positive comovement between inflation and marginal utility, making longer-maturity nominal bonds riskier.

Panel B illustrates that the model can reproduce the well-established empirical fact that the slope of the nominal yield curve forecasts future inflation at business cycle frequencies. The interest rate rule plays an important role in these forecasting regressions. Suppose that inflation falls persistently today, and the monetary authority responds by lowering the short rate. A temporary decrease in the short rate steepens the slope of the yield curve. The responsiveness of the interest rate rule to inflation deviations controls the degree of predictability in the inflation forecasting regressions.

Tables II and III together demonstrate that the model provides a reasonable depiction of the unconditional term structure of interest rates and macroeconomic dynamics. The next section explores key bond pricing and macroeconomic statistics conditional on the monetary and fiscal regimes.

C.2. Conditional Analysis

The first two rows of Table IV, Panel A, report the mean and standard deviation of the nominal five-year term premium, conditional on the monetary and fiscal regimes. The model can explain the higher term premium in the monetary regime. The differences in bond risk premia between the regimes in the model are explained next by analyzing the macroeconomic dynamics conditional on each regime.

The next three rows of Panel A display the standard deviation of inflation, consumption growth, and output growth. The model can reproduce the higher macroeconomic volatility in the fiscal regime observed in the data. The inflation path primarily absorbs the effects of fiscal disturbances (i.e., surplus and maturity shocks) in the fiscal regime, leading to higher inflation volatility. The presence of nominal rigidities transmits fiscal shocks to the real economy. The monetary regime is mostly insulated from fiscal disturbances through offsetting surplus adjustments. While macroeconomic volatility is higher in the fiscal regime, recall that the nominal term premium is lower. Passive monetary policy in the fiscal regime weakens the negative correlation between the time preference shock and inflation, which dominates the effect of higher macro volatility to reduce inflation risk premia. The correlation between the time preference shock and inflation is -0.52 in the monetary regime and -0.20 in the fiscal regime. The final row shows that the model is consistent with the standard deviation of the changes in the debt-to-GDP ratio.

Panel B reports the standard deviation of inflation news, the standard deviation of nominal yield innovations, and the inflation variance ratio for maturities of one, two, and three quarters, with the empirical moments computed following Duffee (2018). Inflation expectations are computed in the data using the consensus forecasts (i.e., mean forecasts across respondents) from the SPF.[10] Inflation news at time t is computed as the difference between the consensus inflation predictions at time t and those at time $t-1$ over the same

[10] The SPF provides inflation expectations over horizons ranging from one to four quarters, at the quarterly frequency, starting in 1968Q4. We lose one quarter because we are interested in the

Table IV

Conditional Statistics

This table reports statistics conditional on the policy regimes. Panel A presents the average term premium followed by the standard deviations of the term premium and other key macro variables. Panel B reports the standard deviation of inflation news and yield innovations and the corresponding inflation variance ratios for horizons ranging from one to three quarters. Inflation news and yield innovations are obtained following the methodology in Duffee (2018). The sample period for data moments is 1957Q1 to 1979Q3 for the fiscal regime and 1981Q4 to 2008Q2 for the monetary regime. The sample period for the fiscal regime is 1968Q4 to 1979Q3 in Panel B because of the availability of the SPF survey data used to compute inflation expectations.

Panel A: Conditional Moments

	Data		Model	
	Monetary	Fiscal	Monetary	Fiscal
E(term premium)	2.27%	0.86%	2.06%	0.84%
σ(term premium)	2.28%	1.92%	0.76%	0.69%
σ(inflation)	0.98%	1.66%	1.04%	1.61%
σ(consumption growth)	1.09%	1.19%	1.98%	2.35%
σ(output growth)	1.23%	2.14%	1.95%	2.35%
σ(change in debt-to-GDP)	2.06%	1.78%	1.73%	1.66%

Panel B: Variance Ratios

	Data		Model	
	Monetary	Fiscal	Monetary	Fiscal
One Quarter				
σ(inflation news)	0.30	0.59	0.64	1.04
σ(yield innovations)	0.69	0.85	0.80	1.11
Variance ratios	0.19	0.47	0.64	0.88
Two Quarter				
σ(inflation news)	0.28	0.55	0.48	0.77
σ(yield innovations)	0.68	0.86	0.68	0.99
Variance ratios	0.18	0.41	0.50	0.61
Three Quarter				
σ(inflation news)	0.26	0.47	0.40	0.63
σ(yield innovations)	0.67	0.84	0.61	0.89
Variance ratios	0.15	0.31	0.43	0.50

horizon. Yield innovations are obtained as the residuals from regressing the future changes in yields on one to four-quarter yields as in Duffee (2018).[11]

The maturity and surplus shocks in the model help generate higher inflation variance ratios in the fiscal regime relative to the monetary regime, with the surplus shocks being quantitatively more important. These fiscal dis-

change in the inflation forecast for a given future period. Outliers are discarded as in Bansal and Shaliastovich (2013).

[11] For robustness, we also looked at a specification in which yields follow martingales so that yield innovations are defined as the change in yields for a given horizon (e.g., Duffee (2002)). The results are quantitatively similar.

Table V

Bond Return Predictability

This table presents the slope coefficient, standard error, and R^2 for forecasts of one-year excess returns on bonds of maturities of two to five years using the Cochrane-Piazzesi factor. First, the factor is obtained by running the regression $\frac{1}{4}\sum_{n=2}^{5} rx_{t+1}^{(n)} = \gamma'\mathbf{f}_t + \bar{\epsilon}_{t+1}$, where $\gamma'\mathbf{f}_t \equiv \gamma_0 + \gamma_1 y_t^{(1)} + \gamma_2 f_t^{(2)} + \cdots + \gamma_5 f_t^{(5)}$. Second, use the factor $\gamma'\mathbf{f}_t$ obtained in the previous regression is used to forecast bond excess returns of maturity n, $rx_{t+1}^{(n)} = \beta^{(n)}(\gamma'\mathbf{f}_t) + \epsilon_{t+1}^{(n)}$. The forecasting regressions use overlapping quarterly data, and Newey-West standard errors are used to correct for heteroskedasticity.

	Data				Model			
	Maturity (in Years)							
	2	3	4	5	2	3	4	5
$\beta^{(n)}$	0.44	0.86	1.25	1.45	0.54	0.92	1.18	1.36
S.E.	0.09	0.16	0.22	0.26	0.12	0.21	0.28	0.33
R^2	0.23	0.26	0.28	0.24	0.08	0.08	0.08	0.07

turbances are absorbed primarily by expected inflation in the fiscal regime, while they are absorbed primarily by expected surplus adjustments in the monetary regime. Passive monetary policy in the fiscal regime further dampens short-rate response to inflationary shocks compared to the monetary regime. The monetary policy and stationary TFP shocks are most important for reducing inflation variance ratios, as these shocks move yield innovations substantially more than inflation news. The time preference and TFP growth shocks both have a similar impact on yield innovations and inflation news. The section below explores the transmission of maturity shocks in this model.

Our model overshoots on the magnitude of the inflation variance ratios for many of the reasons highlighted in Duffee (2018). First, the large value for the intertemporal elasticity of substitution implies that the real short rate does not vary much with respect to expected consumption growth, contributing to a small news component for future real rates. Second, the stagflation risk (arising from productivity shocks) generates a negative correlation between news about future real rates and inflation. Consequently, yield innovations respond significantly less to productivity shocks relative to inflation innovations. Third, term premia variation falls short of its empirical counterparts (documented in Panel B of Table II), further contributing to higher inflation variance ratios from our model compared to the data.

The analysis conducted in Table IV illustrates how the nominal term premium depends on the policy regimes. The policy stance had a significant impact on the comovement between inflation and the preference shock, impacting inflation risk premia. We next show that the persistent regime changes can be a source of time-varying bond risk premia. Table V reports excess bond return forecasts using a linear combination of forward rates for maturities of two to five years as in Cochrane and Piazzesi (2005). The model reproduces the increasing patterns in the slope coefficients across maturities.

Overall, the model provides a reasonable account of bond yields and macroeconomic fluctuations conditional on the policy regimes. Explaining the wide range of bond pricing statistics described above is important for disciplining the quantitative evaluation of the risk transmission mechanisms for maturity operations. Indeed, we showed in the simple model how the effects of maturity operations depend explicitly on the nominal term premium. The next section explores the impact of surprises to debt maturity on the macroeconomy and bond prices conditional on the fiscal and monetary regimes.

D. Maturity Shocks

The transmission of government portfolio risk arising from debt-maturity surprises depends on the policy regime. The simple model demonstrates in a frictionless economy with fixed regimes how portfolio risk is absorbed through distinct economic channels. In the fiscal (monetary) regime, adjustments in the path of inflation (real surpluses) fully offset changes in portfolio risk. However, with regime changes, the deviations from Wallace neutrality in the fiscal regime are propagated to the monetary regime through agents' expectations. The expected inflation adjustments to portfolio shocks also affect real rates and output in the quantitative model due to sticky prices.

Figure 4 plots impulse response functions of a negative shock ($\varepsilon_{\Omega,t} < 0$) to the debt-maturity process specified in equation (50). The blue line corresponds to the response conditional on the fiscal regime and the dashed line corresponds to the response conditional on the monetary regime. The maturity shock used in the responses is calibrated to match the impact of the quantitative easing programs on average debt maturity, computed in the model according to the empirical AMS measure defined in equation (55). Specifically, the first three rounds of quantitative easing reduced average maturity (AMS) by 0.73 years.[12] As the average nominal term premium is positive in both regimes, tilting the bond portfolio weight to shorter maturities reduces the expected return on the nominal government bond portfolio. The decline in the expected portfolio return is larger in the monetary regime as the nominal term premium is larger than that in the fiscal regime.

Satisfying the expected government return identity, $\mathrm{E}_t[r_{g,t+1}] = \mathrm{E}_t[\pi_{t+1}] + \mathrm{E}_t[r_{s,t+1}]$, requires that the decrease in the expected portfolio return produces a compensating reduction in expected inflation or the expected return on real surpluses. In the simple model without regime changes, the risk transmission mechanisms are distinct between the two regimes. However, with stochastic and recurrent regime changes, both the expected inflation and surplus channels absorb portfolio risk since there is a possibility of transitioning between the two policy regimes. Given that the unconditional probability

[12] We compute the change in maturity with a start date at the onset of the financial crisis (2007Q4) and an end date in 2013Q4 when the Fed started tapering QE3.

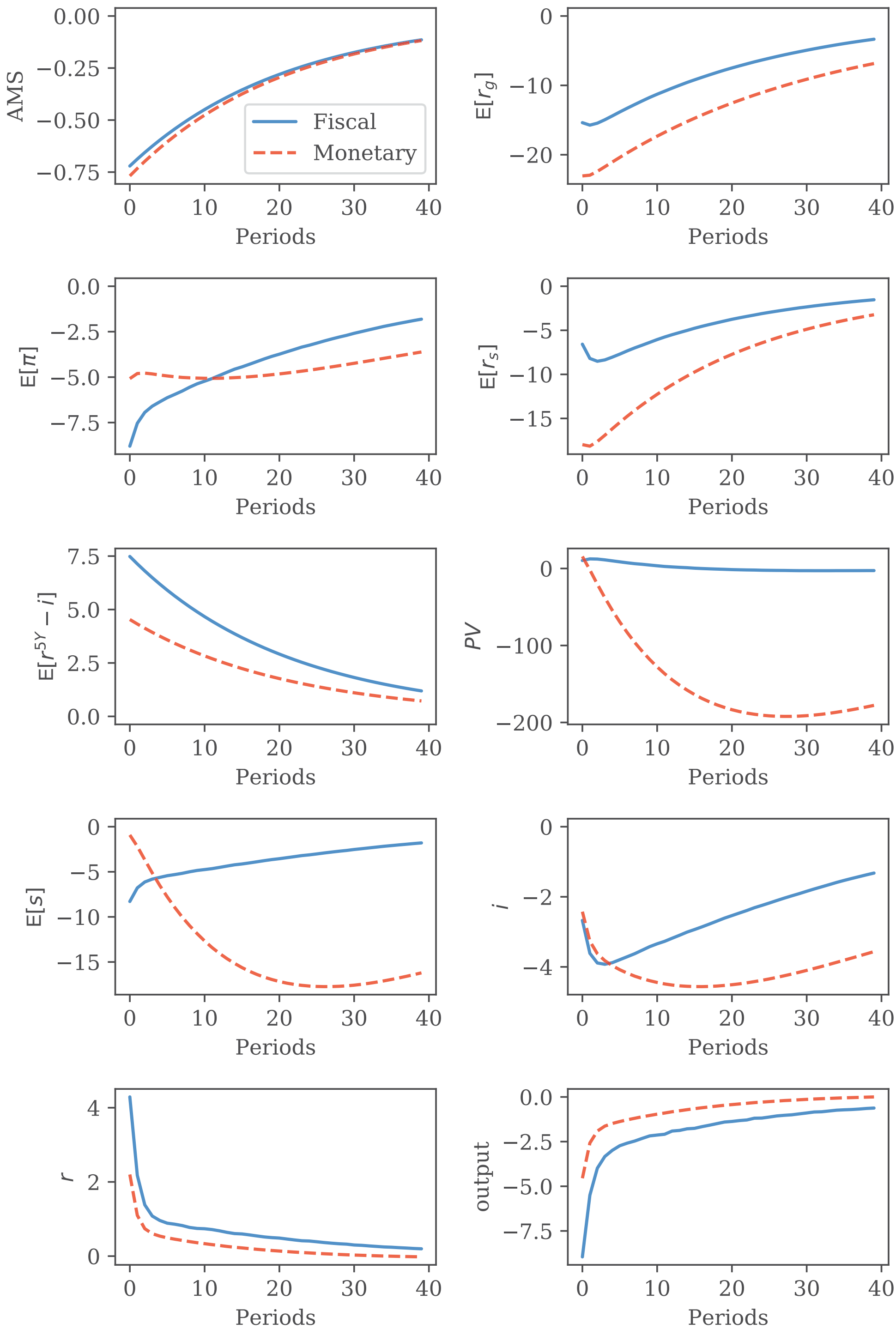

Figure 4. Maturity shortening in different regimes. This figure plots the impulse response functions to a negative shock to debt maturity ($\varepsilon_{\Omega,t} < 0$) displayed in years, conditional on the fiscal

and monetary regimes. $\mathrm{E}[r_g]$ is the expected nominal portfolio return, $\mathrm{E}[\pi]$ is expected inflation, $\mathrm{E}[r_s]$ and PV are the expected return and present value of real surpluses, $\mathrm{E}[s]$ is the expected surplus, $\mathrm{E}[r^{5Y} - i]$ is the term premium, and i (r) is the nominal (real) short rate. The units on the y-axis are annualized basis point deviations from the steady state. (Color figure can be viewed at wileyonlinelibrary.com)

of regime changes is small, the main insights from the simple model carry over, as evidenced in the impulse responses. Portfolio risk is absorbed primarily by expected inflation (expected return on surplus) in the fiscal (monetary) regime.

We focus on describing the remaining responses conditional on the fiscal regime, given that the impact of maturity shocks on prices and the real economy in the monetary regime is attributed to the possibility of entering the fiscal regime. The decrease in expected inflation leads to a decline in the expected path of the nominal short rate due to the interest rate rule. Due to sticky prices in the quantitative model, the drop in nominal goods prices is sluggish so that prices are temporarily too high (relative to the flexible price case), leading to a contraction in aggregate demand as reflected in a decrease in output and an increase in the real short rate. The decline in the real discount rate on real surpluses dominates that in expected surpluses so that the present value of real surpluses increases in the fiscal regime. Also, the increase in the nominal term premium from shortening maturity is consistent with the predictions from the simple model. Overall, these responses highlight potential unintended consequences of quantitative easing programs not accounted for in standard models.

Figure 5 plots the impulse response functions for the same negative maturity shock in the model for the five-year nominal yield innovation with the corresponding news components of inflation, real rates, and excess returns for the fiscal regime (solid blue line) and the monetary regime (dashed red line). This figure shows how inflation news drops significantly more than the nominal yield innovation in the fiscal regime, providing a visual depiction of how the model produces higher inflation variance ratios in the fiscal regime described in Section C.2 above. Surplus shocks also affect inflation news comparatively more than yield innovations like maturity shocks. Expected inflation primarily absorbs such fiscal disturbances to government cash flows or discount rates in the fiscal regime. Refinancing at shorter maturities under a positive nominal term premium reduces the nominal government discount rate, leading to a drop in expected inflation that revalues the nominal debt portfolio to ensure that the intertemporal government budget equation is satisfied. Excess return news also increases in response to the maturity shortening, consistent with predictions of the simple model. The presence of sticky prices allows the maturity shock to affect the real rate. In the monetary regime, the path of real surpluses mostly offsets the portfolio risk, resulting in a weaker expected response to inflation news.

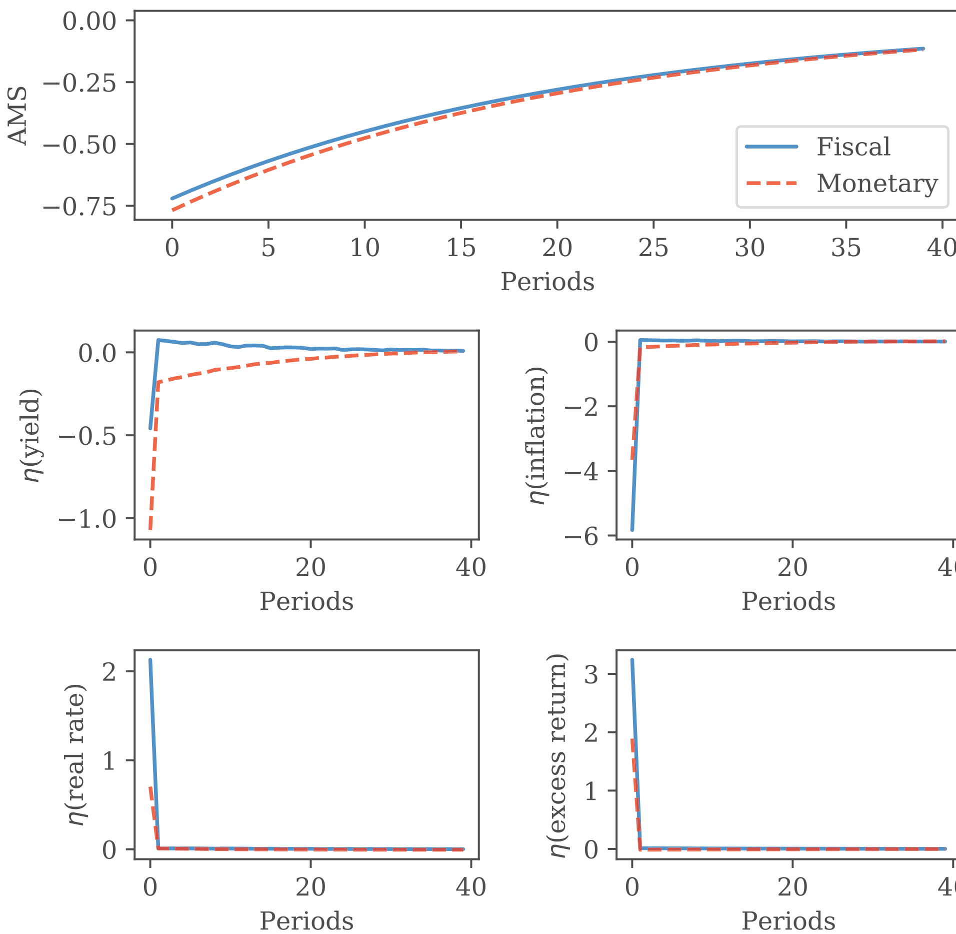

Figure 5. News decomposition of yield innovations. This figure plots the impulse response functions to a negative shock to debt maturity ($\varepsilon_{\Omega,t} < 0$) displayed in years, conditional on the fiscal and monetary regimes for the five-year nominal yield innovation with the corresponding news components of inflation, real short rates, and excess returns. The units on the y-axis are annualized basis point deviations from the steady state. (Color figure can be viewed at wileyonlinelibrary.com)

IV. Additional Analysis

This section considers two extensions of the quantitative model. The first extension is to incorporate an ELB constraint. The second extension considers a reduced-form debt-maturity rule that is state-dependent with a specification that is motivated by the optimal policy obtained from the simple model.

A. Effective Lower Bound

The ELB on nominal interest rate constraint played a prominent role after the Great Recession that provided an impetus for quantitative easing

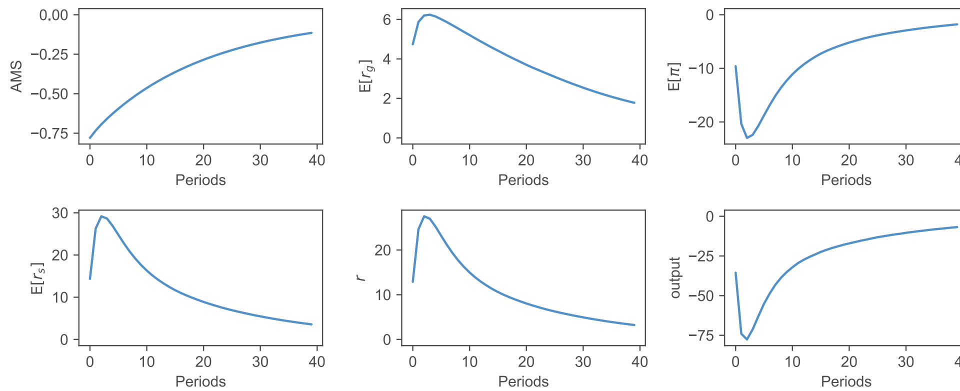

Figure 6. Effective lower bound. This figure plots the difference in impulse response functions to a negative shock to debt maturity ($\varepsilon_{\Omega,t} < 0$), conditional on the fiscal regime with a binding ELB and the fiscal regime without a binding ELB. AMS is the average maturity structure, E[r_g] is the expected nominal portfolio return, E[π] is expected inflation, E[r_s] is the expected return on real surpluses, r is the real short rate. The units on the y-axis of the AMS plot are in years and not difference between the two models. The remaining plots are in annualized basis points. (Color figure can be viewed at wileyonlinelibrary.com)

programs. This section examines how the presence of a binding ELB constraint impacts the risk transmission of maturity shocks. We approximate the ELB as a separate fiscal policy regime in which the nominal short rate is zero following Bianchi and Melosi (2017). We again assume stochastic regime changes. We focus on the fiscal regime for the ELB in our analysis given that Bianchi and Melosi (2017) identify the period after 2008Q3 as a fiscal regime with a binding ELB constraint. Figure 6 plots the difference in the impulse responses of a negative maturity shock ($\varepsilon_{\Omega,t} < 0$) between the fiscal ELB regime and the fiscal regime without a binding ELB. The binding ELB redistributes the timing of the inflation response to the nearer term. The sharper inflation drop generates a larger increase in the real rate and a larger contraction in output. In sum, maturity operations at the ELB distort the timing of the expected inflation responses.

B. State-Dependent Maturity Rules

This section augments the exogenous maturity rule from the quantitative model to include a component that depends on the state of the economy. Motivated by the optimal maturity rule from Section I.H characterized in Figure 3, the maturity target $\widetilde{\Omega}_t$ is specified to depend on expected inflation deviations,

$$\widetilde{\Omega}_t = \zeta_\pi E_t\left[\pi_{t+1} - \pi^\star\right] + \Omega_t, \tag{56}$$

where ζ_π captures the responsiveness of debt maturity to expected inflation deviations and the exogenous component, $\Omega_t = (1-\rho_\Omega)\overline{\Omega} + \rho_\Omega\Omega_{t-1} + \sigma_\Omega\varepsilon_{\Omega,t}$, follows an autoregressive process. The case in which $\zeta_\pi = 0$ corresponds to the

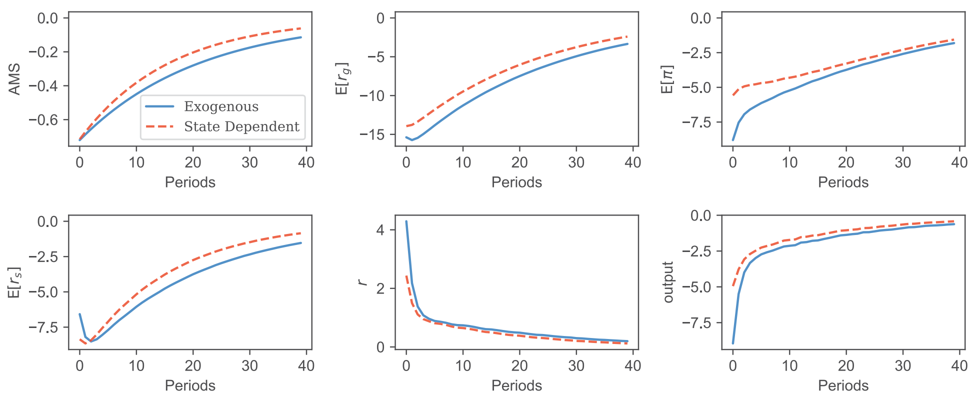

Figure 7. State-dependent maturity rule. This figure plots the impulse response functions to a negative shock to debt maturity ($\varepsilon_{\Omega,t} < 0$), conditional on the fiscal regime for the benchmark exogenous maturity process (solid blue line) and for the maturity rule that depends on expected inflation deviations (dashed red line). E[r_g] is the expected nominal portfolio return, E[π] is expected inflation, E[r_s] is the expected return on real surpluses, and r is the real short rate. The units on the y-axis are annualized basis point deviations from the steady state, except for AMS, which is in years. (Color figure can be viewed at wileyonlinelibrary.com)

benchmark specification from the quantitative model above with a strictly exogenous maturity target. Given a positive nominal term premium, the optimal debt maturity policy in the simple model is negatively related to expected inflation deviations ($\zeta_\pi < 0$).

Figure 7 compares the impulse responses of a negative maturity shock ($\varepsilon_{\Omega,t} < 0$) for the exogenous maturity rule ($\zeta_\pi = 0$), corresponding to the solid blue line, and the maturity rule that is state-dependent ($\zeta_\pi < 0$), corresponding to the dashed black line. The coefficient ζ_π in the state-dependent case is chosen to match the observed negative correlation between debt maturity and expected inflation in the data. The state-dependent component helps smooth expected inflation deviations through the novel risk transmission mechanism of the fiscal regime outlined in Section I.H. If expected inflation is above target, shortening maturity (due to $\zeta_\pi < 0$) when the nominal term premium is positive induces deflationary pressure that brings expected inflation closer to target.

V. Conclusion

This paper examines how the transmission of government portfolio risk arising from maturity operations is affected by the stance of government policy and conditional risk premia. The key theoretical result shows that incorporating bond risk premia in the fiscal theory allows the government portfolio to affect the path of the price level, constituting a deviation from Wallace neutrality, even in a frictionless economy. A simple model without distortions is used to distinguish the risk transmission mechanisms in the fiscal and monetary policy regimes. In particular, changes in portfolio risk arising from debt-maturity operations are absorbed by expected inflation (real surpluses) in the fiscal (monetary) regime, where the sign and magnitude of the effects depend on the conditional nominal term premium. The risk transmission mechanism in the fiscal regime gives rise to an optimal debt-maturity policy that is state-dependent.

We next quantify the intuition from the simple model in a New Keynesian model that is calibrated to match salient features of the nominal term structure and macroeconomic fluctuations. The expected inflation adjustments to portfolio risk in the fiscal regime have real effects due to the presence of nominal rigidities. When the nominal term premium is positive, the novel risk transmission mechanism produces a dampening effect on inflation and output from maturity shortening, highlighting a potential cost of quantitative easing programs. A binding ELB constraint for the nominal short rate redistributes the timing of the expected inflation response to the nearer term. More broadly, this paper demonstrates how accounting for risk premia in the fiscal theory provides a novel framework for thinking about the management of the government portfolio to achieve policy objectives.

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Appendix A: Simple Model Derivations

A. Return Approximations

This section derives the log-linear approximations for the return on real surpluses and the return on the government bond portfolio. Taking a first-order expansion of $r_{s,t+1}$ around the stochastic steady state, we obtain

$$r_{s,t+1} = \log(b_{t+1}) - \log(b_t) + \log\left(1 + s_{t+1}\exp(-\log(b_{t+1}))\right) \tag{A1}$$

$$\approx \kappa_0 + \kappa_1 \log(b_{t+1}) + \kappa_2 s_{t+1} - \log(b_t). \tag{A2}$$

The coefficients κ_0 and κ_1 are obtained iteratively as in Campbell and Koo (1997) via the policy function for the real market value of debt b_t,

$$\kappa_0 \equiv \log\left(b^\star + s^\star\right) - \frac{b^\star \log(b^\star) + s^\star}{b^\star + s^\star}, \tag{A3}$$

$$\kappa_1 \equiv \frac{b^\star}{b^\star + s^\star}, \tag{A4}$$

$$\kappa_2 \equiv \frac{1}{b^\star + s^\star}, \tag{A5}$$

where $b^\star$ is the unconditional average of b_t. Substituting in the surplus rule, the return on real surpluses is given by

$$r_{s,t+1} = \kappa_0 + \kappa_2 s^\star - \kappa_2\delta_b \log(b^\star) + \kappa_1 \log(b_{t+1}) + (\kappa_2\delta_b - 1)\log(b_t). \tag{A6}$$

Next, we use a second-order Taylor approximation of the log nominal portfolio return $r_{g,t+1}$ around the deterministic steady state following the approach of Campbell and Viceira (2001),

$$r_{g,t+1} = i_t + \log\left(1 + \Omega_t\left(\exp\left(r^{(2)}_{t+1} - i_t\right) - 1\right)\right) \tag{A7}$$

$$\approx i_t + \Omega_t\left(r^{(2)}_{t+1} - i_t\right) + \frac{1}{2}\Omega_t(1-\Omega_t)\,\mathrm{var}_t\left(r^{(2)}_{t+1}\right), \tag{A8}$$

where we use the approximation that for short time windows and log-normally distributed returns, $(r^{(2)}_{t+1} - i_t)^2 \approx \mathrm{var}_t(r^{(2)}_{t+1})$.

B. Fiscal Regime

B.1. Debt Solution

In the fiscal regime, the log market value of government debt, $\log(b_t)$, is solved forward. To obtain the solution for debt, we substitute the log-linear approximation for the return on real surpluses from (A6) into the Euler equation,

$$0 = \log \mathrm{E}_t\left[\exp\left(m_{t+1} + r_{s,t+1}\right)\right] \tag{A9}$$

$$\begin{aligned} &= \log \mathrm{E}_t[\exp(-\delta - z_t - \lambda\varepsilon_{t+1} + \kappa_0 + \kappa_2 s^\star \\ &\quad - \kappa_2\delta_b\log(b^\star) + \kappa_1\log(b_{t+1}) + (\kappa_2\delta_b - 1)\log(b_t))]. \end{aligned} \tag{A10}$$

We guess that the log real market value of government debt is linear in the real rate, that is, $\log(b_t) = A_0 + A_1 z_t$. Plugging the expression into the Euler equation above and applying the method of undetermined coefficients leads to

$$A_1 = \frac{1}{\kappa_1\varphi + \kappa_2\delta_b - 1}, \tag{A11}$$

$$\begin{aligned} A_0 = \frac{1}{1-\kappa_1-\kappa_2\delta_b}&\{\kappa_0 + \kappa_1 A_1(1-\varphi)\mu + \kappa_2 s \\ &- \kappa_2\delta_b\log(b^\star) + \frac{1}{2}(\kappa_1 A_1\sigma)^2 - \lambda\kappa_1 A_1\sigma\}. \end{aligned} \tag{A12}$$

Given the solution for the log real market value of government debt, the solution for the return on real surpluses reads

$$r_{s,t+1} = \zeta_0 + \zeta_1 z_{t+1} + \zeta_2 z_t, \tag{A13}$$

$$\zeta_0 \equiv \kappa_0 + (\kappa_1 - 1 + \kappa_2\delta_b)A_0 + \kappa_2\big(s - \delta_b \log(b^\star)\big), \tag{A14}$$

$$\zeta_1 \equiv \kappa_1 A_1, \tag{A15}$$

$$\zeta_2 \equiv (\kappa_2\delta_b - 1)A_1. \tag{A16}$$

The decomposition into the innovation and expected components of the return on surpluses is given by

$$\mathrm{E}_t\big[r_{s,t+1}\big] = \zeta_0 + \zeta_1(1-\varphi)\mu + (\zeta_1\varphi + \zeta_2)z_t \tag{A17}$$

$$r_{s,t+1} - \mathrm{E}_t\big[r_{s,t+1}\big] = \zeta_1\sigma\varepsilon_{t+1}. \tag{A18}$$

B.2. *Inflation Solution*

In the fiscal theory, inflation is determined via the government return identity

$$r_{g,t} - \pi_t = r_{s,t}. \tag{A19}$$

To solve for inflation, we use the return approximation for the log nominal portfolio return given in equation (A8) and the solution of the return on surpluses given in equation (A13). To simplify the derivation of the inflation policy function, we decompose the government return identity into expectation and innovation components. The innovations to the government return identity are given by

$$\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}] = \underbrace{r_{g,t+1} - \mathrm{E}_t\big[r_{g,t+1}\big]}_{=\Omega_t\left(r^{(2)}_{t+1} - \mathrm{E}_t\left[r^{(2)}_{t+1}\right]\right)} - \underbrace{\big(r_{s,t+1} - \mathrm{E}_t\big[r_{s,t+1}\big]\big)}_{=\zeta_1\sigma\varepsilon_{t+1}}. \tag{A20}$$

Using the nominal interest rate rule, the return of the two-period nominal bond can be written as $r^{(2)}_{t+1} = q^{(1)}_{t+1} - q^{(2)}_t = q^{(1)} - \rho_\pi(\pi_{t+1} - \pi^\star) - q^{(2)}_t$. Substituting the return expression into the equation above allows us to express inflation innovations as

$$\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}] = -\rho_\pi \Omega_t(\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}]) - \zeta_1\sigma\varepsilon_{t+1} \tag{A21}$$

$$= \underbrace{-\frac{1}{1+\rho_\pi\Omega_t}\zeta_1\sigma}_{\equiv\sigma_{\pi,t}}\varepsilon_{t+1}, \tag{A22}$$

where $\sigma_{\pi,t} > 0$ is the conditional volatility of inflation. Next, we compute the conditional expected inflation component using the expected government return identity,

$$\mathrm{E}_t[\pi_{t+1}] = \mathrm{E}_t\left[r_{g,t+1}\right] - \mathrm{E}_t\left[r_{s,t+1}\right]. \tag{A23}$$

We derive the conditional expectation of the real surplus return, $\mathrm{E}_t[r_{s,t+1}]$, in the previous subsection. To derive the conditional expectation of the nominal portfolio return, we first compute the risk premium of $r_{g,t+1}$,

$$\mathrm{E}_t\left[r_{g,t+1} - i_t\right] + \frac{1}{2}\mathrm{var}_t\left[r_{g,t+1}\right] = -\mathrm{cov}_t\left(m^{\$}_{t+1}, r_{g,t+1}\right). \tag{A24}$$

Innovations to the nominal portfolio return can be expressed in terms of inflation innovations, $r_{g,t+1} - \mathrm{E}_t[r_{g,t+1}] = -\rho_\pi\Omega_t(\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}])$, which we use to compute the conditional variance and covariance:,

$$\mathrm{E}_t\left[r_{g,t+1}\right] = i_t - \frac{1}{2}\mathrm{var}_t\left[r_{g,t+1}\right] - \mathrm{cov}_t\left(m^{\$}_{t+1}, r_{g,t+1}\right) \tag{A25}$$

$$= i_t - \frac{1}{2}\left(\Omega_t\rho_\pi\sigma_{\pi,t}\right)^2 - \left(\sigma_{\pi,t} + \lambda\right)\sigma_{\pi,t}\Omega_t\rho_\pi. \tag{A26}$$

Thus, expected inflation is given by

$$\begin{aligned}\mathrm{E}_t[\pi_{t+1}] = i_t &- \frac{1}{2}\left(\Omega_t\rho_\pi\sigma_{\pi,t}\right)^2 - \left(\sigma_{\pi,t} + \lambda\right)\sigma_{\pi,t}\Omega_t\rho_\pi \\ &-(\zeta_0 + \zeta_1(1-\varphi)\mu + (\zeta_1\varphi + \zeta_2)z_t).\end{aligned} \tag{A27}$$

Combining the two components (innovations and the conditional expectation of inflation) leads to the inflation policy in the fiscal regime,

$$\pi_{t+1} = \rho_\pi\pi_t + f_1(\Omega_t) + f_2(\Omega_t)z_{t+1} + f_3(\Omega_t)z_t, \tag{A28}$$

$$\begin{aligned}f_1(\Omega_t) \equiv i^\star - \zeta_0 - \rho_\pi\pi^\star &+ \frac{\Omega_t\rho_\pi}{\sigma}\sigma_{\pi,t}(1-\varphi)\mu \\ &- \frac{1}{2}\left(\Omega_t\rho_\pi\sigma_{\pi,t}\right)^2 - \left(\sigma_{\pi,t} + \lambda\right)\sigma_{\pi,t}\Omega_t\rho_\pi,\end{aligned} \tag{A29}$$

$$f_2(\Omega_t) \equiv -\frac{\zeta_1}{1+\rho_\pi \Omega_t}, \tag{A30}$$

$$f_3(\Omega_t) \equiv -\frac{\Omega_t \rho_\pi + \zeta_2}{1+\rho_\pi \Omega_t}. \tag{A31}$$

B.3. Portfolio Risk Transmission

This section derives the partial derivative of expected inflation with respect to a change in the maturity of government debt Ω_t. Given the solutions $r_{g,t+1}$ and $r_{s,t+1}$, expected inflation can be linked to the nominal term premium $TP_t^{(2)} = -\text{cov}_t(m_{t+1}^{\$}, r_{t+1}^{(2)})$ by taking conditional expectations of the government return identity,

$$\text{E}_t[\pi_{t+1}] = \text{E}_t\left[r_{g,t+1}\right] - \text{E}_t\left[r_{s,t+1}\right] \tag{A32}$$

$$\begin{aligned} &= i_t - \frac{1}{2}\text{var}_t\left[r_{g,t+1}\right] + \Omega_t TP_t^{(2)} \\ &\quad - (\zeta_0 + \zeta_1(1-\varphi)\mu + (\zeta_1\varphi + \zeta_2)z_t). \end{aligned} \tag{A33}$$

Simplifying $\zeta_1\varphi + \zeta_2 = 1$ and using the interest rate rule leads to

$$\text{E}_t[\pi_{t+1}] = \xi_\pi + \rho_\pi \pi_t - z_t + \Omega_t TP_t^{(2)} - \frac{1}{2}\text{var}_t\left[r_{g,t+1}\right] \tag{A34}$$

$$\xi_\pi \equiv i^\star - \rho_\pi \pi^\star - \zeta_0 - \zeta_1(1-\varphi)\mu \tag{A35}$$

$$TP_t^{(2)} = \rho_\pi \left(\lambda - \frac{\zeta_1\sigma}{1+\rho_\pi \Omega_t}\right)\frac{\zeta_1\sigma}{1+\rho_\pi \Omega_t}. \tag{A36}$$

The partial derivative of expected inflation with respect to Ω_t is given by

$$\frac{\partial \text{E}_t[\pi_{t+1}]}{\partial \Omega_t} = TP_t^{(2)} + \Omega_t \frac{\partial TP_t^{(2)}}{\partial \Omega_t} - \frac{1}{2}\frac{\partial\, \text{var}_t\left(r_{g,t+1}\right)}{\partial \Omega_t} \tag{A37}$$

$$= \left[\lambda + (\Omega_t\rho_\pi - 1)\frac{\zeta_1\sigma}{1+\rho_\pi\Omega_t}\right]\frac{\rho_\pi\zeta_1\sigma}{(1+\rho_\pi\Omega_t)^2} - \frac{\Omega_t(\rho_\pi\zeta_1\sigma)^2}{(1+\rho_\pi\Omega_t)^3} \tag{A38}$$

$$= \frac{1}{1+\rho_\pi\Omega_t} TP_t^{(2)}. \tag{A39}$$

B.4. Maturity Change and the Nominal Term Premium

This section studies the impact of a change in the government debt maturity on the nominal term premium. We derive the conditions under which shortening the maturity leads to an increase in the term premium. The partial derivative of the nominal term premium with respect to Ω_t is given by

$$\frac{\partial TP_t^{(2)}}{\partial \Omega_t} = \left(\lambda + 2\sigma_{\pi,t}\right)\frac{\rho_\pi^2 \sigma_{\pi,t}}{(1+\rho_\pi \Omega_t)}. \tag{A40}$$

Therefore, a condition that guarantees that a shortening of the maturity increases the nominal term premium, that is, $\frac{\partial TP_t^{(2)}}{\partial \Omega_t} < 0$, is given by

$$-\lambda >> 2\sigma_{\pi,t}. \tag{A41}$$

At the same time, the condition that guarantees a positive term premium is $-\lambda > \sigma_{\pi,t}$. Hence, a positive nominal term premium is required for maturity shortening to increase the nominal term premium.

C. Monetary Regime

C.1. Inflation Solution

In the monetary regime, inflation and nominal bond prices depend only on the real short rate and are insulated from debt maturity changes. The policy function for inflation is given by the interest rate rule together with the Euler equation for the one-period nominal bond,

$$q^{(1)} - \rho_\pi\left(\pi_t - \pi^\star\right) = \log \mathrm{E}_t[\exp\left(m_{t+1} - \pi_{t+1}\right)]. \tag{A42}$$

Thus, inflation is determined by the forward-looking equation

$$\pi_t = \frac{1}{\rho_\pi}\left(q^{(1)} + \rho_\pi \pi^\star\right) - \frac{1}{\rho_\pi}\log \mathrm{E}_t[\exp\left(m_{t+1} - \pi_{t+1}\right)], \tag{A43}$$

which implies that the solution for π_t depends only on the real stochastic discount factor which is exogenous in our simple model. Assuming that the stochastic discount factor and log inflation are bivariate log-linear, we can guess a log-linear solution for inflation, $\pi_t = H_0 + H_1 z_t$. Using the method of undetermined coefficients leads to the policy function for inflation:

$$\begin{aligned} H_0 + H_1 z_t = {} & \frac{1}{\rho_\pi}\left(q^{(1)} + \rho_\pi \pi^\star\right) \\ & + \frac{1}{\rho_\pi}\left[H_0 + H_1(1-\varphi)\mu - \lambda H_1 \sigma - \frac{1}{2}(H_1\sigma)^2\right] + \frac{1}{\rho_\pi}[1 + H_1\varphi] z_t \end{aligned} \tag{A44}$$

$$H_1 = \frac{1}{(\rho_\pi - \varphi)} \tag{A45}$$

$$H_0 = \frac{1}{(\rho_\pi - 1)}\left(q^{(1)} + \rho_\pi \pi^\star + H_1(1-\varphi)\mu - \lambda H_1 \sigma - \frac{1}{2}(H_1\sigma)^2\right). \tag{A46}$$

Bond prices in the monetary regime depend only on the real short rate. The one-period bond price is given by

$$q_t^{(1)} = \log \mathrm{E}_t\left[\exp\left(m_{t+1} - \pi_{t+1}\right)\right] \tag{A47}$$

$$= q^{(1)} - \rho_\pi H_1(z_t - \mu), \tag{A48}$$

where the unconditional average of the bond price is given by $q^{(1)} = -\pi^\star - \mu + \lambda H_1\sigma + \frac{1}{2}(H_1\sigma)^2$. The two-period bond price is given by

$$q_t^{(2)} = \log \mathrm{E}_t\left[\exp\left(m_{t+1} - \pi_{t+1} + q_{t+1}^{(1)}\right)\right] \tag{A49}$$

$$= q^{(2)} - (1 + (1+\rho_\pi)H_1\varphi)(z_t - \mu), \tag{A50}$$

where the unconditional average of the bond price is given by $q^{(2)} = 2q^{(1)} + \lambda\rho_\pi H_1\sigma + \frac{1}{2}(2+\rho_\pi)\rho_\pi(H_1\sigma)^2$. Hence, we can write the return on the two-period nominal bond as

$$r_{t+1}^{(2)} = q^{(1)} - \rho_\pi H_1(z_{t+1} - \mu) - q^{(2)} + (1 + (1+\rho_\pi)H_1\varphi)(z_t - \mu). \tag{A51}$$

The nominal term premium in the monetary regime reads

$$TP_t^{(2)} = -\operatorname{cov}_t\left(m_{t+1}^{\$}, r_{t+1}^{(2)}\right) \tag{A52}$$

$$= -(\lambda + H_1\sigma)\rho_\pi H_1\sigma. \tag{A53}$$

Substituting bond prices into the second-order Taylor approximation for the log nominal government portfolio return $r_{g,t+1} = i_t + \Omega_t(r_{t+1}^{(2)} - i_t) + \frac{1}{2}\Omega_t(1 -$

$\Omega_t)\text{var}_t(r^{(2)}_{t+1})$ gives

$$r_{g,t+1} = \varrho_0 + \varrho_1 z_t + \varrho_2 \Omega_t + \varrho_3 \Omega_t^2 + \varrho_4 \Omega_t z_t + \varrho_5 \Omega_t z_{t+1}, \tag{A54}$$

$$\varrho_0 \equiv -q^{(1)} - \rho_\pi H_1 \mu, \tag{A55}$$

$$\varrho_1 \equiv \rho_\pi H_1, \tag{A56}$$

$$\varrho_2 \equiv 2q^{(1)} - q^{(2)} + (1-\varphi)\rho_\pi H_1 \mu + \frac{1}{2}(\rho_\pi H_1 \sigma)^2, \tag{A57}$$

$$\varrho_3 \equiv -\frac{1}{2}(\rho_\pi H_1 \sigma)^2, \tag{A58}$$

$$\varrho_4 \equiv \rho_\pi H_1 \varphi, \tag{A59}$$

$$\varrho_5 \equiv -\rho_\pi H_1. \tag{A60}$$

C.2. Debt Solution

The debt dynamics in the monetary regime are computed via the return of real government surpluses by using the government return identity together with the inflation policy and the return of the nominal government portfolio,

$$r_{s,t+1} = r_{g,t+1} - \pi_{t+1} \tag{A61}$$

$$= \varrho_0 - H_0 - H_1 z_{t+1} + \varrho_1 z_t + \varrho_2 \Omega_t + \varrho_3 \Omega_t^2 + \varrho_4 \Omega_t z_t + \varrho_5 \Omega_t z_{t+1}. \tag{A62}$$

To link the government surplus return to debt, we use the Campbell-Shiller approximation

$$r_{s,t+1} = \kappa_0 + \kappa_1 \log(b_{t+1}) + \kappa_2 s_{t+1} - \log(b_t). \tag{A63}$$

Substituting in the solution for $r_{s,t+1}$ obtained from the government return identity and plugging in the government surplus rule $s_{t+1} = s^\star + \delta_b(\log(b_t) -$

$\log(b^\star)$) leads to the solution for government debt,

$$\log\left(b_{t+1}\right) = \psi_0 + \psi_1 \log\left(b_t\right) + \frac{1}{\kappa_1} r_{s,t+1} \tag{A64}$$

$$\psi_0 \equiv \frac{-\kappa_0 - \kappa_2 s^\star + \kappa_2 \log(b^\star)}{\kappa_1} \tag{A65}$$

$$\psi_1 \equiv \frac{(1-\kappa_2\delta_b)}{\kappa_1} = 1 + \frac{1}{b^\star}\left(s^\star - \delta_b\right). \tag{A66}$$

C.3. Portfolio Risk Transmission

We derive the effects of a change in the average maturity (AMS) structure of government debt on the expected return on surpluses. Taking the conditional expectations of the government return identity and substituting in the solution for $r_{g,t+1}$ and π_{t+1} leads to

$$\mathrm{E}_t\left[r_{s,t+1}\right] = \mathrm{E}_t\left[r_{g,t+1} - \pi_{t+1}\right] \tag{A67}$$

$$= z_t - (\lambda\rho_\pi H_1 \Omega_t \sigma + \lambda H_1 \sigma) - \frac{1}{2}(1+\rho_\pi\Omega_t)^2 (H_1\sigma)^2. \tag{A68}$$

The partial derivative with respect to Ω_t is then given by

$$\frac{\partial \mathrm{E}_t\left[r_{s,t+1}\right]}{\partial \Omega_t} = -(\lambda + H_1\sigma)\rho_\pi H_1 \sigma - (\rho_\pi H_1 \sigma)^2 \Omega_t \tag{A69}$$

$$= TP^{(2)} - (\rho_\pi H_1\sigma)^2 \Omega_t, \tag{A70}$$

where $H_1 > 0$ and $TP^{(2)} = -(\lambda + H_1\sigma)\rho_\pi H_1\sigma$.

D. Optimal Maturity Policy

The planner's problem can be rewritten as

$$\mathrm{E}_t\left[\left((\pi_{t+1} - \mathrm{E}_t[\pi_{t+1}]) + (\mathrm{E}_t[\pi_{t+1}] - \pi^\star)\right)^2\right] + \omega\left(\Omega_t - \Omega^\star\right)^2$$
$$= \mathrm{E}_t\left[\left(-\frac{1}{1+\rho_\pi\Omega_t}\zeta_1\sigma\varepsilon_{t+1} + (\mathrm{E}_t[\pi_{t+1}] - \pi^\star)\right)^2\right] + \omega\left(\Omega_t - \Omega^\star\right)^2,$$

where we substitute the expression for the innovation of inflation. Taking the first-order condition with respect to Ω_t, we obtain

$$\mathrm{E}_t\left[\left(\pi_{t+1}-\pi^\star\right)\left(\frac{\rho_\pi\zeta_1\sigma}{(1+\rho_\pi\Omega_t)^2}\varepsilon_{t+1}+\frac{1}{(1+\rho_\pi\Omega_t)}TP_t^{(2)}\right)\right]+\omega\left(\Omega_t-\Omega^\star\right)=0,$$

or

$$-\frac{\rho_\pi(\zeta_1\sigma)^2}{(1+\rho_\pi\Omega_t)^3}+\frac{\mathrm{E}_t[\pi_{t+1}-\pi^\star]\times TP_t^{(2)}}{(1+\rho_\pi\Omega_t)}+\omega\left(\Omega_t-\Omega^\star\right)=0.$$

Substituting the expression for expected inflation and the term premium, $\widehat{\Omega}_t$, solves

$$\left(\xi_\pi+\rho_\pi\pi_t-z_t+\Omega_t\frac{\rho_\pi\zeta_1\sigma}{1+\rho_\pi\Omega_t}\left(\lambda-\frac{\zeta_1\sigma}{1+\rho_\pi\Omega_t}\right)-\frac{1}{2}\left(\frac{\Omega_t\rho_\pi\zeta_1\sigma}{1+\rho_\pi\Omega_t}\right)^2-\pi^\star\right)$$
$$\times\frac{\rho_\pi\zeta_1\sigma}{(1+\rho_\pi\Omega_t)^2}\left(\lambda-\frac{\zeta_1\sigma}{1+\rho_\pi\Omega_t}\right)-\frac{\rho_\pi(\zeta_1\sigma)^2}{(1+\rho_\pi\Omega_t)^3}+\omega\left(\Omega_t-\Omega^\star\right)=0.$$

E. Parameter Restrictions

This section derives the joint parameter restrictions for a determinate equilibrium along the deterministic steady state, using the approximate analytical solutions. In the fiscal regime, the real value of debt is solved forward. Substituting the surplus rule into the Euler equation for the return on real surplus yields the equilibrium condition for debt in the fiscal regime,

$$1=\mathrm{E}_t\left[\exp\left(m_{t+1}+\bar{r}_s+\kappa_1\log(b_{t+1})+\theta_s\log(b_t)\right)\right]. \tag{A71}$$

In the deterministic steady state, the equilibrium condition (A71) can be rewritten as a difference equation for the log real value of debt,

$$\log(b_t)=\left(\frac{m_{ss}+\bar{r}_s}{\kappa_2\delta_b-1}\right)+\left(\frac{b^\star}{b^\star+s^\star-\delta_b}\right)\log(b_{t+1}),$$

where m_{ss} is the steady-state value for the exogenous log real pricing kernel, which is determined independently of debt. Provided that the government is a net issuer of debt, $b^\star>0$, a bounded forward solution for debt requires $b^\star/(b^\star+s^\star-\delta_b)<1$, which implies $\delta_b<s^\star$.

Inflation is solved backward in the fiscal regime using the intertemporal government budget equation together with the interest rate rule and given the solution for debt. Using the portfolio return approximation in the intertemporal government budget equation and the government return identity, $\pi_t=r_{g,t}-r_{s,t}$, delivers the equilibrium condition for inflation in this regime,

$$\pi_t=\rho_\pi\pi_{t-1}+f_1(\Omega_{t-1})+f_2(\Omega_{t-1})z_t+f_3(\Omega_{t-1})z_{t-1}. \tag{A72}$$

A bounded backward solution for the difference equation above requires a parameter restriction on the monetary policy rule: $\rho_\pi < 1$. This condition is referred to as a passive monetary policy in Leeper (1991).

In the monetary regime, inflation is solved forward. Replacing the one-period yield using the interest rate rule in the Euler equation gives us the equilibrium condition for inflation in the monetary regime,

$$-i^\star - \rho_\pi(\pi_t - \pi^\star) = \log\left(\mathrm{E}_t\left[\exp\left(m_{t+1} - \pi_{t+1}\right)\right]\right). \tag{A73}$$

The Euler equation above can be expressed in the steady state as the difference equation

$$\pi_t = \frac{-m_{ss} + \rho_\pi - i^\star}{\rho_\pi} + \frac{1}{\rho_\pi}\pi_{t+1}.$$

The parameter restriction on the monetary policy rule for inflation to be bounded in the deterministic steady state is given by $\rho_\pi > 1$.

The real value of debt is solved backward in the monetary regime using the government return identity, $\pi_t = r_{g,t} + r_{s,t}$, together with the surplus rule and the inflation solution from above. Using the approximation for the return on surplus, together with the solutions for inflation and the nominal bond portfolio return in the government return identity, delivers the equilibrium condition for debt,

$$\log(b_t) = \psi_0 + \left(1 + \frac{1}{b^\star}(s^\star - \delta_b)\right)\log(b_{t-1}) + \frac{1}{\kappa_1}(r_{g,t} - \pi_t). \tag{A74}$$

A bounded backward solution for the difference equation above requires that $(1 + (1/b^\star)(s^\star - \delta_b)) < 1$, implying the parameter restriction on the fiscal policy rule, $\delta_b > s^\star$.

F. Face Value Operations

This section describes how the debt-maturity process characterized in terms of proportional market values can be mapped to an equivalent specification in terms of proportional face values. Define the proportion of total face value that is two-period nominal debt as

$$\Gamma_t \equiv \frac{B_t^{(2)}}{B_t}, \tag{A75}$$

where $B_t^{(j)}$ is the nominal face value of debt and $B_t \equiv B_t^{(1)} + B_t^{(2)}$ is the total face value of debt, which are distinct from $\mathcal{B}_t$ defined above that denote the total market value of debt. Recall that in equation (5), the portfolio weight on two-period nominal debt is defined in terms of proportional market values, $\Omega_t = Q_t^{(2)}B_t^{(2)}/(Q_t^{(1)}B_t^{(1)} + Q_t^{(2)}B_t^{(2)})$.

Given a process for Ω_t, we derive a mapping to an equivalent specification in terms of Γ_t. Start by dividing the budget constraint presented in equation (6) by b_{t-1} to obtain

$$\Pi_t R_{s,t} = \frac{1}{b_{t-1}}\Big(B^{(1)}_{t-1}/P_{t-1} + Q^{(1)}_t B^{(2)}_{t-1}/P_{t-1}\Big). \tag{A76}$$

The return identity presented in equation (10) therefore implies that the right-hand side of the equation is equal to the return on the nominal government bond portfolio,

$$R_{g,t} = \frac{1}{b_{t-1}}\Big(B^{(1)}_{t-1}/P_{t-1} + Q^{(1)}_t B^{(2)}_{t-1}/P_{t-1}\Big), \tag{A77}$$

which can be rewritten in terms of proportional face values Γ_{t-1} as

$$R_{g,t} = \frac{(1-\Gamma_{t-1}) + \Gamma_{t-1}Q^{(1)}_t}{(1-\Gamma_{t-1})Q^{(1)}_{t-1} + \Gamma_{t-1}Q^{(2)}_{t-1}}. \tag{A78}$$

Setting equation (A78) equal to the portfolio return defined in terms of proportional market values from above $R_{g,t} = (1-\Omega_{t-1})R^{(1)}_t + \Omega_{t-1}R^{(2)}_t$ yields

$$\frac{(1-\Gamma_{t-1}) + \Gamma_{t-1}Q^{(1)}_t}{(1-\Gamma_{t-1})Q^{(1)}_{t-1} + \Gamma_{t-1}Q^{(2)}_{t-1}} = (1-\Omega_{t-1})\left(\frac{1}{Q^{(1)}_{t-1}}\right) + \Omega_{t-1}\left(\frac{Q^{(1)}_t}{Q^{(2)}_{t-1}}\right), \tag{A79}$$

which defines Γ_{t-1} implicitly as a function of Ω_{t-1}, $Q^{(1)}_{t-1}$, $Q^{(2)}_{t-1}$, and $Q^{(1)}_t$. For the proportional face value policy Γ_{t-1} to be implementable, it can depend only on variables contained in the time $t-1$ information set. Consequently, the solution Γ_{t-1} to equation (A79) must hold for any $Q^{(1)}_t$, which can be satisfied only if the coefficients on $Q^{(1)}_t$ in equation (A79) sum to zero,

$$\frac{\Gamma_{t-1}}{(1-\Gamma_{t-1})Q^{(1)}_{t-1} + \Gamma_{t-1}Q^{(2)}_{t-1}} = \frac{\Omega_{t-1}}{Q^{(2)}_{t-1}}. \tag{A80}$$

Solving for Γ_{t-1} yields an equivalent proportional face value mapping given a process for proportional market values Ω_{t-1},

$$\Gamma_{t-1} = \frac{\Omega_{t-1}Q^{(1)}_{t-1}}{(1-\Omega_{t-1})Q^{(2)}_{t-1} + \Omega_{t-1}Q^{(1)}_{t-1}}, \tag{A81}$$

which we verify is a valid solution by showing that it satisfies equation (A79). Therefore, the debt-maturity process characterized in terms of proportional market values can be mapped to an equivalent specification in terms of proportional face values.

Appendix B: Equilibrium Conditions

Household's first-order conditions:

$$Q_t^{(1)} = \mathrm{E}_t\left[\frac{M_{t+1}}{\Pi_{t+1}}\right], \tag{B1}$$

$$Q_t^{(L)} = \mathrm{E}_t\left[\frac{M_{t+1}}{\Pi_{t+1}}\left(1-\lambda+\lambda Q_{t+1}^{(L)}\right)\right], \tag{B2}$$

$$M_{t+1} = \beta\frac{\varrho_{t+1}}{\varrho_t}\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\psi}}\left(\frac{U_{t+1}}{\mathrm{E}_t\left[U_{t+1}^{\theta}\right]^{\frac{1}{\theta}}}\right)^{\theta-1}, \tag{B3}$$

$$\frac{W_t}{P_t} = \chi_0 C_t^{\frac{1}{\psi}} N_t^{1-\frac{1}{\psi}}\left(\bar{L}-L_t\right)^{-\chi}. \tag{B4}$$

Household's utility:

$$U_t = (1-\beta)\varrho_t\left(\frac{C_t^{1-\frac{1}{\psi}}}{1-\frac{1}{\psi}} + \chi_0 N_t^{1-\frac{1}{\psi}}\frac{\left(\bar{L}-L_t\right)^{1-\chi}}{1-\chi}\right) + \beta\mathrm{E}_t\left[U_{t+1}^{\theta}\right]^{\frac{1}{\theta}}. \tag{B5}$$

Intermediate firm's first-order conditions:

$$\frac{W_t}{P_t} = \left(1-\frac{1}{\nu}\right)Z_t + \Lambda_t\left(\frac{1}{\nu}\right)\frac{Z_t}{Y_t}, \tag{B6}$$

$$\Lambda_t = \phi_R\left(\frac{\Pi_t}{\Pi^\star}-1\right)\frac{\Pi_t}{\Pi^\star}Y_t - \mathrm{E}_t\left[M_{t+1}\phi_R\left(\frac{\Pi_{t+1}}{\Pi^\star}-1\right)\frac{Y_{t+1}\Pi_{t+1}}{\Pi^\star}\right]. \tag{B7}$$

Government policy:

$$i_t - i^\star = \rho_i\left(i_{t-1}-i^\star\right) + (1-\rho_i)\left(\rho_{\pi,\zeta_t}\left(\pi_t-\pi^\star\right)\right) + \epsilon_{it}, \tag{B8}$$

$$s_t - s^\star = \delta_{b,\zeta_t}(\widetilde{b}_{t-1}-\widetilde{b}^\star) + \delta_\pi(\pi_t-\pi^\star) + u_{ct} + u_{pt}, \tag{B9}$$

$$\mathcal{B}_t = \left(\frac{1-\Omega_{t-1}}{Q_{t-1}^{(1)}} + \Omega_{t-1}\frac{1-\lambda+\lambda Q_t^{(L)}}{Q_{t-1}^{(L)}}\right)\mathcal{B}_{t-1} - S_t, \tag{B10}$$

$$R_t^g = \frac{1-\Omega_{t-1}}{Q_{t-1}^{(1)}} + \Omega_{t-1}\frac{1-\lambda+\lambda Q_t^{(L)}}{Q_{t-1}^{(L)}}. \tag{B11}$$

Output:

$$Y_t = Z_t L_t, \tag{B12}$$

$$\log(Z_t) = a_t + n_t. \tag{B13}$$

Market clearing:

$$Y_t = C_t + \frac{\phi_R}{2}\left(\frac{\Pi_t}{\Pi^\star} - 1\right)^2 Y_t. \tag{B14}$$

Stochastic processes:

$$x_{\varrho,t} = \rho_\varrho x_{\varrho,t-1} + \sigma_\varrho \varepsilon_{\varrho,t}, \tag{B15}$$

$$a_t = \rho_a a_{t-1} + \sigma_a \varepsilon_{at}, \tag{B16}$$

$$x_t = \rho_x x_{t-1} + \sigma_x \varepsilon_{xt}, \tag{B17}$$

$$\epsilon_{it} = \varphi_i \epsilon_{it-1} + \sigma_i e_{it}, \tag{B18}$$

$$u_{ct} = \rho_c u_{ct-1} + \sigma_c \epsilon_{ct}, \tag{B19}$$

$$u_{pt} = \rho_p u_{pt-1} + \sigma_p \epsilon_{pt}, \tag{B20}$$

$$\Omega_t = (1 - \rho_\Omega)\overline{\Omega} + \rho_\Omega \Omega_{t-1} + \sigma_\Omega \varepsilon_{\Omega,t}. \tag{B21}$$

Appendix C: Numerical Procedure

The solution to the quantitative model is obtained by solving for the policy functions around the steady state. Following Foerster et al. (2016), a Markov-switching third-order perturbation approximation is implemented. As shown in Foerster et al. (2016), the first-order derivatives can be obtained using different solution methods. In particular, the first-order derivatives are obtained using the minimum of modulus solution method of Cho (2021). Second- and third-order derivatives are calculated by recursively solving linear systems of equations, as demonstrated in Foerster et al. (2016). We use quadrature and monomial integration to calculate conditional expectations following Judd, Maliar, and Maliar (2011).[13]

Nonstationary variables are normalized by the permanent technology component, N_t, following the convention, $\hat{X}_t \equiv X_t/N_t$, except for the variable, $\hat{\mathcal{B}}_t \equiv \mathcal{B}_t/N_{t+1}$. The state-space of the stationary model is 12-dimensional and includes the time preference shock, $x_{\varrho,t}$, the transitory technology component, a_t, the permanent component, x_t, the stochastic process driving bond duration dynamics, Ω_t, the cyclical component of government surplus u_{ct}, the persistent component of government surplus, u_{pt}, the monetary policy surprise, ϵ_{it}, lagged log one-period bond price, $\log Q_{t-1}^{(1)}$, lagged log perpetuity price, $\log Q_{t-1}^{(L)}$, lagged real market value of nominal debt, $b_{t-1} \equiv \hat{\mathcal{B}}_{t-1}/P_{t-1}$, lagged log output, y_{t-1}, and the state variable associated with the monetary/fiscal-led regime, ζ_t. The vector of state variables therefore reads

$$\mathbb{S}_t = \left(x_{\varrho,t}, a_t, x_t, \Omega_t, u_{ct}, u_{pt}, \epsilon_{it}, \log Q_{t-1}^{(1)}, \log Q_{t-1}^{(L)}, b_{t-1}, \log Y_{t-1}, \zeta_t\right). \tag{C1}$$

The effective lower bound (ELB) in the extended model is modeled as a third regime. In this ELB regime, the one-period nominal rate is set to zero by modifying the Taylor rule. In particular, the Taylor rule is modified to

$$i_t = \kappa_{\zeta_t}\left(i^\star + \rho_{i,\zeta_t}(i_{t-1} - i^\star) + \left(1 - \rho_{i,\zeta_t}\right)\rho_{\pi,\zeta_t}\left(\pi_t - \pi^\star\right) + \epsilon_{it}\right), \tag{C2}$$

where κ is a new regime-dependent parameter that controls for the effects of $\pi^\star$ and ϵ_{it} on the one-period nominal rate. Furthermore, notice that ρ_i is now a regime-dependent parameter. To fix the one-period nominal rate to zero, the parameters ρ_π, ρ_r, and κ are set to zero at the ELB. Away from the ELB, the values of the parameters ρ_π and ρ_r remain the same as before (see Table I). The parameter κ is equal to $1/(P_M + P_F)$ away from the ELB, where P_M and P_F are the stationary probabilities of the monetary and fiscal regimes, respectively. By doing this, the ergodic mean of κ is equal to one, eliminating its effects at the steady state. The stationary distribution P solves the equation

$$P = P\mathcal{Q}, \tag{C3}$$

where $\mathcal{Q}$ is the new transition matrix.

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