Fiscal Discount Rates and Debt Maturity

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Abstract

This paper explores the interactions between yield curve dynamics and nominal government debt maturity operations under fiscal stress in a New Keynesian model with endogenous bond risk premia. Violations of debt maturity neutrality occur when the yield curve slope is nonzero in a fiscally-led policy regime. When the risk profiles of government liabilities differ, rebalancing the maturity structure changes the government cost of capital. In the fiscal theory, changes in discount rates affect inflation through the intertemporal government budget equation. When the yield curve is upward-sloping (downward-sloping), the fiscal discount rate channel implies that shortening the maturity structure dampens (amplifies) the stimulative effects of quantitative easing policies.

Keywords: Fiscal theory of the price level, Government debt, Maturity structure, Inflation, Bond risk premia, Markov-switching DSGE, Nonlinear solution methods

1 Introduction

During the recent global financial crisis, central banks, constrained by the zero lower bound (ZLB) on nominal interest rates, conducted open market operations on an unprecedented scale. The series of quantitative easing (QE) operations between 2008 and 2014 reduced the average duration of U.S. government liabilities (including reserve balances) held by the public by over 20%. Fig. 1 illustrates the impact of the QE operations on average maturity.[1] These operations dramatically increased both the size and riskiness of the government balance sheet. Meanwhile, during this period, deepening deficits and ballooning debt-to-gdp levels cast doubt on the sustainability of accommodative fiscal policy to support aggressive inflation-targeting monetary policy. We investigate how the combination of fiscal stress and a monetary policy stance that weakly responds to inflation, a policy mix that characterizes the fiscal theory, contributes to a risk-based transmission channel for unconventional monetary policy.

In the fiscal theory, government discount rates and surplus innovations affect the price level through a fiscal asset pricing equation that relates the market value of nominal liabilities to the present value of future surpluses. Given that the expected bond returns vary by maturity, rebalancing the maturity structure changes the marginal financing costs. When accommodative fiscal policy is not possible, discount rate variation requires compensating changes in the inflation path to satisfy the present value relation (i.e., the *fiscal discount rate channel*). This paper explores the interplay between term structure dynamics and maturity restructuring policies through the fiscal discount rate channel. We illustrate that the effectiveness of operation twist type policies is sensitive to the slope of the nominal yield curve, especially in times of fiscal stress.

To quantitatively examine role of the fiscal discount rate channel, we build a small-scale New Keynesian model that has several distinguishing features. First, households have recursive preferences (e.g., Epstein and Zin (1989)), which allows the model to generate realistic nominal term premia. Second, the supply of nominal government bonds over various maturities is time-varying. Third, the monetary/fiscal policy mix is subject to regime shifts between monetary- and fiscally-led regimes (e.g., Davig and Leeper (2007a), Bianchi and Ilut (2014), and Bianchi and Melosi (2014)). In the *monetary-led* regime, the monetary authority responds strongly to inflation deviations from target while the fiscal authority accommodates monetary policy by adjusting primary surpluses to stabilize debt. In the *fiscally-led* regime, the fiscal authority does not respond strongly to changes in debt while the monetary authority accommodates fiscal policy by allowing inflation to adjust in order to stabilize the real value of debt.

We show that in the presence of a fiscally-led regime, a nonzero slope of the nominal yield curve implies that debt maturity restructuring affects inflation. To isolate the effects of debt maturity, we consider self-financing shocks to the maturity structure that keep the market value of total government bonds the same immediately after the operation (e.g., Maturity Extension Program), but is allowed to adjust freely afterwards. When the financing costs of bonds vary by maturity, changing the financing mix alters the government cost of capital. In the fiscally-led regime, the price level is determined by the ratio of nominal debt to the present value of surpluses. Thus, variation in the government discount rate changes the fiscal backing, and consequently, the price level and expected inflation adjust to revalue debt in order to satisfy the present value condition. Sticky prices are required for this channel to have real effects. More generally, these results illustrate how accounting for heterogeneity in expected returns across different assets in the fiscal theory

[1] When calculating the average maturity of privately-held public debt we include reserve balances with Federal Reserve Banks. Reserve balances are included since the Federal Reserve started to pay interests on reserves in October 2008 making them, effectively, government debt.

contributes to violations of Wallace (1981) neutrality.

The slope of the nominal yield curve dictates the effects of the fiscal discount rate channel for maturity restructuring.[2] When the yield curve is upward-sloping (downward-sloping), the fiscal discount rate effects from shortening the maturity structure dampens (amplifies) the potential stimulative effects of quantitative easing policies (e.g., from providing short-term liquidity). Taking interest rates as given, increasing the proportion of short-term debt in the maturity structure when the yield curve is upward-sloping implies that the government is refinancing at a lower rate. Lowering the government discount rate puts upward pressure on the real value of debt. In anticipation of this, households increase demand for bonds and decrease demand for consumption goods, which puts downward pressure on the price level. With sticky prices, the fall in the price level generates contractionary pressure in production and output. The opposite results are obtained when the yield curve is downward-sloping. Furthermore, the endogenous yield curve reactions reinforce our fiscal discount rate channel.

Under persistent deficits, the discount rate effects from maturity restructuring are attenuated, and can potentially be reversed if the deficit is particularly severe. Consider the case where the yield curve is upward-sloping, then shortening the maturity lowers the discount rate persistently. With a budget deficit today, discounting temporarily negative surpluses at a lower rate has a negative effect on the present value of the fiscal backing. One the other hand, since the deficit is temporary, discounting positive future surpluses at a lower rate has a positive effect on the present value. Hence, if the deficit today is particularly severe or persistent, the discount rate effects from the deficit component can potentially dominate.

When the yield curve is flat, the fiscal discount rate channel is neutral even in the presence of a fiscally-led regime since the cost of financing is the same across maturities. In a monetary-led regime without the possibility of regime shifts, the economy is insulated from fiscal disturbances as surplus policy will completely offset changes to the debt burden. Thus, the discount rate channel is also neutral in this case regardless of the slope of the yield curve. However, with regime shifts and rational expectations, the possibility of entering the fiscally-led regime and a nonzero slope is also sufficient for debt maturity changes to impact inflation through the discount rate channel in the monetary-led regime.

Since the nominal yield curve provides a key transmission channel for the maturity structure shocks, we also calibrate our model to explain key term structure facts. Supply shocks in the model drive countercyclical real marginal costs which generate negative co-movement between consumption growth and inflation similar to Kung (2015). With recursive preferences, these dynamics produce sizable bond risk premia (e.g., Piazzesi and Schneider (2007) and Bansal and Shaliastovich (2013)) and the model matches the average five-year term spread. The model also replicates the persistence in yields and the forecasting ability of the term spread for macroeconomic aggregates in the data.

We consider an extended version of the model to assess the quantitative importance of the fiscal discount rate channel for operations involving maturity twists, such as QE2. In the extended model, we incorporate market segmentation and short-term liquidity demand, two channels that generate expansionary effects from shortening maturity and often cited by policymakers as relevant margins for such actions (e.g., Bernanke (2012)). Also, we start the economy off in the monetary-led regime (with a possibility of entering the fiscal regime), in a budget deficit, and at the zero lower

[2] To be precise, the expected excess bond returns across maturities determines the effect of maturity restructuring. However, when yields are persistent, as in the data, then the average slope and expected return spread are approximately proportional to each each other. We discuss this approximation in further detail in Section 2.3.

bound (ZLB). During the Great Recession, the yield curve was significantly upward-sloping, and we find that the fiscal discount rate channel significantly dampened the stimulative effects of QE arising from the market segmentation and liquidity channels. Indeed, using an estimated process of the maturity structure of debt and calibrating the maturity shock to QE2, we find that the fiscal channel dampened the expansionary response of inflation and output by 53% and 60%, respectively. Thus, we provide a potential channel for explaining the weak inflation responses at the onset and aftermath of such operations.[3]

1.1 Related literature

The literature examining how the interactions between monetary and fiscal policy determine the price level begins with Sargent and Wallace (1981) who show that permanent fiscal deficits have to eventually be financed by seignorage when the government only issues real debt. Further, the money creation leads to inflation. Building on this paper, the fiscal theory of the price level (FTPL) shows that when the government issues nominal debt and does not provide the necessary fiscal backing, deficits are linked to current and expected inflation through the intertemporal government budget equation, without necessarily relying on seignorage revenues (e.g., Leeper (1991), Sims (1994), Woodford (1994), Woodford (1995), Woodford (2001), Schmitt-Grohé and Uribe (2000), Cochrane (1999), Bassetto (2002), Bassetto (2008), Cochrane (2005), and Cochrane (2011)).

Our paper relates to the literature examining the role of the government maturity structure for policy. Angeletos (2002) and Buera and Nicolini (2004) demonstrate how a portfolio of non-state-contingent real debt of different maturities can replicate the complete markets allocation with state-contingent securities. Lustig, Sleet, and Yeltekin (2008), Leeper and Zhou (2013), and Faraglia, Marcet, Oikonomou, and Scott (2013) analyze optimal maturity structure of nominal debt in DSGE models with distortionary taxes and market incompleteness. Greenwood and Vayanos (2014), Chen, Curdia, and Ferrero (2012), and Guibaud, Nosbusch, and Vayanos (2013) analyze nominal maturity restructuring polices in models with preferred habitats. Reis (2015) studies maturity operations in a framework that features an exogenous fiscal limit and endogenous default. We differ from these papers by highlighting a distinct but complementary mechanism for maturity structure non-neutralities. Notably, we demonstrate how accounting for heterogeneity in risk across nominal bonds in the context of the fiscal theory provides a channel for the maturity structure to affect inflation without market segmentation or distortionary taxation.

Our paper is most closely related to Cochrane (2001) who also considers the maturity structure in the fiscal theory. In a partial equilibrium setting with a constant interest rate, Cochrane illustrates how restructuring the face value of nominal government debt alters the timing of inflation. In contrast, we focus on *market value* restructuring operations (i.e., holding the market value of debt constant initially), and highlight how a nonzero yield curve slope is essential for such open market procedures to affect inflation through the fiscal discount rate channel. Furthermore, we also evaluate our mechanism in a Dynamic Stochastic General Equilibrium (DSGE) framework with an estimated process for the average duration of public debt to quantitatively examine effects of maturity restructuring policies.

The Markov-switching Dynamic Stochastic General Equilibrium (DSGE) framework builds on Davig and Leeper (2007a), Davig and Leeper (2007b), Farmer, Waggoner, and Zha (2009), Bianchi and Ilut (2014), and Bianchi and Melosi (2014). In particular, Bianchi and Ilut (2014) and Bianchi and Melosi (2014) also consider stochastic shifts between monetary- and fiscally-led policy regimes. However, our focus is on how the interaction between risk composition and the fiscal policy regime

[3]See, for example, Williams (2014) for a survey on the event-study evidence of QE.

(or expectations of entering the regime) propagates maturity restructuring shocks.

Our paper connects to the theoretical literature studying the effects of unconventional monetary policy and transmission channels. Cúrdia and Woodford (2010), Gertler and Karadi (2011), Araújo, Schommer, and Woodford (2015), and Williamson (2016) analyze the role of financial frictions for central bank purchases of risky assets. Correia, Farhi, Nicolini, and Teles (2013) demonstrate how distortionary tax policy can deliver an economic stimulus when monetary policy is constrained at the zero lower bound. Reis (2015) explores QE operations in an environment with an exogenous fiscal limit, default risk, and a fiscal regime. Gomes, Jermann, and Schmid (2014) illustrate how incorporating nominal corporate debt in a DSGE framework provides an important source of monetary non-neutrality. Kaplan, Moll, and Violante (2016) explore the transmission channels from a heterogeneous agent New Keynesian model. We offer an alternative transmission channel for thinking about unconventional monetary policy that relies on the interaction between the fiscal theory and bond risk premia to break Wallace neutrality.

More broadly, this paper relates to general equilibrium models that link policy to risk premia. For example, Rudebusch and Swanson (2012), Palomino (2012), Dew-Becker (2014) Campbell, Pflueger, and Viceira (2014), and Kung (2015) link asset prices to monetary policy. Croce, Kung, Nguyen, and Schmid (2012), Pastor and Veronesi (2012), Gomes, Michaelides, and Polkovnichenko (2013), and Belo, Gala, and Li (2013) look at fiscal policy and asset prices.

The paper is organized as follows. Section 2 provides a simple partial equilibrium model to qualitatively illustrate the basic mechanisms. Section 3 presents the benchmark model. Section 4 examines the quantitative implications of the model and considers a policy experiment relating to the QE operations. Section 5 concludes.

2 Simple Model

In this section we propose a simple partial equilibrium model to illustrate how the risk composition of the government portfolio affects inflation. Using approximate analytical solutions, we explicitly show how the impact of changing debt maturity on inflation depends on the slope of the yield curve. These concepts are then formalized and quantified in the benchmark general equilibrium model.

2.1 Government Budget Equation

We assume that the government finances nominal surpluses by issuing one- and two-period nominal debt. The flow government budget constraint at time t is therefore given by:

$$B_{f,t}^{(1)} + Q_t^{(1)} B_{f,t}^{(2)} = Q_t^{(1)} B_{f,t+1}^{(1)} + Q_t^{(2)} B_{f,t+1}^{(2)} + S_t, \tag{1}$$

where $B_{f,t}^{(n)}$ is the nominal face value of debt issued by the treasury with a maturity of n periods, Q_t^n is the corresponding nominal bond price, and $S_t \equiv T_t - G_t$ is the nominal primary surplus. The relative supply of government bonds (portfolio weights) is assumed to be exogenous and constant. In particular, we define the relative supply of the one-period bond (in terms of market values) as:

$$\frac{Q_t^{(1)} B_{f,t+1}^{(1)}}{Q_t^{(1)} B_{f,t+1}^{(1)} + Q_t^{(2)} B_{f,t+1}^{(2)}} \equiv w_t = w, \tag{2}$$

which we assume to be constant.

2.2 Monetary/Fiscal Policy

We assume that the monetary/fiscal policy mix is permanently characterized by a fiscally-led policy regime (without regime shifts). We consider a particular policy mix that allows for analytical tractability.

2.2.1 Fiscal Policy

Fiscal policy sets the real surplus independently of debt. We assume that $s_t \equiv S_t/P_t$, follows an exogenous stochastic process:

$$s_t = (1-\rho_s)\bar{s} + \rho_s s_{t-1} + \sigma_s \epsilon_{s,t}, \tag{3}$$

where $\epsilon_{s,t} \sim iid\ N(0,1)$.

2.2.2 Monetary Policy

Monetary policy sets the short-term nominal interest rate independently of inflation. Specifically, the nominal short rate is determined by an exogenously specified nominal stochastic factor M_t via the Euler equation:

$$\log(R_t) = -\log\left(E_t[M_{t+1}]\right).$$

2.3 Stochastic Discount Factor

The log nominal stochastic discount factor is assumed to follow an ARMA(1,1) as in Backus and Zin (1994):

$$-\log(M_t) = (1-\rho)\delta - \rho\log(M_{t-1}) + \epsilon_t + \theta\epsilon_{t-1}, \tag{4}$$

where $\epsilon_t \sim iid\ N(0,\sigma^2)$. This specification of the pricing kernel allows for various average slopes of the nominal yield curve.

2.3.1 Real Rate and Fisher Equation

The real rate is assumed to be constant and given by the parameter, $R_{real} > 0$. To close model, we assume that the Fisher equation holds:

$$\log(R_t) = \log(R_{real}) + E_t[\log(\Pi_{t+1})], \tag{5}$$

where Π_t is gross inflation.

2.3.2 Bond Pricing

The nominal price of a n-period nominal zero-coupon bond can be written recursively using the Euler equation:

$$Q_t^{(n)} = E_t\left[M_{t+1}Q_{t+1}^{(n-1)}\right], \tag{6}$$

where $Q^{(0)} \equiv 1$ and $Q_t^{(1)} \equiv 1/R_{t+1}^{(1)}$. The corresponding yield-to-maturity for the n-period bond is defined as:

$$y_t^{(n)} \equiv -\frac{1}{n} \log Q_t^{(n)}. \tag{7}$$

When yields are persistent, there is tight relation between the yield spread and the corresponding return spread:

$$E[\log(R_t^{(2)}) - \log(R_t^{(1)})] \approx 2 \cdot E[y_t^{(2)} - y_t^{(1)}], \tag{8}$$

where $R_t^{(2)} \equiv Q_t^{(1)}/Q_{t-1}^{(2)}$ and $R_t^{(1)} \equiv 1/Q_{t-1}^{(1)}$.[4]

2.4 Fiscal Discount Rate Channel

We can rewrite the flow government budget constraint in terms of market values of debt and returns:

$$R_t^{(1)} B_t^{(1)} + R_t^{(2)} B_t^{(2)} = B_{t+1}^{(1)} + B_{t+1}^{(2)} + S_t, \tag{9}$$

where $B_t^{(i)} \equiv Q_{t-1}^{(i)} B_{f,t}^{(i)}$, $R_t^{(2)} \equiv Q_t^{(1)}/Q_{t-1}^{(2)}$, $R_t^{(1)} \equiv 1/Q_{t-1}^{(1)}$, $B_t \equiv B_t^{(1)} + B_t^{(2)}$, $R_t^g \equiv wR_t^{(1)} + (1-w)R_t^{(2)}$. Iterating Eq. (9) forward and imposing the transversality condition, we obtain the present value formula relating the real value of government liabilities at $t = 0$ to the present value of future surpluses (see Appendix C for derivation):

$$b_1 \equiv \frac{B_1}{P_0} = E_1 \sum_{i=0}^{\infty} \left[\frac{s_{i+1}}{\prod_{j=0}^{i} \left\{ R_{j+1}^g / \Pi_{j+1} \right\}} \right]. \tag{10}$$

In the fiscally-led regime, today's price level, P_0, is determined by the intertemporal government budget equation (Eq. (10)). Any current or expected fiscal disturbances directly affect the price level.

The slope of the nominal yield curve determines the relative cost of debt financing across maturities. When the yield curve is not flat, rebalancing the maturity structure changes the government cost of capital, R_g, which directly affects the price level through Eq. (10). Importantly, the sign of effect on the price level depends on the sign of the slope of the nominal yield curve. Suppose the yield curve is downward-sloping, then shortening the maturity structure increases R^g. To satisfy the intertemporal government budget equation, the increase in discount rates is compensated by a devaluation of the debt portfolio through inflation (increases in P_0). The effects are reversed when the yield curve is upward-sloping and neutral when the yield curve is flat. If we add *sticky prices* (and the slope is nonzero), rebalancing the maturity structure will also have real effects, so that the fiscal discount rate channel violates *Wallace neutrality*.

Fig. 2 illustrates comparative statics from shortening the maturity structure (i.e., increasing w) on the government discount rate (top figure) and inflation (bottom figure). We show these comparative statics for parameterizations of the SDF where the nominal yield curve is upward-sloping (solid line), flat (line with circles), downward-sloping (dashed line). Consistent with the intuition above, the sign of the slope determines the sign of the responses to changes in maturity

[4] Note that $\log(R_t^{(2)}) = 2y_{t-1}^{(2)} - y_t^{(1)}$ and $\log(R_t^{(1)}) = y_{t-1}^{(1)}$. Thus, if yields are persistent, then $E[R_t^{(2)} - R_t^{(1)}] \approx E[2y_t^{(2)} - 2y_t^{(1)}] = 2 \cdot E[y_t^{(2)} - y_t^{(1)}]$.

restructuring.

2.4.1 Approximate Analytical Solution

We can directly link the impact of debt maturity changes on inflation to the slope by means of an approximate analytical solution. Define $B_t \equiv B_t^{(1)} + B_t^{(2)}$ as the total nominal market value of the debt portfolio. Substituting this definition in the government budget equation (Eq. (9)), we can write the return on the government bond portfolio as:

$$R_t^g = \frac{B_{t+1} + S_t}{B_t}. \tag{11}$$

Rewriting this return in terms of real surpluses and debt:

$$\frac{R_t^g}{\Pi_t} = \frac{b_{t+1} + s_t}{b_t},$$

where $b_{t+1} \equiv B_{t+1}/P_t$. Define $\log(x) \equiv \widetilde{x}$, and take logs of Eq. (12):

$$\widetilde{R}_t^g - \widetilde{\Pi}_t = \widetilde{b}_{t+1} + \log\left(1 + \frac{s_t}{b_{t+1}}\right) - \widetilde{b}_t. \tag{12}$$

Since surpluses can be negative, substitute $s_t = \tau_t - g_t$ (τ_t and g_t are real taxes and government expenditures, respectively) into Eq. (12) and rearrange:

$$\widetilde{R}_t^g - \widetilde{\Pi}_t = \widetilde{b}_{t+1} - \widetilde{b}_t + \log\left(1 + \exp\left(\widetilde{\tau}_t - \widetilde{b}_{t+1}\right) - \exp\left(\widetilde{g}_t - \widetilde{b}_{t+1}\right)\right). \tag{13}$$

Following Berndt, Lustig, and Yeltekin (2012), log-linearize Eq. (13) with respect to the log tax-to-debt and the log government expenditure-to-debt ratios around the steady-state:

$$\widetilde{R}_t^g - \widetilde{\Pi}_t = \theta_1 \widetilde{b}_{t+1} - \widetilde{b}_t + \theta_0 + (1-\theta_1)(\mu_\tau \widetilde{\tau}_t - \mu_g \widetilde{g}_t), \tag{14}$$

where $\theta_1, \theta_0, \mu_\tau$, and μ_g are parameters of linearization that are defined in Appendix D. Iterating Eq. (14) forward and imposing the transversality condition:

$$\widetilde{b}_0 = \frac{\theta_0}{1-\theta_1} + \sum_{j=0}^{\infty} \theta_1^j \left((1-\theta_1)(\mu_\tau \widetilde{\tau}_j - \mu_g \widetilde{g}_j) - \widetilde{R}_j^g + \widetilde{\Pi}_j\right). \tag{15}$$

Take expectations of Eq. (15), solve for expected inflation using the Fisher equation, and substitute $\widetilde{R}_t^g \approx \omega \widetilde{R}_t^{(1)} + (1-\omega)\widetilde{R}_t^{(2)}$:[5]

$$E\left[\widetilde{\Pi}_0\right] = E\left[\widetilde{b}_0\right] - \frac{\theta_0}{1-\theta_1} - E\left[\mu_\tau \widetilde{\tau}_j - \mu_g \widetilde{g}_j\right] + \frac{E\left[\widetilde{R}_j^{(2)} - \omega(\widetilde{R}_j^{(2)} - \widetilde{R}_j^{(1)})\right]}{1-\theta_1} - \theta_1 \frac{E\left[\widetilde{R}_{j-1}\right] - \widetilde{R}^{real}}{1-\theta_1} \tag{16}$$

Taking derivative of expected inflation with respect to ω we see that the sign and magnitude from

[5] To obtain the relation between log returns, $\widetilde{R}_t^g \approx \omega \widetilde{R}_t^{(1)} + (1-\omega)\widetilde{R}_t^{(2)}$, we are using the approximation that $\log(R) \equiv \widetilde{R} \approx R - 1$.

shortening maturity on inflation depends negatively on the average slope of the nominal yield curve:

$$\frac{dE\left[\widetilde{\Pi}_0\right]}{d\omega} = \frac{-E\left[\widetilde{R}_j^{(2)} - \widetilde{R}_j^{(1)}\right]}{1-\theta_1} \tag{17}$$

where the last approximate equality uses Eq. (8). Thus, the impact of shortening maturity on expected inflation is negatively related to the slope of the nominal yield curve.

2.4.2 Other Asset Classes

The fiscal discount rate channel also extends beyond maturity restructuring operations to other asset classes with different risk profiles. Accounting for differences in expected returns across financing instruments, regardless of maturity, in the fiscal theory provides a direct channel for changes in the government portfolio to affect inflation. Assume now that the government issues one-period riskless nominal debt $B_t^{(1)}$ and one-period defaultable nominal debt D_t:

$$R_t^{(1)} B_t^{(1)} + R_t^{(d)} D_t \quad = \quad B_{t+1}^{(1)} + D_{t+1} + S_t. \tag{18}$$

The return of the defaultable bond is:

$$R_t^{(d)} \quad \equiv \quad 1/Q_{t-1}^{(d)}, \tag{19}$$

where the price, $Q_t^{(d)}$, is given by the Euler equation:

$$Q_t^{(d)} \quad = \quad E_t\left[\frac{M_{t+1}}{\Pi_{t+1}} e^{-\kappa_{t+1}}\right], \tag{20}$$

and κ_{t+1} is the fraction of debt that is defaulted at time t, which follows an exogenous process:

$$\kappa_t \quad = \quad (1-\rho_\kappa)\kappa + \rho_\kappa \kappa_{t-1} + \sigma_\kappa \varepsilon_{\kappa,t}. \tag{21}$$

The discount rate of the government is given by:

$$R_t^{(g)} \quad = \quad (1-w_d) R_t^{(1)} + w_d R_t^{(d)}. \tag{22}$$

Given default risk, we can show that $E[R_t^{(d)}] > E[R^{(1)}]$. Therefore, increasing the financing weight on risky debt will increase the government discount rate and generate inflation. These comparative statics are illustrated in Fig. 3.

3 Benchmark Model

This section presents the benchmark model which builds on and quantifies the insights from the simple model.

3.1 Households

The representative household is assumed to have Epstein-Zin preferences over streams of consumption C_t and labor L_t:

$$U_t = \left\{(1-\beta)\left(C_t^{\star}\right)^{1-1/\psi} + \beta\left(E_t\left[U_{t+1}^{1-\gamma}\right]\right)^{\frac{1}{\theta}}\right\}^{\frac{\theta}{1-\gamma}}, \tag{23}$$

$$C_t^{\star} = C_t\left(\frac{\bar{L}}{L_t}\right)^{\varphi}, \tag{24}$$

where γ is the coefficient of risk aversion, ψ is the elasticity of intertemporal substitution, $\theta \equiv \frac{1-\gamma}{1-1/\psi}$ is a parameter defined for convenience, β is the subjective discount rate, and $\bar{L}$ is the agent's time endowment. The time t budget constraint of the household is

$$P_tC_t + B_{t+1} = P_tD_t + W_tL_t + R_tB_t - T_t, \tag{25}$$

where P_t is the aggregate price level, B_t is the nominal market value of a portfolio of government bonds, D_t represents real dividends received from the intermediate firms, R_t is the gross nominal interest rate on the bond portfolio, W_t is the nominal competitive wage, and T_t are lump sum taxes from the government. The household chooses sequences of C_t, L_t, and B_t to maximize lifetime utility subject to the budget constraints.

3.2 Firms

Production in our economy is comprised of two sectors: the final goods sector and the intermediate goods sector.

3.2.1 Final Goods

A representative firm produces the 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:

$$Y_t = \left(\int_0^1 X_{i,t}^{\frac{\nu-1}{\nu}}\right)^{\frac{\nu}{\nu-1}}, \tag{26}$$

where ν is the elasticity of substitution between intermediate goods. The profit maximization problem of the final goods firm yields the following isoelastic demand schedule with price elasticity ν:

$$X_{i,t} = Y_t\left(\frac{P_{i,t}}{P_t}\right)^{-\nu}, \tag{27}$$

where P_t is the nominal price of the final goods and $P_{i,t}$ is the nominal price of the intermediate goods i. The inverse demand schedule is

$$P_{i,t} = P_tY_t^{\frac{1}{\nu}}X_{i,t}^{\frac{-1}{\nu}}. \tag{28}$$

3.2.2 Intermediate Goods

The intermediate goods sector is characterized by a continuum of monopolistic firms. Each intermediate goods firm produces $X_{i,t}$ using labor $L_{i,t}$:

$$X_{i,t} = Z_t L_{i,t} - \Phi Z_t, \tag{29}$$

where Z_t represents an aggregate productivity shock common across firms, and is composed of both transitory and permanent components (e.g., Croce (2014) and Kung and Schmid (2015)):

$$\begin{aligned} Z_t &= e^{z^\star + a_t + n_t}, && (30)\\ a_t &= \rho_a a_{t-1} + \sigma_a \epsilon_{at}, && (31)\\ \Delta n_t &= \rho_n \Delta n_{t-1} + \sigma_n \epsilon_{nt}, && (32) \end{aligned}$$

where $z^\star$ is the unconditional mean of $\log(Z_t)$, $\Delta n_t = n_t - n_{t-1}$, ϵ_{at} and ϵ_{nt} are standard normal shocks with a contemporaneous correlation equal to ρ_{an}. The low-frequency component in productivity, Δn_t, generates long-run risks and sizeable risk premia (i.e., Bansal and Yaron (2004)). The fixed cost of production Φ is multiplied by Z_t to ensure that it does not become trivially small along the balanced growth path.

Using the inverse demand function from the final goods sector, nominal revenues for intermediate firm i can be expressed as

$$P_{i,t} X_{i,t} = P_t Y_t^{\frac{1}{\nu}} \left[Z_t L_{i,t} - \Phi Z_t \right]^{1-\frac{1}{\nu}}. \tag{33}$$

The intermediate firms face a cost of adjusting the nominal price à la Rotemberg (1982), measured in terms of the final good as

$$G(P_{i,t}, P_{i,t-1}) = \frac{\phi_R}{2} \left(\frac{P_{i,t}}{\Pi_{ss} P_{i,t-1}} - 1 \right)^2 Y_t, \tag{34}$$

where $\Pi_{ss} \geqslant 1$ is the steady-state inflation rate and ϕ_R is the magnitude of the costs.

The source of funds constraint is

$$P_t D_{i,t} = P_{i,t} X_{i,t} - W_t L_{i,t} - P_t G(P_{i,t}, P_{i,t-1}; P_t, Y_t), \tag{35}$$

where $D_{i,t}$ is the real dividend paid by the firm. The objective of the firm is to maximize shareholder's value $V_t^{(i)} = V^{(i)}(\cdot)$ taking the pricing kernel M_t, the competitive nominal wage W_t, and the vector of aggregate state variables $\Upsilon_t = (P_t, Z_t, Y_t)$ as given:

$$V^{(i)}(P_{i,t-1}; \Upsilon_t) = \max_{P_{i,t}, L_{i,t}} \left\{ D_{i,t} + E_t \left[M_{t+1} V^{(i)}(P_{i,t}; \Upsilon_{t+1}) \right] \right\}, \tag{36}$$

subject to

$$\begin{aligned} D_{i,t} &= \frac{P_{i,t}}{P_t} X_{i,t} - W_t L_t - G(P_{i,t}, P_{i,t-1}; P_t, Y_t), && (37)\\ \frac{P_{i,t}}{P_t} &= \left(\frac{X_{i,t}}{Y_t} \right)^{-\frac{1}{\nu}}. && (38) \end{aligned}$$

The corresponding first-order conditions are listed in Appendix A.

3.2.3 Government

The flow budget constraint of the government is given by:

$$\sum_{i=1}^{N} B_{t+1}^{(i)} = \sum_{i=1}^{N} R_t^{(i)} B_t^{(i)} - S_t, \tag{39}$$

where $B_{t+1}^{(i)}$ is the nominal debt of maturity i issued at the end of period t, $R_t^{(i)}$ is the nominal interest paid on debt of maturity i, S_t denotes the nominal value of primary surpluses. For parsimony, we assume that the government only levies lump-sum taxes and government expenditures are excluded. Thus, the primary surplus equals lump-sum taxes. Denoting the total market value of public debt by B_t and scaling the budget constraint by nominal output P_tY_t,

$$b_{t+1} = \frac{R_t^g}{\Pi_t \Delta Y_t} b_t - s_t, \tag{40}$$

where $b_{t+1} \equiv B_{t+1}/(P_tY_t)$, $s_t \equiv S_t/(P_tY_t)$ and $R_t^g = \sum_{i=1}^{N} w_t^{(i)} R_t^{(i)}$ is the nominal gross interest paid on the portfolio of government debt. The government issues nominal debt at N different maturities and we assume that each period the government retires outstanding debt and issues new debt over the N maturities. The proportion of the debt financed with bonds of maturity i is given by:

$$w_t^{(i)} = \bar{w}^{(i)} + \beta^{(i)} x_{mt}, \tag{41}$$

where the constants $\bar{w}^{(i)}$'s determine the steady state maturity structure of debt and the $\beta^{(i)}$'s determine the sensitivity to x_{mt}, a stochastic process drives the dynamics of the maturity structure. The evolution of x_{mt} is given by:

$$x_{mt} = \rho_m x_{mt-1} + \sigma_m \epsilon_{mt}, \tag{42}$$

subject to $\sum_{i=1}^{N} \bar{w}_t^{(i)} = 1$. Note that these shocks are self-financing so that the total market value of debt B_{t+1} is unaffected initially, but is allowed to adjust freely afterwards.

3.2.4 Monetary and Fiscal Rules

The central bank follows an interest rate feedback rule:

$$\ln\left(\frac{R_t^{(1)}}{R^{(1)}}\right) = \rho_r \ln\left(\frac{R_{t-1}^{(1)}}{R^{(1)}}\right) + (1-\rho_r)\left(\rho_{\pi,\zeta_t} \ln\left(\frac{\Pi_t}{\Pi}\right) + \rho_y \ln\left(\frac{\widehat{Y}_t}{\widehat{Y}}\right)\right) + \sigma_r \epsilon_{rt}, \tag{43}$$

where $R_{t+1}^{(1)}$ is the gross one-period nominal interest rate, Π_t is inflation, $\widehat{Y}_t$ is detrended output, and ϵ_{rt} is a normal i.i.d. shock. Note that the coefficient ρ_{π,ζ_t} is indexed by ζ_t, which determines the policy mix at time t.

The fiscal authority adjusts the primary surplus-to-GDP ratio, $s_t \equiv S_t/(P_tY_t)$, according to the following rule:

$$s_t - s = \rho_s(s_{t-1} - s) + (1-\rho_s)\,\delta_{b,\zeta_t}(b_t - b) + \sigma_s \epsilon_{s_t}. \tag{44}$$

The coefficient δ_{b,ζ_t} is also indexed ζ_t and is therefore depends on the policy mix at time t.

3.2.5 Monetary/Fiscal Policy Mix

Leeper (1991) distinguishes four policy regions in a model with fixed policy parameters. Two of the parameter regions admit a unique bounded solution for inflation. One of the determinacy regions is what Leeper refers to as the Active Monetary/Passive Fiscal (AM/PF) regime, which is the familiar textbook case (e.g., Woodford (2003) and Galí (2015)). The Taylor principle is satisfied ($\rho_\pi > 1$) and the fiscal authority adjusts taxes to stabilize debt ($\delta_b > \left(\beta \Delta Y^{1-\frac{1}{\psi}}\right)^{-1} - 1$). In this policy mix, monetary policy determines inflation while fiscal policy passively provides the fiscal backing to accommodate the inflation targeting objectives of the monetary authority. We refer to this regime as the *monetary-led* regime.

The other determinacy region is the Passive Monetary/Active Fiscal (PM/AF) regime. The fiscal authority is not committed to stabilizing debt ($\delta_b < \left(\beta \Delta Y^{1-\frac{1}{\psi}}\right)^{-1} - 1$), but instead the monetary authority passively accommodates fiscal policy ($\rho_\pi < 1$) by allowing the price level to adjust (to satisfy the government budget constraint). In this setting, fiscal policy determines inflation while monetary policy stabilizes debt and anchors expected inflation. Importantly, in this regime, fiscal disturbances, including non-distortionary taxation, have a direct impact on the price level via the government budget constraint because households know that changes in taxes will not be offset by future tax changes.[6] We refer to this regime as the *fiscally-led* regime.

When both the fiscal and monetary authorities are active (AM/AF), no stationary equilibrium exists. When both authorities are passive, there exist multiple equilibria. In our regime-switching specification, we assume that the policy mix alternates between monetary- and fiscally-led regimes according to a two-state Markov chain with the following transition matrix:

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

where $p_{ij} \equiv Pr(\zeta_{t+1} = i | \zeta_t = j)$ and M denotes the monetary-led regime and F denotes the fiscally-led regime.

4 Results

This section presents the key results of the model. We begin with a description of the calibration of the model followed by a quantitative analysis. The model is solved using a global projection method that is outlined in Appendix B.

4.1 Calibration

Table 1 presents the quarterly calibration. Panel A reports the values for the preference parameters. The elasticity of intertemporal substitution ψ is set to 1.5 and the coefficient of relative risk aversion γ is set to 10.0, which are standard values in the long-run risks literature (e.g., Bansal and Yaron (2004)). The subjective discount factor β is calibrated to 0.9935 to be consistent with the average return on the government bond portfolio (see Panel A of Table 2). The relative preference for leisure φ is set so that the household works one-third of the time in the steady-state.

[6] In this regime, the government budget constraint is an equilibrium condition rather than a constraint that has to hold for any price path, which Cochrane (2005) refers to as the government debt valuation equation.

Panel B reports the calibration of the technological parameters. The price elasticity of demand ν is set to 2. The fixed cost of production Φ is set such that the dividend is zero in the deterministic steady state. The price adjustment cost parameter ϕ_R is set to 10.[7] The mean growth rate of productivity $z^\star$ is set to obtain a mean growth rate of output of 2%. The parameters ρ_a and σ_a are set to be consistent with the standard deviation and persistence of output growth, respectively (see Panel B of Table 2). The parameters ρ_n and σ_n are set to match the standard deviation and persistence of expected productivity growth.

For parsimony, we assume that shocks to the short-run and long-run components of productivity are perfectly correlated ($\epsilon_{a,t} = \epsilon_{n,t}$). Indeed, Kung and Schmid (2015) and Kung (2015) show that a stochastic endogenous growth framework produces a very strong positive correlation between these components (i.e., around 0.98). Kung (2015) illustrates that these productivity dynamics help to generate countercyclical real marginal costs, which implies a negative relation between inflation and expected growth. Further, these inflation and growth dynamics imply an upward sloping nominal yield curve (see Table 3).

Panel C reports the calibration of the policy rule parameters. We set the steady state debt-to-GDP ratio to match the empirical average. The persistence and volatility parameters, ρ_s and σ_s, are chosen to match primary surplus dynamics. The surplus rule parameter, δ_b, is set to 0.05 and 0.00 in the AM/PF and PM/AF regimes, respectively. The interest rate rule parameter, ρ_π, is set to 1.5 and 0.4 in the AM/PF and PF/AM regimes, respectively. The calibration of these policy parameters, conditional on regime, are consistent with structural estimation evidence from Bianchi and Ilut (2014). The persistence of the interest rate rule ρ_R is calibrated to 0.5. For parsimony, we abstract from monetary policy shock and output smoothing. Steady-state inflation Π_{ss} is calibrated to match the average level of inflation. Following Bianchi and Melosi (2014), we assume that the transition matrix governing the dynamics of the policy/mix is symmetric: $p_{MM} = p_{FF} \equiv p$ is set to 0.9875, implying that the economy stays on average 20 years in a given regime.

Panel D reports the calibration of the government bond supply dynamics. Fig. 1 plots the average maturity of net government liabilities, including reserves, from Q1:2005 to Q3:2013. Note that the three QE operations and the Maturity Extension Program (MEP), show up quite visibly as each of these operations significantly shortened the maturity structure of debt.[8] We calibrate the bond supply process to capture salient features of the maturity structure dynamics. We set $N = 40$, so that we include bonds up to a maturity of 10 years, as in our data sample. The steady state maturity structure $\{\bar{w}^{(i)}\}$ is set to match the sample average. To calibrate the dynamics of the process driving the duration of government liabilities, x_{mt}, we proceed as follows. First, we run a principal component analysis on the panel data of maturity structure. Next, we extract the first principal component (PC_1) and fit the time series to an AR(1) process.[9] The estimates for ρ_m and σ_m are 0.9513 and 1.28%, respectively. The loadings $\{\beta^{(i)}\}$ for bonds of each maturity are also obtained from the first principal component.

[7]For example, in a log-linear approximation, the parameter ϕ_R can be mapped directly to a parameter that governs the average price duration in a Calvo pricing framework. In this calibration, $\phi_R = 10$ corresponds to an average price duration of 3.7 quarters, a standard value in the macroeconomics literature (e.g. Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramirez (2015)).

[8]Details on the data construction are described in Appendix E.

[9]The first principal component explains about 62% of the cross-sectional dynamics of the debt maturity structure

4.2 Yield Curve

The dynamics of the nominal yield curve provide the key transmission channel for maturity restructuring operations in the fiscal theory. In this section, we show that the model endogenously generates realistic term structure implications. Table 3 reports the mean, standard deviation, and first autocorrelation of nominal yields for maturities of one quarter to five years. The model does a fairly good job in explaining the level and persistence of yields. In particular, the negative link between inflation and expected consumption growth implies that long nominal bonds are riskier than short nominal bonds, which helps the model explain the upward-sloping average yield curve (five-year minus one-quarter yield spread is 0.55%). The volatility of yields falls short of the empirical moments, however Kung (2015) shows that incorporating volatility shocks to productivity and interest rate rule shocks in a similar DSGE framework helps to fit the second moments better.

The model can explain the joint dynamics between bond yields and macroeconomic variables. Table 4 shows that the slope of the nominal yield curve can positively forecast consumption and output growth while negatively forecast inflation as in the data. The interest rate rule plays an important role in these forecasting regressions. Suppose that inflation falls persistently today, then the monetary authority responds by lowering the short rate. A temporary fall in the short rate steepens the slope of the yield curve. Further, due to the negative inflation-growth link, a fall in inflation is also associated with higher expected growth rates.

4.3 Maturity Structure Shocks

As described in the simple model, the combination of a fiscally-led regime and a non-zero slope implies that rebalancing the maturity structure affects inflation. We again can derive a similar present value relation by iterating forward the government budget equation (Eq. (39)) from our benchmark model (see Appendix C for the derivation):

$$b_t \equiv \frac{B_t}{P_t} = E_t\left[\sum_{i=0}^{\infty} \frac{s_{t+i}}{\prod_{j=0}^{i} R^g_{t+j}/\left(\Pi_{t+j}\Delta Y_{t+j}\right)}\right]. \tag{45}$$

In the fiscally-led regime, Eq. (45) is an equilibrium asset pricing condition that determines the price level. This equation is similar to the present value relation derived in the simple model except that there is now debt issued up to N-periods and the equation accounts for growth. When the expected returns of bonds vary by maturity, changing the financing mix alters the government cost of capital, R_g, which leads to an adjustment in inflation (and expected inflation) to satisfy Eq. (45). The addition of sticky prices in the benchmark model implies that the fiscal discount rate channel has real effects and therefore violates Wallace neutrality. We show that the direction of these effects is determined by the sign of the expected return spread between long and short maturity bonds. As discussed in Section 2.3, when yields are persistent (like in the data and the model), the average return spread and the yield spread are approximately proportional. Thus, for ease of exposition, we state the subsequent results in terms of the yield curve slope.

Fig. (4) plots impulse response functions, conditional on staying in the fiscally-led regime, to a shock that reduces average maturity by 0.18 years (similar magnitude as in QE2). We illustrate the effects of the maturity shock for when the yield curve is upward-sloping (solid line), flat (line with circles), and downward-sloping (dashed line). Since the average slope in the model is positive, for the downward-sloping case we look at maturity structure shocks conditional on periods when the slope is negative. For the upward-sloping case, we consider the average effects from maturity restructuring (without conditioning on the realized slope). For the flat yield curve scenario, we assume that the monetary authority implements an interest rate peg.

In the positive slope case, shortening the maturity structure implies that the government is refinancing at a lower rate. In the fiscally-led regime, a persistent decline in the government discount rate leads requires that inflation fall persistently to revalue nominal debt obligations to satisfy the intertemporal government equation. A heuristic interpretation of the discount rate-inflation link is as follows (e.g., Cochrane (2011)). A fall in the government discount rate puts upward pressure on the real value of debt. Households, in anticipation of the appreciation in their debt portfolio, increase demand for debt and decrease demand for consumption goods. The fall in aggregate demand leads to a decline in the price level. Without sticky prices, the fall in prices will be sufficient to leave households content with their original consumption allocation. However, with sticky prices, the fall in prices is sluggish, so that prices are temporarily too high relative to the flexible price case, which depresses production (output) and increases the real rate. Thus, when the yield curve is upward-sloping, the fiscal channel implies a potential "cost" of QE operations.

The endogenous yield curve responses to the maturity structure shocks provide a feedback channel that amplifies the fiscal channel. For example, the fall in inflation (in the upward-sloping case) leads to a decline in the short rate due to the interest rate rule. A temporary fall in the short rate steepens the slope of the nominal yield curve, which deepens the fall in the government discount rate from shortening maturity. Furthermore, the fall in the overall level of the yields from falling inflation further depresses the nominal bond portfolio return.

In the negative slope case, shortening the maturity structure gives the *opposite effects* compared to when the slope is positive, which is illustrated in Fig. (4). In particular, reducing maturity in this case means that the government is refinancing at a higher rate. In the fiscal regime, an increase in the discount rate requires a devaluation in the real value of the bond portfolio via higher inflation to satisfy the intertemporal government budget constraint. With sticky prices, the increase in inflation stimulates an expansion in output. Also, flattening of the yield curve due to the increase in the short rate amplifies the maturity restructuring effects, following a similar logic as above. Finally, when the yield curve is flat, our fiscal channel is neutral even in the fiscally-led regime, as the financing costs are the same across maturities. These results illustrate how monetary policy is important for open market operations even when it is "passive". Overall, we highlight the importance of the yield curve for maturity restructuring in the fiscal theory.

Due to the recurrent regime shifts and rational expectations, maturity restructuring also has non-neutral effects in the monetary-led regime when the yield curve is nonzero. Fig. (5) displays impulse response functions, conditional on *staying* in the fiscally-led (dashed line) and the monetary-led (solid line) regimes for the relevant period, to a shock to maturity structure that reduces average maturity by 0.18 years. We show these plots for the upward-sloping case. Without regime shifts, changes in fiscal discount rates are neutral in the monetary-led regime due to offsetting surplus policy. However, the possibility of entering the fiscally-led regime propagates the restructuring effects, through agent's expectations, to the monetary-led regime.

Indeed, the responses in the monetary-led regime are qualitatively similar to the reactions in the fiscally-led regime. However, since the probability of changing regimes is small, the responses of macroeconomic quantities in the monetary-led regime are significantly smaller. For example, output drops by 33 basis points in the fiscal regime compared to 5 basis points in the monetary-led regime. Note that the responses of the short rate and yield spread are of similar magnitude despite the much smaller response of inflation in the monetary-led regime. This is because the short rate responds more aggressively to inflation deviations in the monetary-led regime than in the fiscally-led regime.

4.4 Macroeconomic Fluctuations

Table 2 reports basic macroeconomic summary statistics from the data and the model counterparts. The 'model' column reports the unconditional moments while 'fiscal' and 'monetary' columns report the moments conditional on the regime. Macroeconomic volatility is significantly higher in the fiscally-led regime because the economy is less insulated from fiscal disturbances than in the monetary-led regime. This was highlighted in the previous section when we compared responses from changes in government discount rates due to maturity restructuring operations in the two regimes.

Fig. 6 plots impulse response functions to a positive one standard deviation shock to real surpluses, conditional on staying in the monetary-led (solid line) and fiscally-led (dashed line) regimes for the relevant period. In the fiscally-led regime, an increase in real surpluses raises the fiscal backing for debt. To satisfy the intertemporal government budget constraint, the price level needs to fall to increase the real value of debt. In the monetary-led regime without regime shifts, surplus shocks are offset by stabilizing future surplus policy which implies that surplus shocks are neutral. However, the possibility of entering the fiscally-led regime propagates the effects to the monetary regime. Qualitatively, the responses are similar in the two regimes, but quantitatively, the responses are significantly larger in the fiscally-led regime since the regimes are persistent.

4.5 Market Timing Policies

Fig. 7 plots impulse response functions from a shock that lengthens average maturity, conditional on staying in the fiscally-led regime, for various slopes as in Fig. 4. The effects of lengthening maturity are the opposite to shortening maturity. When the yield curve is upward-sloping (downward-sloping), lengthening maturity is expansionary (contractionary). These results suggest that there might be a role for market timing maturity operations based on the slope of the nominal yield curve.

Consider a maturity restructuring policy that depends directly on the slope of the nominal yield curve:

$$x_{m,t} = \rho_m x_{m,t-1} + \phi \left(y_t^{5Y} - y_t^{1Q} \right) + \sigma_m \epsilon_{m,t}. \tag{46}$$

A positive coefficient ($\phi > 0$) implies that the government shortens the maturity structure when yield curve is upward-sloping and lengthens the maturity structure when the yield curve is downward-sloping. A negative coefficient implies the opposite policy. Fig. 8 plots comparative statics for varying ϕ from -1 to 1. Note that more negative values of ϕ smooth macroeconomic fluctuations, reduce risk premia, and improve welfare through the fiscal discount rate channel. In contrast, more positive values of ϕ increase consumption and inflation volatility, and, in turn, increase welfare costs. Negative values of ϕ shorten the maturity structure when the yield curve is downward sloping, which stimulates the economy and generates fiscal inflation exactly during low expected growth states. Using similar logic, positive values for ϕ deepen recessions and increase deflationary pressure.

4.6 Policy Experiment

In this section we explore the quantitative significance of the fiscal discount rate channel for quantitative easing operations during the Great Recession. To enrich this analysis, we augment the benchmark model with a zero lower bound (ZLB) constraint on nominal interest rates and include market segmentation through transaction costs. We also assume that the economy starts in the monetary-led regime (with the possibility of entering the fiscally-led regime) along with a government budget deficit calibrated to match the data during the Great Recession.

At the onset and during the aftermath of the Great Recession, interest rates were near zero, and therefore the monetary authority was unable to prevent deflationary/contractionary pressure by lowering interest rates using conventional measures. Consequently, policymakers resorted to unconventional monetary policy, such as maturity twist operations (e.g., the Maturity Extension Program and QE2). One motivation for implementing the maturity twist operations is because of market segmentation, so that government purchases of long-term debt would lower long-term borrowing costs. Indeed, there is empirical evidence suggesting that the QE operations were effective in flattening the yield curve in the short-run.[10] We analyze each new feature before we combine these elements in our policy experiment.

4.6.1 ZLB

To capture periods where the ZLB constraint is binding for multiple periods, we also incorporate time preference shocks (e.g., Eggertsson and Woodford (2003)):

$$\ln(\beta_t) = (1-\rho_\beta)\ln(\beta) + \rho_\beta \ln(\beta_{t-1}) + \sigma_\beta \epsilon_\beta. \tag{47}$$

The ZLB constraint is given by:

$$\ln\left(\frac{R_t^{(1)}}{R^{(1)}}\right) = \max\left\{0, \rho_r \ln\left(\frac{R_{t-1}^{(1)}}{R^{(1)}}\right) + (1-\rho_r)\left(\rho_{\pi,\zeta_t}\ln\left(\frac{\Pi_t}{\Pi}\right) + \rho_y \ln\left(\frac{\widehat{Y}_t}{\widehat{Y}}\right)\right) + \sigma_r \epsilon_{rt}\right\}. \tag{48}$$

As in Aruoba, Cuba-Borda, and Schorfheide (2013), Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramirez (2015), and Gust, López-Salido, and Smith (2012), we use global projection methods and rational expectations (as in our bechmark model) to approximate the policy functions with the ZLB constraint.

Fig. 9 plots impulse response functions for a shock that reduces average maturity by 0.18 years (e.g., QE2), conditional on starting in the monetary-led regime, for when the ZLB binds (dashed line) and when the ZLB is not binding (solid line). For the binding case, we use a time preference shock to send the economy to the ZLB for an average of four quarters as in Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramirez (2015). Also, we consider the benchmark case where the yield curve is, on average, upward-sloping.

The effects of maturity restructuring are amplified at the ZLB. This is because the demand shock that temporarily sends the economy to the ZLB steepens the slope of the nominal yield curve. Indeed, during the aftermath of the Great Recession when interest rates were close to zero (2008 - 2015), the average slope was about 50% larger than the longer sample (1953 - 2015). With a steeper slope, shortening debt maturity decreases the government discount rate more than being away from the ZLB. Consequently, a binding ZLB enhances the contractionary effects of the fiscal discount rate channel when the yield curve is upward-sloping. More broadly, this example with the ZLB illustrates how the magnitude of the slope dictates the magnitude of the effects from the fiscal channel.

[10]See, for example, Gagnon, Raskin, Remache, and Sack (2011), Krishnamurthy and Vissing-Jorgensen (2011), Swanson (2011), d'Amico, English, López-Salido, and Nelson (2012), Hamilton and Wu (2012), Greenwood and Vayanos (2014).

4.6.2 Market Segmentation

While this paper highlights a potential cost of QE through the fiscal discount rate channel, for our policy experiment, we also account for a key proposed benefit of maturity operations - lowering long-term borrowing costs. To this end, we incorporate market segmentation via transaction costs for bonds of different maturities (e.g., Bansal and Coleman (1996)).

The transaction costs captures, in a reduced-form, a preferred habitat motive (e.g., Vayanos and Vila (2009)). These costs imply that operations shortening debt maturity flattens the yield curve by reducing the risk premium of bonds at a specific maturity. More specifically, the household pays an additional fee e^{χ_t} for each unit of long-term bond purchased. We modify the budget constraint of the representative household in the following way:

$$P_t C_t + (1 + e^{\kappa_t}) B^m_{f,t+1} Q^m_t(\lambda_t) = P_t D_t + W_t L_t + \left[(1 - \lambda_{t-1}) + \lambda_{t-1} Q^m_t(\lambda_{t-1})\right] B^m_{f,t} - S_t. \tag{49}$$

Solving the household problem, the nominal price of the long-term bond is

$$Q^m_t(\lambda_t) = E_t \left[\frac{M_{t+1}}{\Pi_{t+1}} \frac{(1 - \lambda_t) + \lambda_t Q^m_{t+1}(\lambda_t)}{1 + e^{\kappa_t}} \right]. \tag{50}$$

Note that the existence of transaction costs gives rise to a liquidity premium that depends on κ_t. Following the literature on preferred habitats, we assume that the transaction cost depends on the average maturity of the government bond portfolio. More specifically, longer-term bond are relatively more costly to trade than shorter-term bonds. We capture this, by specifying κ_t as

$$\kappa_t = \kappa_0 + \kappa_1 \tilde{\lambda}_t, \tag{51}$$

where e^{κ_0} is the steady state transaction cost for long-term bonds, $\kappa_1 > 0$ captures the idea that longer-term bonds are relatively less liquid, and $\tilde{\lambda}_t$ denotes the log-deviation from the steady state of λ_t.

Fig. 10 shows impulse response functions from shortening maturity with (solid line) and without (dashed line) market segmentation. To isolate the effects of the new ingredients, we shut down the fiscal discount rate channel by assuming the economy can only be in the monetary-led regime without the possibility of entering the fiscally-led regime. The market segmentation parameters are calibrated such that a QE2-type operation reduces the five-year nominal yield spread, on average, by around 15 basis points on impact to be consistent with empirical estimates from Krishnamurthy and Vissing-Jorgensen (2011), while still matching the average yields implied by the benchmark model (Table 3).

Without the fiscal discount rate channel or market segmentation, maturity restructuring policies are neutral. However, with market segmentation, shortening maturity drives down long-term interest rates while stimulating economic activity (e.g., increasing inflation and output).

4.6.3 Persistent Deficits

Fig. 11 explores the impact of persistent budget deficits on maturity restructuring policies at the zero lower bound. This figure displays impulse response functions, conditional on starting in the monetary-led regime and an upward-sloping nominal yield curve, to a shock that reduces average maturity by 0.18 years under positive surpluses around the steady-state level as in the benchmark (solid line), a budget deficit shock calibrated to the data during the Great Recession (line with circles), and a severe deficit shock that is eight times the magnitude of the deficit during the Great

Recession (dashed line).[11] Restructuring under a deficit attenuates the fiscal discount rate effects on inflation. In the case where the yield curve is upward-sloping, shortening the maturity lowers the discount rate persistently. For the negative surpluses today and in the immediate future, lowering the discount rate has a negative effect on the present value of the fiscal backing. Since the surplus process is mean-reverting, surpluses will be positive at some point in the future, and a lower discount rate applied to these cash flows has a positive effect on the present value.[12] Hence, if the deficit today is particularly severe or persistent, the discount rate effects from the deficit component can potentially dominate. Quantitatively, when the magnitude of the deficit is calibrated to the recent U.S. data, we have similar responses as the positive surplus case (benchmark), albeit somewhat weakened. For the responses to be reversed (i.e., negative component dominates), it requires a deficit that is almost an order of magnitude larger than the current deficit.

4.6.4 Full Analysis

We analyze these responses with (solid line) and without (dashed line) the fiscal discount rate channel. In the latter case, we shut down the fiscal channel by eliminating regime changes and assuming policy is always characterized by the monetary-led regime. Given that the yield curve is upward-sloping, we find that the fiscal discount rate channel significantly dampens the expansionary effects, due to market segmentation, from maturity restructuring. Comparing the impulse response functions, we find that the fiscal discount rate channel dampens inflation responses by 21% after 5 quarters, and 53% after 10 quarters. Similarly, the fiscal channel dampens output responses by 17% after 5 quarters, and 60% after 10 quarters. The increasing effects by horizon reflect that the cumulative probability of switching to the fiscally-led regime increases over time. In addition, the fiscal channel also partially undoes the flattening of the yield curve from market segmentation. Interpreting these results, accounting for the fiscal discount rate channel provides a potential explanation for why there was not a strong response in inflation after the QE operations.

5 Conclusion

This paper explores the interactions between yield curve dynamics and nominal government debt maturity operations through the fiscal discount rate channel. Self-financing debt maturity operations are non-neutral when the slope of the nominal yield curve is nonzero in the fiscal theory. When the risk profile of bonds varies by maturity, rebalancing the maturity structure affects the cost of government financing. Changes in government discount rates then directly affect inflation through the intertemporal government budget equation. With sticky prices, the fiscal discount rate channel has real effects and therefore breaks Wallace neutrality. When the yield curve is upward-sloping (downward-sloping) the effects of maturity restructuring implied by the fiscal channel are contractionary (expansionary). In contrast, the effects are neutral when the slope is zero. Thus, when the yield curve is upward-sloping, we illustrate a potential cost for QE operations.

We quantitatively assess the fiscal discount rate channel in a DSGE framework with a stochastic maturity structure and policy regime changes between monetary-led and fiscally-led regimes. Without regime shifts, the effects of maturity restructuring are neutral in the monetary-led regime. However, with regime shifts, the possibility of entering in the fiscally-led regime along with a nonzero

[11] During the onset of crisis, the surplus dropped sharply, which corresponds to a negative 3.5-sigma shock to the surplus process. In the severe deficit case, the shock is set to be eight times the magnitude of the deficit shock at the onset of the crisis.

[12] This is implicitly assuming that the maturity structure shock is more persistent than the deficit.

slope also implies violations of nominal debt maturity neutrality in the monetary-led regime. Using an estimated process for the maturity structure of public debt, we show that the fiscal discount rate channel had substantial dampening effects on inflation and output responses to QE2, given an upward-sloping yield curve. Overall, this paper highlights the importance of the term structure of interest rates as a transmission channel for quantitative easing policies in the fiscal theory.

Appendix A Equilibrium

The equilibrium is given by the sequence $\{Y_t, C_t, U_t, L_t, w_t, \Lambda_t, b_t, M_t, Z_t, a_t, \Delta n_t, s_t, x_t, w_t^{(i)}, R_t^{(1)}, \Pi_t\}_{t=0}^{\infty}$ determined by:

1. Household's first-order conditions:

$$1 = E_t\left[\frac{M_{t+1}}{\Pi_{t+1}} R_{t+1}^{(i)}\right], \tag{52}$$

$$M_{t+1} = \beta\left(\frac{C_{t+1}\left(\frac{\bar{L}}{L_{t+1}}\right)^{\varphi}}{C_t\left(\frac{\bar{L}}{L_t}\right)^{\varphi}}\right)^{1-\frac{1}{\psi}}\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(\frac{U_{t+1}^{1-\gamma}}{E_t\left[U_{t+1}^{1-\gamma}\right]}\right)^{1-\frac{1}{\theta}}, \tag{53}$$

$$w_t = \frac{\varphi C_t}{L_t}. \tag{54}$$

2. Household's utility:

$$U_t = \left\{(1-\beta)\left(C_t\left(\frac{\bar{L}}{L_t}\right)^{\varphi}\right)^{1-1/\psi} + \beta\left(E_t\left[U_{t+1}^{1-\gamma}\right]\right)^{\frac{1}{\theta}}\right\}^{\frac{\theta}{1-\gamma}}. \tag{55}$$

3. Intermediate firm's first-order conditions:

$$w_t = \left(1-\frac{1}{\nu}\right)Z_t + \Lambda_t\left(\frac{1}{\nu}\right)\frac{Z_t}{Y_t}, \tag{56}$$

$$\Lambda_t = \phi_R\left(\frac{\Pi_t}{\Pi_{ss}}-1\right)\frac{\Pi_t Y_t}{\Pi_{ss}} - E_t\left[M_{t+1}\,\phi_R\left(\frac{\Pi_{t+1}}{\Pi_{ss}}-1\right)\frac{Y_{t+1}\Pi_{t+1}}{\Pi_{ss}}\right]. \tag{57}$$

4. Government policy:

$$\ln\left(\frac{R_t^{(1)}}{R^{(1)}}\right) = \rho_r \ln\left(\frac{R_{t-1}^{(1)}}{R^{(1)}}\right) + (1-\rho_r)\left(\rho_{\pi,\varrho_t}\ln\left(\frac{\Pi_t}{\Pi}\right) + \rho_y \ln\left(\frac{\widehat{Y}_t}{\widehat{Y}}\right)\right) + \sigma_r \epsilon_{rt}, \tag{58}$$

$$s_t - s = \rho_s(s_{t-1}-s) + (1-\rho_s)\,\delta_{b,\varrho_t}(b_t - b) + \sigma_s \epsilon_{s_t}, \tag{59}$$

$$b_{t+1} = \frac{R_t^g}{\Pi_t \Delta Y_t} b_t - s_t, \tag{60}$$

$$R_t^g = \sum_{i=1}^{N}\left(\bar{w}^{(i)} + \beta^{(i)} x_{mt}\right) R_t^{(i)}. \tag{61}$$

5. Output:

$$Y_t = Z_t L_t - \Phi Z_t. \tag{62}$$

6. Market clearing:

$$Y_t = C_t + \frac{\phi_R}{2}\left(\frac{\Pi_t}{\Pi_{ss}}-1\right)^2 Y_t. \tag{63}$$

7. Stochastic processes:

$$\ln(Z_t) = z^\star + a_t + n_t, \tag{64}$$
$$a_t = \rho_a a_{t-1} + \sigma_a \epsilon_{at}, \tag{65}$$
$$\Delta n_t = \rho_n \Delta n_{t-1} + \sigma_n \epsilon_{nt}, \tag{66}$$
$$x_{mt} = \rho_m x_{mt-1} + \sigma_m \epsilon_{mt}. \tag{67}$$

Appendix B Numerical Procedure

The model is solved using a global method following Maliar and Maliar (2015) and Judd, Maliar, Maliar, and Valero (2014). A subset of the policy functions are approximated by piece-wise ordinary polynomials of the state variables. The state variables are:

$$\mathbb{S}_t = \left(r_{t-1}, a_{t-1}, s_{t-1}, b_{t-1}, x_{mt}, Y_{t-1}, \Delta n_{t-1}, \beta_t, +\epsilon_{at}, \epsilon_{nt}, \epsilon_{st}, \{Q^{(n)}_{t-1}\}_{i=2}^{N}\right), \tag{68}$$

where r_{t-1} is the nominal one-period risk-free rate, a_{t-1} is the transitory productivity shock, s_{t-1} is the governments' surplus, b_{t-1} is the total debt of the government, x_{mt} is the stochastic process driving the maturity structure, Y_{t-1} is the final consumption goods, Δn_{t-1} is the permanent productivity shock, β_t is the subjective discount rate, e_{at} is the innovation to the transitory productivity shock, e_{nt} is the innovation to the permanent productivity shock, e_{st} is the innovation to the government's surplus, and $\{Q^{(i)}_{t-1}\}_{i=2}^{N}$ are the nominal bond prices. The approximated policy functions are:

$$\mathbb{G} = \left(F_t, C_t, \mathrm{U}_t, \{Q^{(i)}_t\}_{i=2}^{N}, E\Delta C_t, E\pi_t\right), \tag{69}$$

where

$$F_t = \left(\frac{\Pi_t}{\Pi_{ss}} - 1\right)\frac{\Pi_t}{\Pi_{ss}}, \tag{70}$$

C_t is consumption, U_t is household utility, $\{Q^{(i)}_t\}_{i=2}^{N}$ are nominal bond prices, $E\Delta C_t$ is expected consumption growth, and $E\pi_t$ is expected inflation.

Let $\mathcal{L}$ be a policy function, the policy function is approximated as:

$$\widehat{\mathcal{L}} = \mathbb{1}_F p_F + \mathbb{1}_M p_M, \tag{71}$$

where $\mathbb{1}_j$ is an indicator function equals to one in regime j and zero otherwise, and p_j is a polynomial. Note that a different polynomial is used in each regime as indicated by the F, and M subscript.

The model is solved by finding the set of polynomial coefficients Θ that minimizes the mean squared residuals for the approximated decision rules over a fixed grid. For each point j on the grid the residuals $\{\mathfrak{R}^j_k\}_{k=1}^{N+4}$ are calculated as:

$$\mathfrak{R}^j_1 = \phi_R F^j_t Y^j_t - E^j_t\left[M_{t+1}\ \phi_R F_{t+1} Y_{t+1}\right] - \Lambda_t, \tag{72}$$
$$\mathfrak{R}^j_2 = E^j_t\left[M_{t+1} R^W_{t+1}\right] - 1, \tag{73}$$
$$\mathfrak{R}^j_3 = U^j_t - \left\{(1-\beta)\left(C^{j\star}_t\right)^{1-1/\psi} + \beta\left(E^j_t\left[U^{1-\gamma}_{t+1}\right]\right)^{\frac{1}{\theta}}\right\}^{\frac{1}{1-1/\psi}}, \tag{74}$$
$$\mathfrak{R}^j_4 = E^j_t\left[Cg_{t+1}\right] - ECg^j_t, \tag{75}$$
$$\mathfrak{R}^j_5 = E^j_t\left[\pi_{t+1}\right] - E\pi^j_t, \tag{76}$$
$$\mathfrak{R}^j_{i+4} = E^j_t\left[\frac{M_{t+1}}{\Pi_{t+1}} Q^{(i-1)}_{t+1}\right] - Q^{j,(i)}_t\ \forall i = 2..N. \tag{77}$$

$\mathfrak{R}^j_1$ is calculated using the first order condition (in equilibrium) of the firms in the intermediate goods sector,

$\mathfrak{R}_2^j$ is calculated using the Euler equation for the return on the wealth portfolio, $\mathfrak{R}_3^j$ is computed using the value function equation. $\mathfrak{R}_4^j$ and $\mathfrak{R}_5^j$ are calculated directly from their definition. Finally, $\{\mathfrak{R}_i^j\}_{i=6}^{N+4}$ are computed using the Euler equations for the nominal bonds.

The grid on the state variables space is calculated in 5 steps. First, for each of the regimes the model is solved using a second-order perturbation approximation to obtain an initial guess for the set of coefficients Θ. Second, the regime-specific model is simulated and the principal components of the state variables are calculated. Third, an auxiliary grid on the principal components space is calculated using the Smolyak algorithm. Fourth, the regime-specific grid on the state variables space is calculated by performing a linear transformation of the auxiliary grid calculated in the previous step. Finally, the grid is calculated as the union of the two single regime grids (fiscally-led regime and monetary-led regime).

The Smolyak algorithm is used for the auxiliary grid because it is a highly efficient method to calculate a sparse grid in a hypercube. The drawback of the Smolyak algorithm is that the points are not chosen to maximize the number of points on the region of the state space where the ergodic distribution of the model is located. The Smolyak algorithm is improved by adapting it to the characteristics of the model using the principal components transformation.

Second-order standard ordinary polynomials are used for each of the regime-specific polynomials. The nominal bond prices are approximated as linear combinations of variables that are known to be important to understand the dynamics of the yield curve (see Bansal and Shaliastovich (2013) and Kung (2015)), namely, expected consumption growth and expected inflation. These approximations can be thought of as being second-order approximations on the state variables where the coefficients are restricted to be linear combinations of the coefficients for expected consumption growth and expected inflation. The minimization is done using a numerical optimizer. To improve the speed of the code, an analytical gradient and monomial integration are used. The mean square error is of the order of 10^{-6}.

Appendix C Present Value Relations

The flow budget constraint of the government for the simple model Eq. (9) can be written as

$$\frac{B_t}{P_{t-1}} = \frac{\Pi_t}{R_t^g}\left(\frac{B_{t+1}}{P_t} + s_t\right), \tag{78}$$

where $B_t = B_t^{(1)} + B_t^{(2)}$ is the total nominal value of government debt, s_t is the real surplus, and $R_t^g = R_t^{(1)}\frac{B_t^{(1)}}{B_t} + R_t^{(2)}\frac{B_t^{(2)}}{B_t}$ is the nominal gross interest rate paid on the portfolio of government debt. In real terms we have:

$$b_t = \frac{\Pi_t}{R_t^g}(b_{t+1} + s_t). \tag{79}$$

Leading Eq. (79) for one period and taking the conditional expectation at time t,

$$E_t[b_{t+1}] = E_t\left[\frac{\Pi_{t+1}}{R_{t+1}^g}b_{t+2}\right] + E_t\left[\frac{\Pi_{t+1}}{R_{t+1}^g}s_{t+1}\right]. \tag{80}$$

Iterating forward on $E_t[b_{t+1}]$ using the law of iterated expectations and assuming a transversality condition on real debt, we have

$$E_t[b_{t+1}] = E_t\left[\sum_{i=1}^{\infty}\frac{P_{t+i}}{P_{t-1}}\frac{1}{\prod_{j=1}^{i}R_{t+j}^g}s_{t+i}\right]. \tag{81}$$

Using Eq. (79) and Eq. (81) together, the present value of government surpluses is

$$b_t = E_t\left[\sum_{i=0}^{\infty}\frac{s_{t+i}}{\prod_{j=0}^{i}\left\{R_{t+j}^g/\Pi_{t+j}\right\}}\right]. \tag{82}$$

Evaluating Eq. (82) at time $t = 0$ yields Eq. (10).

The present value relation for the benchmark model can be calculated in a similar way. Leading Eq. (40) for one period and taking the conditional expectation at time t we get:

$$E_t[b_{t+1}] = E_t\left[\frac{\Pi_{t+1}\Delta Y_{t+1}}{R^g_{t+1}} b_{t+2}\right] + E_t\left[\frac{\Pi_{t+1}\Delta Y_{t+1}}{R^g_{t+1}} s_{t+1}\right]. \tag{83}$$

Iterating forward on $E_t[b_{t+1}]$ using the law of iterated expectations and assuming a transversality condition on real debt,

$$E_t[b_{t+1}] = E_t\left[\sum_{i=1}^{\infty} \frac{P_{t+i}\, Y_{t+i}}{P_{t-1}\, Y_{t-1}} \frac{1}{\prod_{j=1}^{i} R^g_{t+j}} s_{t+i}\right]. \tag{84}$$

Simplifying, we get that the present value of government surpluses is

$$b_t = E_t\left[\sum_{i=0}^{\infty} \frac{s_{t+i}}{\prod_{j=0}^{i} \Pi^{-1}_{t+j}\Delta Y^{-1}_{t+j} R^g_{t+j}}\right]. \tag{85}$$

Appendix D Simple Model: Approximate Analytical Solution

The real return of the government portfolio is:

$$\frac{R^g_t}{\Pi_t} = \frac{b_{t+1} + s_t}{b_t}, \tag{86}$$

where lowercase variables denote real variables. Define $\log x \equiv \widetilde{x}$, and take logs of Eq. (86):

$$\begin{aligned} \widetilde{R}^g_t - \widetilde{\Pi}_t &= \log\left(b_{t+1} + s_t\right) - \log\left(b_t\right), & (87)\\ &= \widetilde{b}_{t+1} + \log\left(1 + \frac{s_t}{b_{t+1}}\right) - \widetilde{b}_t. & (88) \end{aligned}$$

Since surpluses can be negative, substitute $s_t = \tau_t - g_t$ (τ_t and g_t are real taxes and government expenditures, respectively) into Eq. (87) and rearrange:

$$\begin{aligned} \widetilde{R}^g_t - \widetilde{\Pi}_t &= \widetilde{b}_{t+1} + \log\left(1 + \frac{\tau_t - g_t}{b_{t+1}}\right) - \widetilde{b}_t, & (89)\\ &= \widetilde{b}_{t+1} - \widetilde{b}_t + \log\left(1 + \exp\left(\widetilde{\tau}_t - \widetilde{b}_{t+1}\right) - \exp\left(\widetilde{g}_t - \widetilde{b}_{t+1}\right)\right). & (90) \end{aligned}$$

Following Berndt, Lustig, and Yeltekin (2012), we log-linearize the last term in Eq. (90) with respect to the log tax-to-debt and the log government expenditures-to-debt ratios around the steady-state:

$$\begin{aligned} &\log\left(1 + \exp\left(\widetilde{\tau}_t - \widetilde{b}_{t+1}\right) - \exp\left(\widetilde{g}_t - \widetilde{b}_{t+1}\right)\right) \simeq \log\left(1 + \exp\left(\widetilde{\tau} - \widetilde{b}\right) - \exp\left(\widetilde{g} - \widetilde{b}\right)\right)\\ &+ \frac{\exp\left(\widetilde{\tau} - \widetilde{b}\right)}{1 + \exp\left(\widetilde{\tau} - \widetilde{b}\right) - \exp\left(\widetilde{g} - \widetilde{b}\right)}\left(\widetilde{\tau}_t - \widetilde{b}_{t+1} - \left(\widetilde{\tau} - \widetilde{b}\right)\right)\\ &- \frac{\exp\left(\widetilde{g} - \widetilde{b}\right)}{1 + \exp\left(\widetilde{\tau} - \widetilde{b}\right) - \exp\left(\widetilde{g} - \widetilde{b}\right)}\left(\widetilde{g}_t - \widetilde{b}_{t+1} - \left(\widetilde{g} - \widetilde{b}\right)\right). \qquad (91) \end{aligned}$$

Collecting constant terms and rearranging:

$$\log\left(1+\exp\left(\widetilde{\tau}_t-\widetilde{b}_{t+1}\right)-\exp\left(\widetilde{g}_t-\widetilde{b}_{t+1}\right)\right)\simeq\theta_0+(1-\theta_1)\left(\mu_\tau\widetilde{\tau}_t-\mu_g\widetilde{g}_t-\widetilde{b}_{t+1}\right), \tag{92}$$

where

$$\begin{aligned}
\mu_\tau &= \frac{\exp\left(\widetilde{\tau}-\widetilde{b}\right)}{\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)}\ ,\ \mu_g=\frac{\exp\left(\widetilde{g}-\widetilde{b}\right)}{\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)}\ ,\ \theta_1=\frac{1}{1+\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)},\\
\text{and } \theta_0 &= \log\left(1+\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)\right)-\frac{\exp\left(\widetilde{\tau}-\widetilde{b}\right)}{1+\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)}\left(\widetilde{\tau}-\widetilde{b}\right)\\
&+ \frac{\exp\left(\widetilde{g}-\widetilde{b}\right)}{1+\exp\left(\widetilde{\tau}-\widetilde{b}\right)-\exp\left(\widetilde{g}-\widetilde{b}\right)}\left(\widetilde{g}-\widetilde{b}\right).
\end{aligned}$$

Eq. (90) can be written as:

$$\widetilde{R}_t^g-\widetilde{\Pi}_t=\theta_1\widetilde{b}_{t+1}-\widetilde{b}_t+\theta_0+(1-\theta_1)(\mu_\tau\widetilde{\tau}_t-\mu_g\widetilde{g}_t). \tag{93}$$

Iterating Eq. (93) forward and imposing the transversality condition, the present value relation at time 0 is:

$$\widetilde{b}_0=\frac{\theta_0}{1-\theta_1}+\sum_{j=0}^{\infty}\theta_1^j\left((1-\theta_1)(\mu_\tau\widetilde{\tau}_j-\mu_g\widetilde{g}_j)-\widetilde{R}_j^g+\widetilde{\Pi}_j\right). \tag{94}$$

taking unconditional expectations:

$$E\left[\widetilde{b}_0\right]=\frac{\theta_0}{1-\theta_1}+\sum_{j=0}^{\infty}\theta_1^j\left((1-\theta_1)E\left[\mu_\tau\widetilde{\tau}_j-\mu_g\widetilde{g}_j\right]-E\left[\widetilde{R}_j^g\right]+E\left[\widetilde{\Pi}_j\right]\right). \tag{95}$$

Applying the unconditional Fisher equation $\left(E\left[\widetilde{\Pi}_{j+1}\right]=E\left[\widetilde{R}_j\right]-\widetilde{R}^{real}\right)$ to Eq. (95) we get:

$$\begin{aligned}
E\left[\widetilde{b}_0\right]&=\frac{\theta_0}{1-\theta_1}+E\left[(1-\theta_1)(\mu_\tau\widetilde{\tau}_0-\mu_g\widetilde{g}_0)-\widetilde{R}_0^g+\widetilde{\Pi}_0\right]\\
&+\sum_{j=1}^{\infty}\theta_1^j\left((1-\theta_1)E\left[(\mu_\tau\widetilde{\tau}_j-\mu_g\widetilde{g}_j)\right]-E\left[\widetilde{R}_j^g\right]+E\left[\widetilde{R}_{j-1}\right]-\widetilde{R}^{real}\right).
\end{aligned} \tag{96}$$

Since the unconditional expectation is the same for all j, we can simplify the expression:

$$\begin{aligned}
E\left[\widetilde{b}_0\right] &= \frac{\theta_0}{1-\theta_1}+(1-\theta_1)\frac{E\left[\mu_\tau\widetilde{\tau}_j-\mu_g\widetilde{g}_j\right]}{1-\theta_1}-\frac{E\left[\widetilde{R}_j^g\right]}{1-\theta_1}+E\left[\widetilde{\Pi}_0\right]+\theta_1\frac{E\left[\widetilde{R}_{j-1}\right]-\widetilde{R}^{real}}{1-\theta_1}, && (97)\\
&= \frac{\theta_0}{1-\theta_1}+E\left[\mu_\tau\widetilde{\tau}_j-\mu_g\widetilde{g}_j\right]-\frac{E\left[\widetilde{R}_j^g\right]}{1-\theta_1}+E\left[\widetilde{\Pi}_0\right]+\theta_1\frac{E\left[\widetilde{R}_{j-1}\right]-\widetilde{R}^{real}}{1-\theta_1}. && (98)
\end{aligned}$$

Solving for $E\left[\widetilde{\Pi}_0\right]$:

$$E\left[\widetilde{\Pi}_0\right] = E\left[\widetilde{b}_0\right] - \frac{\theta_0}{1-\theta_1} - E\left[\mu_\tau \widetilde{\tau}_j - \mu_g \widetilde{g}_j\right] + \frac{E\left[\widetilde{R}^g_j\right]}{1-\theta_1} - \theta_1 \frac{E\left[\widetilde{R}_{j-1}\right] - \widetilde{R}^{real}}{1-\theta_1}, \tag{99}$$

$$= E\left[\widetilde{b}_0\right] - \frac{\theta_0}{1-\theta_1} - E\left[\mu_\tau \widetilde{\tau}_j - \mu_g \widetilde{g}_j\right] + \frac{E\left[\omega \widetilde{R}^{(1)}_j + (1-\omega)\widetilde{R}^{(2)}_j\right]}{1-\theta_1} - \theta_1 \frac{E\left[\widetilde{R}_{j-1}\right] - \widetilde{R}^{real}}{1-\theta_1} \tag{100}$$

In Eq. (100) we substituted[13] $\widetilde{R}^g_t$ for $\omega \widetilde{R}^{(1)}_t + (1-\omega)\widetilde{R}^{(2)}_t$. Reordering the previous equation we have:

$$E\left[\widetilde{\Pi}_0\right] = E\left[\widetilde{b}_0\right] - \frac{\theta_0}{1-\theta_1} - E\left[\mu_\tau \widetilde{\tau}_j - \mu_g \widetilde{g}_j\right] + \frac{E\left[\widetilde{R}^{(2)}_j - \omega(\widetilde{R}^{(2)}_j - \widetilde{R}^{(1)}_j)\right]}{1-\theta_1} - \theta_1 \frac{E\left[\widetilde{R}_{j-1}\right] - \widetilde{R}^{real}}{1-\theta_1}. \tag{101}$$

Finally, we can calculate the derivative of expected inflation with respect to the weight of the 1-period bond ω:

$$\frac{dE\left[\widetilde{\Pi}_0\right]}{d\omega} = \frac{-E\left[\widetilde{R}^{(2)}_j - \widetilde{R}^{(1)}_j\right]}{1-\theta_1}. \tag{102}$$

Appendix E Data

We obtain quarterly data for consumption and output from the Bureau of Economic Analysis (BEA). Consumption is measured as real personal consumption expenditures (DPCERX1A020NBEA). Output is measured as real gross domestic product (GDPC1). Inflation is computed by taking the log return on the Consumer Price Index for All Urban Consumers (CPIAUCSL), obtained from the Bureau of Labor Statistics (BLS). Monthly yield data are from CRSP. Nominal yield data for maturities of 4, 8, 12, 16, and 20 quarters are from the CRSP Fama-Bliss discount bond file. The one-quarter nominal yield is from the the CRSP Fama risk-free rate file. Finally we build our bond supply maturity structure data using the same methodology as Doepke and Schneider (2006) and Greenwood and Vayanos (2014). In particular, in each month we collect the complete history of U.S. government bonds issued from the CRSP historical bond database. We then break the stream of each bonds cash flows into principal and coupon payments. Summing the streams from each outstanding bond vintage over their respective maturity give us the monthly maturity structure of government debt. The sample period runs from Q1-1964 to Q3-2013. We obtain the maturity distribution of privately-held Treasury marketable securities from Table FD-5 of the Treasury Bulletin. We supplement the information on the Treasury Bulletin by including reserve balances with Federal Reserve Banks from the Federal Reserve H.4.1.

[13] We used the fact that $e^{\tilde{R}} - 1 \approx \tilde{R}$.

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Table 1: Quarterly Calibration

Parameter	Description	Model
A. Preferences		
β	Subjective discount factor	0.9935
ψ	Elasticity of intertemporal substitution	1.5
γ	Risk aversion	10
B. Production		
ν	Price elasticity for intermediate goods	2
ϕ_R	Magnitude of price adjustment costs	10
$z^\star$	Unconditional mean growth rate	0.5%
ρ_a	Persistence of a_t	0.95
σ_a	Volatility of transitory shock e_{at}	0.7%
ρ_n	Persistence of Δn_t	0.99
σ_n	Volatility of permanent shock e_{nt}	0.015%
C. Policy		
ρ_s	Persistence of government surpluses	0.92
σ_s	Volatility of government surpluses e_{st}	0.05%
$\delta_b(M/F)$	Sensitivity of taxes to debt	0.05 / 0.0
ρ_r	Degree of monetary policy inertia	0.5 / 0.5
$\rho_\pi(M/F)$	Sensitivity of interest rate to inflation	1.5 / 0.4
p	Switching probability	0.9875
D. Bond Supply		
$\bar{b}$	Steady state Debt-to-GDP ratio	0.5
ρ_m	Persistence of x_{mt}	0.958
σ_m	Volatility of e_{mt}	1.28%

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

Table 2: Summary Statistics

	Data	Model	Monetary	Fiscal
A. Means				
$\mathrm{E}\left(y^{(20)} - y^{(1)}\right)$ (in %)	1.02	0.55	0.89	0.18
$\mathrm{E}\left(r_g\right)$ (in %)	5.47	6.06	5.95	6.21
B. Standard Deviations				
$\sigma(\Delta y)$ (in %)	2.22	2.90	1.47	4.07
$\sigma(\Delta c)$ (in %)	1.42	2.85	1.44	4.02
$\sigma(\pi)$	1.64	1.20	0.32	1.62
$\sigma(\Delta l)/\sigma(\Delta y)$	0.92	0.51	0.21	0.57
$\sigma\left(r_g\right)$ (in %)	4.53	1.22	0.81	1.52
C. Correlations				
$\mathrm{corr}(\pi, \Delta c)$ (low-frequency)	-0.85	-0.91	-0.91	-0.92

This table presents the means, and standard deviations for key macroeconomic variables from the data and the model. The model is calibrated at a quarterly frequency and the reported statistics are annualized.

Table 3: Term structure

	Maturity						
	1Q	1Y	2Y	3Y	4Y	5Y	5Y - 1Q
Mean (Model) (in %)	5.68	5.91	6.03	6.11	6.17	6.23	0.55
Mean (Data) (in %)	5.03	5.29	5.48	5.66	5.80	5.89	1.02
Std (Model) (in %)	1.20	1.00	0.90	0.80	0.70	0.60	0.70
Std (Data) (in %)	2.97	2.96	2.91	2.83	2.78	2.72	1.05
AC1 (Model)	0.95	0.90	0.90	0.90	0.90	0.92	0.95
AC1 (Data)	0.93	0.94	0.95	0.95	0.96	0.96	0.74

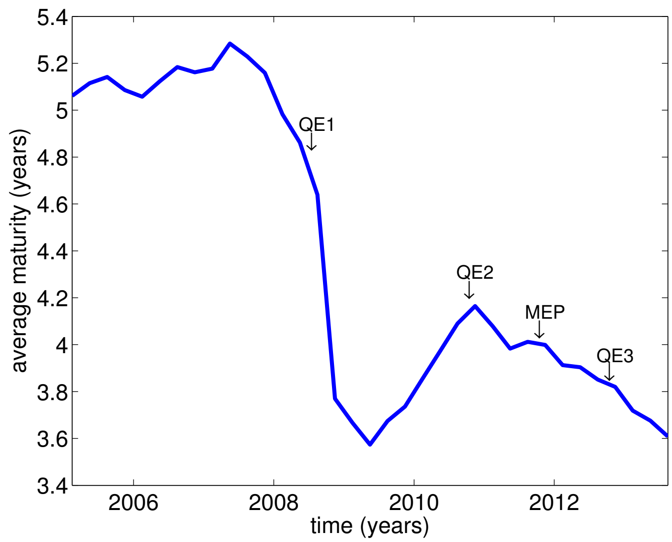
This table presents the mean, standard deviation, and first autocorrelation of the one-quarter, one-year, two-year, three-year, four-year, and five-year nominal yields and the 5-year and one-quarter spread from the model and the data. The model is calibrated at a quarterly frequency and the moments are annualized.

Table 4: Forecasts with the Yield Spread

	Data			Model		
	Horizon (in quarters)					
	1	4	8	1	4	8
A. Output						
β	1.023	0.987	0.750	1.694	1.211	0.820
S.E.	0.306	0.249	0.189	0.413	0.217	0.169
R^2	0.067	0.148	0.147	0.045	0.147	0.176
B. Consumption						
β	0.731	0.567	0.373	1.650	1.179	0.800
S.E.	0.187	0.163	0.153	0.398	0.211	0.165
R^2	0.092	0.136	0.088	0.045	0.145	0.173
C. Inflation						
β	-1.328	-1.030	-0.649	-2.370	-1.784	-1.266
S.E.	0.227	0.315	0.330	0.154	0.215	0.237
R^2	0.180	0.157	0.071	0.484	0.355	0.235

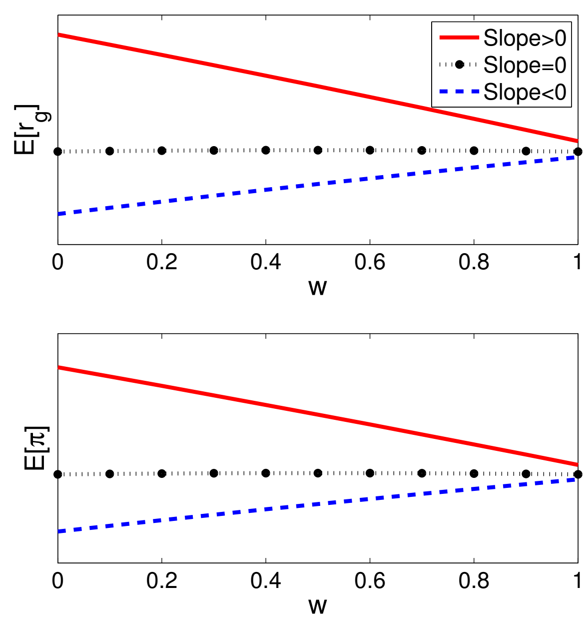
This table presents output growth, consumption growth, and inflation forecasts for horizons of one, four, and eight quarters using the five-year nominal yield spread from the data and the model. The n-quarter regressions, $\frac{1}{n}(x_{t,t+1}+\cdots+x_{t+n-1,t+n}) = \alpha+\beta(y_t^{(5)}-y^{(1Q)})+\epsilon_{t+1}$, are estimated using overlapping quarterly data and Newey-West standard errors are used to correct for heteroscedasticity.

Figure 1: Average Maturity of Public Debt



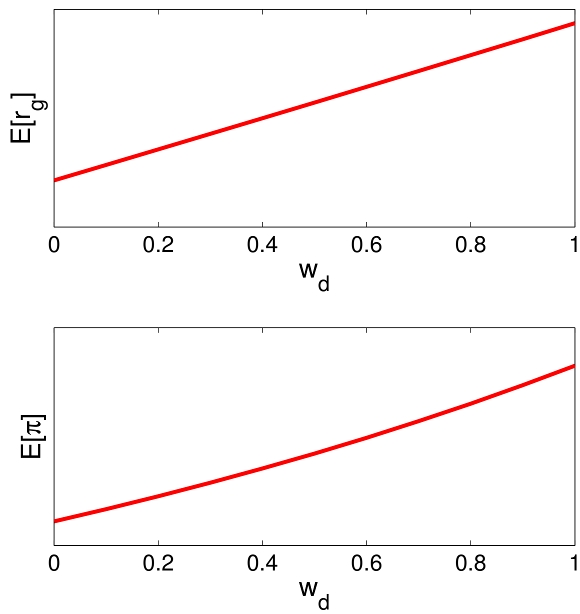
This figure plots the average maturity structure of government debt held by the public from Q1-2005 to Q3-2013.

Figure 2: Comparative Statics: Shortening Maturity



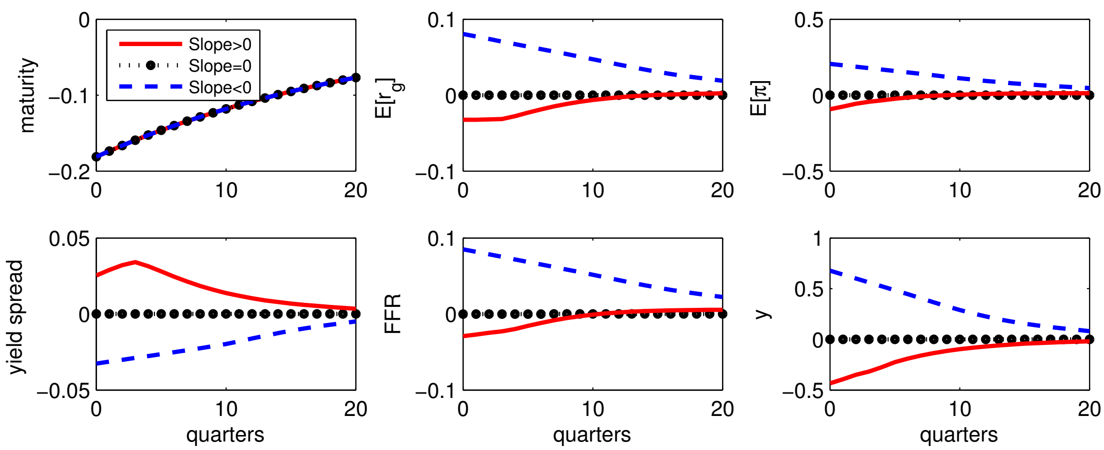
This figure plots the average effect from increasing the portfolio weight on short-term debt, w, on the government discount rate R^g (top figure) and log inflation π (bottom figure) for when the average yield curve is upward-sloping (solid line), downward-sloping (dashed line), and flat (line with circles).

Figure 3: Comparative Statics: Defaultable Debt



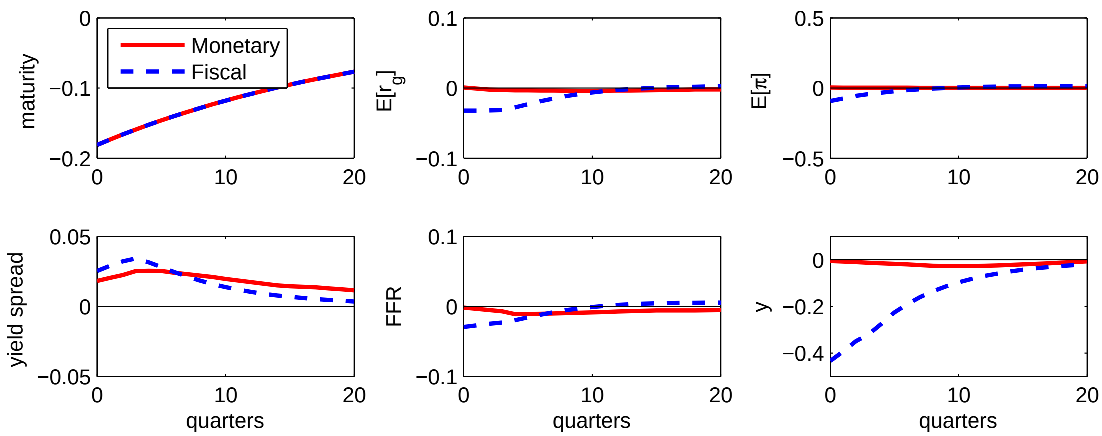
This figure plots the average effect from increasing the portfolio weight on risky debt, w_d, on the government discount rate R^g (top figure) and log inflation π (bottom figure).

Figure 4: Maturity Restructuring with Different Slopes



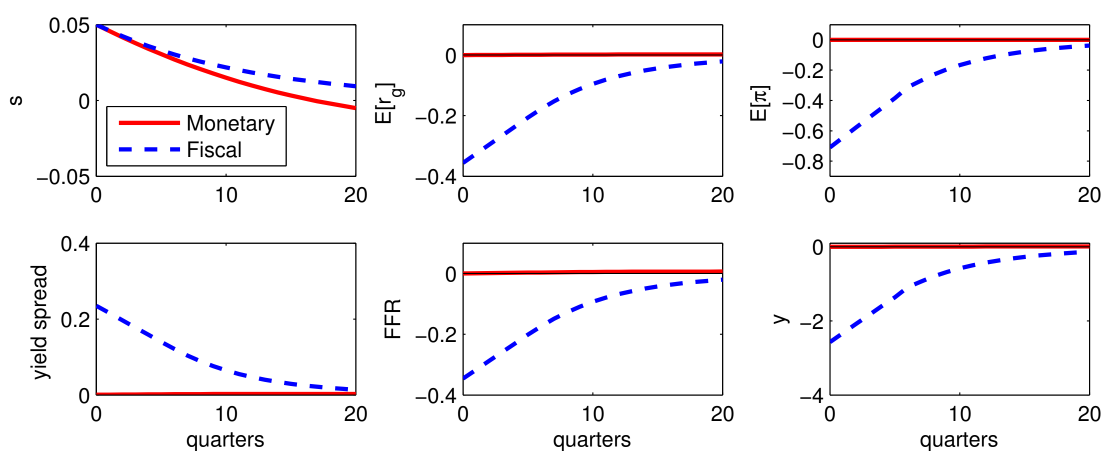
This figure plots conditional impulse response functions for the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar in magnitude as QE2) in the fiscal regime. Results are reported for when the yield curve is upward-sloping (solid line), flat (line with circles), and downward-sloping (dashed line). The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years.

Figure 5: Maturity Restructuring in Different Regimes



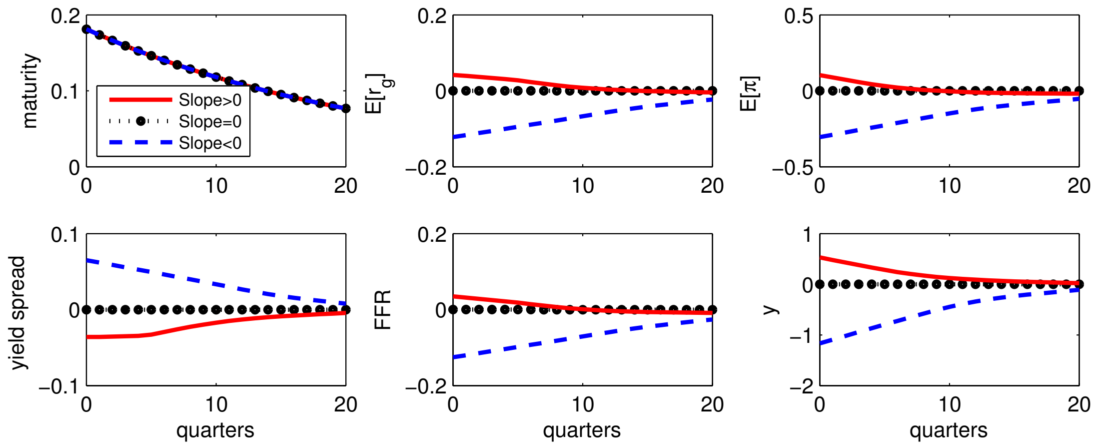
This figure plots the conditional impulse response functions for the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar magnitude as QE2) in the monetary regime (solid line) and fiscal regime (dashed line). The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years.

Figure 6: Surplus Shocks in Different Regimes



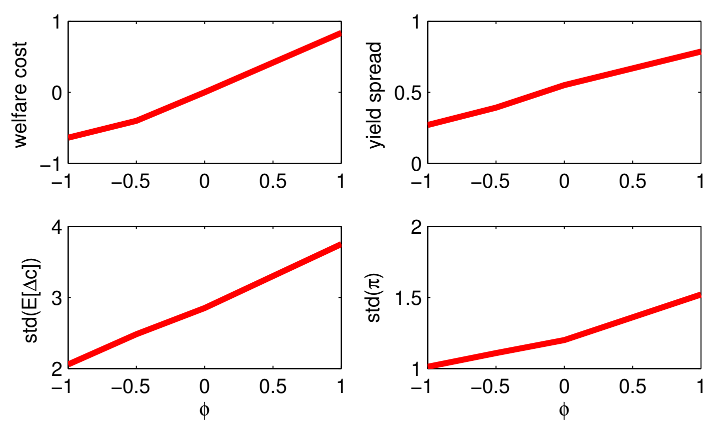
This figure plots conditional impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a positive one standard deviation surplus shock in the monetary (solid line) and fiscal (dashed line) regime. The units of the y-axis are annualized percentage deviations from the steady-state, except for the surplus that is in levels.

Figure 7: Lengthening Maturity



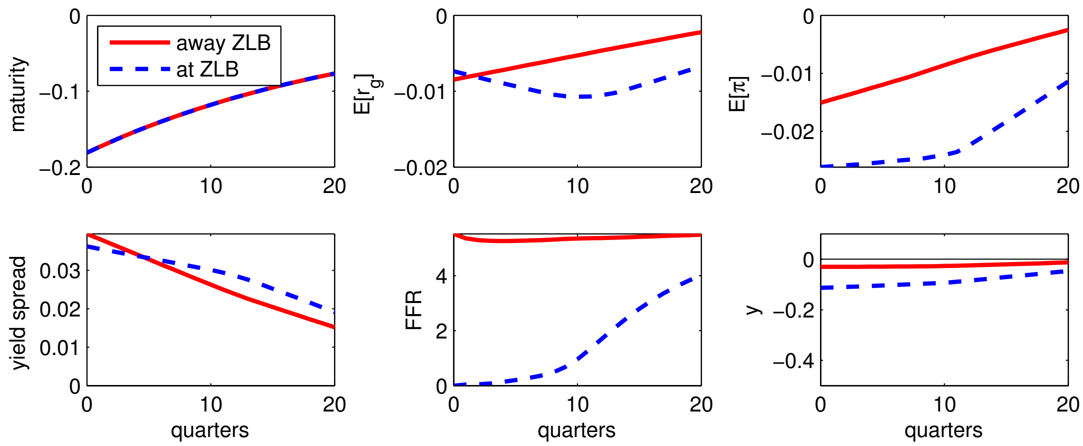
This figure plots conditional impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to an increase in the average maturity of government debt in the fiscal regime. Results are reported for when the yield curve is upward sloping (solid line), flat (line with circles), and downward sloping (dashed line). The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years.

Figure 8: Market Timing Policies



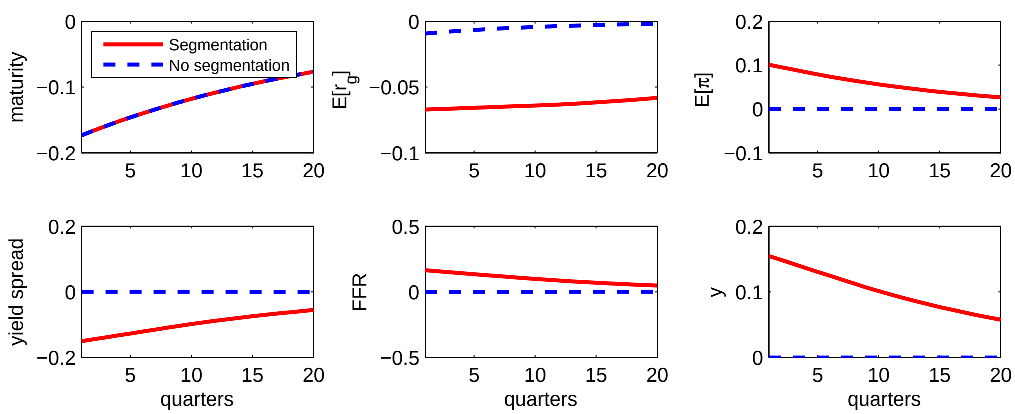
This figure plots comparative statics for the welfare cost, average yield spread, standard deviation of consumption growth, and the standard deviation of inflation when the market timing sensitivity to the yield spread varies.

Figure 9: Maturity Restructuring at the ZLB



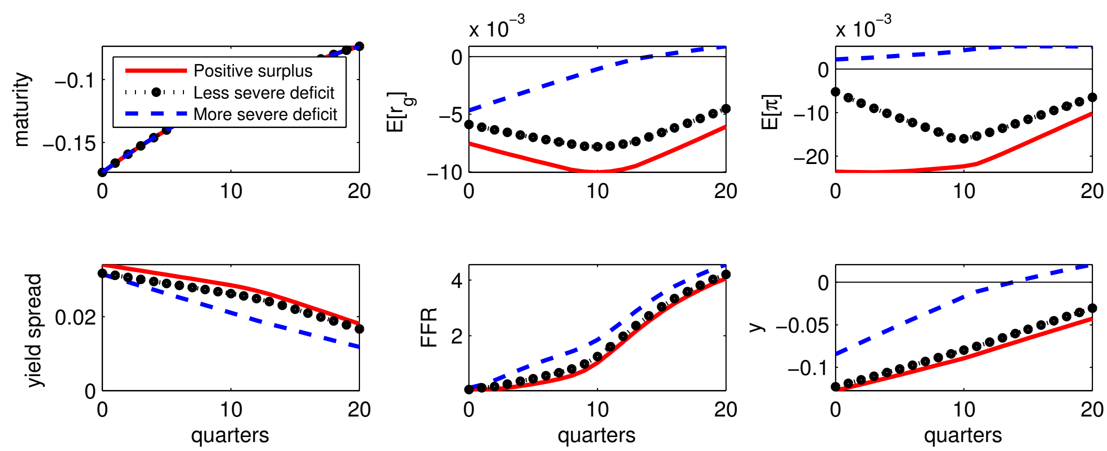
This figure plots the conditional impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar magnitude as QE2) when in the monetary regime. The dashed line represents the response at the zero lower bound and the solid line represents the response away from the zero lower bound. The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years and the fed funds rate that is in levels.

Figure 10: Maturity Restructuring with Market Segmentation



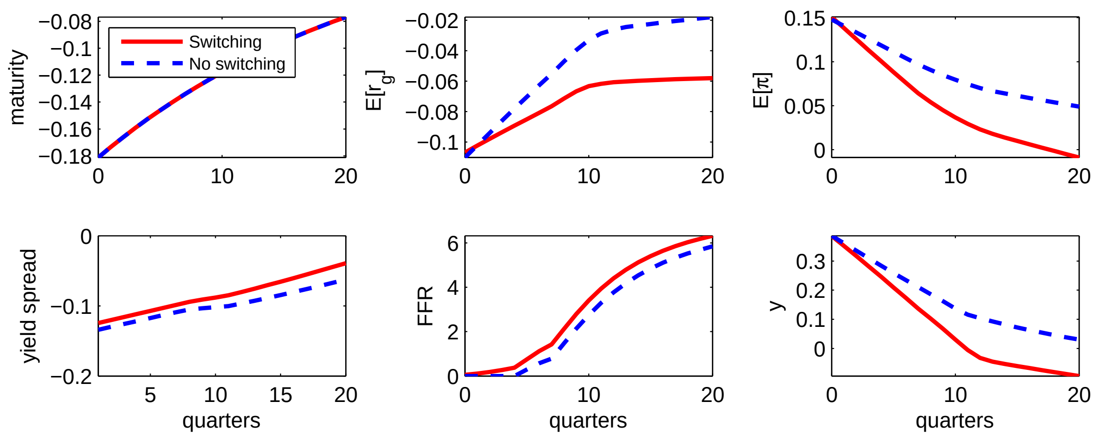
This figure plots the impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar magnitude as QE2) in the monetary regime (without regime shifts). The dashed line represents the response without market segmentation and the solid line, the response with market segmentation. The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years.

Figure 11: Maturity Restructuring with Persistent Deficits



This figure plots the conditional impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar magnitude as QE2) when the economy starts initially in the monetary regime at the zero lower bound. The solid line represents the response under positive surpluses. The line with circles represents the response under a deficit shock (-3.5 sigma) calibrated to the data during the Great Recession (2008-2010). The dashed line represents a severe deficit shock that is eight times the magnitude of the deficit during the Great Recession. The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years and the fed funds rate that is in levels.

Figure 12: Policy Experiment



This figure plots the conditional impulse response functions of the government discount rate, expected inflation, the 5-year minus 1-quarter nominal yield spread, the fed funds rate, and output to a decrease in the average maturity of government debt (similar magnitude as QE2) when the economy starts initially in the monetary regime at the zero lower bound. These plots come from the augmented model that also incorporates market segmentation and a short-term liquidity demand. The solid line represents the response with switching to the fiscal regime and the dashed line represents the response without the possibility of switching to the fiscal regime. The units of the y-axis are annualized percentage deviations from the steady-state, except for the average duration that is in years and the fed funds rate that is in levels.