Discount Rates, Debt Maturity, and the Fiscal Theory

Alexandre Corhay*  Thilo Kind†  Howard Kung‡  Gonzalo Morales§

October 2018 ¶

Abstract

This paper explores interactions between the term structure and government debt maturity in the fiscal theory using a macroeconomic model. As the expected returns of government liabilities differ across maturities, 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 nominal yield curve is upward- (downward-) sloping, the fiscal discount rate channel implies that shortening maturity dampens (amplifies) the stimulative effects of quantitative easing policies. These discount rate effects can help explain the weak inflation responses following the quantitative easing operations.

Keywords: Term structure of interest rates, Fiscal theory of the price level, Bond risk premia, Government debt, DSGE models, Nonlinear solution methods

*Rotman School of Management, University of Toronto. alexandre.corhay@rotman.utoronto.ca
†London Business School. tkind@london.edu
‡London Business School & CEPR. hkung@london.edu
§University of Alberta. gonzalo.morales@ualberta.ca
¶We also thank Marco Bassetto, Frederico Belo, Luigi Bocola, Francesco Bianchi, Ian Dew-Becker, Mike Chernov, Greg Duffee, Francisco Gomes, Francois Gourio, Christopher Hennessy, Urban Jermann, Tim Landvoigt, Leonardo Melosi, Francisco Palomino, Morten Ravn, Lukas Schmid, and seminar participants at the University of Minnesota, Northwestern University, Chicago Fed, University of Southern California, University of British Columbia, Universidad Carlos III, University College of London, London Business School, Vienna GSF, SED Meetings, CEPR European Summer Symposium, WFA Meetings, 6th Macro Finance Society Workshop, EEA Meetings, Econometric Society Meetings, CAPR Workshop, and BI-SHoF Conference for helpful comments.
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. These operations increased the size and composition of the government balance sheet. Meanwhile, fiscal stress in the form of deepening deficits and ballooning debt-to-gdp levels cast doubt on the sustainability of accommodative fiscal policy required to support inflation-targeting monetary policy. This paper illustrates a novel discount rate channel for the transmission of unconventional monetary policy that arises precisely when the fiscal authority is unable to raise taxes sufficiently to stabilize government debt and the monetary authority responds weakly to inflation (i.e., a policy combination characterizing the fiscal theory of the price level). We show that this channel can help explain the weak inflation responses following the QE operations.

In the fiscal theory, government discount rates and cash flow (surplus) innovations affect the price level through a fiscal asset pricing equation that links the real market value of nominal government liabilities to the present value of future real surpluses, akin to the present value stock relations. Given that expected bond returns vary by maturity, rebalancing the maturity structure changes marginal financing costs. When accommodative fiscal policy is not possible, discount rate variation leads to offsetting changes in the inflation path to revalue nominal liabilities in order to satisfy the present value relation. We refer to this link between government discount rates and inflation as the fiscal discount rate channel. Specifically, we explore the interplay between term structure dynamics and maturity restructuring policies in the presence of the fiscal theory. We illustrate how the effectiveness of operation-twist-type policies depends on the slope of the nominal yield curve.

---

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.

2 The fiscal theory 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))
To quantitatively examine the 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, which allows the model to generate realistic nominal term premia. Second, the supply of nominal government bonds over various maturities is time-varying and stochastic. Third, the monetary/fiscal policy mix is subject to stochastic changes between monetary-led and fiscally-led regimes. The monetary authority follows a short-term nominal interest rate rule while the fiscal authority raises lump-sum taxes and follows a surplus rule. In the monetary-led regime, the monetary authority aggressively targets inflation using the short-term nominal interest rate while the fiscal authority accommodates monetary policy by adjusting primary surpluses to stabilize debt. In the fiscally-led regime, the fiscal authority pursues spending or tax objectives other than stabilizing debt while the monetary authority accommodates fiscal policy by stabilizing the interest obligations on debt.

We show that in a fiscally-led policy regime, when the slope of the nominal yield curve is nonzero, debt maturity restructuring has a non-neutral effect on inflation, absent any other frictions. To isolate the effects of debt maturity composition from the total market value of debt, we consider self-financing shocks to the maturity structure that keep the market value of total government bonds the same initially (e.g., Maturity Extension Program or Operation Twist), but adjusts freely afterwards through market clearing forces. 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 for debt. Consequently, the price level and expected inflation adjust to revalue debt in order to satisfy the present value relation in equilibrium. Sticky prices allow this discount rate channel to have real effects. More generally, these results illustrate how accounting for heterogeneity in expected returns across different assets in the fiscal theory contributes to violations of Wallace (1981) neutrality.

The slope of the nominal yield curve dictates both the sign and magnitude of the effects of the fiscal discount rate channel for maturity restructuring. When the yield curve is upward-sloping (downward-sloping), the fiscal discount rate effects from shortening maturity dampens (amplifies) the potential stimulative effects of quantitative easing policies (e.g., from providing short-term liq-
uidity). Taking interest rates as given, increasing the proportion of short-term debt in the maturity structure when expected bond returns are increasing by maturity implies that the government is refinancing at a lower rate. A lower discount rate increases the present value of surpluses. Absent Ricardian tax policy, a fall in the aggregate price level is needed to align the real market value of debt with the higher present value of surpluses. With sticky prices, the fall in the price level leads to a contraction in production and output. The drop in inflation leads to a drop in the short rate. The opposite results are obtained when expected bond returns are decreasing by maturity. The endogenous yield curve reactions to maturity shocks reinforce the fiscal discount rate channel.

When the yield curve is flat, the fiscal discount rate channel is neutral, even in a fiscally-led regime, since the cost of financing is the same across all maturities. In a monetary-led regime – without the possibility of shifting into a fiscally-led regime – the economy is insulated from fiscal disturbances as surplus policy completely offsets 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 an array of term structure facts. Supply shocks in the model imply sizable inflation risk premia (i.e., a negative consumption-inflation relation) similar to that of 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 nominal term spread. The model also replicates the persistence in yields and the forecasting ability of the term spread for future inflation. Regime shifts in the monetary/fiscal policy mix generate persistent movements in the volatility of macroeconomic fundamentals, such as consumption growth and inflation, which translate to excess bond return predictability.

We consider an extended version of the model to assess the quantitative importance of the fiscal discount rate channel for maturity changes due to the quantitative easing policies in the aftermath of the Great Recession. In the extended model, we augment our baseline model with market segmentation and a preference for short-term liquidity demand, two channels that generate
expansionary effects from quantitative easing, and often cited by policymakers as a motivation for such actions. Also, we start the economy off in the monetary-led regime (with the implicit possibility of entering the fiscally-led regime), in a budget deficit, and at the zero lower bound (ZLB). During the Great Recession, the nominal slope was sizable, and our model suggests that the fiscal discount rate channel significantly dampened the stimulative effects of QE from the market segmentation and liquidity channels. Indeed, using an estimated process for bond supply and considering a maturity shock that replicates the effects on debt maturity from the QE operations, we find that the fiscal channel dampened the expansionary response of inflation and output by 37% and 52%, respectively, after 10 quarters. Thus, we provide a potential channel for explaining the weak inflation responses at the onset and aftermath of such operations.3

Overall, our paper makes several contributions to the literature. First, we theoretically document a novel risk-based transmission channel for nominal debt maturity operations that works through the discount rate channel in the context of the fiscal theory. Second, we show that our fiscal discount rate channel is quantitatively important, and provides a potential explanation for the weak observed inflation responses after the QE operations. Lastly, to the best of our knowledge, we are the first paper to explore the asset pricing implications in the fiscal theory. Notably, we show how regime changes in the monetary/fiscal policy mix provide an important source of time-varying bond risk premia.

Our paper relates to papers that quantitatively examine risk-based transmission channels for policy interventions in macroeconomic models featuring sizable risk premia, such as, Begenau and Landvoigt (2017), Elenev, Landvoigt, and Van Nieuwerburgh (2018), Gourio, Kashyap, and Sim (2018), Lenel, Piazzesi, and Schneider (2018), and Lenel (2017). We complement this literature by documenting a distinct mechanism that illustrates how the intertemporal government budget equation provides a quantitatively significant risk propagation channel for large scale asset purchases.

We also connect to the broader literature theoretically examining the transmission channels associated with debt maturity operations. Greenwood and Vayanos (2014) and Williamson (2016) study debt maturity changes with market segmentation while Leeper, Leith, and Liu (2016) and Lustig, Sleet, and Yeltekin (2008) considers distortionary taxation. Chernov, Schmid, and Schneider

3See, for example, Williams (2014) for a survey on the event-study evidence of QE.
(2016), Reis (2017) and Gomes, Jermann, and Schmid (2016) examine the role of defaultable nominal debt in the maturity structure. We differ from these papers by showing how accounting for differences in expected returns across nominal bonds of different maturities – in the fiscal theory – provides a risk-based channel for the maturity structure to affect inflation without market segmentation, distortionary taxation, or default risk.

The Markov-switching Dynamic Stochastic General Equilibrium (DSGE) framework builds on Bianchi and Ilut (2017) and Bianchi and Melosi (2017). We differ in that we focus on how maturity structure shocks affect inflation in the fiscally-led regime (or expectations of entering this regime) through a novel discount rate channel. Also, the aforementioned papers consider linearized systems, while we use global nonlinear solution methods to capture endogenous bond risk premia, which is central for our main mechanism, and to approximate the presence of occasionally binding constraints in the extended model.

Our paper closely relates to Cochrane (2001) who also considers the role of the maturity structure in the context of the fiscal theory. We distinguish our paper along two key dimensions. First, he considers a risk-neutral setting where the yield curve is flat and constant. Thus, the self-financing maturity structure shocks that we consider are neutral in his setting. When expected returns are the same across bonds, rebalancing the maturity structure does not affect the government discount rate, and therefore inflation does not need to adjust to satisfy the intertemporal government budget equation. In our paper, we illustrate a novel discount rate mechanism, distinct from his paper, where maturity shocks have non-neutral effects on inflation when the slope of the nominal yield curve is non-zero. Specifically, we show that the sign and magnitude of the effects depend on the average slope. Second, in our benchmark and extended models we embed our mechanism in a calibrated general equilibrium setting with endogenous risk premia that allows for a quantitative assessment, whereas he considers a partial equilibrium setting with flexible prices. The presence of sticky prices in our model also allows us to study the real effects of fiscally-induced inflation through the intertemporal government budget equation, especially in the context of the policy counterfactuals in the extended model.

More generally, our paper relates to general equilibrium models that link policy to risk premia. For example, Rudebusch and Swanson (2012), Palomino (2012), Dew-Becker (2014), Campbell,

The paper is organized as follows. Section 2 provides a simple partial equilibrium model to qualitatively illustrate the basic mechanisms. Section 3 presents the quantitative model. Section 4 studies the implications of the quantitative model. Section 5 describes an extended model and considers a policy experiment relating to QE2. Section 6 concludes.

2 Simple Model

In this section, we build a simple model linking inflation to the government cost of capital to illustrate the main insight of the paper. In particular, we show that the effect of changing the maturity structure of government debt on inflation depends on the slope of the nominal yield curve. These concepts are then integrated into a more general model in the next section, where bond risk premia is endogenized.

2.1 Government

The government in our economy finances a stream of nominal purchases, $G_t$, by collecting taxes from households, $T_t$, and issuing one- and two-period nominal debt. Consequently, the government budget equation at time $t$ satisfies

$$B_t^{(1)} + Q_t^{(1)} B_{t-1}^{(1)} = Q_t^{(2)} B_{t-1}^{(2)} + Q_t^{(1)} B_{t-1}^{(1)} + S_t,$$

where $B_t^{(n)}$ is the face value of nominal debt with a maturity of $n$ periods, $Q_t^{(n)}$ is the corresponding bond price, and $S_t = T_t - G_t$ is the nominal primary surplus.

The government consists of two branches, a fiscal and a monetary authority, each of which follows a policy rule specified below. We consider a particular parametrization of the policy regime that characterizes the fiscal theory and allows for analytical tractability. In the benchmark model,
we illustrate how the intuition carries over to more general policy rules. More specifically, the fiscal
authority follows a fixed surplus rule:

$$s_t = \bar{s}, \quad (2)$$

where $s_t = S_t/P_t$ is the real government surplus and $\bar{s} > 0$. The monetary authority passively
accommodates fiscal policy by setting the short-term nominal interest rate independently of inflation
using an interest rate peg:

$$R_t^{(1)} = \bar{R} \quad (3)$$

Finally, the maturity structure of the government debt portfolio is determined by setting the
relative supply of the two-period bond, in terms of market values, as:

$$\frac{B_t^{(2)}}{B_t^{(1)} + B_t^{(2)}} = \Omega_t, \quad (4)$$

where $B_t^{(n)} = Q_t^{(n)}P_t^{(n)}$ is the total market value of government bond with a maturity of $n$ periods
and $\Omega_t$ is an exogenous process that drives the average maturity structure of the government debt
portfolio.

### 2.2 Bond prices

Assume a risk-neutral representative household, with a time discount factor of $\beta$, that invests in
the two bonds issued by the government. When the household trades the two-period bond, an
additional transaction cost $\kappa$, proportional to the amount traded, is incurred. Equilibrium bond
prices are given by the following Euler equations:

$$Q_t^{(1)} = E_t \left[ \frac{\beta}{\Pi_{t+1}} \right], \quad (5)$$

$$Q_t^{(2)} = E_t \left[ \frac{\beta}{\Pi_{t+1}(1 + \kappa)} \right], \quad (6)$$
where $\Pi_t$ is gross inflation.

The transaction cost parameter $\kappa$ allows the model to generate different expected returns for bonds across different maturities while maintaining analytical tractability. The benchmark model in the next section features an endogenous risk-based term premium. The parameter $\kappa$ determines the magnitude of the premium on the two-period bond, i.e.\textsuperscript{4}

$$E \left[ R_{t+1}^{(2)} - R_{t+1}^{(1)} \right] = \kappa \bar{R}, \quad (7)$$

and therefore $\kappa$ also determines the sign of the nominal yield curve:\textsuperscript{5}

$$E \left[ y_t^{(2)} - y_t^{(1)} \right] \approx \frac{\kappa}{2}, \quad (8)$$

where $y_t^{(n)}$ is the yield on a $n$-period nominal bond.

### 2.3 Fiscal theory of the price level

We now examine how inflation is determined in the fiscal theory. Denoting the total market value of government debt by $B_t = B_t^{(1)} + B_t^{(2)}$, we can rewrite the flow government budget equation in terms of total market values of debt and returns:

$$R_t^g B_{t-1} = B_t + S_t, \quad (9)$$

where $R_t^g = (1 - \Omega_{t-1})R_t^{(1)} + \Omega_{t-1}R_t^{(2)}$ is the government cost of capital which is equal to the gross interest rate paid on the government debt portfolio. Note that in the presence of transaction costs, i.e., $\kappa \neq 0$, the government cost of capital depends on the composition of the debt portfolio:

$$R_t^g = (1 + \kappa \Omega_{t-1}) \bar{R}. \quad (10)$$

\textsuperscript{4}More generally, $\kappa$ determines the net transaction cost associated with the trading of the two-period bond relative to that of the one-period bond. Therefore cases where $\kappa < 0$ can be thought of as situations where the two-period bond is in relative high demand as compared to the one-period bond.

\textsuperscript{5}Note that individual bond returns are given by $R_t^{(1)} = 1/Q_t^{(1)}$, and $R_t^{(2)} = Q_t^{(1)}/Q_t^{(2)}$. In addition, the slope of the yield curve is given by: $-\log \left( Q_t^{(2)} \right)/2 + \log \left( Q_t^{(1)} \right) = \log(1 + \kappa)/2 \approx \kappa/2$. 

8
Iterating Eq. (9) forward and imposing a transversality condition, we obtain the present value formula relating the real value of government liabilities at the beginning of \( t \) to the present value of future surpluses:

\[
 b_t = \frac{B_{t-1}}{P_{t-1}} = E_t \left[ \sum_{i=0}^{\infty} \frac{s_{i+t}}{\prod_{j=0}^{i} \left\{ R^9_{j+t}/\Pi_{j+t} \right\}} \right]. \tag{11}
\]

In the fiscally-led regime, the path of inflation is determined by the intertemporal government budget equation (Eq. (11)). Any changes to either government surpluses (cash flows) or the government cost of capital (discount rates) affect current and future inflation.

### 2.4 Fiscal discount rates and the maturity structure

In this paper, we are interested in the link between fiscal discount rates and inflation. As evidenced in Eq. (10), the slope of the nominal yield curve and the composition of the government debt portfolio pin down the government cost of capital. Therefore, when the yield curve is not flat, rebalancing the maturity structure changes the government cost of capital, \( R^9 \), which directly affects inflation through the present value relation given by Eq. (11). Importantly, the sign of the effect of the restructuring policy on inflation depends on the sign of the slope of the nominal yield curve. To illustrate this point, consider the following restructuring operation. At time \( t \), the government changes the maturity structure from \( \Omega_{t-1} = \Omega \) to \( \Omega_t = \Omega + \Delta\Omega \) and commits to keep the proportion of two-period debt at that level from time \( t \) onwards. Under this policy, we can rewrite Eq. (11) as:

\[
 b_{t-1} = \frac{\Pi_t}{(1 + \kappa\Omega)\bar{R}} \left( \sum_{i=0}^{\infty} \frac{s_{i}}{(1 + \kappa(\Omega + \Delta\Omega))\bar{R}/\Pi^{i+1}} \right), \tag{12}
\]

where \( \Pi = E_t[\Pi_{t+1}] \).

The left-hand side of Eq. 12 is predetermined as of date \( t \), therefore changes to the maturity
structure directly affect inflation today. Taking the derivative of $\Pi_t$ with respect to $\Delta \Omega$ yields

$$\frac{\partial \Pi_t}{\partial \Delta \Omega} = \kappa \left[ \Pi \frac{1 + \kappa \Omega}{(1 + \kappa (\Omega + \Delta \Omega))^2} \frac{b_{t-1}}{s} \right].$$

(13)

The expression in brackets is strictly positive. Therefore, the effect of maturity restructuring depends on the relative cost of financing across maturity (i.e., $\kappa$). Suppose the yield curve is upward-sloping (i.e., $\kappa > 0$), then lengthening the maturity structure increases the government cost of capital. To satisfy the intertemporal government budget equation, the increase in discount rates is reflected by a devaluation of the debt portfolio through higher inflation. The effects are therefore deflationary when the yield curve is downward-sloping (i.e., $\kappa < 0$), and neutral when the yield curve is flat (i.e., $\kappa = 0$).

This simple example documents a novel discount rate channel through which nominal debt maturity operations affect inflation. When firms face nominal frictions, the fiscal inflation generated by maturity changes has real effects. We quantitatively explore these channels in the subsequent sections.

3 Quantitative Model

This section integrates and quantifies the insights of the simple model in a standard New Keynesian model with several departures. First, the representative household has recursive preferences, which allows the model to endogenously generate a sizeable bond risk premia. Second, we allow the monetary/fiscal policy mix to vary stochastically between monetary- and fiscally-led regimes. Third, the government varies the supply of nominal debt across different maturities according to a stochastic process. Differences in expected returns across bonds of varying maturities in the presence of a fiscally-led regime imply that self-financing maturity operations have non-neutral effects on inflation.
3.1 Households

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

$$U_t = u(C_t, L_t) + \beta E_t[U_{t+1}^{\theta}]^\frac{1}{\theta},$$

(14)

where $\theta = \frac{1 - \gamma}{1 - \psi}$, $\gamma$ is the coefficient of risk aversion, and $\psi$ is the elasticity of intertemporal substitution. The utility kernel is additively separable in consumption and leisure:

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

(15)

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

The objective of the household is to choose the sequences of $C_t$, $L_t$, and $B_t$ that maximize lifetime utility subject to the following budget constraint:

$$P_tC_t + B_t = P_tD_t + W_tL_t + R^gb_{t-1} - T_t,$$

(16)

where $P_t$ is the aggregate price level, $B_t$ is the market value of the portfolio of nominal government bonds, $D_t$ represents the aggregate payout received from firms, $R^g_t$ is the gross nominal interest rate on the bond portfolio, $W_t$ is the nominal competitive wage, and $T_t$ are nominal lump sum taxes raised by the government.

3.2 Firms

Production in our economy consists of a final goods and an 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, \( X_{i,t} \), as input in a constant elasticity of substitution (CES) production technology:

\[
Y_t = \left( \int_0^1 X_{i,t}^{\nu-1} \, dt \right)^{\frac{1}{\nu}},
\]

(17)

where \( \nu \) is the elasticity of substitution between intermediate goods. The profit maximization problem of the final goods firm yields the following isoelastic demand schedule:

\[
X_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\nu} Y_t,
\]

(18)

where \( P_{i,t} \) is the nominal price of the intermediate goods \( i \).

3.2.2 Intermediate goods

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

\[
X_{i,t} = Z_t L_{i,t},
\]

(19)

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

\[
\log(Z_t) = a_t + n_t,
\]

(20)
where \(a_t\) is the cyclical component and \(n_t\) is the trend component. The evolution of these components are given by:

\[
a_t = \rho_a a_{t-1} + \sigma_a \varepsilon_{at},
\]

(21)

\[
x_t = \rho_x x_{t-1} + \sigma_x \varepsilon_{xt},
\]

(22)

\[
\Delta n_t = \mu + x_{t-1},
\]

(23)

where \(\varepsilon_{at}\) and \(\varepsilon_{xt}\) are correlated standard normal shocks with a contemporaneous correlation equal to \(\rho_{ax}\), and \(\mu\) is the unconditional mean of productivity growth.

The intermediate firms face a cost of adjusting their nominal price. Following Rotemberg (1982), the cost is assumed to be quadratic:

\[
\frac{\phi_R}{2} \left( \frac{P_{i,t}}{\Pi_{ss} P_{i,t-1}} - 1 \right)^2 Y_t,
\]

(24)

where \(\Pi_{ss} \geq 1\) is the gross inflation rate in the deterministic steady state and \(\phi_R\) dictates the magnitude of the costs.

The source of funds constraint of the firm, in real terms is:

\[
D_{i,t} = \frac{P_{i,t}}{P_t} X_{i,t} - \frac{W_t}{P_t} L_{i,t} - \frac{\phi_R}{2} \left( \frac{P_{i,t}}{\Pi_{ss} P_{i,t-1}} - 1 \right)^2 Y_t,
\]

(25)

where \(D_{i,t}\) represents firm payouts.

The objective of the firm is to choose a sequence of intermediate goods prices, \(P_{i,t}\), and labor, \(L_{i,t}\), in order to maximize the value of the firm, subject to the inverse demand for its product and the source of funds constraint. Taking the pricing kernel, \(M_t\), as given and denoting the vector of aggregate state variables by \(\Upsilon_t = (P_t, Z_t, Y_t)\), the firm’s problem in recursive form is:

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

(26)

subject to Eqs. (18) and (25).

13
3.3 Government and bond supply

The government issues both short-term and long-term nominal bonds. The short-term bonds have a maturity of one period, and promises a payment of $1 at maturity. The total nominal face value of short-term bonds outstanding at time $t$ is given by $B^{(1)}_t$. The long-term bond has an infinite maturity and pays coupons every period at a geometrically declining rate; that is, the coupon payment in period $t + 1 + j$ is $\lambda^j$, for $j = 0, \ldots, \infty$. We denote the total nominal face value of the long-term bonds outstanding at time $t$ by $B^{(L)}_t$.

The price of the short- and long-term government bonds are given, respectively, by the following equilibrium conditions:

$$Q^{(1)}_t = E_t[M^{\$}_{t+1}],$$

(27)

$$Q^{(L)}_t = E_t \left[ M^{\$}_{t+1} \left( 1 + \lambda Q^{(L)}_{t+1} \right) \right],$$

(28)

where $M^{\$}_{t,t+j} = M_{t,t+j}/\Pi_{t,t+j}$ is the $j$-period nominal stochastic discount factor.

For parsimony, we abstract from government expenditures. Therefore, primary surplus are equal to the household lump-sum taxes. The flow consolidated budget equation of the government at time $t$ is given by:

$$B^{(1)}_{t-1} + (1 + \lambda Q^{(L)}_t) B^{(L)}_{t-1} = S_t + Q^{(1)}_t B^{(1)}_t + Q^{(L)}_t B^{(L)}_t.$$  

(29)

As in the simple model, we allow the government to choose the maturity structure of the government debt portfolio. In particular, we assume that each period, the government retires outstanding debt through surpluses and issues new liabilities to obtain a target maturity structure, which boils down to determining the fraction of debt financed by long-term bonds, $\Omega_t$. We assume that $\Omega_t$ evolves as:

$$\Omega_t = \frac{B^{(L)}_t}{B^{(1)}_t + B^{(L)}_t} = \frac{1}{1 + e^{-\omega_t}},$$

(30)

$$\omega_t = (1 - \rho_\omega) \bar{\omega} + \rho_\omega \omega_{t-1} + \sigma_\omega \epsilon_{\omega t},$$

(31)
where $B_t^{(n)} \equiv Q_t^{(n)} B_t^{(n)}$ is the total market value of type-$n$ government bonds, for $n \in \{1, L\}$.

### 3.4 Monetary and fiscal rules

This section describes the policy rules followed by the monetary and fiscal authorities. In contrast to the simple model, we generalize the policy rules and allow them to vary over time by adding an index $\zeta_t$ to the parameters that determine the policy mix at time $t$.

The monetary authority sets the nominal short rate of interest according to a Taylor rule that depends on the lagged interest rate, in addition to, inflation and output deviations from steady-state:

$$r_{t+1}^{(1)} = \rho_r r_t^{(1)} + (1 - \rho_r) \left( r_t^{(1)} + \rho_{\pi,\zeta} \log \left( \frac{\Pi_t}{\Pi_t^*} \right) + \rho_{y,\zeta} \log \left( \frac{\hat{Y}_t}{Y_t} \right) \right),$$

where $r_t^{(1)} = \log(R_t^{(1)})$ is the log gross one-period nominal interest rate, $\hat{Y}_t = Y_t/N_t$ is detrended output, and the variables without the time subscripts denote deterministic steady-state values.

The fiscal authority adjusts the real primary surplus-to-output ratio, $s_t = S_t/(P_t Y_t)$, according to the following rule:

$$s_t - s = \rho_s (s_{t-1} - s) + (1 - \rho_s) \delta_b \zeta (b_{t-1} - b_{ss}) + \sigma_s \varepsilon_{st},$$

where $B_t = B_t^{(1)} + B_t^{(L)}$ and $b_t = \frac{B_t}{P_t Y_t}$.

### 3.5 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 ($\delta_b > (\beta \Delta Y^{1-1/\psi})^{-1} - 1$). In this

6Specifically, Leeper (1991) derives the partition of the policy regimes in a linearized model where the interest rate rule only depends on inflation and the fiscal rule only depends on debt. For parsimony, we use this case to characterize the regimes only for the exposition.
policy mix, monetary policy determines inflation while fiscal policy passively provides the fiscal backing to accommodate the inflation targeting objectives of the monetary authority. This regime is referred to 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 ($\delta_b < (\beta \Delta Y^{1-1/\psi})^{-1} - 1$), but instead the monetary authority passively accommodates fiscal policy ($\rho_\pi < 1$) by allowing the price level to adjust (to satisfy the government budget equation). 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 equation because households know that changes in taxes will not be offset by future tax changes.\(^7\) This regime is referred to as the fiscally-led regime.

When both the fiscal and monetary authorities are active, no stationary equilibrium exists. When both authorities are passive, there are 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 following Bianchi and Ilut (2017) with the following transition matrix:

\[
M = \begin{pmatrix}
    p_{MM} & 1 - p_{FF} \\
    1 - p_{MM} & p_{FF}
\end{pmatrix},
\]

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

The full set of equilibrium conditions are listed in Appendix A.

### 4 Results

This section presents the results from the quantitative 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.

\(^7\)In this regime, the government budget equation is an equilibrium condition rather than a constraint that has to hold for any price path.
4.1 Calibration

Table 1 presents the quarterly calibration. Panel A reports the values for the preference parameters. The elasticity of intertemporal substitution $\psi$ is set to 1.5 and the coefficient of relative risk aversion $\gamma$ is set to 10, which are within the standard values of the long-run risks literature (e.g., Bansal and Yaron (2004)). The mean of the time discount factor, $\beta$, is calibrated to 0.997 to match the average return on the government bond portfolio. The parameters $\chi$ and $\chi_0$ are calibrated such that labor supply is a third of the household’s leisure endowment and imply a Frisch elasticity of labor of 4 (e.g., King and Rebelo (1999)).

Panel B reports the calibration of the parameters relating to production and price-setting. The price elasticity of demand $\nu$ is set to 6. The price adjustment cost parameter $\phi_R$ is set to 10.\footnote{For example, in a log-linear approximation, the parameter $\phi_R$ 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.} The mean growth rate of productivity $\mu$ is set to obtain a mean annualized output growth rate of 2%. The parameters dictating the cyclical dynamics of productivity, $\rho_a$ and $\sigma_a$, are set to be consistent with the standard deviation and persistence of realized consumption growth. The parameters governing the dynamics of the trend component of productivity, $\rho_x$ and $\sigma_x$, are calibrated to be consistent with the expected consumption growth dynamics from Bansal and Yaron (2004). The correlation between the cyclical and trend shocks, $\rho_{ax}$, is set to 0.95 to match the endogenous relation generated in the innovation-based growth models of Kung (2015) and Kung and Schmid (2015).\footnote{A strong positive correlation between trend and cycle components of TFP help to generate sizable inflation risk premia, as discussed in Kung (2015). We find that the results for the yield curve are robust for a range of parameter values for $\rho_{ax}$ between 0.85 and 1.}

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, $\rho_s$ and $\sigma_s$, are chosen to match primary surplus dynamics. The surplus rule parameter determining the degree of debt smoothing, $\delta_b$, is set to 0.05 and 0.00 in the monetary and fiscally-led regimes, respectively. The interest rate rule parameter governing the degree of inflation smoothing, $\rho_\pi$, is set to 1.7 and 0.55 in the monetary- and fiscally-led regimes, respectively, and $\rho_y$ to 0.25 and 0. The calibration of these policy parameters, conditional on regime, are consistent with structural estimation evidence.
from Bianchi and Ilut (2017). Steady-state inflation $\Pi_{ss}$ is set to 1.006 to match average inflation. Following Bianchi and Melosi (2017), we assume that the transition matrix governing the dynamics of the policy/mix is symmetric, $p_{MM} = p_{FF} = p$, and is equal to 0.99, implying that the economy stays on average for 25 years in a given regime.

We use this framework to quantitatively examine the effects of maturity restructuring through the lens of the fiscal theory. To this end, we calibrate the bond supply process to capture salient features of the maturity structure dynamics (reported in Panel D of Table 1). The value for the coupon decay rate $\lambda$ implies an average duration of the long-term bond of ten years. The steady state maturity structure $\bar{\omega}$ is set to match the average duration, while the standard deviation and persistence of the stochastic process driving the bond duration dynamics, $\omega_t$, are calibrated to match the empirical counterparts.

Overall, the model produces realistic macroeconomic dynamics and bond risk premia, as evidenced in the summary statistics reported in Panel A of Table 2.

### 4.2 Yield Curve

The dynamics of the nominal yield curve provide the key transmission channel – both qualitatively and quantitatively – for maturity restructuring operations in the fiscal theory. In this section, we show that the model endogenously generates realistic term structure implications. Panel A of Table 3 reports the mean, standard deviation, and first autocorrelation of nominal yields for maturities of one quarter to five years. The model closely matches the mean and volatility of the 5-year minus 1-quarter nominal term spread. The volatility of nominal yields falls short of the empirical targets, however Kung (2015) shows that a richer DSGE model that incorporates exogenous volatility and monetary policy can fit the second moments. For the sake of parsimony, we abstract from these additional shocks.

The positively-related stationary and trend technology shocks generate an upward-sloping nominal term structure of interest rates. A good technology shock simultaneously raises expected consumption growth through the trend component and increases the marginal product of labor through the stationary component. The increase in the marginal product of labor is large enough to offset the higher real wages induced by the wealth effect from the higher trend component so
that real marginal costs decline. Since equilibrium inflation is related to the present value of current and future marginal costs (at the first order), lower marginal costs imply lower inflation. In sum, the technology shock structure produce a negative relation between inflation and expected consumption growth, which implies that long nominal bonds are riskier than short nominal bonds. Persistently higher inflation erodes the real payoff of long nominal bonds more than short nominal bonds. Higher inflation is also associated with low expected growth which are high marginal utility states. Therefore, long nominal bonds provide less insurance than short ones when marginal utility is high.

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

The regime changes generate endogenous variation in macroeconomic volatility and is a source of time-varying bond risk premia. Panel B of Table 2 reports macroeconomic dynamics conditional on being in the monetary and fiscally-led regimes, respectively. The volatility of consumption growth, labor hours, and inflation is significantly lower in the monetary-led regime relative to the fiscally-led regime. The economy is primarily insulated from fiscal disturbances in the monetary-led regime due to the Ricardian tax/surplus policy characterizing this regime. In contrast, fiscal disturbances directly impact inflation and expected inflation through the intertemporal government budget equation in the fiscally-led regime. Panel A of Table 2 illustrates that the policy regime shifts generate a significant degree of consumption and inflation heteroskedasticity. With recursive preferences, the time-varying inflation and consumption volatility lead to predictable excess nominal bond returns. Indeed, Table 4 shows that excess bond returns are forecastable by a linear combination of forward rates (Cochrane and Piazzesi (2005)), as in the data.

\[10\] Due to the regime shifts and rational expectations, fiscal disturbances are not perfectly neutral in the monetary-led regime.
Tables 2, 3, and 4 collectively demonstrate that the model provides a reasonable account of nominal bond yields and macroeconomic dynamics. In the following sections, we use this framework to quantitatively explore the interactions between the term structure and maturity operations in the fiscal theory.

### 4.3 Maturity Structure Shocks

As described in the simple model from Section 2, 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 in the quantitative model from Section 3 by iterating forward the government budget equation:

\[
  b_{t-1} = \frac{B_{t-1}}{P_{t-1}Y_{t-1}} = E_t \left[ \sum_{\ell=0}^{\infty} \prod_{j=0}^{i} \frac{R_{t+j}^q}{(\Pi_{t+j} \Delta Y_{t+j})} s_{t+i} \right],
\]

where \( R_{t}^g B_{t-1} = B^{(1)}_{t-1} + (1 + \lambda Q^{(L)}_t) B^{(L)}_{t-1} \) is the nominal market value of outstanding government liabilities, \( R_{t}^q = (1 - \Omega_{t-1}) R^{(1)}_{t-1} + \Omega_{t-1} R^{(L)}_{t-1}, R^{(1)}_{t-1} = 1/Q^{(1)}_{t-1}, \) and \( R^{(L)}_{t-1} = (1 + \lambda Q^{(L)}_t)/Q^{(L)}_{t-1}. \)

In the fiscally-led regime, Eq. (35) 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 a long-term bond with a geometric maturity structure and that the equation accounts for trend growth. When the expected returns of bonds vary by maturity, changing the financing mix alters the government cost of capital, \( R_{t}^g \), which leads to an adjustment in inflation (and expected inflation) to satisfy Eq. (35). 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 illustrate 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.
4.3.1 Conditional on Different Slopes

Fig. 2 plots impulse response functions, conditional on staying in the fiscally-led regime, to a shock that corresponds to an open market operation that reduces average maturity by 0.18 years, a 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 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 requires that inflation falls persistently to revalue nominal debt obligations so that the intertemporal government equation is satisfied. A heuristic interpretation of the discount rate-inflation link is as follows. 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 highlights a potential “cost” of QE operations.

In the negative slope case, shortening the maturity structure gives the opposite effects compared to when the slope is positive. In particular, reducing maturity in this case means that the government is refinancing at a higher rate. In the fiscally-led 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 equation. With sticky prices, the increase in inflation stimulates an expansion in output. 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.
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 further deepens the fall in the government discount rate. Furthermore, the fall in the overall level of the yields from falling inflation further depresses the nominal bond portfolio return. A similar logic for the amplification effect also applies for the downward-sloping case.

4.3.2 Conditional on Different Regimes

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. 3 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 that reduces the average maturity of the government bond portfolio 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 Ricardian tax 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 unconditional probability of changing regimes is small, the responses of macroeconomic quantities in the monetary-led regime are smaller. For example, output drops by 54 basis points in the fiscally-led regime compared to 6.5 basis points in the monetary-led regime.

4.4 Market Timing Policies

Consider modifying the maturity restructuring process so it depends directly on the slope of the nominal yield curve:

$$\omega_t = (1 - \rho_\omega)\bar{\omega} + \rho_\omega \omega_{t-1} + \rho \left( y_t^{5Y} - y_t^{1Q} \right) + \sigma_\omega \varepsilon_{\omega,t}.$$  \hspace{1cm} (36)
A positive coefficient ($\phi > 0$) implies that the government lengthens the maturity structure when yield curve is upward-sloping and shortens it when the yield curve is downward-sloping. A negative coefficient implies the opposite policy. Fig. 4 plots the comparative statics for varying $\phi$ from -1 to 1. More positive values of $\phi$ smooth macroeconomic fluctuations, reduce risk premia, and improve welfare through the fiscal discount rate channel. In contrast, more negative values of $\phi$ increase consumption and inflation volatility, and, in turn, decrease welfare. Positive values of $\phi$ shorten the maturity structure when the yield curve is downward sloping, which stimulates the economy and generates fiscal inflation exactly during low growth states. Using similar logic, negative values for $\phi$ deepen recessions and increase deflationary pressure.

5 Extended Model and Policy Experiment

In this section we investigate the quantitative importance of the fiscal discount rate channel in the context of the quantitative easing operations during the Great Recession. To enrich the analysis, we augment the quantitative model from Section 3 with other salient features characterizing this period: (i) a zero lower bound (ZLB) constraint on nominal interest rates, (ii) market segmentation, and (iii) short-term liquidity demand shocks. The economy is hit with large negative surplus shocks to replicate the sizable budget deficits during this period. The extended model is recalibrated to fit the macroeconomic and term structure dynamics from Tables 2, 3, and 4. We take a conservative approach in evaluating the fiscal channel by analyzing the effects in the monetary-led regime.

At the onset and during the aftermath of the Great Recession, short-term nominal 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 the maturity twist operations (e.g., the Maturity Extension Program and QE2). Market segmentation and providing short-term liquidity are often-cited motivations by policymakers for implementing the maturity restructuring operations (e.g., Bernanke (2012)). Indeed, absent the fiscal channel, these channels imply that shortening maturity on the scale of QE2 would have a powerful inflationary and expansionary effect. As outlined in the previous section, the impact of the fiscal channel depends on the slope of the
nominal yield curve. Given that the slope was large and positive during the Great Recession, the
fiscal channel provides an opposing force that weakens the stimulative effects of QE on inflation
and output.

In the following sections, we introduce each new model ingredient in isolation and then discuss
their role in the transmission of maturity shocks. At the end of this section, we integrate all of
the new ingredients together for counterfactual analysis, where we discuss tradeoffs for QE2-type
operations and quantitatively evaluate the significance of the fiscal discount rate channel.

5.1 ZLB

We incorporate a ZLB constraint in the extended model:

\[
\rho_{r^1_t} = \max \left\{ 0, \rho_r \rho_{r^1_t} + (1 - \rho_r) \left( \rho_{r^1_t} + \rho_{\pi,\zeta} \log \left( \frac{\Pi_t}{\Pi} \right) + \rho_{\pi,\zeta} \log \left( \frac{\hat{Y}_t}{\hat{Y}} \right) \right) \right\}.
\]

As in Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramirez (2015), we use global
projection methods and rational expectations, as in the previous model analysis, to approximate
the policy functions with the ZLB constraint.

To capture periods where the ZLB constraint is binding for multiple periods, we allow the time
discount parameter, \( \beta_t \), to follow a two-state Markov process (indexed by \( \tau_t \)). The corresponding
transition matrix reads:

\[
P = \begin{pmatrix}
p_{LL} & 1 - p_{HH} \\ 1 - p_{LL} & p_{HH}
\end{pmatrix},
\]

where \( p_{ij} \equiv Pr(\tau_{t+1} = i|\tau_t = j) \), and \( L \) and \( H \) denotes the low- and high-\( \beta \) state, respectively. In
the calibration, we choose a value for \( \beta_H \) such that the ZLB constraint binds in state \( H \).

Fig. 5 plots impulse response functions for a shock that reduces average maturity by 0.18 years
(e.g., QE2), conditional on being in the monetary-led regime, for an economy that is either at the
ZLB (dashed line) or away from the ZLB (solid line). The at the ZLB case is obtained by assuming
that \( \beta_t \) is in state \( H \) for the time of the experiment. The responses at the ZLB are relative to a
counterfactual economy at the ZLB, but without the maturity structure shock. We consider the
benchmark case where the yield curve is, on average, upward-sloping.

The preference shock causing the ZLB to bind steepens the slope of the nominal yield curve as the short-term interest rates are anchored at zero. Consequently, the negative maturity structure shock leads to a larger decline in the government discount rate compared to being away from the ZLB. The larger discount rate effect is reflected in the more pronounced contractionary effect on inflation and output. This amplification of the fiscal discount rate effects is further reinforced by the fact that the monetary authority loses the ability to offset such disturbances through inflation smoothing. Interestingly, at the ZLB, the response of the slope of the yield curve – controlling for the impact of the preference shock – flips sign relative to the benchmark case away from the ZLB. In the benchmark case away from the ZLB, the drop in inflation lowers the short rate through the Taylor rule which increases the slope. At the ZLB, the short rate is anchored at zero while the fall in inflation lowers the longer-term yields, which decreases the slope.

5.2 Market Segmentation and Liquidity Demand

While this paper highlights a potential cost of QE through the fiscal discount rate channel, for our policy experiment, we also account for some of the key proposed benefits of shortening maturity during the Great Recession – lowering long-term borrowing costs and meeting short-term liquidity needs. These additional channels allow for a richer analysis of policy tradeoffs from maturity restructuring considered in the next section. To this end, we incorporate market segmentation via transaction costs for bonds of different maturities (e.g., Bansal and Coleman (1996)) and short-term liquidity demand shocks (e.g., Krishnamurthy and Vissing-Jorgensen (2012)) in the extended model.

The transaction costs captures, in 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 now pays an additional fee $\varepsilon_{k^t} - 1$ per unit of long-term bond traded. The budget constraint of the representative household is modified in the following way:

$$P_tC_t + Q_t^{(1)}B_t^{(1)} + \varepsilon_{k^t}Q_t^{(L)}B_t^{(L)} = P_tD_t + W_tL_t + B_{t-1}^{(1)} + B_{t-1}^{(L)}[1 + \lambda Q_t^{(L)}] - T_t. \quad (39)$$
With transaction costs, the government budget equation is the same as before, except that long-term bond prices now include an additional premium:

\[
Q_t^{(1)} B_t^{(1)} + Q_t^{(L)} B_t^{(L)} = B_{t-1}^{(1)} + B_{t-1}^{(L)} \left[ 1 + \lambda Q_t^{(L)} \right] - S_t
\] (40)

\[
Q_t^{(L)} = e^{-\kappa_t} E^t \left[ \frac{M_{t+1}}{\Pi_{t+1}} \left( 1 + \lambda Q_{t+1}^{(L)} \right) \right]
\] (41)

Note that the existence of transaction costs gives rise to a liquidity premium that depends on \( \kappa_t \).

Following the literature on preferred habitats, it is assumed that the liquidity premium on a bond of specific maturity depends on its total supply. We adopt the following specification for \( \kappa_t \):

\[
\kappa_t = \kappa_0 + \kappa_1 \left[ \log \left( \frac{B_t^{(L)}}{B_{t-1}^{(L)}} \right) - \log \left( \frac{B_t^{(L)}}{B_{t-1}^{(L)}} \right) \right]
\] (42)

\[
= \kappa_0 + \kappa_1 (\omega_t - \bar{\omega})
\] (43)

where \( \kappa_0 > 0 \) is the steady state transaction cost and \( \kappa_1 > 0 \). This means that, on average, long-term bonds have a transaction premium (\( \kappa_0 > 0 \)), and that this premium increases when the relative supply of long-term bond increases (\( \kappa_1 > 0 \)). Demand for short-term liquidity is captured by replacing consumption \( C_t \) with a “consumption” composite, \( C_t^* \), that captures, in a reduced form a preference for short-term debt:\footnote{One can think of this specification as having preference for the aggregate supply of short term relative to the supply of any longer-term debt. To see this, note that \( \log(V_t) = \varrho \left[ \log(B_t^{(1)}/B_t^{(L)}) - \log(B_{ss}^{(1)}/B_{ss}^{(L)}) \right] \) simplifies to \( \log(V_t) = -\varrho(\omega_t - \bar{\omega}) \).}

\[
C_t^* = C_t V_t,
\] (44)

\[
\log(V_t) = -\varrho(\omega_t - \bar{\omega}),
\] (45)

where \( \varrho \geq 0 \) captures preference for short-term debt.

Fig. 6 shows impulse response functions from shortening maturity with market segmentation and short-term liquidity demand. To isolate the effects of these two new transmission channels, we shut down the fiscal discount rate channel by assuming that the economy is permanently in the monetary-led regime without the possibility of regime changes. The market segmentation parameters are
calibrated so that a QE2-type shock reduces the five-year minus one quarter 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). The liquidity demand parameter is calibrated to match the 5-year inflation expectation reactions to QE2 of 3 basis points inferred from inflation swaps. With market segmentation and a short-term liquidity demand, shortening maturity pushes down long-term rates while stimulating economic activity.

5.3 Policy Experiment

In this section, we combine all of the new ingredients into the quantitative model from Section 3 to evaluate the significance of the fiscal channel in the context of QE2. We start the economy off in the monetary-led regime (and allow for the policymakers to switch to the fiscally-led regime in the future), at the ZLB, and with a sizeable budget deficit calibrated to the data around this period. In Fig. 7 we evaluate the impact of a QE2-type shock on the economy in the extended model (dashed line) and in an alternative economy (solid line) that shuts down the fiscal channel (i.e., policy mix is permanently characterized by the monetary-led regime without the possibility of regime changes). These responses are deviations from a counterfactual economy where the maturity shock does not occur. As discussed above, the market segmentation and liquidity preference parameters are calibrated to match the responses of the yield spread and inflation to QE2 in the extended model.

Given that the yield curve is sharply upward-sloping during this period, which is replicated in the model, the fiscal discount rate channel significantly dampens the expansionary effects of QE2 on output and inflation arising from liquidity demand and market segmentation. Due to the ZLB, the fiscal channel reinforces the flattening of the yield curve from market segmentation, consistent with empirical evidence that QE2 was effective in lowering long-term interest rates (e.g., Krishnamurthy and Vissing-Jorgensen (2011)). Shortening maturity when the slope is positive puts downward pressure on government discount rates. When there is a possibility of entering the fiscally-led regime, the downward pressure in discount rates imparts a downward force on inflation through the intertemporal government budget equation presented in Eq. 35. Comparing the impulse response
functions, we find that the fiscal discount rate channel dampens inflation responses by 63% after 5 quarters and 58% after 10 quarters. Similarly, the fiscal channel dampens output responses by 36% after 5 quarters and 33% after 10 quarters. Interpreting these results, accounting for the fiscal discount rate channel at the ZLB provides a potential explanation for why strong responses in inflation were not observed after the QE operations, despite the effectiveness in reducing long-term yields.

6 Conclusion

This paper explores the interactions between yield curve dynamics and nominal government debt maturity operations through the fiscal discount rate channel. Open market 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 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). The effects are neutral when the slope is zero. In the nonzero slope cases, the discount rate effects are magnified when the likelihood of entering the fiscally-led regime is higher or the magnitude of the nominal yield curve slope is larger. Thus, we highlight a novel risk-based transmission channel for unconventional monetary policy that depends on the state of bond yields and expectations regarding the monetary/fiscal policy mix. We show that the power of maturity restructuring operations implemented during, and in the aftermath, of the Great Recession are attenuated during periods of fiscal stress and positive term premia.

We quantify the fiscal discount rate channel in a small scale New Keynesian model with a stochastic maturity structure and policy regime changes between monetary-led and fiscally-led regimes. Calibrating the model to explain salient features of the term structure of interest rates, macroeconomic dynamics, and bond supply data we find that changes in fiscal discount rates
arising from maturity restructuring shocks have sizable effects on inflation and output. In the policy experiment, we examine policy tradeoffs in a counterfactual economy and demonstrate that the fiscal channel significantly dampened the stimulative effects of QE2 on inflation and output, but reinforced the flattening of the yield curve. Overall, we provide a potential channel for explaining the weak inflation responses following the quantitative easing operations.
Appendix A Equilibrium Conditions

1. Household’s first-order conditions:
   \[ Q_t^{(1)} = E_t \left[ \frac{M_{t+1}}{\Pi_{t+1}} \right] \]  (46)
   \[ Q_t^{(L)} = E_t \left[ \frac{M_{t+1}}{\Pi_{t+1}} \left( 1 + \lambda Q_t^{(L)} \right) \right] \]  (47)
   \[ M_{t+1} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\psi}} \left( \frac{U_{t+1}}{E_t[U_{t+1}^{\theta}]} \right)^{\theta-1} \]  (48)
   \[ W_t = \chi_0 C_t^{\frac{1}{\psi}} N_t^{1-\frac{1}{\psi}} \left( L - L_t \right)^{-\chi} \]  (49)

2. Household’s utility:
   \[ U_t = C_t^{1-\frac{1}{\psi}} + \chi_0 N_t^{1-\frac{1}{\psi}} \left( L - L_t \right)^{1-\chi} + \beta E_t [U_{t+1}^{\theta}]^{\frac{1}{\psi}} \]  (50)

3. Intermediate firm’s first-order conditions:
   \[ W_t = \left( 1 - \frac{1}{\nu} \right) Z_t + \Lambda_t \left( \frac{1}{\nu} \right) \frac{Z_t}{Y_t} \]  (51)
   \[ \Lambda_t = \phi_R \left( \frac{\Pi_t}{\Pi_{ss}} - 1 \right) \frac{\Pi_t}{\Pi_{ss}} Y_t - E_t \left[ M_{t+1} \phi_R \left( \frac{\Pi_{t+1}}{\Pi_{ss}} - 1 \right) \frac{Y_{t+1}\Pi_{t+1}}{\Pi_{ss}} \right] \]  (52)

4. Government policy:
   \[ r_t^{(1)} = \rho_r r_t^{(1)} + (1 - \rho_r) \left( r_t^{(1)} + \rho_{\pi,\xi} \log \left( \frac{\Pi_t}{\Pi} \right) + \rho_{y,\zeta} \log \left( \frac{\hat{Y}_t}{Y} \right) \right) \]  (53)
   \[ s_t = s_t - s = \rho_s (s_{t-1} - s) + (1 - \rho_s) \delta_{b,\xi} \left( b_{t-1} - b_{ss} \right) + \sigma_s \varepsilon_s \]  (54)
   \[ b_t = \frac{R^q_t}{\Pi_t \Delta Y_t} \frac{b_{t-1} - s_t}{s_t} \]  (55)
   \[ R^q_t = \frac{1 - \Omega_{t-1}}{Q_{t-1}^{(1)}} + \Omega_{t-1} \frac{1 + \lambda Q_t^{(L)}}{Q_{t-1}^{(L)}} \]  (56)

5. Output:
   \[ Y_t = Z_t L_t \]  (57)

6. Market clearing:
   \[ Y_t = C_t + \frac{\phi_R}{2} \left( \frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 Y_t \]  (58)
7. Stochastic processes:

\[
\begin{align*}
\log(Z_t) &= a_t + n_t \\
a_t &= \rho_a a_{t-1} + \sigma_a \varepsilon_{at} \\
x_t &= \rho_x x_{t-1} + \sigma_x \varepsilon_{xt} \\
\Delta n_t &= \mu + x_{t-1} \\
\omega_t &= (1 - \rho_\omega) \bar{\omega} + \rho_\omega \omega_{t-1} + \sigma_\omega \varepsilon_{\omega t}
\end{align*}
\]

(59) (60) (61) (62) (63)

Appendix B Numerical Procedure

The solution to the extended quantitative model is obtained by solving for the policy functions globally. Following Fernández-Villaverde, Gordon, Guerrón-Quintana, and Rubio-Ramirez (2015), we implement a time-iteration procedure and approximate the equilibrium functions using the projection method with a Chebyshev polynomial basis. To approximate the integrals, we apply Gauss-Hermite quadrature and verify the algorithm’s accuracy by increasing the polynomial degree and the number of integration points till the Euler equation errors converge towards zero.

First, non-stationary variables are normalized by the permanent technology component \( N_t \) following the convention \( \tilde{X}_t \equiv X_t / N_t \) except for \( \tilde{U}_t \equiv \bar{U}_t / N_t^{1-1/\psi} \) and \( \tilde{B}^{(i)}_t \equiv B^{(i)}_t / S_{t+1} \). Then, the stationary model’s state space is eight dimensional and includes the transitory technology component \( a_t \), the permanent component \( x_t \), the stochastic process driving bond duration dynamics \( \omega_t \), the government surplus to output ratio \( s_t \), the lagged log one-period bond price \( \log \hat{Q}_{t-1}^{(1)} \), the lagged real face value of short-term bonds \( \hat{B}_{r,t-1}^{(1)} \), \( \hat{B}_{r,t-1}^{(L)} \), and the state variable associated with the monetary/fiscal-led regime \( \zeta_t \). Thus, the vector of state variables reads

\[
S_t = \left( a_t, x_t, \omega_t, s_t, \log \hat{Q}_{t-1}^{(1)}, \hat{B}_{r,t-1}^{(1)}, \hat{B}_{r,t-1}^{(L)}, \zeta_t \right).
\]

To insure that the problem is a contraction, the four equilibrium functions over \( S_t \) are regime dependent. In particular, we iterate output, long-term bond price, utility, and inflation in the monetary regime \( K_t = \left( \log \hat{Y}_t, \log \hat{Q}_t^{(L)}, \log \hat{\Pi}_t, \log \Pi_t \right) = \Pi_t \). In the fiscal regime, we update the present value of real government surplus, \( \hat{J}_t \), instead of inflation such that \( K_t = \left( \log \hat{Y}_t, \log \hat{Q}_t^{(L)}, \log \hat{\Pi}_t, \hat{\Pi}_t \hat{J}_t \right) = \Pi_t \). The corresponding stationary updating equations read in the monetary regime

\[
\log \Pi_t = \log \Pi_{ss} - \frac{1}{\rho_x} \bar{\xi}_{t-1}^{(1)} - \frac{\rho_x}{\rho_x(1 - \rho_x)} \bar{\xi}_{t-1}^{(1)} - \frac{\rho_y}{\rho_x} \log \left( \frac{\hat{\Pi}_t}{Y_t} \right) - \frac{1}{\rho_x(1 - \rho_x)} \log \left( E_t \left[ \frac{M_{t+1}}{\Pi_{t+1}} \right] \right)
\]

(65)

\[
\hat{J}_t = \frac{\hat{B}_{r,t-1}^{(1)} + \left[ 1 + \lambda Q_t^{(L)} \right] \hat{B}_{r,t-1}^{(L)}}{\hat{\Pi}_t}.
\]

(66)

In the fiscal regime real, government surplus and inflation are updated using

\[
\hat{J}_t = \hat{Y}_t s_t + e^{\Delta n_{t+1}} E_t \left[ M_{t+1} \hat{J}_{t+1} \right]
\]

(67)

\[
\log \Pi_t = \log \left( \frac{\hat{B}_{r,t-1}^{(1)} + \left[ 1 + \lambda Q_t^{(L)} \right] \hat{B}_{r,t-1}^{(L)}}{\hat{J}_t} \right).
\]

(68)
Then, the other variables are obtained via

\[ \log Q^{(1)}_t = -\rho_t r^{(1)}_t - (1 - \rho_t) \left( \pi^{(1)}_t + \rho_{\pi, \zeta} \log \left( \frac{\Pi_t}{\Pi} \right) + \rho_{y, \zeta} \log \left( \frac{Y_t}{Y} \right) \right) \]  

(69)

\[ \log Q^{(L)}_t = \log \left\{ Q^{(1)}_t + \lambda E_t \left[ \frac{M_{t+1} Q^{(L)}_{t+1}}{\Pi_{t+1}} \right] \right\} \]  

(70)

\[ \frac{\hat{\Lambda}_t}{Y_t} = \phi_R \left( \frac{\Pi_t}{\Pi_{ss}} - 1 \right) \frac{\Pi_t}{\Pi_{ss}} - E_t \left[ M_{t+1} \phi_R \left( \frac{\Pi_{t+1}}{\Pi_{ss}} - 1 \right) \frac{\hat{Y}_{t+1}}{Y_t} e^{\Delta n_{t+1}} \frac{\Pi_{t+1}}{\Pi_{ss}} \right] \]  

(71)

\[ \Upsilon_t = \frac{1}{\nu \chi_0} \left( \nu - 1 + \frac{\hat{\Lambda}_t}{Y_t} \right) \left( 1 - \frac{\phi_R}{2} \left( \frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right) \]  

(72)

\[ \log \hat{Y}_t = \psi \chi \log \left( \frac{L - \hat{Y}_t}{Z_t} \right) + \psi \log \Upsilon_t \]  

(73)

\[ \hat{C}_t = \left( 1 - \frac{\phi_R}{2} \left( \frac{\Pi_t}{\Pi_{ss}} - 1 \right)^2 \right) \hat{Y}_t \]  

(74)

\[ \log \hat{U}_t = \log \left( \frac{\hat{C}_{t+1}^{1-\frac{1}{\psi}} + \chi_0 \frac{(L - L_t)^{1-\chi}}{1-\chi} + \beta e^{(1-\frac{1}{\psi}) \Delta n_{t+1}} \left( E_t \left[ \hat{U}_{t+1}^{\theta} \right] \right)^{\frac{1}{\psi}}}{1 - \frac{1}{\psi}} \right) \]  

(75)

### Appendix C Data

We obtain quarterly data for consumption and output from the Bureau of Economic Analysis (BEA). Consumption is measured as real personal consumption expenditures. Output is measured as real gross domestic product. Inflation is computed by taking the log return on the Consumer Price Index for All Urban Consumers, 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 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 excess reserve balances maintained with Federal Reserve Banks, which we obtain from the Board of Governors of the Federal Reserve System. The average maturity structure of government debt is calculated as a the weighted average (by amount outstanding) of the four maturity bins reported in the Bulletin augmented with the reserves. The average maturity in each bin is obtained assuming bonds are uniformly distributed within a bin. Reserves are assigned a maturity of 0, while the last bin (maturity of 10 or more years) is assigned an average maturity of 20 years.
References


Lenel, M., 2017. Safe Assets, Collateralized Lending and Monetary Policy.


Table 1: Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Preferences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>Mean of the time discount factor</td>
<td>0.997</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Elasticity of intertemporal substitution</td>
<td>1.5</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Risk aversion</td>
<td>10</td>
</tr>
<tr>
<td>$\varepsilon^F$</td>
<td>Frisch labor supply elasticity</td>
<td>4</td>
</tr>
<tr>
<td>$L/\bar{L}$</td>
<td>Steady state labor supply</td>
<td>0.333</td>
</tr>
<tr>
<td><strong>B. Production</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>Price elasticity for intermediate goods</td>
<td>6</td>
</tr>
<tr>
<td>$\phi_R$</td>
<td>Magnitude of price adjustment costs</td>
<td>10.0</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Unconditional mean growth rate</td>
<td>0.50%</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Persistence of $a_t$</td>
<td>0.925</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Volatility of transitory shock $\varepsilon_{at}$</td>
<td>0.60%</td>
</tr>
<tr>
<td>$\rho_x$</td>
<td>Persistence of $x_t$</td>
<td>0.996</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>Volatility of shock $\varepsilon_{xt}$</td>
<td>0.015%</td>
</tr>
<tr>
<td>$\rho_{ax}$</td>
<td>Correlation between trend and cycle</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>C. Policy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>Persistence of government surpluses</td>
<td>0.92</td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>Volatility of government surpluses $\varepsilon_{st}$</td>
<td>0.052%</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>Persistence of the interest rate</td>
<td>0.7</td>
</tr>
<tr>
<td>$\delta_{\pi}(M/F)$</td>
<td>Sensitivity of taxes to debt</td>
<td>0.05/0.0</td>
</tr>
<tr>
<td>$\rho_{\pi}(M/F)$</td>
<td>Sensitivity of interest rate to inflation</td>
<td>1.7/0.55</td>
</tr>
<tr>
<td>$\rho_{y}(M/F)$</td>
<td>Sensitivity of interest rate to output</td>
<td>0.25/0.0</td>
</tr>
<tr>
<td>$p$</td>
<td>Regime switching probability</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>D. Bond Supply</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{b}$</td>
<td>Steady state Debt-to-GDP ratio</td>
<td>0.5</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Coupon decay rate</td>
<td>0.975</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>Steady state maturity structure</td>
<td>0.487</td>
</tr>
<tr>
<td>$\rho_\omega$</td>
<td>Persistence of $\omega_t$</td>
<td>0.98</td>
</tr>
<tr>
<td>$\sigma_\omega$</td>
<td>Volatility of $\omega_t$</td>
<td>1.42%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>A. Unconditional Moments</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Means</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E(y^{(5Y)} - y^{(1Q)})$ (in %)</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>II. Standard deviations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(\Delta c)$ (in %)</td>
<td>1.42</td>
<td>1.47</td>
</tr>
<tr>
<td>$\sigma(\pi)$ (in %)</td>
<td>1.64</td>
<td>1.71</td>
</tr>
<tr>
<td>$\sigma(\Delta l)/\sigma(\Delta y)$</td>
<td>0.92</td>
<td>0.91</td>
</tr>
<tr>
<td>$\sigma(Vol_{c,t+1,t+4})$ (in %)</td>
<td>0.71</td>
<td>0.48</td>
</tr>
<tr>
<td>$\sigma(Vol_{\pi,t+1,t+4})$ (in %)</td>
<td>0.59</td>
<td>0.54</td>
</tr>
<tr>
<td>III. Correlations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>corr($\pi, \Delta c$)</td>
<td>-0.56</td>
<td>-0.33</td>
</tr>
<tr>
<td>AC1(\Delta c)</td>
<td>0.25</td>
<td>0.086</td>
</tr>
<tr>
<td>AC1(\pi)</td>
<td>0.73</td>
<td>0.66</td>
</tr>
<tr>
<td>AC1(Vol_{c,t+1,t+4})</td>
<td>0.91</td>
<td>0.88</td>
</tr>
<tr>
<td>AC1(Vol_{\pi,t+1,t+4})</td>
<td>0.93</td>
<td>0.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Conditional moments</th>
<th>Monetary</th>
<th>Fiscal</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Means</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E(y^{(5Y)} - y^{(1Q)})$ (in %)</td>
<td>1.56</td>
<td>0.49</td>
</tr>
<tr>
<td>II. Standard deviations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(\Delta c)$ (in %)</td>
<td>1.16</td>
<td>1.74</td>
</tr>
<tr>
<td>$\sigma(\pi)$ (in %)</td>
<td>1.35</td>
<td>1.95</td>
</tr>
<tr>
<td>$\sigma(\Delta l)/\sigma(\Delta y)$</td>
<td>0.45</td>
<td>1.20</td>
</tr>
<tr>
<td>III. Correlations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>corr($\pi, \Delta c$)</td>
<td>-0.53</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

Panel A presents the unconditional means, standard deviations, and correlations of key variables. Panel B presents summary statistics from the model conditional on being in the monetary and fiscal regimes. The series for realized volatility are filtered and computed as follows. First, a series is fitted to an AR(1): $w_t = a_0 + a_1 w_{t-1} + u_t$. Then, annual (four-quarter) realized volatility is computed as $Vol_{w,t+1,t+4} = \sum_{j=1}^{4} |u_{t+j}|$ before applying the Bandpass filter with frequencies between 8 and 50 years. The quantitative model is calibrated at a quarterly frequency and the reported statistics are annualized.
Table 3: Term Structure of Interest Rates

A. Unconditional Moments

<table>
<thead>
<tr>
<th>Nominal yields</th>
<th>1Q</th>
<th>1Y</th>
<th>2Y</th>
<th>3Y</th>
<th>4Y</th>
<th>5Y</th>
<th>5Y-1Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (Model) (in%)</td>
<td>4.65</td>
<td>4.88</td>
<td>5.17</td>
<td>5.39</td>
<td>5.55</td>
<td>5.68</td>
<td>1.02</td>
</tr>
<tr>
<td>Mean (Data) (in%)</td>
<td>4.58</td>
<td>4.96</td>
<td>5.16</td>
<td>5.34</td>
<td>5.49</td>
<td>5.60</td>
<td>1.02</td>
</tr>
<tr>
<td>Std (Model) (in%)</td>
<td>1.01</td>
<td>0.91</td>
<td>0.77</td>
<td>0.66</td>
<td>0.57</td>
<td>0.50</td>
<td>0.57</td>
</tr>
<tr>
<td>Std (Data) (in%)</td>
<td>3.12</td>
<td>3.12</td>
<td>3.11</td>
<td>3.03</td>
<td>2.97</td>
<td>2.90</td>
<td>1.00</td>
</tr>
<tr>
<td>AC1 (Model)</td>
<td>0.95</td>
<td>0.93</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
<td>0.96</td>
</tr>
<tr>
<td>AC1 (Data) (in%)</td>
<td>0.95</td>
<td>0.95</td>
<td>0.96</td>
<td>0.96</td>
<td>0.97</td>
<td>0.97</td>
<td>0.75</td>
</tr>
</tbody>
</table>

B. Inflation Forecasts

<table>
<thead>
<tr>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizon (in Quarters)</td>
<td>1</td>
</tr>
<tr>
<td>β</td>
<td>-1.33</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.23</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Panel A presents the mean, standard deviation, and first autocorrelation of the one-quarter, one-year, two-year, three-year, four-year, and five-year yields and the 5-year minus one-quarter spread for nominal yields. Panel B presents inflation forecasts for horizons of one, four, and eight quarters using the five-year nominal yield spread. The \( n \)-quarter regressions, \( \frac{1}{n}(x_{t+1} + \ldots + x_{t+n-1, t+n}) = \alpha + \beta(y_5^{(5)} - y_4^{(1Q)}) + \varepsilon_{t+1} \), are estimated using overlapping quarterly data and Newey-West standard errors are used to correct for heteroscedasticity. The model is calibrated at a quarterly frequency and the moments are annualized.
Table 4: Bond Return Predictability

<table>
<thead>
<tr>
<th>Maturity (in Years)</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β((n))</td>
<td>S.E.</td>
</tr>
<tr>
<td>2</td>
<td>0.46</td>
<td>0.027</td>
</tr>
<tr>
<td>3</td>
<td>0.87</td>
<td>0.014</td>
</tr>
<tr>
<td>4</td>
<td>1.23</td>
<td>0.011</td>
</tr>
<tr>
<td>5</td>
<td>1.45</td>
<td>0.030</td>
</tr>
</tbody>
</table>

This table presents forecasts of one-year excess returns on bonds of maturities of two to five years. It reports forecasts of excess bond returns using the Cochrane-Piazzesi factor. First, the factor is obtained by running the regression: \( \frac{1}{5} \sum_{n=2}^{5} r_{x_{t+1}^{(n)}} = \gamma' f_t + \eta_{t+1} \), where \( \gamma' f_t = \gamma_0 + \gamma_1 y_t^{(1)} + \gamma_2 y_t^{(2)} + \cdots + \gamma_5 y_t^{(5)} \). Second, use the factor \( \gamma' f_t \) obtained in the previous regression to forecast bond excess returns of maturity \( n: r_{x_{t+1}^{(n)}} = b_n(\gamma' f_t) + \epsilon_{t+1}^{(n)} \). The forecasting regressions use 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 1-2005 to Q3-2013.

Figure 2: Maturity Restructuring with Different Slopes

This figure plots conditional impulse response functions for the expected government discount rate, inflation, the nominal yield spread between the yield on the long-term bond and the 1-quarter nominal yield, the 1-quarter nominal yield, 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 (dotted line), and downward-sloping (dashed line). The units of the y-axis are annualized percentage deviations from the steady-state. The units for average maturity are in years.
Figure 3: Maturity Restructuring in Different Regimes

This figure plots the conditional impulse response functions for the government discount rate, inflation, the nominal yield spread between the yield on the long-term bond and the 1-quarter nominal yield, 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. The units for average maturity are in years.

Figure 4: Market Timing Policies

This figure plots comparative statics for the welfare, average yield spread, and the standard deviation of inflation when the market timing sensitivity to the yield spread varies.
Figure 5: Maturity Restructuring at the ZLB

This figure plots conditional impulse response functions for the expected government discount rate, inflation, the nominal yield spread between the yield on the long-term bond and the 1-quarter nominal yield, the 1-quarter nominal yield, and output to a decrease in the average maturity of government debt (similar in magnitude as QE2) in the monetary regime. The solid line represents the response away from the zero lower bound and the dashed line represents the response at the zero lower bound. The units of the y-axis are annualized percentage deviations from a counterfactual economy where the decrease in average maturity does not occur. The units for average maturity are in years.

Figure 6: Maturity Restructuring with Market Segmentation and Liquidity Demand

This figure plots impulse response functions for the expected government discount rate, inflation, the nominal yield spread between the yield on the long-term bond and the 1-quarter nominal yield, the 1-quarter nominal yield, and output to a decrease in the average maturity of government debt (similar in magnitude as QE2) in the monetary regime (without regime shifts) with market segmentation. The units of the y-axis are annualized percentage deviations from the steady-state. The units for average maturity are in years.
This figure plots conditional impulse response functions for the expected government discount rate, inflation, the nominal yield spread between the yield on the long-term bond and the 1-quarter nominal yield, the 1-quarter nominal yield, and output to a decrease in the average maturity of government debt (similar in magnitude as QE2) in the monetary regime at the zero lower bound and under a deficit shock of magnitude $-3.5\sigma_s$. These plots come from the extended model that also incorporates market segmentation and a short-term liquidity demand. The dashed line represents the response from the extended model that allows for policymakers to switch to the fiscally-led regime and the solid line represents the response from an alternative economy where the policy mix is permanently characterized by the monetary regime without the possibility of regime changes. The units of the y-axis are annualized percentage deviations from a counterfactual economy where the decrease in average maturity does not occur. The units for average maturity are in years.