Public Debt and the Slope of the Term Structure*

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Abstract

This paper documents that the public debt-to-GDP ratio predicts negatively one- to five-year cumulative nominal consumption growth. Moreover, a higher debt-to-GDP ratio is associated with higher yield spreads, controlling for output gap and inflation. I examine these facts in a New Keynesian DSGE model in which growth and inflation are endogenous. In this model, high government debt forecasts low growth and deflation, making bonds attractive assets in high debt states. Furthermore, due to mean-reversions of fundamental processes that drive the economy, longer-term bonds are better hedges than shorter-term ones, resulting in increases in the slope of the term structure at times of high public debt and hence the empirical regularities seen in the data. My paper thus furthers our understanding of what determine bond yields and the impact of quantitative easing.

Keywords: Government Debt, Fiscal Policy, Term Structure of Interest Rates, Endogenous Growth Risk

JEL classification: E43, E44, E62, G12, G18, H32

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1. Introduction

Following the recent Great Recession, governments around the world have responded by implementing fiscal stabilization measures to stimulate their economies. The resulting surges in public debt and subsequent budget consolidations create the potential for first-order effects on asset returns and economic activity, due to the distortionary nature of most relevant fiscal policy instruments. Understanding these potential impacts thus is crucial and could shed light on how fiscal policy should be set over the business cycle.

Within the Treasury bond markets, Greenwood and Vayanos (2014) document that the ratio of maturity-weighted public debt to GDP ($MDGDP$) is positively related to bond yields, controlling for the short-term interest rate. This result is puzzling from a standard representative-agent model perspective (Barro (1974)). Greenwood and Vayanos present a preferred-habitat model in which an increase in the supply of long-term bonds is absorbed mainly by agents with particular preferences for long-horizon bonds. Because of the increase in interest-rate risk they must hold, they require bonds to provide higher compensation in terms of yields. This view is policy relevant, as central bankers have used the preferred-habitat theory as a rationale for quantitative easing operations. Moreover, researchers have argued that market segmentation could play an important role in understanding the term structure of interest rates especially during financial crises (Gurkaynak and Wright (2012)).

In this paper, I propose an alternative mechanism based on fundamentals and with no market segmentation in which the debt-to-GDP ratio is positively correlated with the slope of the term structure of interest rates. In my framework, interest rates, inflation, and the macroeconomic aggregates are determined endogenously. I start by showing that an increase in the debt-to-GDP ratio predicts lower cumulative nominal consumption growth up to five years with R^2s as high as 23 percent; controlling for output gap and inflation strengthens these results. Furthermore, high debt-to-GDP correlates strongly with steeper slopes of the term structure as measured by the yield spreads between the two-, three-, four-, and five-year zero-coupon bonds relative to the one-year bond. These results are robust to controlling for output gap, inflation, and unemployment gap—important factors that affect the term structure.

To rationalize these facts, I build a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model with endogenous growth in which the government issues debt and levies distortionary taxation on corporate profits to finance its (unproductive) expenditures. (See Belo and Yu (2013) for a study on productive government expenditures.) Fluctuations of debt thus drive the tax rate dynamics and alter investment incentives, hiring decisions, and consequently the equilibrium wage. In this model, where both growth and inflation are endogenous, an unexpected increase in debt level drives up the cumulative tax burden and lowers investment and labor demand. Lower investment leads to lower real growth. At the same time, weak labor market conditions reduce wages and marginal costs. As is typical in New Keynesian models, lower marginal costs imply that inflation will drop going forward. Thus, as in the data, the model predicts a negative relationship between debt-to-GDP and nominal growth.

Additionally, bonds in the model are attractive assets with respect to fiscal risk because they have high real payoffs in bad fiscal times, that is, times with low growth but also low inflation. Moreover, due to mean-reversion of fundamental shocks that drive the economy, longer-term bonds are better hedges than shorter-term ones because they are less exposed to short-term fluctuations in nominal growth and thus are less exposed to short-term movements in debt and tax.[1] Consequently, an unexpected increase in debt results in a drop in yield across maturities (lower expected consumption growth), but the drop is more severe for bonds with shorter maturities than longer ones. Hence, in terms of yield spreads, the increases are larger for longer maturity bonds relative to the one-year bond. These increases in the yield spreads as a result of a shock to public debt lead to the positive correlations of spreads and

[1]Notice that as shown by Piazzesi and Schneider (2007) *deviations* of bond yield from its unconditional mean are driven entirely by the expected nominal consumption growth over the lifetime of the bond.

the debt-to-GDP ratio, as seen in the data.

The model also produces a large term spread and yields with volatilities decreasing with maturities, as in the data. This large term spread is a result of the endogenous positive correlation between consumption growth and inflation and is driven mainly by productivity shocks. A negative total factor productivity (TFP) shock leads to a drop in investment and hence a decrease in growth. At the same time, marginal productivity of labor also drops, causing an increase in the marginal cost, which in turn induces a spike in inflation. This makes bonds unattractive assets when it comes to hedging productivity shocks, because they have low real payoffs in bad times, giving rise to a sizable slope of the term structure as longer-term bonds are more exposed to inflation risk.

Hence, a simple model with endogenous inflation and relevant tax instruments can generate a sizable term spread and, at the same time, rationalize the positive connection between yield spreads and the debt-to-GDP ratio. My mechanism thus complements the work of Greenwood and Vayanos in understanding the behavior of bond yields and the impact of quantitative easing. My model is also set in general equilibrium with production and can be readily embedded into a larger macro model for policy analysis.

1.1. Related literature

This paper contributes to several strands of literature. First, my model ties interest rates to macroeconomic fundamentals. In this respect, my analysis is related to the literature on consumption-based models of term structure (see, among others, Piazzesi and Schneider (2007); Bansal and Shaliastovich (2013); Branger, Schlag, Shaliastovich, and Song (2017); Gomez-Cram and Yaron (2017); Gallmeyer, Hollifield, Palomino, and Zin (2017); Ehling, Gallmeyer, Heyerdahl-Larsen, and Illeditsch (2018)) as well as settings in which macro quantities are endogenous (see, for example, Rudebusch and Swanson (2012); van Binsbergen, Fernandez-Villaverde, Koijen, and Rubio-Ramirez (2012); Kung (2015)). Gallmeyer, Hollifield, and Zin (2005) analyze the McCallum rules and the failure of the expectation hypothesis. Jermann (2013) studies term structure in a investment-based framework. Shaliastovich and Yamarthy (2015) investigate the role of monetary policy fluctuations on the bond markets. Bretscher, Hsu, and Tamoni (2018) examine government spending shocks and how they impact interest rates. Corhay, Kind, Kung, and Morales (2018) focus on maturity structure and the effect of fiscal policy on inflation. Distinct from these studies, my paper focuses on the positive correlation of bond yields and the debt-to-GDP ratio and at the same time matches key features of interest rates across different maturities.

Belo, Gala, and Li (2013) and Belo and Yu (2013) study the effect of government spending as well as investment on equity returns. Berndt, Lustig, and Yeltekin (2012) and Lustig, Sleet, and Yeltekin (2008) study optimal fiscal policy and the role of nominal debt in financing government spending. In contrast to these studies, my paper examines the impact of fiscal policy risk on interest rates as well as the slope of the term structure.

Moreover, my model is set in a New Keynesian framework with sticky prices; my paper thus is related to that of Weber (2015) and Gorodnichenko and Weber (2016) who study the impact of price rigidities on asset prices, as well as those of Belo, Lin, and Bazdresch (2014); Favilukis and Lin (2016a); Favilukis and Lin (2016b); and Belo, Li, Lin, and Zhao (2017), who study wage rigidities and labor market frictions and equity returns.

My analysis highlights the role of political risk in explaining the government cost of debt across maturities. In this regard, my work is related to the literature on policy uncertainty and asset markets (see Kelly, Pastor, and Veronesi (2016); Pastor and Veronesi (2012, 2013); Fernandez-Villaverde, Guerron-Quintana, Kuester, and Rubio-Ramirez (2015); Gomes, Michaelides, and Polkovnichenko (2010, 2013); Gomes, Kotlikoff, and Viceira (2011); Glover, Gomes, and Yaron (2010); Sialm (2006); Sialm (2009); Croce, Kung, Nguyen, and Schmid (2012); and Croce, Nguyen, Raymond, and Schmid (2018), among others).

Methodologically, my model features endogenous long-run growth risk, which builds on recent papers by Comin and Gertler (2006); Comin, Gertler, and Santacreu (2009); Kung and Schmid (2015); and Corhay, Kung, and Schmid (2015). These papers add endogenous growth to real business cycle models. In contrast, my paper focuses on the role of government debt and taxation on inflation, investment, and consumption growth. In this sense, my paper is related to that of Croce, Nguyen, and Schmid (2012), who introduce fiscal policy into a simple stochastic endogenous growth model.

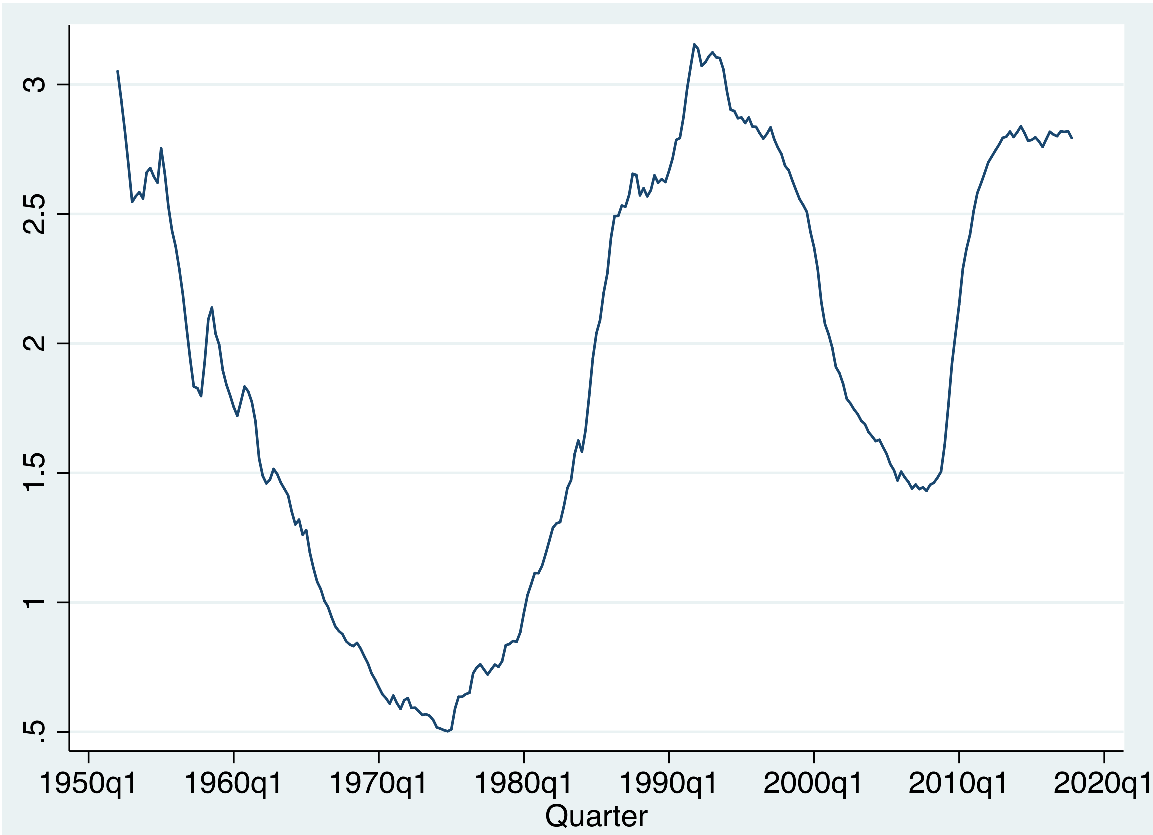
More broadly, my paper belongs to the growing literature on asset pricing in general equilibrium models with production and recursive preferences (see, for example, Tallarini (2000); Campanale, Castro, and Clementi (2010); Kuehn (2008, 2009); Kaltenbrunner and Lochstoer (2010); and Croce (2014) for recent examples). Gourio (2012, 2013) and Petrosky-Nadeau, Zhang, and Kuehn (2018) examine disaster risks, an important dimension that could impact public debt and bond yields but is not a part of the current analysis.

The rest of the paper is structured as follows. In section 2, I describe the data used in the paper and the empirical evidence of nominal growth predictability using debt-to-GDP ratio as well as bond yield correlation with this ratio. Section 3 develops the model. The calibration and results are detailed in section 4. Section 5 concludes.

2. Empirical analysis

In this section, I provide the stylized facts on the relationship between the ratio of maturity-weighted debt to GDP, nominal consumption growth, and bond yields. I begin with the data sources and then discuss the empirical results.

Fig. 1.
Ratio of maturity-weighted debt to GDP



Notes – The ratio of maturity-weighted debt to GDP, $MDGDP$, is constructed by multiplying debt payments, both coupons and principals, by their respective maturities, adding across maturity and scaled by lagged GDP. See section 2.1 for details.

2.1. Data

My data mainly come from CRSP. Following Greenwood and Vayanos (2014), I calculate the ratio of maturity-weighted debt to GDP ($MDGDP$) using historical bond database. As opposed to merely total debt outstanding, this measure puts a dollar of debt with a maturity of three months and one with a maturity of 30 years on similar footing. The total payments due τ quarters from date t are

$$D_t^{(\tau)} = \sum_i PR_{it}^{(\tau)} + \sum_i C_{it}^{(\tau)}, \tag{1}$$

Table 1
Data Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	Median
$i_t^{(1)}$	4.74	3.17	.11	15.43	4.61
$i_t^{(2)}$	4.94	3.13	.23	15.35	4.71
$i_t^{(3)}$	5.12	3.06	.30	15.06	4.85
$i_t^{(4)}$	5.27	3.00	.44	14.92	4.97
$i_t^{(5)}$	5.39	2.93	.61	14.50	4.99
$MDGDP$	2.17	1.39	.50	8.61	1.98
Output gap	.00	.02	−.06	.04	.00
Inflation	3.44	3.86	−15.96	17.78	2.94
Unemployment gap	.30	1.59	−2.86	4.92	.06

Notes – Yield data span 1952Q3–2017Q4 and are from the Fama-Bliss file in CRSP. Yields are continuously compounded, annualized and in percentages. $i_t^{(n)}$ denotes the continuously compounded yield to maturity at time t of a zero-coupon bond that matures in n years. Output gap is the residual from a Hodrick-Prescott filter of log real GDP. Inflation is the log difference of the consumer price index expressed in percent at an annual rate. Unemployment gap is the long-term natural rate of unemployment minus the unemployment rate and is also reported in percent. Macroeconomic data span 1947Q1–2017Q4 and are obtained from the St. Louis FRED database. $MDGDP$ is the ratio of maturity-weighted debt to GDP. See section 2.1 for details on the construction of this variable.

where $PR_{it}^{(\tau)}$ is the principal payment bond i is due to make τ quarters from date t, and similarly $C_{it}^{(\tau)}$ is the coupon payment bond i is due to make τ quarters from date t. For bonds that mature in more than 30 years, all are added to quarter 120. Debt in each quarter is then scaled by the GDP of the last quarter. Formally, maturity-weighted debt over GDP is then

$$MDGDP_t = \frac{\frac{1}{4}\sum_{0<\tau\leq 120} D_t^{(\tau)}\tau}{GDP_{t-1}}. \tag{2}$$

Lagged GDP is used to make sure that any innovations in $MDGDP$ come from innovations in public debt rather than output, and to ease the concern that the impact of $MDGDP$ on interest rates is conflated with shocks to GDP. Figure 1 plots the time series of $MDGDP$, which decreases from the early 1950s to mid-1970s and then rises to a high of more than 300% in the early 1990s. $MDGDP$ drops to a low after the financial crisis and then sharply

Table 2

MDGDP and bond yields (I)

	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
$MDGDP_t$	0.551***	0.579***	0.634***	0.649***
	(0.176)	(0.177)	(0.177)	(0.177)
Constant	−0.089	−0.009	−0.019	−0.018
	(0.259)	(0.261)	(0.260)	(0.261)
Observations	262	262	262	262
Adjusted R^2	0.100	0.110	0.133	0.140

Notes – This table reports results from the following regressions:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n *years*, and $MDGDP$ is maturity weighted debt to output ratio. Data spans 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively.

increases again and stays high until the end of the sample, likely due to the implementation of fiscal stabilization measures to support the economy.

Data on the one- through five-years-to-maturity zero-coupon bond yields come from the Fama-Bliss discount bond database in CRSP. This is a well-known dataset, making it easy to compare my results to those of prior works. Consumption returns data come from Lustig, Van Nieuwerburgh, and Verdelhan (2013).[2] Output gap is the residual from a Hodrick-Prescott filter of log real GDP. Inflation is the log difference of the consumer price index expressed in percent at an annual rate. Unemployment gap is the long-term natural rate of unemployment minus the unemployment rate. Macroeconomic data span 1947Q1–2017Q4 and are obtained from the St. Louis FRED database. Table 1 gives the summary statistics for the data. As is well known, the average yield curve is upward sloping and has volatilities that decrease with maturity.

[2] I thank these authors for kindly sharing their data.

2.2. *Empirical regularities*

Table 2 shows the results of estimating regressions of yield spreads on $MDGDP$. The regressions are of the form

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \epsilon_t, \tag{3}$$

where $i_t^{(n)}$ denotes the continuously compounded yield to maturity at time t of a zero-coupon bond that matures in n *years*. Similar to the findings of Greenwood and Vayanos (2014), an increase in the ratio of maturity-weighted debt to GDP leads to an increase in the slope of the term structure of interest rates. $\beta^{(n)}$s range from 0.55 to 0.65 for two- to five-year zero-coupon bond yield spreads and are strongly statistically significant. These results corroborate evidence about the impact of public debt on the financial markets found by Liu (2016) and Croce, Nguyen, Raymond, and Schmid (2018) using equity market data.

Monetary authorities conduct policies based on macroeconomic conditions, and since these operations directly affect the term structure of interest rates, one might suspect that $MDGDP$ picks up information that monetary authorities use to set their rate targets. This suggests that controlling for other macro variables is important. As shown in table 3, the positive relationship between $MDGDP$ and yields js robust to the adding additional controls. This table reports the results from running regressions of the form

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t, \tag{4}$$

where $\boldsymbol{X}$ is one or more macroeconomic controls. In panel A of table 3, I control for the output gap, a measure that the Federal Reserve considers in conducting its monetary policy. The coefficients on $MDGDP$ remain positive and significant. In panel B of the same table, I control for the inflation rate. As before, $\beta^{(n)}$s are positive and statistically significant across maturities. Panel C of table 3 reports results when output gap and inflation are included

Table 3
MDGDP and bond yields (II)

Panel A	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
$MDGDP_t$	0.537***	0.562***	0.618***	0.633***
	(0.146)	(0.140)	(0.142)	(0.144)
Output gap$_t$	−0.505***	−0.557***	−0.537***	−0.535***
	(0.082)	(0.078)	(0.079)	(0.080)
Constant	−0.066	0.016	0.005	0.006
	(0.215)	(0.207)	(0.210)	(0.212)
Observations	262	262	262	262
Adjusted R^2	0.327	0.388	0.392	0.396
Panel B				
$MDGDP_t$	0.454**	0.410**	0.474***	0.481***
	(0.181)	(0.177)	(0.178)	(0.178)
Inflation$_t$	−0.242*	−0.418***	−0.396***	−0.416***
	(0.140)	(0.137)	(0.136)	(0.136)
Constant	0.173	0.445	0.411	0.434
	(0.296)	(0.289)	(0.289)	(0.289)
Observations	262	262	262	262
Adjusted R^2	0.113	0.155	0.173	0.184
Panel C				
$MDGDP_t$	0.511***	0.472***	0.534***	0.540***
	(0.153)	(0.145)	(0.147)	(0.148)
Output gap$_t$	−0.498***	−0.532***	−0.514***	−0.509***
	(0.082)	(0.078)	(0.079)	(0.079)
Inflation$_t$	−0.063	−0.227**	−0.211*	−0.233**
	(0.120)	(0.114)	(0.114)	(0.115)
Constant	0.002	0.261	0.234	0.258
	(0.250)	(0.237)	(0.240)	(0.242)
Observations	262	262	262	262
Adjusted R^2	0.326	0.399	0.401	0.408

Notes – This table reports results from estimating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n years, $MDGDP$ is is the ratio of maturity-weighted debt to GDP, and $\boldsymbol{X}$ is one or more controls. Data span 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively.

in the regressions. These two macro variables are inputs of the Taylor rule, which is known to be a good approximation of the Fed's responses to changes in economic conditions when it sets the nominal short-rate. Again $MDGDP$ remains relevant; all $\beta^{(n)}$s are significantly different from zero at the 1% level.

Given the Federal Reserve's dual mandate of maximizing employment and price stability, unemployment gap should play an important role in determining the term structure. In table C1 in appendix C, I report the results of ran the same regressions, controlling for unemployment gap. As seen in panel A of table C1, unemployment gap indeed predicts yields; however, the role of $MDGDP$ remains positive. Including both unemployment gap and inflation does not change the results (see panel B of table C1). In panel C, I include all macro controls discussed so far, and the results remain unchanged.

Consumption-based models suggest that deviations of nominal bond yield from its mean are determined by expected nominal consumption growth rates over the lifetime of the bond (Piazzesi and Schneider (2007)).[3] Thus the association between the debt-to-GDP ratio and yield spreads relies on the ratio's power to predict nominal consumption growth. To gauge this channel, in panel A of table 4 I regress the average of the cumulative nominal consumption growth of one- to five-year horizons on $MDGDP$. In particular, using quarterly data I run regressions of the following form:

$$\frac{1}{J}\sum_{j=1}^{J}\Delta c_{t+j}^{\$} = \lambda_0 + \lambda^J \cdot MDGDP_t + \text{controls}_t + \epsilon_t,$$

for $J \in \{4, 8, 12, 16, 20\}$. As seen in this panel, a high public-debt-to-output ratio indeed predicts lower future consumption growth, with R^2s as high as 23 percent. These results are

[3] In particular, they show that

$$i_t^{(k)} - \mu^{(k)} \propto \frac{1}{k}\,\mathbb{E}_t \sum_{j=1}^{k}\left(\Delta c_{t+j}^{\$} - \mu_c\right),$$

where $\mu^{(k)}$ is mean yield, $\Delta c_t^{\$}$ denotes the mean of nominal consumption growth rate, and μ_c is mean nominal consumption growth.

Table 4
Predicting nominal consumption growth

Horizon J (quarters)	4	8	12	16	20
Panel A					
$MDGDP_t$	-0.337^{**}	-0.421^{***}	-0.418^{**}	-0.454^{**}	-0.475^{**}
	(0.141)	(0.163)	(0.207)	(0.225)	(0.233)
Constant	2.360^{***}	2.764^{***}	2.887^{***}	3.014^{***}	3.087^{***}
	(0.242)	(0.313)	(0.396)	(0.443)	(0.476)
Observations	281	277	273	269	265
Adjusted R^2	0.111	0.177	0.176	0.211	0.234
Panel B					
$MDGDP_t$	-0.304^{***}	-0.387^{***}	-0.380^{**}	-0.416^{**}	-0.435^{**}
	(0.111)	(0.117)	(0.154)	(0.169)	(0.174)
Output gap$_t$	-0.254^{**}	-0.255^{**}	-0.249^{**}	-0.215^{***}	-0.210^{***}
	(0.102)	(0.100)	(0.098)	(0.083)	(0.072)
Inflation$_t$	0.515^{***}	0.535^{***}	0.584^{***}	0.575^{***}	0.596^{***}
	(0.106)	(0.125)	(0.121)	(0.130)	(0.131)
Constant	2.024^{***}	2.413^{***}	2.500^{***}	2.628^{***}	2.684^{***}
	(0.193)	(0.209)	(0.275)	(0.309)	(0.332)
Observations	281	277	273	269	265
Adjusted R^2	0.232	0.307	0.321	0.341	0.370

Notes – This table reports results from estimating the following predictive regression:

$$\frac{1}{J}\sum_{j=1}^{J} \Delta c_{t+j}^{\$} = \lambda_0 + \lambda^J \cdot MDGDP_t + \text{controls}_t + \epsilon_t,$$

where $\Delta c_t^{\$}$ denotes nominal consumption growth, and $MDGDP$ is the ratio of maturity-weighted debt to output. Macroeconomic data span 1947Q1–2017Q4 and are obtained from the St. Louis FRED database. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with J lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively.

robust to controlling for output gap and inflation (panel B).

Motivated by these facts, I build a model in which consumption and inflation, as well as public debt and output, are endogenously determined by profit- and utility-maximizing agents. My model can generate the nominal growth predictability results and the positive correlation between the debt-to-GDP ratio and bond yield spreads and thus provides a structural interpretation of the empirical regularities. The model also produces asset prices and macroeconomic quantities that are consistent with the data.

3. Model

I use a New Keynesian DSGE model to quantitatively examine the links between public debt, inflation, bond yields, and the macroeconomy. The economy is populated by a representative household with recursive preferences that supplies labor to firms and saves using public bonds and corporate equity; a final-goods firm that produces using intermediate goods which it obtains from monopolistic producers; and a government that determines tax rates and sets short-term interest rates according to a Taylor rule. I start by describing the household and then the other agents in turn.

3.1. Representative household

The household has Epstein and Zin (1989) preferences defined over consumption goods, C_t:

$$U_t = \left[(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta(\mathbb{E}_t[U_{t+1}^{1-\gamma}])^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right]^{\frac{1}{1-\frac{1}{\psi}}},$$

where γ is the coefficient of relative risk aversion and ψ is the elasticity of intertemporal substitution. When $\psi \neq \frac{1}{\gamma}$, the agent cares about news regarding long-run growth prospects, inflation, and taxation. The household is endowed with one unit of labor, and since it doesn't value leisure, it supplies all labor inelastically and earns a competitive nominal wage W_t.

As shown in Epstein and Zin (1989), the stochastic discount factor in this setting is

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\psi}}\left(\frac{U_{t+1}}{\left[\mathbb{E}_t U_{t+1}^{1-\gamma}\right]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}.$$

The budget constraint is standard:

$$C_t + a_t\mathcal{P}_t + B_t = e^{i_t}B_{t-1}/\Pi_t + a_{t-1}(\mathcal{D}_t + \mathcal{P}_t) + (W_t/P_t)L_t, \tag{5}$$

where a_t is the number of equity shares (in equilibrium, $a_t = 1$ for all t); $\mathcal{P}_t$ is the ex-dividend equity price per share; $\mathcal{D}_t$ is the equity payout; P_t is the price level; Π_t is the gross inflation rate; i_t is the continuously compounded nominal one-period interest rate; and B_t is the amount of public debt held by the household, as specified in section 3.4.

3.2. Final-goods firm

Final goods are produced by a competitive producer using technology

$$Y_t = \left(\int_0^1 Y_{jt}^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}},$$

where intermediate goods Y_{jt} can be bought at price P_{jt} and $\epsilon > 1$ is the elasticity of substitution between intermediate goods. Profit maximization implies the demand for goods j can be written as

$$Y_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\epsilon} Y_t, \tag{6}$$

where the nominal price of the final goods is

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

3.3. Intermediate-goods firms

There is a measure one of intermediate-goods firms. Each monopolistic intermediate-goods firm j produces goods j using labor L_{jt} and intangible capital N_{jt} according to the technology

$$Y_{jt} = A_{jt} L_{jt}^{1-\alpha},$$

where, as in Kung (2015), measured TFP is $A_{jt} = Z_t N_t^{1-\eta} N_{jt}^{\eta}$.[4] Z_t is the aggregate productivity, and $N_t = \int_0^1 N_{jt} dj$ is the aggregate stock of intangible capital. Thus there is technological spillover from intangible capital investment, the degree of which is captured by η. This externality is important in generating endogenous growth in the model, and when taxation affects investment incentives, this translates into long-run growth risk that is crucial for the quantitative performance of the model. Furthermore, log aggregate productivity follows an $AR(1)$ process:

$$\log Z_t = \rho \log Z_{t-1} + \epsilon_t,\ \epsilon_t \sim N(0, \sigma^2). \tag{7}$$

The intermediate-goods firm can improve its productivity by making intangible capital investment S_{jt} units of final goods, subject to the adjustment costs $\Phi(S_{jt}/N_{it})$. The law of motion for its intangible capital is

$$N_{j,t+1} = (1-\delta) N_{jt} + \Phi(S_{jt}/N_{jt}) N_{jt}, \tag{8}$$

where δ is the rate at which technology becomes obsolete. As in Jermann (1998), the adjustment cost is

$$\Phi(x) = \frac{\alpha_1}{1 - 1/\zeta} x^{1-1/\zeta} + \alpha_2,$$

where α_1 and α_2 are chosen so that in the nonstochastic steady state there are no adjustment costs and $\Phi'(\cdot) = 1$. Moreover, as in Rotemberg (1982), firm j chooses price P_{jt} subject to quadratic price adjustment costs

$$AC(P_{j,t-1}, P_{jt}) = \frac{a}{2}(P_{jt}/P_{j,t-1} - \Pi)^2 Y_t,$$

[4] For simplicity, I abstract away from tangible capital accumulation and investment.

where Π is the nonstochastic steady-state gross rate of inflation.

The intermediate-goods firm's problem is

$$V_{jt} = \max_{\{P_{jt}, N_{j,t+1}, S_{jt}, L_{jt}\}} D_{jt} + \mathbb{E}_t\, M_{t+1} V_{j,t+1}$$

subject to the final-goods firm's demand (6), law of motion for intangible capital (8), and the resource constraint

$$P_t D_{jt} = (1 - \tau_t)(P_{jt} Y_{jt} - W_t L_{jt} - P_t AC(P_{j,t-1}, P_{jt})) - P_t S_{jt},$$

where W_t is the nominal wage, and τ_t is the tax rate on operating profits.

3.4. Government

Fiscal authority. The government faces an exogenous and stochastic real expenditure stream, G_t, that evolves as follows:

$$\frac{G_t}{GDP_t} = \frac{1}{1 + e^{-gy_t}}, \tag{9}$$

where

$$gy_t = (1 - \rho_g)\overline{gy} + \rho_g gy_{t-1} + \epsilon_{gt}, \quad \epsilon_{gt} \sim N(0, \sigma_g^2). \tag{10}$$

This specification ensures that government expenditure is positive and less than GDP for all dates t, and it can replicate key features of the expenditure-to-output ratio observed in the US data. GDP_t is final-goods output less the total price adjustment costs.

The government can finance these expenditures by raising public debt and/or by levying distortionary profit taxes on corporations at the time-varying rate τ_t. When doing either of these things, the government is subject to the following budget constraint:

$$B_t = e^{i_t} B_{t-1}/\Pi_t + G_t - T_t, \tag{11}$$

where T_t denotes its real total tax income and B_t real public debt. The tax base will be specified below.

In the spirit of Favero and Monacelli (2005), Schmitt-Grohe and Uribe (2007), Bi and Leeper (2010), and Leeper, Plante, and Traum (2010), the fiscal authority in this model accommodates taxation and deficit financing through simple, implementable, and plausible fiscal rules. I focus on a tax rule that allows for tax smoothing and lets the government adjust its fiscal stance according to prevailing macroeconomic conditions. I concentrate on two aspects of tax smoothing, namely the persistence and intensity of swings in the tax rate. The government's policy is specified in terms of a debt-management rule, with tax rates implied by the budget constraint, as follows:

$$\frac{B_t}{GDP_{t-1}} = (1 - \rho_B)\mu_B + \rho_B \frac{B_{t-1}}{GDP_{t-2}} + \epsilon_t^B, \tag{12}$$

$$\epsilon_t^B = \phi_B \cdot (\Delta c_t - \Delta c) + \epsilon_{by,t}, \tag{13}$$

where ϕ_B is a constant that determines both the intensity and cyclicality of the government response to shocks, Δc_t is consumption growth, and Δc is its steady-state value. $\epsilon_{by,t} \sim \mathcal{N}(0, \sigma_{by}^2)$ is a pure policy shock. As discussed below, this fiscal shock is important in understanding Treasury bond market data. The parameter μ_B captures the long-run level of debt, and $\rho_B \in (0, 1)$ is a measure of the speed of repayment of debt: the higher the value of ρ_B, the slower the repayment of debt relative to GDP.

This simple specification accomplishes two goals. With $\rho_B \in [0, 1)$, the debt-to-GDP ratio is guaranteed to be stationary, consistent with the empirical evidence documented in Bohn (1998). This debt-policy rule anchors expectations about future debt and rules out unstable paths (Bi and Leeper (2010)). Moreover, this specification replicates key empirical properties of the US debt-to-GDP ratio. Similar fiscal rules have been used by Croce, Kung, Nguyen, and Schmid (2012) and Croce, Nguyen, Raymond, and Schmid (2018) in studying the impact of fiscal policies on corporate investment and equity returns.

Monetary authority. The government follows a Taylor rule in setting the nominal continuously compounded one-period interest rate i_t:

$$i_{t+1} - i = \rho_r \left(i_t - i\right) + \left(1 - \rho_r\right) \left(\rho_\pi \left(\pi_t - \pi\right) + \rho_y \left(gdp_t - gdp\right)\right) + \epsilon_{rt}, \tag{14}$$

where $\epsilon_{rt} \sim N(0, \sigma_r^2)$ is the monetary policy shock, $gdp_t = \log(GDP_t/N_t)$ is the log of detrended gross domestic product, gdp is its steady state, and i is the nominal steady-state one-period interest rate. I used lowercase to denote the log of levels, for example, $\pi_t = \log \Pi_t$. The parameter $\rho_r \in [0, 1)$ controls interest rate smoothing, while $\rho_\pi > 0$ and $\rho_y \geq 0$ capture the responses of the central bank to deviations of inflation and output from their target levels, respectively.

3.5. Equilibrium

I consider the symmetric equilibrium where all intermediate-goods firms make the same decisions. Thus, $L_{jt} = L_t$, $Y_{jt} = Y_t$, $P_{jt} = P_t$, $N_{jt} = N_t$, and $S_{jt} = S_t$. The aggregate resource constraint is $Y_t = C_t + S_t + G_t + \frac{a}{2}(\Pi_t - \Pi)^2 Y_t$, $GDP_t = Y_t - \frac{a}{2}(\Pi_t - \Pi)^2 Y_t$, and gross inflation $\Pi_t = P_t/P_{t-1}$. Finally, the tax base is given by taxable corporate profits and in equilibrium is such that

$$T_t = \tau_t \left(Y_t - W_t L_t - \frac{a}{2}(\Pi_t - \Pi)^2 Y_t\right) = \tau_t (GDP_t - W_t L_t).$$

3.6. Bond yields

Denote by $p_t^{(k)}$ the price at time t of a k-period zero-coupon bond that pays \$1 at maturity k periods hence; then

$$p_t^{(k)} = \mathbb{E}_t\, M_{t+1}^{\$} p_{t+1}^{(k-1)}, \tag{15}$$

where the nominal stochastic discount factor $M_t^{\$} = M_t/\Pi_t$ and $p_t^{(0)} \equiv 1$. The continuously compounded yield to maturity is then

$$i_t^{(k)} = -\frac{1}{k}\log p_t^{(k)}.$$

Recursively substitute in prices, and if $\log M_t^{\$} = m_t^{\$}$ is approximately log-normal, one can show that

$$i_t^{(k)} \approx -\frac{1}{k}\,\mathbb{E}_t\left(\sum_{j=1}^{k} m_{t+j}^{\$}\right) - \frac{1}{k}\frac{1}{2}\text{var}_t\left(\sum_{j=1}^{k} m_{t+j}^{\$}\right).$$

Thus yields are determined by expected consumption growth and inflation as well as their covariances over the lifetime of the bond.

4. Quantitative results

4.1. Calibration

I report my benchmark quarterly calibration in table 5. The preference parameters are standard in the literature. The household's subjective discount factor (β) is set to 0.997. The risk aversion is set to 10 in line with reasonable upper bounds (see, for example, Mehra and Prescott 1985), and the intertemporal elasticity of substitution (ψ) is set to 1.4, consistent with empirical results in the long-run risk literature.

Turning to the technology parameters, I choose α so that the labor income share $(1-\alpha)$

Table 5
Benchmark calibration

Parameter	Symbol	Value
Preferences:		
Subjective discount factor	β	0.998
Intertemporal elasticity of substitution	ψ	1.4
Relative risk aversion	γ	10
Technology:		
Labor income share	$1-\alpha$	0.6
Intangible capital depreciation	δ	0.0375
Intangible capital adjustment costs, elasticity	ζ	2.9
Price elasticity of demand	ϵ	4
Magnitude of price adjustment costs	a	20
Degree of technological spillover	η	0.087
Exogenous processes:		
Productivity shock, volatility	σ	0.0077
Productivity shock, persistence	ρ	0.99
Average expenditure-output ratio	$1/(1+e^{-\overline{gy}})$	0.2
Expenditure shock, volatility	σ_g	0.015
Expenditure shock, persistence	ρ_g	0.97
Fiscal policy parameters:		
Average quarterly debt-to-GDP ratio	μ_B	2
Persistence of debt-to-GDP	ρ_B	0.96
Policy responsiveness shocks	ϕ_B	1.9
Fiscal policy shock, volatility	σ_{by}	0.1
Monetary policy parameters:		
Degree of monetary policy inertia	ρ_r	0.8
Sensitivity of interest rate to inflation	ρ_π	1.5
Sensitivity of interest rate to GDP	ρ_π	0.124
Monetary policy shock, volatility	σ_r	0.003

Notes – This table reports my benchmark quarterly calibration. See section 4.1 for detail discussion.

is 0.6 as in Cooley and Prescott (1995). Corporate profits determine the size of the tax base and therefore the equilibrium tax rate. The price elasticity of demand (ϵ), which determines profits, is set to 4 to match the average tax rate. The intangible capital depreciation rate (δ) is chosen to be 0.0375, consistent with the US Bureau of Economic Analysis (BEA) annual depreciation rate for R&D of 15%. The degree of technological spillover (η) determines the level of the growth rate and is chosen to match consumption growth. Price and investment adjustment cost parameters are set to moderate levels to avoid an implausibly high adjustment cost. These values are consistent with those used in the literature (see, for example, Fernandez-Villaverde, Guerron-Quintana, Kuester, and Rubio-Ramirez (2015) and Kung (2015), among others).

Exogenous processes are estimated directly from the data. Using the utilization-adjusted productivity from Fernald (2012), the estimation of equation (7) gives

$$\log Z_t = \underset{(0.001)}{.007} + \underset{(0.002)}{.99} \log Z_{t-1} + \epsilon_t, \tag{16}$$

and volatility of the residuals of 0.008. Newey and West (1987) standard errors are in parentheses. Consistent with these estimates, I set the persistence of TFP to 0.99 and assign the volatility of TFP shock a value of 0.0077. For government expenditures, I transform the expenditure-to-output ratio according to equation (9), and the estimation of equation (10) gives

$$gy_t = -\underset{(0.017)}{.022} + \underset{(0.012)}{.98} gy_{t-1} + \epsilon_{gt}, \tag{17}$$

with a standard deviation for the residuals of 0.02. The volatility and persistence of the transformed government-expenditures-to-GDP ratio are set to 0.015 and 0.97, respectively. These values are within the empirical confidence intervals. $\overline{gy}$ comes directly from the data and implies an average government-expenditure-to-output ratio of 20%.

As for policy rules, μ_B is set to match average $MDGDP$. Using consumption growth data and the ratio of maturity-weighted debt to GDP, the estimation of equations (12) and (13) results in

$$MDGDP_t = \underset{(.014)}{.058} + \underset{(.005)}{.96} MDGDP_{t-1} + \underset{(.780)}{1.98} \Delta c_t + \epsilon_{by,t}, \tag{18}$$

with a volatility of the residuals of 0.1 and Newey and West (1987) standard errors in parentheses. These point estimates imply significant short-run stabilization in the data. The values used in the calibration are closely matched to those from the estimation. The monetary policy parameters are set to values that are standard in the literature (see Clarida, Gali, and Gertler (2000); Fernandez-Villaverde, Guerron-Quintana, Kuester, and Rubio-Ramirez (2015) and Kung (2015), among others). Finally, Π is set to match the average inflation rate. Table 5 reports the final calibration.

4.2. *Findings*

4.2.1. *Basic moments*

In table 6, I report the basic moments from model simulations for quantities and returns. My model is broadly consistent with the data. Consumption is smooth and has a low autocorrelation, as in the data. Thus the model does not generate implausibly high long-run growth risk. As in the data, inflation is similarly volatile and has the same level of persistence. More importantly, consumption growth and inflation are negatively correlated. It is well known that this is key in generating a positive term spread in a model (see, for example, Piazzesi and Schneider (2007); Rudebusch and Swanson (2012); Bansal and Shaliastovich (2013); and Kung (2015), among others).

The model generates an average tax rate of 36.20 percent compared to 35.12 percent in the data. The dynamics of $MDGDP$ are also broadly consistent with the data, although the model has difficulty matching its volatility. The model produces a volatile pricing kernel and high consumption returns, as in the data.

4.2.2. *Term structure of interest rates*

The model generates realistic bond yields across maturities. As reported in table 7, the slope of the nominal term structure of interest rates is large, as in the data. For the one-year bond, the yield is 4.69% compared to 4.74% in the data, and for the five-year bond, it is 5.37% compared to 5.39%. Yields are almost exactly as volatile as in the data across

Table 6
Model summary statistics

	Data	SE	Model
$\mathbb{E}(\Delta c)$	2.08	0.20	2.20
$\sigma(\Delta c)$	1.62	0.14	1.89
$ACF1(\Delta c)$	0.08	0.14	0.15
$\mathbb{E}(\pi)$	3.44	0.27	3.63
$\sigma(\pi)$	3.86	0.16	3.01
$ACF1(\pi)$	0.40	0.07	0.40
$\text{corr}(\pi, \Delta c)$	-0.11	0.06	-0.44
$\sigma(\Delta s)$	3.02	0.25	5.18
$\mathbb{E}(\tau)$	35.12	0.72	36.20
$\mathbb{E}(MDGDP)$	2.17	0.12	2.20
$\sigma(MDGDP)$	1.39	0.06	0.37
$ACF1(MDGDP)$	0.96	0.01	0.96
$\sigma(m)$			35.57
$\mathbb{E}(r^c)$	3.57	1.16	3.46

Notes – This table reports the summary statistics from the model. All statistics are in percentages except for autocorrelations and correlations. Consumption growth (Δc) is the log difference of real personal consumption expenditures per capita, and R&D growth (Δs) is constructed from real research and development. The tax rate (τ) is constructed as in McGrattan and Prescott (2005) using nonfinancial corporate business profits before and after tax. All of these series are obtained from the St. Louis FRED database. r^c is returns to consumption claimed. Its data counterpart comes from Lustig, Van Nieuwerburgh, and Verdelhan (2013). Other data come from sources reported in table 1. Model statistics are obtained from a long-sample simulation.

maturities; specifically, volatilities decrease with maturity (see the last two rows of table 7).

To gain insight into the quantitative performance of the model, let us turn our attention to figure 2. This figure plots the impulse responses to structural shocks of key quantities that determine bond yields. The first column from the left reports the responses of the intangible capital investment rate (s), expected consumption growth ($\mathbb{E}_t\, \Delta c_{t+1}$), log of real marginal cost (mc)—which determines inflation, as is standard in a New Keynesian framework[5]—and expected inflation ($\mathbb{E}_t\, \pi_{t+1}$) to a negative one-standard-deviation shock to technology. Upon impact, expected consumption growth drops below steady state because of a drop in investment, whereas expected inflation spikes up due to an increase in marginal cost as

[5] See appendix B for a derivation.

Table 7
Term structure of nominal yields

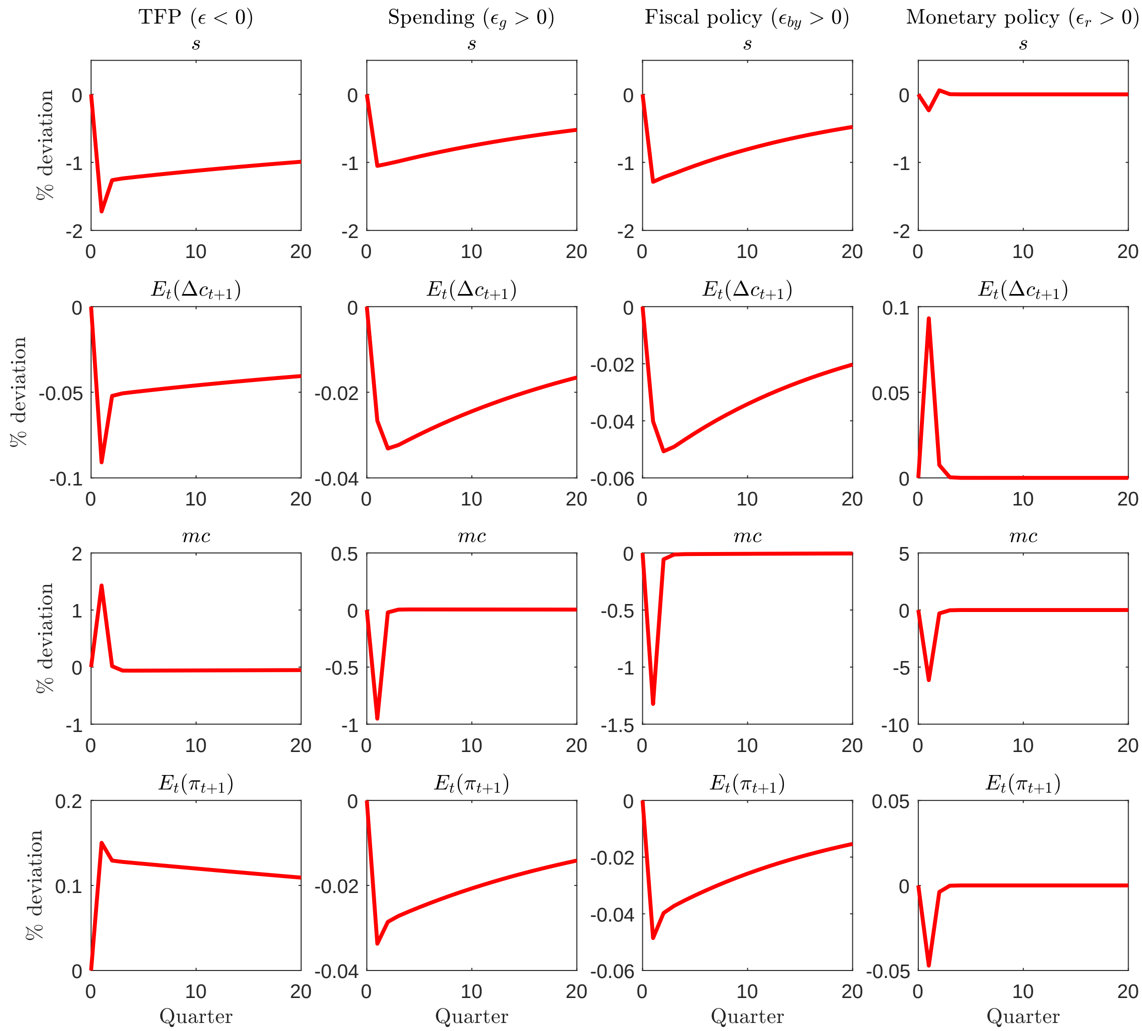
	Maturity (years)				
Statistics	1	2	3	4	5
Mean – model	4.69	4.85	5.02	5.19	5.37
Mean – data	4.74	4.94	5.12	5.27	5.39
Standard deviation – model	3.18	3.12	3.06	3.01	2.95
Standard deviation – data	3.17	3.13	3.06	3.00	2.93

Notes – Data span 1952Q3–2017Q4 and are from the Fama-Bliss file in CRSP. Yields are continuously compounded, in percentages and expressed at an annual rate. Model statistics are obtained from a long-sample simulation.

a result of low productivity. This *negative* covariation between consumption and inflation makes nominal bonds unattractive assets. In bad times, when marginal utility is high, bonds have low real payoffs. Similarly, a positive one-standard-deviation monetary policy shock (right-most column of figure 2) generates a negative correlation between consumption and inflation, although quantitatively monetary shock plays only a small role in generating the term premium due to its small and short-lived impact.

As opposed to TFP and monetary shocks, a positive one-standard-deviation shock to government spending (second-left column of figure 2) gives rise to a *positive* covariance between consumption and inflation. The intuition is as follows. An increase in government spending crowds out consumption and investment, and as a result consumption growth drops. Since fiscal policy follows a short-run stabilization, as seen in equation (12), the government responds to this consumption drop by increasing the tax rate in order to discourage investment and push resources toward consumption. This results in a drop in $MDGDP$ and a further drop in investment and ultimately leads to lower expected growth in the model. The increase in the tax rate lowers not only investment but also demand for labor, because after-tax corporate profits are now lower. For the labor market to clear, the wage rate falls. As a result, marginal cost declines (third panel of the second-left column of figure 2) and leads to lower expected inflation. Thus, with respect to government spending shocks, bonds are

Fig. 2.
Impulse responses to structural shocks

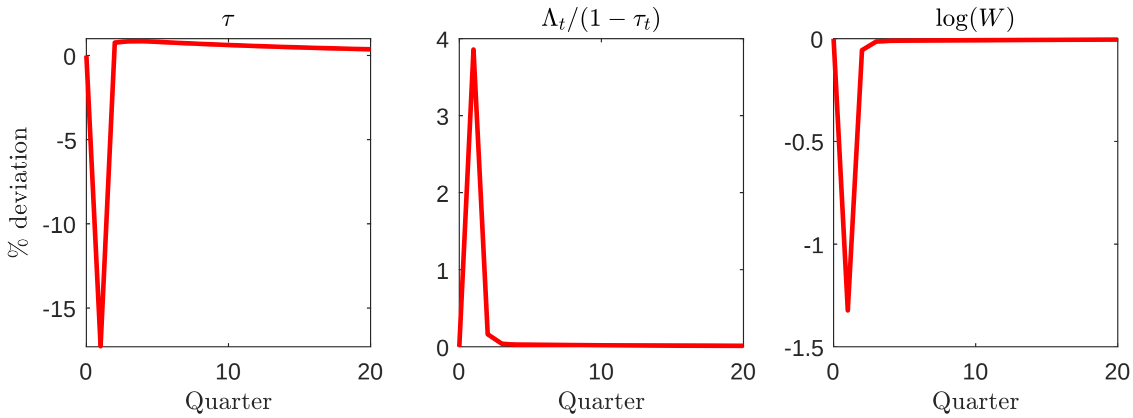


Notes – Impulse responses to one-standard-deviation shocks to technology, government spending, fiscal policy, and monetary policy. s denotes the log of intangible investment rate, and mc denotes the log of real marginal cost, i.e., $\exp(mc_t) = MC_t = (W_t/P_t)/[(1-\alpha)Y_t/L_t]$. All variables are expressed in percentage of deviation from steady state. All parameters are calibrated as in table 5.

attractive assets, because they feature high real payoffs in bad times and that makes them good hedges for spending shocks.

As with a spending shock, a pure fiscal policy shock (third column from the left of figure 2) leads to an increase in $MDGDP$ and induces a *positive* covariance between consumption and inflation. To see this result notice that according to the fiscal rule in equations (12)–(13), a

Fig. 3.
Impulse responses to a fiscal policy shock



Notes – Impulse responses to a positive one-standard-deviation shock to fiscal policy. Variables are in percentage of deviation from steady state, except for the pre-tax shadow cost, $\Lambda_t/(1-\tau_t)$, which is in percent. All parameters are calibrated as in table 5.

pure fiscal policy shock leads to an increase in public debt and a reduction in the tax rate, as the government now finances the same expenditure with more debt. Going forward, as the budget has to balance, corporate taxation and hence the tax rate have to be higher as seen in the left panel of figure 3.

Since intangible capital takes one period to build, forward-looking firms start to disinvest now because they are aware of the future tax increases (top panel, second-right column of figure 2). This decrease in investment causes expected growth to be lower (second panel, second-right column of figure 2).

To see why real wages falls, notice that in this model, the cost of using one additional unit of labor is twofold. First, firm has to pay wage. Second, using more labor leads to an increase in output which in turn lowers the price of the intermediate goods according to equation (6) and hence firm's profits. Formally, as shown in appendix A, the first-order condition with respect to labor can be expressed as

$$\frac{W_t}{P_t} + \frac{\Lambda_t}{1-\tau_t}(1/\epsilon)(1-\alpha)\frac{1}{L_t} = \left[(1-1/\epsilon)(1-\alpha)\left(\frac{Y_t}{L_t}\right)\right], \tag{19}$$

where Λ_t the (after-tax) multiplier on equation (6). In response to a pure fiscal policy shock, the right-hand side of equation (19) does not change. Thus whether real wages falls depends on whether the pre-tax shadow cost a price change, $\Lambda_t/(1-\tau_t)$, increases. From equation (A2), we have

$$\frac{\Lambda_t}{1-\tau_t} = -a\left(\Pi_t - \Pi\right)\Pi_t Y_t + \mathbb{E}_t\left[M_{t+1}\left(\frac{1-\tau_{t+1}}{1-\tau_t}\right)a\left(\Pi_{t+1} - \Pi\right)\Pi_{t+1}Y_{t+1}\right]. \tag{20}$$

The large drop in the tax rate in the current period compared to the small increase in the next period tax rate (left panel, figure 3) implies that the last term in the equation above dominates the first term on the right-hand side and leads to a spike in $\Lambda_t/(1-\tau_t)$ as seen in the middle panel of figure 3. Intuitively, the after-tax marginal benefit on an (indirect) increase in price dominates the after-tax marginal cost of the price change resulting in an increase in the pre-tax shadow cost of a price change according to equation (20).

It follows that the equilibrium wage has to drop (right panel of figure 3), and the fall in the equilibrium wage entails lower real marginal costs and hence lower expected inflation, as seen in the third column of figure 2. Thus, in response to a fiscal policy shock, there is a distortion in the intermediate-goods market which spillovers into the labor market and leads to a drop in wage. Consequently, just as with spending shocks, bonds are good hedges to fiscal policy shocks because of the positive correlation between consumption and inflation.

Given these opposite effects, the term structure of interest rates depends crucially on the underlying shocks driving the economy. Similar to Rudebusch and Swanson (2012), TFP is the main driver in this model and produces a net negative covariance between inflation and consumption growth, as in the data, consistent with the estimate by Piazzesi and Schneider (2007), which suggests the important role of TFP. In my model, this net negative correlation makes bonds risky and in turn brings about the sizable and upward-sloping term structure of interest rates, as also seen in the data.

Table 8
Predicting nominal consumption growth with $MDGDP$

Horizon J (quarters)	4	8	12	16	20
Panel A			*Data*		
$MDGDP_t$	-0.337^{**}	-0.421^{***}	-0.418^{**}	-0.454^{**}	-0.475^{**}
	(0.141)	(0.163)	(0.207)	(0.225)	(0.233)
Adjusted R^2	0.111	0.177	0.176	0.211	0.234
			Model		
$MDGDP_t$	-0.523	-0.558	-0.562	-0.558	-0.549
Adjusted R^2	0.274	0.311	0.316	0.311	0.301
Panel B			*Data*		
$MDGDP_t$	-0.304^{***}	-0.387^{***}	-0.380^{**}	-0.416^{**}	-0.435^{**}
	(0.111)	(0.117)	(0.154)	(0.169)	(0.174)
Output gap$_t$	-0.254^{**}	-0.255^{**}	-0.249^{**}	-0.215^{***}	-0.210^{***}
	(0.102)	(0.100)	(0.098)	(0.083)	(0.072)
Inflation$_t$	0.515^{***}	0.535^{***}	0.584^{***}	0.575^{***}	0.596^{***}
	(0.106)	(0.125)	(0.121)	(0.130)	(0.131)
Adjusted R^2	0.232	0.307	0.321	0.341	0.370
			Model		
$MDGDP_t$	-0.280	-0.284	-0.275	-0.263	-0.250
Output gap$_t$	-0.495	-0.565	-0.597	-0.617	-0.632
Inflation$_t$	0.059	0.055	0.053	0.049	0.044
Adjusted R^2	0.501	0.599	0.635	0.647	0.650

Notes – This table reports results from estimating the following predictive regression:

$$\frac{1}{J}\sum_{j=1}^{J}\Delta c^{\$}_{t+j} = \lambda_0 + \lambda^J \cdot MDGDP_t + \text{controls} + \epsilon_t,$$

where $\Delta c^{\$}_t$ denotes nominal consumption growth, and $MDGDP$ is the ratio of maturity-weighted debt to output.. Output gap is defined as real GDP minus real potential GDP scaled by real potential GDP. Inflation is the log difference of the consumer price index, expressed in percent at an annual rate. Macroeconomic data span 1947Q1–2017Q4 and are obtained directly from the St. Louis FRED database. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with J lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively. Model statistics are obtained from a long-sample simulation. All parameters are calibrated as in table 5.

4.2.3. MDGDP and nominal consumption growth

As discussed before, the positive correlation between yield spreads and $MDGDP$ depends on the ratio's power to forecast nominal consumption growth. To test this mechanism in the

Table 9
Model: $MDGDP$ and bond yields (I)

	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
	Data			
$MDGDP_t$	0.551***	0.579***	0.634***	0.649***
	(0.176)	(0.177)	(0.177)	(0.177)
Adjusted R^2	0.100	0.110	0.133	0.140
	Model			
$MDGDP_t$	0.758	0.771	0.778	0.783
Adjusted R^2	0.575	0.595	0.606	0.613

Notes – This table reports results from estimating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n *years*, and $MDGDP$ is the ratio of maturity-weighted debt to output. Data span 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively. Model statistics are obtained from a long-sample simulation. All parameters are calibrated as in table 5.

model, in table 8 (panel A) I show the results of regressing cumulative nominal consumption growth on $MDGDP$ for horizons from one year to five years. Consistent with the data, a high debt-to-GDP ratio predicts lower growth going forward, with similar strengths and R^2s. As shown in panel B, these results are robust to controlling for output gap and inflation: the coefficients on the debt-to-GDP ratio remain negative and significant. Output gap predicts consumption growth negatively and inflation positively, consistent with the data. The success of the debt-to-GDP ratio in predicting growth foretells its positive association with yield spreads, which I will discuss next.

4.2.4. $MDGDP$ and bond yields

Table 9 reports the results of regressing yield spreads on $MDGDP$ in the model. For ease of comparison, I also reproduce the data counterpart in the table. As in the data, the model produces a positive relationship between yield spreads and the debt-to-GDP ratio.

An increase in $MDGDP$ is strongly correlated with an increase in the slope of the term structure of interest rates. The strength of the correlation in the model is similar to that in the data.

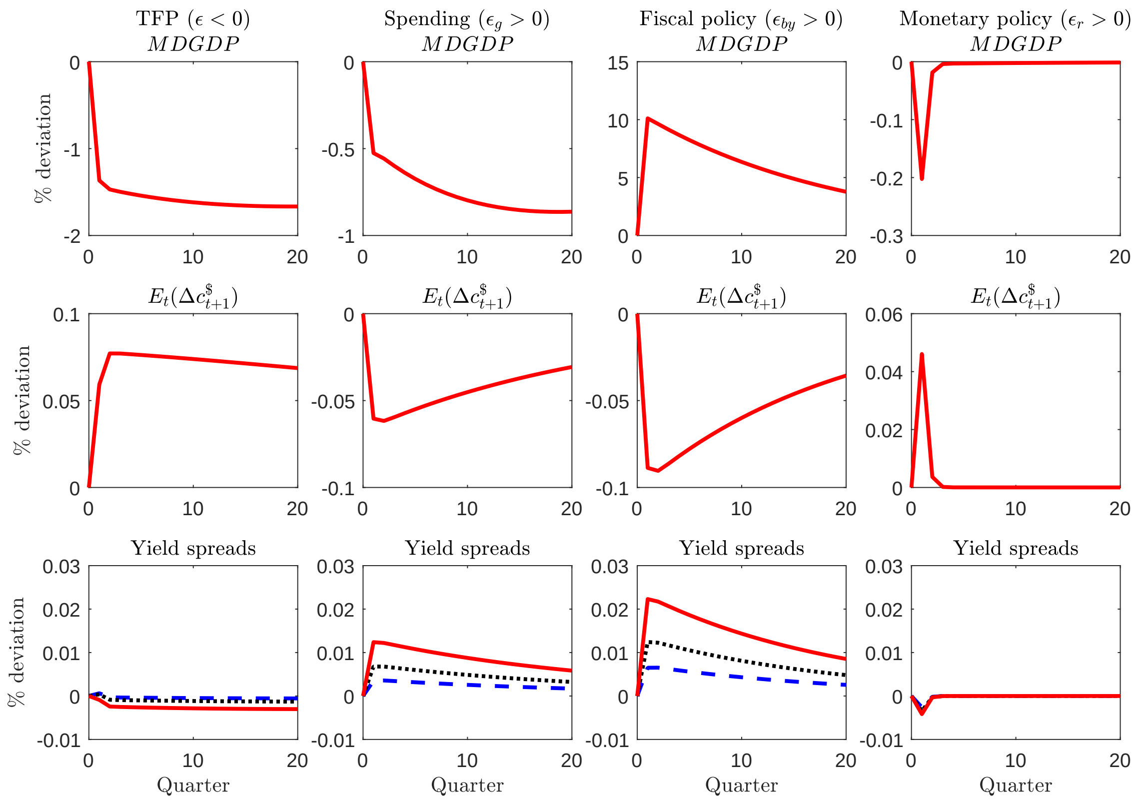
To understand these results, recall that deviations of bond yield from its mean are determined by the expected nominal consumption growth over the lifetime of the bond. Hence, deviations of the yield *spread* between the n-year bond and the one-year bond, $i_t^{(n)} - i_t^{(1)}$, are governed by the *difference* between the averages of the expected nominal consumption growth in the first n years and the first year.

Now let us turn our attention to figure 4, which reports the impulse responses of the variables of interest to one-standard-deviation shocks to technology, government spending, fiscal policy, and monetary policy. As seen in the leftmost column, $MDGDP$ positively predicts bond yield spreads, although these are quantitatively small. To gain insight into this result, notice that upon impact of a negative productivity shock, $MDGDP$ drops. This comes about because of fiscal stabilization: the government increases tax to discourage investment and push resources toward consumption, and the increase in taxation leads to lower debt. As discussed in section 4.2.2, productivity shocks create a negative correlation between *real* consumption growth and inflation, and the net impact is a positive and importantly persistent response of *nominal* consumption growth (leftmost middle panel). Given this observation, the results depicted in the bottom left panel of figure 4 are not surprising: the persistent expected nominal growth rate mean-reverting from above gives rise to small and negative deviations in yield spreads as the n-year average growth is similar to that of the first year.

In response to monetary shock (rightmost column of figure 4), $MDGDP$ also predicts yield spreads positively. Quantitatively monetary shock is not too important for the performance of the model mainly because of its short-lived impact on nominal growth.

In responses to a government spending shock (second-left column of figure. 4), there is a drop in $MDGDP$ but increases in yield spreads. Thus *in the absence of other shocks*,

Fig. 4.
Impulse responses of $MDGDP$ and yield spreads to structural shocks



Notes – Impulse responses to one-standard-deviation shocks to technology, government spending, fiscal policy, and monetary policy. For the yield spread figures (bottom row), the solid red line is $i_t^{(5)} - i_t^{(1)}$, the dotted black line is $i_t^{(3)} - i_t^{(1)}$, and the dashed blue line is $i_t^{(2)} - i_t^{(1)}$. All variables are expressed in percentage of deviation from steady state. All parameters are calibrated as in table 5.

a higher $MDGDP$ would predict a *lower* slope of the term structure, opposite to that seen in the data. As discussed in section 4.2.2, short-run stabilization implies a drop in $MDGDP$ in response to a spending shock and a drop in both expected real consumption growth and expected inflation. This positively correlated drop leads to a pronounced drop in expected nominal consumption growth, as seen in the second panel of the second column in figure 4. The quick mean-reversion from a lower-than-expected level of the expected nominal consumption growth implies large and positive yield spreads, as now the differential of the average growths are positive and large (second-left column, bottom panel).

Table 10
Model: $MDGDP$ and bond yields (II)

	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
Panel A		*Data*		
$MDGDP_t$	0.537***	0.562***	0.618***	0.633***
	(0.146)	(0.140)	(0.142)	(0.144)
Output gap_t	−0.505***	−0.557***	−0.537***	−0.535***
	(0.082)	(0.078)	(0.079)	(0.080)
Adjusted R^2	0.327	0.388	0.392	0.396
		Model		
$MDGDP_t$	0.809	0.810	0.803	0.794
Output gap_t	−0.115	−0.086	−0.056	−0.026
Adjusted R^2	0.586	0.601	0.608	0.613
Panel B		*Data*		
$MDGDP_t$	0.454**	0.410**	0.474***	0.481***
	(0.181)	(0.177)	(0.178)	(0.178)
Inflation_t	−0.242*	−0.418***	−0.396***	−0.416***
	(0.140)	(0.137)	(0.136)	(0.136)
Adjusted R^2	0.113	0.155	0.173	0.184
		Model		
$MDGDP_t$	0.734	0.745	0.748	0.747
Inflation_t	−0.062	−0.066	−0.077	−0.090
Adjusted R^2	0.578	0.599	0.611	0.620

Notes – This table reports results from estimating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n years, $MDGDP$ is the ratio of maturity-weighted debt to output, and $\boldsymbol{X}$ is one or more controls. Data span 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively. Model statistics are obtained from a long-sample simulation. All parameters are calibrated as in table 5.

Given the small roles of TFP and monetary shocks and the counterfactual implication of government spending shock on bond yield-public debt relation, the quantitative performance of the model, as shown in table 9, hinges crucially on fiscal policy shock. As seen in the second-right column of figure 4, a positive fiscal shock leads directly to higher $MDGDP$ and a large drop in both expected inflation and real consumption growth. The result is a prominent reduction in nominal growth and large increases in yield spread (second-right

Table 11
Model: $MDGDP$ and bond yields (III)

	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
	Data			
$MDGDP_t$	0.511***	0.472***	0.534***	0.540***
	(0.153)	(0.145)	(0.147)	(0.148)
Output gap$_t$	−0.498***	−0.532***	−0.514***	−0.509***
	(0.082)	(0.078)	(0.079)	(0.079)
Inflation$_t$	−0.063	−0.227**	−0.211*	−0.233**
	(0.120)	(0.114)	(0.114)	(0.115)
Adjusted R^2	0.326	0.399	0.401	0.408
	Model			
$MDGDP_t$	0.785	0.787	0.782	0.774
Output gap$_t$	−0.232	−0.193	−0.157	−0.123
Inflation$_t$	−0.195	−0.177	−0.167	−0.161
Adjusted R^2	0.607	0.618	0.623	0.628

Notes – This table reports results from estimating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n years, $MDGDP$ is the ratio of maturity-weighted debt to output, and $\boldsymbol{X}$ is one or more controls. Data span 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively. Model statistics are obtained from a long-sample simulation. All parameters are calibrated as in table 5.

column, bottom panel). Thus, in response to a fiscal shock, $MDGDP$ would be high when yield spreads are high, replicating the patterns in the data.

In table 10 I report the results of projecting yield spreads onto $MDGDP$, controlling for other factors both in the data and in the model. In panel A, I add output gap as an additional covariate, and in the model, as in the data, $MDGDP$ remains positively related to yield spreads. Moreover, though smaller in magnitude, output gap is negatively correlated to the slope of the term structure, as in the data. In panel B, I control for inflation, and the results are unchanged: consistent with the data, a high $MDGDP$ coincides with a larger yield spread, and inflation is negatively associated with the slope of the term structure.

Table 12
Sensitivity analysis: The roles of structure shocks

	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
Panel A	*Model – No fiscal policy shock* ($\sigma_{by} = 0$)			
$MDGDP_t$	-1.579	-1.610	-1.597	-1.571
Output gap_t	1.814	1.912	1.951	1.967
Inflation_t	-0.126	-0.103	-0.089	-0.079
Adjusted R^2	0.565	0.623	0.656	0.680

Panel B	*Model – No TFP shock* ($\sigma = 0$)				
	Maturity (years)				
	1	2	3	4	5
Nominal yields	4.87	4.76	4.67	4.59	4.51

Notes – In panel A, I report results from estimating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n years, $MDGDP$ is the ratio of maturity-weighted debt to output, and $\boldsymbol{X}$ is one or more controls. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively. In panel B I report yield of nominal bonds from one to five years to maturity. Model statistics are obtained from a long-sample simulation. All parameters are calibrated as in table 5, except for the volatilities as indicated in each panel.

Table 11 reports results when both output gap and inflation are added as controls, and the results again remain unchanged: the debt-to-GDP ratio and yield spread are positively correlated at different horizons, and output gap and inflation are both negatively associated with bond yield spread across the maturities, consistent with empirical regularities.

4.3. Sensitivity

4.3.1. No fiscal policy risk

As discussed previously, pure fiscal policy shocks play an important role in the success of the model. To quantitatively illustrate the point, in panel A of table 12 I report the results of the same regressions when fiscal policy shocks are shut off by setting σ_{by} to zero. As seen in this panel, $MDGDP$ now has the wrong sign: higher $MDGDP$ leads to lower yield spreads across time to maturity. Moreover, the implications for output gap are also counterfactual, predicting an increase in the slope of the term structure instead of a decrease as in the data. Thus, taking into account fiscal policies is important for understanding the data of not only equity markets but also Treasury bond markets.

4.3.2. The role of TFP shocks

Technology shocks are the main driver of macroeconomic aggregates in the model. To quantify the role of TFP, I resolve the model with $\sigma = 0$. In panel B of table 12, I report the average bond yields for maturities between one and five years. The nominal yield curve is now downward sloping instead of upward as in the data. To see this result, recall from figure 2 that with respect to spending and fiscal risks, bonds are attractive assets because they give higher real payoffs in bad times, times of low expected consumption growth. However, with respect to TFP and monetary policy risks, bonds are unattractive assets. Moreover, monetary policy shocks have a larger impact on shorter-term bonds (rightmost column of figure 2). When TFP shocks are muted, it is not surprising that the term structure is downward sloping, because longer-term bonds are then a better hedge.

5. Conclusion

In this paper I document that the ratio of public debt-to-GDP negatively predicts one- to five-year cumulative nominal consumption growth with high R^2s. Moreover, an increase in $MDGDP$ leads to higher yield spreads as measured by the two-, three-, four- and five-year yield relative to the one-year yield. These results are robust to controlling for output gap, inflation, and unemployment gap. In this paper, I develop a model to rationalize these facts.

In my model, the government issues debt and levies distortionary taxation on corporate profits to finance its expenditures. Fluctuations of debt thus drive tax-rate dynamics and alter investment incentives, hiring decisions, and consequently the equilibrium wage. In the model, an unexpected increase in the debt level drives up the cumulative tax burden and consequently lowers investment and labor demand, which in turn lead to deflation and lower growth.

Bonds in the model therefore are attractive assets with respect to fiscal risk because they have high real payoffs in high debt times, that is, times with low growth but also low inflation. Moreover, due to mean-reversion, longer-term bonds are better hedges than shorter-term ones because they are less exposed to short-term fluctuations in nominal growth and thus are less exposed to short-term movements in debt and tax. Consequently, an unexpected increase in debt results in a decrease in yield across maturities (lower expected consumption growth), but the drop is more severe for bonds with shorter maturities than longer ones. Therefore, in terms of yield spread relative to the one-year, the increases are larger for longer maturity bonds. These increases in yield spreads at the times of high public debt result in the positive correlations seen in the data.

A model with endogenous inflation and relevant tax instruments can generate a sizable term spread and, at the same time, rationalize the predictability of nominal growth using the debt-to-GDP ratio and therefore the strong and positive correlations of public debt and bond yield spreads. My mechanism thus complements the models in the extant literature in furthering the understanding of what determine bond yields and the impact of quantitative easing.

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Appendix A. Problem of the intermediate-goods firm

After plugging in the demand for intermediate-goods equation (6), the intermediate-goods firm's problem becomes

$$V_{jt} = \max_{\{P_{jt}, N_{j,t+1}, S_{jt}, L_{jt}\}} (1-\tau_t)\left(Y_t^{1/\epsilon} \left(Z_t N_t^{1-\eta} N_{jt}^{\eta} L_{jt}^{1-\alpha} \right)^{1-1/\epsilon} - \frac{W_t}{P_t} L_{jt} - AC(P_{j,t-1}, P_{jt}) \right)$$
$$- S_{jt} + \mathbb{E}_t\, M_{t+1} V_{j,t+1}$$

subject to (8) and

$$\frac{P_{jt}}{P_t} = Y_t^{1/\epsilon} \left(Z_t N_t^{1-\eta} N_{jt}^{\eta} L_{jt}^{1-\alpha} \right)^{-1/\epsilon}. \tag{A1}$$

Let q_t and Λ_{jt} denote the multipliers for (8) and (A1), respectively. The first-order conditions are

$$\begin{aligned}
0 &= -(1-\tau_t) a \left(\frac{P_{jt}}{P_{j,t-1}} - \Pi \right) Y_t \frac{1}{P_{j,t-1}} + \mathbb{E}_t\, M_{t+1} \frac{\partial V_{j,t+1}}{\partial P_{jt}} - \Lambda_{jt}/P_t \\
0 &= -q_t + \mathbb{E}_t\, M_{t+1} \frac{\partial V_{j,t+1}}{\partial N_{j,t+1}} \\
0 &= -1 + q_t \Phi'(S_{jt}/N_{jt}) \\
0 &= (1-\tau_t) \left[(1-1/\epsilon)(1-\alpha) \left(Y_t^{1/\epsilon} Y_{jt}^{-1/\epsilon} \right) \left(\frac{Y_{jt}}{L_{jt}} \right) - \frac{W_t}{P_t} \right] \\
&\quad - \Lambda_{jt} (1/\epsilon)(1-\alpha) \left(Y_t^{1/\epsilon} Y_{jt}^{-1/\epsilon} \right) \frac{1}{L_{jt}}.
\end{aligned}$$

Moreover, the envelope conditions are

$$\begin{aligned}
\frac{\partial V_{jt}}{\partial N_{jt}} &= (1-\tau_t)(1-1/\epsilon)\eta \left(Y_t^{1/\epsilon} Y_{jt}^{1-1/\epsilon} \right) \frac{1}{N_{jt}} - (1/\epsilon)\eta \Lambda_{jt} \left(Y_t^{1/\epsilon} Y_{jt}^{-1/\epsilon} \right) \frac{1}{N_{jt}} \\
&\quad + q_t \left(1 - \delta + \Phi'(S_{jt}/N_{jt})(S_{jt}/N_{jt}) + \Phi(S_{jt}/N_{jt}) \right)
\end{aligned}$$

and

$$\frac{\partial V_{jt}}{\partial P_{jt}} = (1-\tau_t)a\left(\frac{P_{jt}}{P_{j,t-1}} - \Pi\right) Y_t \frac{P_{jt}}{P_{j,t-1}} \frac{1}{P_{j,t-1}}.$$

Plugging the envelope conditions into the first-order conditions and imposing the symmetric equilibrium gives

$$0 = \Lambda_t + (1-\tau_t)a\left(\Pi_t - \Pi\right)\Pi_t Y_t - \mathbb{E}_t\, M_{t+1}(1-\tau_{t+1})a\left(\Pi_{t+1} - \Pi\right)\Pi_{t+1}Y_{t+1} \tag{A2}$$

$$q_t = \mathbb{E}_t\, M_{t+1}\Bigg[(1-\tau_{t+1})(1-1/\epsilon)\eta\frac{Y_{t+1}}{N_{t+1}} - (1/\epsilon)\eta\Lambda_{t+1}\frac{1}{N_{t+1}} \tag{A3}$$

$$+\, q_{t+1}\left(1-\delta+\Phi'(S_{t+1}/N_{t+1})(S_{t+1}/N_{t+1}) + \Phi(S_{t+1}/N_{t+1})\right)\Bigg] \tag{A4}$$

$$q_t = 1/\Phi'(S_t/N_t) \tag{A5}$$

$$0 = -(1-\tau_t)\frac{W_t}{P_t} - \Lambda_t(1/\epsilon)(1-\alpha)\frac{1}{L_t} + (1-\tau_t)\left[(1-1/\epsilon)(1-\alpha)\left(\frac{Y_t}{L_t}\right)\right]. \tag{A6}$$

This system of equations completely characterizes the behavior of intermediate-goods firms.

Appendix B. Real marginal cost and inflation

Substituting out Λ_t from (A2) and (A6) gives

$$\frac{\epsilon}{1-\alpha}(1-\tau_t)\left(\frac{W_t L_t}{P_t}\frac{1}{Y_t} - (1-1/\epsilon)(1-\alpha)\right) =$$
$$(1-\tau_t)a\left(\Pi_t - \Pi\right)\Pi_t - \mathbb{E}_t\left(M_{t+1}(1-\tau_{t+1})a\left(\Pi_{t+1}-\Pi\right)\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right). \tag{B1}$$

Notice that W_t is the nominal wage. Let MC_t denote the real marginal cost, i.e.,

$$MC_t \equiv (W_t/P_t)/MPL_t,$$

where the marginal productivity of labor $MPL_t = (1-\alpha)Y_t/L_t$. Then (B1) becomes

$$(1-\tau_t)a\left(\Pi_t - \Pi\right)\Pi_t = (1-\tau_t)(\epsilon MC_t - \epsilon + 1) + \mathbb{E}_t\left(M_{t+1}(1-\tau_{t+1})a\left(\Pi_{t+1} - \Pi\right)\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right).$$

Thus, an increase in the real marginal cost brings about higher inflation, all else being held equal.

Appendix C. Additional results

In table C1 I provide additional results on the relationship between $MDGDP$ and bond yields, controlling for unemployment, output gap, and inflation.

Table C1
MDGDP and bond yields (III)

Panel A	$i_t^{(2)} - i_t^{(1)}$	$i_t^{(3)} - i_t^{(1)}$	$i_t^{(4)} - i_t^{(1)}$	$i_t^{(5)} - i_t^{(1)}$
$MDGDP_t$	0.423***	0.440***	0.487***	0.493***
	(0.157)	(0.155)	(0.150)	(0.147)
Unemployment gap$_t$	0.435***	0.471***	0.499***	0.528***
	(0.090)	(0.088)	(0.086)	(0.084)
Constant	−0.015	0.071	0.066	0.072
	(0.228)	(0.225)	(0.218)	(0.213)
Observations	262	262	262	262
Adjusted R^2	0.280	0.322	0.371	0.407
Panel B				
$MDGDP_t$	0.328**	0.274*	0.330**	0.329**
	(0.160)	(0.152)	(0.147)	(0.143)
Unemployment gap$_t$	0.434***	0.470***	0.498***	0.527***
	(0.087)	(0.083)	(0.080)	(0.078)
Inflation$_t$	−0.237*	−0.412***	−0.390***	−0.410***
	(0.123)	(0.117)	(0.113)	(0.109)
Constant	0.242	0.519**	0.490**	0.517**
	(0.259)	(0.245)	(0.238)	(0.231)
Observations	262	262	262	262
Adjusted R^2	0.293	0.367	0.411	0.452
Panel C				
$MDGDP_t$	0.427***	0.378***	0.418***	0.405***
	(0.152)	(0.142)	(0.141)	(0.138)
Output gap$_t$	−0.347***	−0.365***	−0.307***	−0.269***
	(0.101)	(0.094)	(0.093)	(0.091)
Unemployment gap$_t$	0.232**	0.257***	0.319***	0.370***
	(0.103)	(0.097)	(0.096)	(0.094)
Inflation$_t$	−0.114	−0.283***	−0.282***	−0.315***
	(0.117)	(0.109)	(0.108)	(0.105)
Constant	0.090	0.359	0.356	0.400*
	(0.244)	(0.229)	(0.226)	(0.222)
Observations	262	262	262	262
Adjusted R^2	0.364	0.433	0.461	0.491

Notes – This table reports results from esitmating the following regression:

$$i_t^{(n)} - i_t^{(1)} = \beta_0 + \beta^{(n)} MDGDP_t + \boldsymbol{X_t \beta_2} + \epsilon_t,$$

where $i_t^{(n)}$ denotes the yield to maturity at time t of a zero-coupon bond that matures in n years, $MDGDP$ is the ratio of maturity-weighted debt to output, and $\boldsymbol{X}$ is one or more controls. Data span 1952Q3–2017Q4. Variables are scaled by their respective standard deviations. Newey and West (1987) standard errors with four lags are in parentheses. One, two, and three asterisks denote significance at the 10%, 5%, and 1% levels, respectively.