The Risks of Safe Assets

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How much safety and liquidity can the US government provide? Should it accommodate demand for these attributes because high convenience yields in Treasuries lower its borrowing cost? We evaluate a novel fiscal risk channel limiting the government's capacity to issue debt through the lens of a general equilibrium asset pricing model with a rich fiscal sector. Expanding safe asset supply lowers safety premia and improves liquidity in financial markets, but creates tax and consumption volatility, raising risk premia, credit spreads, and firms' cost of capital. Our model predicts that this risk channel leads to depressed growth prospects, rising Treasury yields, and elevated consumption risk, for which we find strong empirical evidence. We use our model to quantitatively evaluate current proposals on stimulus and stabilization packages and find that the risk channel is exacerbated in times of fiscal stress. Increasing safe asset supply can thus be risky, and have a significant fiscal cost.

Keywords: Government debt, safe assets, liquidity premium, uncertainty, growth, fiscal costs, consumption risk, risk premia, credit spreads, r minus g, unconventional stabilization policies, nonlinear methods

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1 Introduction

US government bonds exhibit many characteristics often attributed to safe assets: They are very liquid and lenders readily accept them as collateral. Indeed, as pointed out in the literature by Longstaff (2003), Krishnamurthy and Vissing-Jorgensen (2012), or Nagel (2016), for example, Treasuries exhibit many money-like features suggesting that investors attach a 'liquidity premium' or 'safety premium', captured by a convenience yield, to holding these assets. These attributes lower Treasury rates and thus the US government's borrowing costs. As a consequence, the US economic environment has long been characterized by low interest rates that are, notably, below growth rates, thereby plausibly reducing the fiscal costs of debt service substantially. In fact, Blanchard (2019) forcefully argues 'that the current U.S. situation in which safe interest rates are expected to remain below growth rates for a long time, is more the historical norm than the exception', so that, 'put bluntly, public debt may have no fiscal cost'. Arguably thus, by issuing Treasuries and raising debt, the US government can provide liquidity services and accommodate investors' safety demands without resorting to raising taxes to maintain budget balance.

In this paper, we ask, how much safety and liquidity can the US government provide? Should it accommodate investors' demand for these attributes because high convenience yields in Treasuries lower its cost of borrowing? Can it do so without incurring fiscal costs given low interest rates and high growth? To provide a perspective regarding these questions, we start by empirically documenting a novel fiscal risk channel that limits the safety benefits of US government debt. We then evaluate and provide a quantitative assessment of its effects on asset prices and macroeconomic dynamics through the lens of a novel general equilibrium asset pricing model with a rich government sector. Such a quantitative assessment is critical in the light of the swift policy response to the Covid crisis in the form of unprecedented fiscal stimulus and stabilization packages. Our empirical evidence linking Treasury supply and risk premia provides a novel approach to tightly discipline the quantitative analysis and highlights the relevance of exploiting information in asset prices to draw inference about macroeconomic dynamics and public policy.

Our analysis starts from the novel empirical observation that the government debt to GDP ratio is a powerful predictor of risk premia, especially in credit markets. Indeed, we find that it positively predicts corporate bond credit spreads and excess returns, and thus firms' costs of financing. Notably, this predictive power is exacerbated in times of fiscal stress. Together with extant evidence regarding the predictive power of government debt for stock excess returns[1], this suggests that through a risk channel, a rising government debt burden is linked to a rise in corporations' costs of capital and thus likely dimmer growth prospects, especially when fiscal slack is low.

Such a novel risk channel of Treasury supply contrasts sharply with a widely documented fiscal safety channel in that the government debt to GDP ratio negatively predicts measures of convenience yields on government bonds in the data, such as spreads between repo rates and Treasury bill yields [2] . Under this view, by expanding the supply of safe Treasuries, the government accommodates investors' demand for safety and liquidity, lowering spreads, and thus facilitating transactions and stimulating the economy.

Motivated by the evidence on these contrasting channels, we propose and evaluate a dual view of the role of government debt for credit markets and the macroeconomy. To identify and quantitatively assess sources of the risk channel jointly with the safety channel of government debt, we solve a novel general equilibrium asset pricing model with a rich fiscal sector. In the model, risk-sensitive agents with Epstein-Zin preferences invest in portfolios of government bonds, corporate bonds as well as stocks to smooth their consumption. The government finances debt by levying taxes on wages and corporate income, while corporations issue defaultable bonds to finance investment according to their advantageous tax treatment, in line with the US tax code. Households are subject to sporadic liquidity shocks creating funding needs that they can cover by trading their asset positions subject to transaction costs in the market place. In our model, different asset classes provide differential liquidity benefits to investors across time and states reflected in endogenously time-varying liquidity and safety premia.

In the model, in line with the safety channel, increasing the supply of government bonds facilitates covering liquidity needs in the market place and thus endogenously leads to a decline in liquidity premia on safe assets. However, to maintain budget balance, issuing debt also raises the government's future funding needs. We show that higher debt burden not only leads to higher average, but also to more volatile future tax obligations. Intuitively, the real distortions stemming from elevated tax pressure depress the tax base, so that adverse shocks have to be absorbed by even higher future taxes, leading to fiscal amplification. Our model thus identifies

[1]See, for example, Liu (2018) and Croce, Nguyen, Raymond, and Schmid (2019).

[2]See e.g. Longstaff (2003), Krishnamurthy and Vissing-Jorgensen (2012), or Nagel (2016). A more exhaustive review of the literature is provided in section 1.1.

a source of fiscal risk underlying the risk channel of government debt. We show that in our general equilibrium model, rising government debt, tax pressure and tax volatility ultimately lead to elevated consumption volatility. With a high debt burden and the ensuing high average tax pressure, even small changes in taxes are reflected in substantial consumption risk. Through movements in taxes, a rising supply of safe assets not only facilitates transactions, but also gives rise to elevated risk premia, credit spreads, and firms' costs of financing. This effect not only depresses corporate investment, and growth, but also raises their volatilities. Increasing safe asset supply can thus be risky. We document novel empirical evidence supporting this prediction regarding the link between government debt, taxes, and consumption volatility.

Quantitatively, our dual mechanism of safety provision versus fiscal risk provides a realistic account of the empirical evidence. It rationalizes liquidity premia declining with safe asset supply, and credit spreads rising with it, in line with the data. Our model with endogenous leverage delivers a sizeable equity premium and credit spreads, in a setting with realistically modest macroeconomic risks. Risk premia are endogenously time-varying reflecting consumption volatility that endogenously moves with the supply of government debt. Key to our quantitative implications is a global nonlinear solution that adequately captures the payoffs of risky corporate bond instruments. Equilibrium policies in the model are sharply nonlinear in relevant regions of the state space. With looming fiscal stress, the effects of government debt on risk premia are exacerbated, while the liquidity benefits rapidly shrink. At the same time, tax pressure, tax volatility, and ultimately, consumption volatility rise sharply.

Given its realistic account of the data, our model, in which safety attributes of government debt and growth are jointly determined, provides a plausible quantitative perspective on the fiscal costs of rising public debt and the ongoing debate on its sustainability in a low interest rate environment. While our model rationalizes low average interest rates and elevated growth rates, our equilibrium policies imply that rising government debt can lead to prolonged episodes in which Treasury yields dwarf expected growth when growth prospects are subject to aggregate risk. Indeed, Treasury yields rise with government debt in response to adverse shocks, as liquidity premiums and safety attributes decline. At the same time, the government budget constraint dictates that with an elevated debt burden tax pressure and tax risk increase, thereby depressing growth. A growing debt burden can thus push Treasury yields and thus debt servicing costs above growth rates. In other words, with aggregate risk, public debt may quickly become unsustainable[3]. These quantitative results are tightly disciplined by our empirical results on the links between government debt and risk premia[4].

Evaluating the long term implications of rising Treasury supply is especially important in light of recent unconventional policy measures and proposals in response to the covid crisis. Our model can directly speak to quantitative easing policies implemented recently in response to the Covid-19 crisis through corporate bond purchases by the Federal Reserve, proposals regarding government grant extensions to financially distressed firms to avoid bankruptcies, as well as to liquidity provision around financial crises such as the great recession of 2008 or fragility in corporate bond mutual funds in 2021. Our results underscore that providing short-run stabilization through the purchase of risky assets requires quantitatively significantly stronger fiscal adjustment going forward, possibly in worse times.

1.1 Related Literature

Our work is related to and links several strands of literature. We build on the observation, well-known e.g. from Longstaff (2003), Krishnamurthy and Vissing-Jorgensen (2011), Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), Jiang, Krishnamurthy, and Lustig (2018), He, Krishnamurthy, and Milbradt (2019) and Jiang, Krishnamurthy, and Lustig (2019), that U.S. Treasuries are arguably among the world's safest and most liquid financial assets and investors attach a 'liquidity premium' or 'safety premium', captured by a convenience yield, to holding these assets. While this literature recognizes the specialness of U.S. Treasuries, in important work, Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2019) argue that commonly estimated convenience yields alone cannot explain the valuation of government debt, so that these have to be either larger than previously estimated, or U.S. Treasury markets have failed to enforce the no-bubble condition. Brunnermeier, Merkel, and Sannikov (2021) rationalize such a bubble in models with incomplete markets where government bonds generate a service flow as trading them allows agents to hedge

[3]The term 'unsustainable' is only vaguely defined, but here is a revealing comment from Tom Sargent's Nobel Prize Press Conference:'Here's a phrase that you hear. You hear that 'US fiscal policy is unsustainable'. You hear it from both parties. That can't possibly be true, because government budget constraints are going to make it sustainable. What they mean is that certain promises people have made (taxes, entitlements, medicare, medicaid) those are incredible, they're not going to fit together. So US fiscal policy is sustainable, [but] it's very uncertain. It's uncertain because it's not clear which of these incredible promises is going to be broken first'. We would like to thank Espen Henriksen for pointing it out to us.

[4]We follow, e.g., Alvarez and Jermann (2004) and Alvarez and Jermann (2005) in using information from asset prices to draw inference about macroconomic risks.

idiosyncratic risk. We connect this stylized fact to the recent, and growing, evidence in Liu (2018) and Croce, Nguyen, Raymond, and Schmid (2019) that a rising supply of Treasuries significantly predicts rising excess returns in a variety of asset classes. While we present novel evidence in the context of credit, these papers provide further evidence across asset classes. Similarly, Ye (2020) connects liquidity premia on Treasuries to aggregate risk through an alternative financial intermediation channel. More generally, Reis (2021) presents an elegant qualitative analysis of the constraints on government debt in environments with low interest rates and high equity premia.

Our model embeds defaultable corporate debt along the lines of Gomes, Jermann, and Schmid (2016), or Miao and Wang (2010), and into a general equilibrium asset pricing model with a rich fiscal sector, similar to Croce, Nguyen, Raymond, and Schmid (2019), Gomes, Michaelides, and Polkovnichenko (2009), Gomes, Michaelides, and Polkovnichenko (2013), Coeurdacier, Coimbra, Gomes, and Faraglia (2017), and Lustig, Sleet, and Yeltekin (2008) or Lustig, Berndt, and Yeltekin (2012). Pastor and Veronesi (2012) and Pastor and Veronesi (2013) examine links between government uncertainty and risk premia.

Disciplined by the empirical results in Croce, Nguyen, Raymond, and Schmid (2019), and similar to Jaimovich and Rebelo (2017), taxes in our model have a negative long-run effect on productivity growth, so that effectively fiscal policy provides a source of 'long-run productivity risk' and 'long-run volatility risks' as specified in Croce (2014) and micro-founded in a setting with endogenous growth in Kung and Schmid (2015), or Corhay, Kung, and Schmid (2017). We therefore connect the empirical evidence of rising risk premia with growing Treasury supply to the pricing of volatility risks. In this sense, our work builds on and exploits the ideas regarding pricing of uncertainty risks with recursive preferences in Bansal and Yaron (2004), and Drechsler and Yaron (2011). While these mechanisms operate in endowment economies, volatility risks arise endogenously in our work in a fully-fledged general equilibrium production economy, similar to Bloom, Floetotto, Jaimovich, Saporta-Eksten, and Terry (2018).

Our work also contributes to the literature on equilibrium models of corporate bond pricing, motivated by the observation, often referred to as the 'credit spread puzzle' that credit spreads tend to be high relative to the average losses bondholders have to expect in default. Our model gives a general equilibrium perspective on the recent literature that attributes a large component of credit spreads to a default risk premium compensating bondholders for incurring losses in high marginal utility episodes, as spearheaded by Chen, Collin Dufresne, and Goldstein (2009), Bhamra, Kuehn, and Strebulaev (2010), and Chen (2010), or Gourio (2013). While we abstract from significant cross-sectional heterogeneity as in Gomes and Schmid (2019), we emphasize the liquidity attributes of bonds similar to Chen, Cui, He, and Milbradt (2018) and He and Milbradt (2014). In that respect, our model of liquidity attributes builds on and generalizes the work of Amihud and Mendelson (1986) and, more recently, He and Xiong (2012). A related strand of literature endogenizes liquidity premia in models with search (see e.g. Duffie, Garleanu, and Pedersen (2005), Lagos and Rocheteau (2009), Weill (2020), Vayanos and Weill (2008), Milbradt (2017), Uslu and Velioglu (2019), discussed below), adverse selection (Eisfeldt (2004), Eisfeldt and Rampini (2006)), or collateral (Shi (2015)). Our work contributes to the literature on liquidity premia by integrating a model of differential liquidity attributes across assets into a quantitative general equilibrium asset pricing model. We apply this class of models to provide a quantitative perspective on recent unconventional economic policies, similar to Elenev, Landvoigt, Shultz, and Van Nieuwerburgh (2021), or Haddad, Moreira, and Muir (2021), for example.

More broadly, our work contributes to the literature on production-based asset pricing in general equilibrium models, along the lines of Jermann (1998), Kaltenbrunner and Lochstoer (2010), Gourio (2012), Garleanu, Panageas, and Yu (2012) or Kuehn, Petrosky-Nadeau, and Zhang (2014). Relative to that work, our model also implies that part of the resolution to the low risk-free rate puzzle embedded in the equity premium, may stem from the liquidity services or the convenience yields that safe assets provide, similar to Bansal and Coleman (1996).

2 Empirical Motivation

We start by collecting and documenting some stylized facts regarding the links between safe asset supply and liquidity and default premiums, respectively. Doing so, we connect and put in perspective novel results with patterns reported previously in the literature. Therefore, the objective of this section is to set the stage and provide some context on the empirical regularities our model is meant to capture and explore.

Figure 1 provides some first suggestive graphical evidence regarding the links between safe asset supply and liquidity and default premiums. We focus on the GZ spread in Gilchrist and Zakrajŝek (2012) as the relevant corporate bond spread, and the spreads between general collateral repo rate (Repo) and treasury bill rate as a measure of the liquidity premium. The figure illustrates the dynamic relationship of liquidity and default premiums in our sample by plotting the demeaned corporate bond spread in Gilchrist and Zakrajŝek (2012) and the spreads between general collateral repo rate (Repo) and treasury bill rate. While naturally default premiums jump up during recessions (indicated by the shaded bars), when government debt tends to rise, liquidity premiums tend to fall. This pattern is especially pronounced in more recent recessions, such as the great recession following the financial crisis which constituted a severe liquidity crisis. In the recessions at the beginning of our sample, the pattern is somewhat weaker, but nevertheless, there tends to be downward pressure on liquidity premiums in the earlier stages of the downturns.

In Table 1 we report some preliminary regression evidence using our main default and liquidity measures[5]. Panels A and B in the table document that government debt, as measured by the log debt-to-GDP ratio, is significantly positively related to default premia, while significantly negatively so to liquidity premia [6]. This holds both in levels as well as in first differences. Moreover, the results get stronger when controlling for another well-known determinant of both liquidity and default premia, namely volatility, as measured by realized stock return volatility. In terms of predictive regressions, panel C documents that government debt predicts significantly higher expected corporate bond excess returns going forward, especially so for high yield bonds. Notably, the returns of a strategy going short investment-grade and long high yield bonds are predictable by the debt-to-gdp ratio as well. These results complement earlier results, e.g. in Liu (2018) and Croce, Nguyen, Raymond, and Schmid (2019), that government debt predicts higher excepted stock returns in the time series, and further corroborates the strong connection between the debt-to-gdp ratio and risk premia.

Panel D of Table 1 gives a glimpse of another important aspect of the relationship between government debt and risk on the one hand and liquidity on the other hand side, namely its nonlinearity. In particular, by interacting changes in government debt with their levels, we find that changes are associated with higher credit spreads, and through the interaction term, especially so when government debt is high. On the other hand, the effects of changes on liquidity premia are alleviated when government debt is high, although this effect is statistically weaker.

Together, these results provide suggestive evidence that increasing the supply of government

[5] See Liu (2018) for rich alternative specifications, and robustness.

[6] We abstract from the role of monetary policy in our empirical and theoretical analysis, focusing on a consolidated government budget constraint. Given substitution between Treasuries and bank deposits as liquid assets, there is an ongoing debate on the extent to which movements in liquidity premiums can be absorbed by monetary policy instruments in levels (see Nagel (2016), Li (2020), and Li, Ma, and Zhao (2020)), but the effects of Treasury supply on growth rates in uncontroversial.

bonds provides liquidity and safety services to investors by lowering liquidity premiums, but at the same time, raises default risk and default premia in the corporate sector. A natural concern, clearly, is reverse causation as rising government debt may reflect adverse macroeconomic shocks that both raise safety needs and risk premia. While we cannot entirely rule this out, to alleviate this concern, we elaborate on this link by providing some more formal econometric evidence on the dynamic relationship between government debt and yield spreads by means of a vector autoregression framework.

Going beyond the mere correlations documented in Table 1, the VAR framework allows to trace out the responses of liquidity premia and credit spreads to empirically identified innovations to the Treasury supply. In particular, we estimate an eight-variable VAR of the following form

$$Z_t = \Phi Z_{t-1} + u_t$$

$$Z_t = [ffr_t,\ \Delta ip_t,\ vol_t,\ r_t^{ex},\ by_t,\ GZ_t,\ GZp_t,\ repobill_t]$$

The VAR includes the fed funds rate (ffr_t), industrial production growth (Δip_t), stock return volatility (vol_t), corporate bond excess return (r_t^{ex}), debt-to-GDP ratio (by_t), corporate bond spread (GZ_t) and the premium (GZp_t) in Gilchrist and Zakrajšek (2012), as well as the spreads between general collateral repo rates and treasury bill rates ($repobill_t$). The corporate bond premium, (GZp_t), is constructed in Gilchrist and Zakrajšek (2012) to provide an empirical measure of the component of credit spreads that reflects compensation for systematic default risk, as defaults tend to cluster in downturns. We use this measure as our primary empirical proxy for default risk premia, capturing systematic rather than idiosyncratic default risk.

Following the literature, we use an identification strategy that recursively orders the variables as above. Accordingly, we identify innovations to the fifth variable as a non-discretionary increase of government debt, or, in other words, a debt shock. This shock increases the debt-to-GDP ratio but is orthogonal to the feds fund rate, IP, volatility, and corporate bond excess return contemporaneously. Therefore, plausibly, the shock is not driven by movements in the macroeconomy, monetary policy, stock markets, treasury market, and the corporate bond market, as captured by our empirical proxies[7]. The estimated impulse responses of yield spreads therefore provide

[7] An alternative approach, with arguably somewhat narrower scope, would entail examining empirically well-identified fiscal shocks. In that spirit, for example, consistent with our results, Boons, Ottonello, and Valkanov (2021) document that countercyclical defense spending news shocks raise credit spreads, especially through their effects on risk premia. Given the lack of well-identified debt shocks in the literature, we opt for a more agnostic

evidence on the effects of debt shocks on credit market conditions.

Figure 2 shows the impulse response of the spreads in the corporate bond market where credit risks are important. In that market, the debt shock significantly increases not only credit spreads, but also default risk premia (as measured by (GZp_t)) and expected excess returns on corporate bonds. The latter distinction is important as credit spreads also reflect compensation for idiosyncratic default risk, while the risk premium measures isolate compensation for systematic risk, so that this observation suggests a debt shock indeed creates macroeconomic risk compensated in corporate bond markets. In contrast, we find a negative response of the Repo/Bill spreads in the money market where credit risks are of second order, in line with the notion of falling liquidity premia familiar from the literature. These results confirm that government debt has differential effects on different markets. Naturally, lower economic growth or higher volatility could lead to higher debt and credit spreads simultaneously. This is indeed the case in our estimation. Since we use the recursive identification to orthogonalize the shocks, the effect of a debt shock plausibly is not driven by these channels[8].

We expect movements in credit spreads and premia to be reflected in firms' financing choices, and especially debt issuance. To provide evidence on such effects, we augment the VAR with two other variables, namely the net increases of corporate bond and commercial paper of nonfinancial corporate business, normalized by GDP. As shown in the leftmost panel in Figure 3, the debt shock significantly reduces the issuance of corporate bonds and commercial paper. This suggests substantial changes in firms' issuance and financing activities subsequent to movements in government debt.

In our VAR framework, we can similarly estimate the response of corporate debt issuance activity to unexpected movements in other variables. We focus on innovations prevalent in the literature, such as credit shocks (e.g. Jermann and Quadrini (2012)) and liquidity shocks. Following the recursive identification strategy adopted above, we identify the innovations to the corporate bond spread as credit shocks and the innovations to the spreads between general collateral repo rate and treasury bill rate as liquidity shocks. As shown in the middle and right panels in Figure 3, the corresponding responses of corporate issuance activity are negative to both shocks. The responses to a liquidity shocks are somewhat muted, but statistically significantly negative over medium horizons in case of credit shocks.

approach.

[8]Results are unchanged if we use the Chicago Fed National Activity Index or GDP in a quarterly VAR.

These observations, perhaps suggestive, prompt us to develop a formal model to examine, and to quantify, the role of government debt supply for liquidity and default premiums, and the macroeconomy. We turn to the model next.

3 Model

We develop a general equilibrium asset pricing model with endogenous liquidity and default premiums. There is a consumer sector with risk-sensitive households, a production sector in which firms finance investment with equity and defaultable bonds, and a government that finances expenditures by levying taxes and issuing bonds. Households face stochastic liquidity needs which they can cover by selling off financial assets, subject to transaction costs. These liquidity needs lead to endogenous, state and asset dependent liquidity premia that households attribute to various financial assets. Taxes are endogenously determined via the government's budget constraint.

We start by describing the household, production, and government sectors, and then detail the pricing of financial assets.

3.1 Households

The economy is populated by a continuum of households of measure one. Households have Epstein-Zin recursive preferences preferences defined over a composite of aggregate consumption, C_t, and labor, L_t, defined as $\tilde{C}_t = C_t(1 - L_t)^{1-\vartheta}$, so that lifetime utility is given by

$$U_t = [(1-\delta)\tilde{C}_t^{\frac{1-\gamma}{\theta}} + \delta(E_t[U_{t+1}^{1-\gamma}])^{\frac{1}{\theta}}]^{\frac{\theta}{1-\gamma}},$$

where δ is the time discount factor, γ is the relative risk aversion, ψ denotes the intertemporal elasticity of substitution (IES), and $\theta \equiv \frac{1-\gamma}{1-/\psi}$. We assume that $\psi > \frac{1}{\gamma}$, so that the agent has a preference for early resolution of uncertainty following the long-run risks literature.

Households maximize utility by supplying labor and by participating in financial markets. Specifically, the household can take positions in the stock market, S_t, in corporate bonds, B_t, and in government bond markets, B_t^g. For convenience, we scale these positions by GDP (Y_t, defined below), so that the values of stocks, corporate bonds, and government bonds over GDP are denoted by $V_{e,t} = P_t^e S_t/Y_t, V_{c,t} = Q_t B_{t+1}/Y_t, V_{g,t} = Q_t^g B_{t+1}^g/Y_t$ respectively. Here, P_t denotes the price per share of equity, Q_t is the price of a corporate bond, and Q_t^g is the price of a government bond. These prices will be determined endogenously below. Participating in financial markets exposes households to liquidity needs in the magnitude ξ_t with probability λ_t, covering which involves trading in financial assets that is associated with costs $\lambda_t \nu_t(V_{g,t}, V_{c,t})$ that we endogenize below. Moreover, wages w_t are subject to income taxes $\tau_{l,t}$. Households also receive transfers TR_t from the government and intermediaries. Accordingly, in our notation, households' budget constraint becomes

$$\begin{aligned} &C_t + V_{g,t}Y_t + V_{c,t}Y_t + V_{e,t}Y_t + \lambda_t \nu_t(V_{g,t}, V_{c,t})Y_t \\ =&V_{g,t-1}Y_{t-1}R_{g,t} + V_{c,t-1}Y_{t-1}R_{c,t} + V_{e,t-1}Y_{t-1}R_{e,t} + w_t L_t(1-\tau_{l,t}) + TR_t, \end{aligned}$$

so that the stochastic discount factor is given, in a standard manner, by

$$M_{t+1} = \delta(\frac{C_{t+1}}{C_t})^{-1}(\frac{\tilde{C}_{t+1}}{\tilde{C}_t})^{1-1/\psi}(\frac{U_{t+1}^{1-\gamma}}{E_t[U_{t+1}^{1-\gamma}]})^{1-1/\theta}.$$

3.1.1 Endogenous Liquidity

A critical feature of our model is that all financial assets endogenously exhibit different liquidity attributes, and thus, liquidity premiums. To embed a model of endogenous liquidity in our equilibrium asset pricing model, we adopt a market structure similar to Amihud and Mendelson (1986) and He and Xiong (2012) in which trading assets is subject to transaction costs[9]. The key innovation is that our agents can choose between several different assets to sell when they are hit by a liquidity shock. This feature generates interdependence of liquidity across different markets in a general equilibrium setting with aggregate risk. To that end, we assume that every period t contains an intra-period t^+ in which agents in each household serve distinct roles as workers, firm managers, (equity) investors, (fixed income) asset managers, and intermediaries, respectively. While we cast the problem in terms of assets' liquidity attributes here, we discuss below that the same setup naturally allows for an interpretation in terms of attributes that are commonly linked

[9] It would be appealing to endogenize transaction costs in the spirit of the search-based theory of liquidity premiums, following e.g. Duffie, Garleanu, and Pedersen (2005) or Lagos and Rocheteau (2009), as recently surveyed by Weill (2020). However, most of this literature examines one-asset models and analyzing multiple asset models with interdependence of liquidity premiums across assets is challenging. See Vayanos and Weill (2008), or Milbradt (2017), for examples with multiple indivisible assets, and the recent advance in Uslu and Velioglu (2019) for divisible multiple assets. Given our quantitative and computational approach, we thus take transaction costs as exogenous.

to safety, such as collateral value, as well [10].

Timeline We start by detailing the timeline.

- Time t.

Households make their asset allocation decisions. Holdings of government bonds and corporate bonds are V_g, and V_c, respectively. As noted above, these are scaled by GDP.

- Time t^+. The intra-period.

Within each household, investors manage the stock holdings, while asset managers manage the government and corporate bond portfolios. Given our focus on credit markets, only asset managers play a critical role in our model[11]. Indeed, each asset manager is hit by a liquidity shock with probability λ_t[12] with size $\xi_t \equiv \xi_{t^+} Y_t$. We assume that liquidity shocks are log-normally distributed, so that $\xi \sim \log N(\mu_\xi,\ \sigma_\xi^2)$. While, assuming so, we are implicitly effectively attributing all corporate bond trading to liquidity trades, we can, realistically perhaps, interpret the liquidity shocks in our model as capturing funding shocks, and portfolio rebalancing needs, shocks to individual beliefs, or idiosyncratic preference shocks, more broadly. Liquidity shocks bring about funding needs, which asset managers can choose to cover either by selling off an amount of ξ_t of their asset holdings to the competitive intermediaries, or by liquidating subject to liquidation costs φ_l. Liquidated assets are returned in the form of cash to workers who deposit the proceeds with intermediaries. The intermediaries buy these assets using deposits. The intermediaries, thus, essentially provide a technology of liquidity transformation.

To cover funding needs through asset holdings, asset managers have to sell the assets off at a price lower than the equilibrium price at time t and incur transaction costs φ. We assume that government bonds and corporate bonds come with different transaction costs in that $\varphi_g < \varphi_c$, and those are lower than the liquidation costs φ_l, in that $\varphi_g < \varphi_c < \varphi_l$. Intermediaries are competitive and use households' stochastic discount factor to value assets, so that $Q_{t^+} = Q_t$. Bidding at $Q_{t^+}(1-\varphi)$, their profits amount to $Q_{t^+}\varphi$, which they return back to the household.

[10]Empirically, liquidity and safety premia are hard to disentangle, as assets may be easy to trade because investors perceive them as safe and appreciate their role as collateral, and vice versa, and the implementations in our model are likely linked in the data. We therefore use the terms interchangeably in our empirical and quantitative analysis.

[11]It would be straightforward to combine investors and asset managers, at the cost of introducing additional parameters into an already rich model.

[12]In our baseline specification, we set that probability to be constant, that is, we set $\lambda_t \equiv \lambda$. We provide an extension with stochastic λ_t to account for liquidity crises in section 5.

- Time $t+1$.

Workers, firm managers, investors, asset managers, and intermediaries all convene back at the household and make consumption decisions. We have perfect consumption risk sharing in the households.

Household's Liquidation Problem When hit by a liquidity shock, asset managers need to decide how to optimally cover their liquidity needs by either selling off government bond holdings of size u_g and corporate bond holdings of size u_c, or to liquidate some of their positions. The liquidity shock and asset holdings are scaled by GDP. We assume that asset managers choose u_g and u_c to minimize liquidation costs, which amounts to a static problem. More formally, their liquidation choices satisfy

$$\min_{u_g,u_c} \varphi_l \max[\xi - (u_g + u_c), 0] + \varphi_g u_g + \varphi_c u_c, \quad \text{subject to} \quad u_g \leqslant V_g, u_c \leqslant V_c.$$

The liquidation problem has a straightforward solution. As the liquidation cost exceeds the transaction costs, the solution follows a pecking order:

$$\begin{cases} u_g = \xi & \xi \leqslant V_g \\ u_g = V_g,\ u_c = \xi - V_g & V_g < \xi \leqslant V_g + V_c \\ u_g = V_g,\ u_c = V_c & \xi > V_g + V_c \end{cases}$$

In words, households find it optimal to first sell off government bonds, then cover the remaining liquidity needs by selling corporate bonds, and only liquidate assets in case liquidity needs exceed joint government and corporate bond holdings.

Liquidity Premium In our model, liquidity premiums arise endogenously from the marginal savings of liquidation costs given some government and corporate bonds holdings. Integrating over ξ, we obtain expected liquidation costs for a given bond portfolio as

$$\begin{aligned} \nu(V_g, V_c) = &\int_0^{V_g} \varphi_g \xi d\Phi_\xi + \int_{V_g}^{V_g+V_c} \left[\varphi_g V_g + \varphi_c(\xi - V_g)\right] d\Phi_\xi \\ &+ \int_{V_g+V_c}^{\infty} \left[\varphi_g V_g + \varphi_c V_c + \varphi_l(\xi - V_g - V_c)\right] d\Phi_\xi. \end{aligned}$$

Given our assumptions, $\nu(V_g, V_c)$ is differentiable, so that the marginal benefits of a government bond satisfy

$$\frac{\partial}{\partial V_g}\nu(V_g, V_c) = -(\varphi_c - \varphi_g)\int_{V_g}^{V_g+V_c} d\Phi_\xi - (\varphi_l - \varphi_g)\int_{V_g+V_c}^{\infty} d\Phi_\xi < 0, \tag{1}$$

given the parameter restrictions. Accordingly, the benefits of an additional unit of government bonds stem from saving liquidation costs if households either sell corporate bonds (first term) or liquidate assets (second term). Similarly, the marginal benefits of corporate bond holdings stem from saving liquidation costs in that

$$\frac{\partial}{\partial V_c}\nu(V_g, V_c) = -(\varphi_l - \varphi_c)\int_{V_g+V_c}^{\infty} d\Phi_\xi < 0.$$

Notably, the liquidation costs that emerge endogenously in our model share many properties with common reduced-form specifications of liquidity premiums, in that, formally, we have that $\nu > 0, \nu' < 0, \lim \nu\text{'} \to 0$, and $\nu'' > 0$. In contrast to such specifications, however, liquidity premiums endogenously depend on the state variables in our model. Moreover, a number of important economic properties of our liquidation costs are straightforward to establish. Increasing the supply of government bonds decreases the liquidity benefits, in that it renders government bonds less useful as assets to buffer liquidity shocks, in that

$$\frac{\partial^2}{\partial V_g^2}\nu(V_g, V_c) = (\varphi_l - \varphi_c)\phi_\xi(V_g + V_c) + (\varphi_c - \varphi_g)\phi_\xi(V_g) > 0,$$

given the pecking order of transaction and liquidation costs. Similarly, we have

$$\frac{\partial^2}{\partial V_c \partial V_g}\nu(V_g, V_c) = (\varphi_l - \varphi_c)\phi_\xi(V_g + V_c) > 0,$$

so that a higher government bond supply reduces the relevance of corporate bond holdings in buffering liquidity shocks.

Liquidity premium versus safety premium In our baseline implementation, so far, convenience yields in bonds reflect a liquidity premium as debt instruments allow households to absorb sporadic liquidity shocks. We now briefly discuss another implementation of our setting in which the convenience yields capture more directly a safety premium in that debt instruments serve as collateral in repurchase agreements (repos).

In this implementation, we assume that asset managers can choose to cover funding needs either by borrowing through repos from competitive intermediaries, or by liquidating subject to liquidation costs φ_l. We assume that government bonds and corporate bonds come with different repo rates $\varphi_g < \varphi_c$, as well as haircuts $\chi_g < \chi_c$. Here, fund managers sell bonds at price $Q_t(1-\chi)$ only to buy them back at $Q_t(1-\chi)(1+\varphi)$ in an instant.

More formally, in this setting, households borrow through government bond repos of size u_g and corporate bond repos of size u_c. These borrowing choices satisfy

$$\min_{u_g,u_c} \varphi_l \max[\xi - (u_g + u_c), 0] + \varphi_g u_g + \varphi_c u_c, \quad \text{subject to} \quad u_g \leqslant V_g, u_c \leqslant V_c.$$

As above, the solution obeys a pecking order:

$$\begin{cases} u_g = \xi & \xi \leqslant V_g(1-\chi_g) \\ u_g = V_g(1-\chi_g),\ u_c = \xi - V_g & V_g(1-\chi_g) < \xi \leqslant V_g(1-\chi_g) + V_c(1-\chi_c) \\ u_g = V_g(1-\chi_g),\ u_c = V_c(1-\chi_c) & \xi > V_g(1-\chi_g) + V_c(1-\chi_c) \end{cases}$$

Accordingly, in the absence of haircuts, the household's problem is exactly identical to the liquidation problem described previously. If we allow for different haircuts, the pecking order is preserved, but the cutoffs are adjusted.

Trading Volume Our model also has implications for the endogenous trading volumes of government and corporate bonds. In particular, the expected trading volume over GDP, conditional on the arrival of a liquidity shock, of government bonds is straightforward to determine as

$$\int u_g d\Phi_\xi = \int_0^{V_g} \xi d\Phi_\xi + V_g \int_{V_g}^{\infty} d\Phi_\xi.$$

That is, as long as the liquidity shock ξ is sufficiently small, so that it can be covered by government bonds alone, realized volume in Treasuries is precisely the size of the shock, while for larger liquidity shocks, all government bonds will be sold off to begin with. Similarly, we find that the expected trading volume of corporate bonds satisfies

$$\int u_c d\Phi_\xi = \int_{V_g}^{V_g+V_c} (\xi - V_g) d\Phi_\xi + V_c \int_{V_g+V_c}^{\infty} d\Phi_\xi.$$

3.2 Firms

There is a continuum of ex ante identical firms. Firms invest, hire labor, and produce according to a constant returns to scale technology. Given advantageous tax treatment in line with the US tax code, firms issue debt as well as equity to finance expenditures. Ex post, firms are subject to an iid cash flow shock, which may be potentially large, and can prompt firms to declare bankruptcy. The trade-offs between tax advantages, liquidity benefits and default costs determine firms' capital structure decisions.

Production and Revenues Firms use capital, K_t and labor, L_t, to produce according to the constant returns to scale production technology

$$Y_t = K_t^\alpha (A_t L_t)^{1-\alpha},$$

where A_t is a stochastic productivity process, whose evolution is given as

$$\Delta a_{t+1} = \mu + x_t - \phi_\tau(\tau_t - \tau_{ss}) + \sigma_a \eta_{a,t+1}. \tag{2}$$

Here x_t, with $x_{t+1} = \rho_x x_t + \sigma_x \eta_{x,t+1}$ captures a persistent long-run component in productivity[13], and τ_t is the prevailing tax rate, which will be pinned down endogenously below through the government's budget constraint. This specification, with $\phi_\tau > 0$, captures negative long-run effects of elevated taxation on economic growth in a parsimonious and tractable way. While the notion that rising tax rates exert a negative effect on productivity growth emerges endogenously in models with endogenous growth, for tractability, we directly specify that link here[14].

Solving out the static labor choice problem, we can define firms' profit function as $\Pi_t = \alpha K_t^{\alpha-1}(A_t L_t)^{1-\alpha}$. To introduce firm heterogeneity in a meaningful and tractable manner, we

[13]See, for example, Comin and Gertler (2006),Croce (2014), or Kung and Schmid (2015) for evidence and models.

[14]See, for example in Croce, Nguyen, Raymond, and Schmid (2019), which also provides empirical support from firm-level data in the US. Relatedly, Jaimovich and Rebelo (2017) provide an endogenous growth model with political economy considerations that render the link sharply nonlinear, so that as tax rates rise, their negative impact on growth rises dramatically.

assume that firms are subject to additive, idiosyncratic shocks on their cash flows in the overall amount of $-z_{i,t}K_t$. The shock $z_{i,t}$ is scaled by capital. The scaling is important for aggregation. We assume that these shocks are i.i.d. across firms and time, and follow a normal distribution, so $z_{i,t} \sim N(0, \sigma^2_{z,t})$. Moreover, we specify idiosyncratic volatility as countercyclical in that $\sigma_{z,t} = \sigma_{z,0} \exp(-\phi_{\sigma,a}(E_t \Delta a_{t+1} - \mu))$.

We think of these as direct shocks to firms' operating income and not necessarily output. They summarize the overall firm specific component of their business risk. Although they average to zero in the cross section, they can potentially be very large for any individual firm.

Investment and Financing We assume that investment is subject to convex adjustment costs. Firm-level capital accumulation is thus given by

$$K_{t+1} = \Phi(I_t/K_t)K_t + (1-\delta)K_t$$

where Φ denotes the adjustment cost function.

Given the advantageous tax treatment of debt in the tax code, firms fund investment by issuing both equity and defaultable debt. For tractability, we assume that debt comes in the form of one-period securities and refer to the stock of outstanding defaultable debt at the beginning of the period as B_t. In addition to the principal, the firm is also required to pay a coupon C per unit of outstanding debt. Let Q_t denote the price of a new bond issue that comes due at time $t+1$. We will determine the bond pricing function endogenously below.

With this notation at hand, we can, taking into account investment expenses and net debt outlays, write firms' equity distributions as

$$D_{i,t} = (1-\tau_t)\Pi(K_t) - z_{i,t}K_t - I_t + Q_t B_{t+1} - (1 + (1-\tau_t)C)B_t.$$

The last term reflects the fact that interest payments are tax deductible, in line with the tax code.

Firms' Problem Firms' objective is to maximize equity value, that is, $V_{i,t}(K_t, B_t, z_{i,t}; S_t)$. The individual state variables are capital K_t, corporate bonds B_t, and the idiosyncratic shock $z_{i,t}$. We denote the aggregate state variables as S_t, which contain long-run productivity x_t and fiscal policies specified below. If a firm does not default, it invests, issues new debt, and pays dividends. We can therefore write the equity value function as

$$V_{i,t}(K_t, B_t, z_{i,t}; S_t) = \max_{I_{i,t},K_{t+1},B_{t+1}} D_{i,t} + E_t[M_{t+1} \int^{z^*_{t+1}} V_{i,t+1}(K_{t+1}, B_{t+1}, z_{i,t+1}; S_{t+1})dF]$$

The truncation of the integral reflects the possibility of default: a sufficiently severe cash flow shock implies an equity value of zero. In this case, equity holders are unwilling to inject further capital in the firm, and are better off defaulting. In our setup, default occurs whenever cash flow shocks exceed an endogenous and state-dependent cutoff level of z^*_t, which is implicitly defined by the condition $V_{i,t}(K_t, B_t, z^*_t; S_t) = 0$.

We note that given our assumption of iid cash flow shocks, outside default, all firms make identical investment and financing decisions.

Optimal Policies Denoting the capital price by $q_{k,t}$, optimal firm investment satisfies

$$q_{k,t} = \frac{\partial Q_t}{\partial K_{t+1}} B_{t+1} + E_t \left[M_{t+1} \int^{z^*_{t+1}} \frac{\partial V_{i,t+1}}{\partial K_{t+1}} dF \right],$$

so that, at the optimum, the cost of investment is offset by the increase of the bond price $\frac{\partial Q_t}{\partial K_{t+1}} B_{t+1}$ and the increase in future equity value $E_t \left[M_{t+1} \int^{z^*_{t+1}} \frac{\partial V_{i,t+1}}{\partial K_{t+1}} dF \right]$). Indeed, we have that $\frac{\partial Q_t}{\partial K_{t+1}} B_{t+1} > 0$, as higher corporate bond prices reflect higher collateral. Similarly, regarding corporate debt issuance, we have

$$\frac{\partial Q_t}{\partial B_{t+1}} B_{t+1} + Q_t + E_t \left[M_{t+1} \int^{z^*_{t+1}} \frac{\partial V_{i,t+1}}{\partial B_{t+1}} dF \right] = 0,$$

so that the fall in bond prices $\frac{\partial Q_t}{\partial B_{t+1}} B_{t+1}$ and future equity values $E_t \left[M_{t+1} \int^{z^*_{t+1}} \frac{\partial V_{i,t+1}}{\partial B_{t+1}} dF \right]$) is offset by the issuance in the magnitude of Q_t. Here, additional debt financing depresses future equity values through higher default probablilites, stemming from a falling default cutoff z^*_{t+1}.

Indeed, the default boundary z^*_t satisfies $V_{i,t}(K_t, B_t, z^*_t; S_t) = 0$, which we can solve for

$$z^*_t = \frac{q_{k,t-1} R_{k,t} K_t - q_{k,t} K_{t+1} + Q_t B_{t+1} - (1 + (1 - \tau_t)C) B_t + V^{ex}_t}{K_t}.$$

Formally thus, we find $\frac{\partial z^*_t}{\partial B_t} < 0$. Below, we show that corporate bond prices, and thus default cutoffs and corporate investment depend on the government debt supply.

3.3 Government

We assume that the government faces an exogenous and stochastic expenditure stream that evolves as

$$\frac{G_t}{Y_t} = \mu_g + \rho_g \frac{G_{t-1}}{Y_{t-1}} + \sigma_g \varepsilon_{b,t}.$$

Moreover, the government also faces an exogenous and stochastic stream of transfers that we specify as

$$\frac{TR_t}{Y_t} = \mu_{tr} + \sigma_b \varepsilon_{b,t}.$$

Both spending and transfers are required outlays that the government needs to finance by issuing debt or raising taxes, at an endogenous, and possibly, time-varying tax rate τ_t. We assume that spending and transfers are driven by the same shock $\varepsilon_{b,t}$, which we refer to as a *fiscal shock*. Spending and transfers exhibit some relevant economic differences. Spending affects the resource constraint so that it raises aggregate demand and has to be met by a higher supply of goods in equilibrium. However, transfers *within* representative households do not affect aggregate demand directly, so that these shocks purely affect government outlays.

The government issues one-period zero-coupon bonds with price Q_t^g. We assume that the government conducts fiscal policy by sticking to a fiscal rule. In particular, we assume that the market value $Q_t^g B_{t+1}^g$ (detrended by Y_t) follows the law of motion

$$\frac{Q_t^g B_{t+1}^g}{Y_t} = \mu_b + \rho_b \frac{B_t^g}{Y_t} + \kappa_\tau (\sigma_g + \sigma_b) \varepsilon_{b,t}, \tag{3}$$

and thus inherits the stochastic properties of fiscal shocks. Rather than trying to characterize the optimal fiscal policy in our quantitatively driven setting, we view such a rule as a way to provide a quantitatively realistic and implementable representation of actual government debt management in a positive context, given the challenges to characterizing optimal policies, especially in risk-sensitive settings with Epstein-Zin preferences such as ours (see, e.g., Karantounias (2018)[15]).

Here, κ_τ captures a tax smoothing policy in that a part of the spending and transfer shock $\varepsilon_{b,t}$ is financed by debt issuance. The rest will be absorbed by taxes, as implied by the government budget constraint. In particular, the government is subject to a standard budget constraint of the

[15] In the author's words, in light of the optimal fiscal policy with recursive preferences, "actual fiscal policy is even worse than we thought" (p1).

form

$$Q_t^g B_{t+1}^g = B_t^g + G_t + TR_t - T_t.$$

where T_t denotes the government's overall tax revenue. The government budget constraint implies that these receipts satisfy

$$\frac{T_t}{Y_t} = \mu_g + \mu_{tr} - \mu_b + (1-\rho_b)\frac{Y_{t-1}}{Y_t}\frac{B_t^g}{Y_{t-1}} + \rho_g \frac{G_{t-1}}{Y_{t-1}} + (1-\kappa_\tau)(\sigma_g + \sigma_b)\varepsilon_{b,t}. \tag{4}$$

As the tax base is the sum of capital and labor tax income in that $T_t = \tau_t(\Pi(K_t) + w_t L_t)$, we can compute the corresponding equilibrium tax rate.

Tax Dynamics Although the tax rate is endogenous and depends on the state of the economy and other policy choices, it qualitatively follows intuitive dynamics. First, tax rates increase with the spending and transfer shocks, though the increases are not one-for-one. Second, tax rates increase with the existing government debt as a form of fiscal consolidation. Indeed, because $(1-\rho_b)\frac{Y_{t-1}}{Y_t} > 0$ in expression (4) above, we see that higher debt implies high taxes. Third, the *volatility* of tax rates also increases with the existing government debt. Formally, this is because $(1-\rho_b)^2(\frac{B_t^g}{Y_{t-1}})^2 Var_t(\frac{Y_{t-1}}{Y_t}) > 0$ in equation (4). Intuitively, on the other hand, the real distortions stemming from elevated tax pressure depress production and thus lead to a slowly shrinking average tax base. This effect is reinforced by our specification of productivity growth, expression (2), whereby taxes lead to a long-run productivity slowdown. In such a scenario, adverse shocks have to be absorbed by even higher future tax commitments. Effectively, thus, the model captures excess fiscal volatility at elevated tax levels. We illustrate these dynamics by means of our numerical solution below.

3.4 Equilibrium and Asset Prices

To complete the model, we require markets to clear. We assume that the liquidation costs effectively are the profits of the intermediaries. On the other hand, losses in default are absorbed as profits of the households (e.g. lawyers). These profits are also part of the output. The aggregate resource constraint therefore takes the standard form

$$Y_t = C_t + I_t + G_t.$$

For tractability, this specification embeds the arguably extreme assumption that government spending is effectively entirely waste.

A critical feature of our model is the interplay between securities' liquidity benefits and their default risk. We now turn to a detailed examination of the endogenous linkages that emerge in our setup.

Government Bonds We can use households' optimality conditions to determine their valuations of a government bond, and find that its price Q_t^g satisfies

$$Q_t^g(1+\lambda_t\nu_{g,t}) = E_t\left[M_{t+1}\right],$$

where $\nu_{g,t} \equiv \frac{\partial}{\partial V_g}\nu(V_g, V_c)$ denotes the marginal value of government bonds' liquidity services. The expression shows that households do not only value government bonds because of their future payments, but also because they are valuable in covering households' liquidity needs in case they are hit by a liquidity shock of size λ_t. Importantly, recall that $\nu_{g,t} < 0$, so that yields on government bonds are lower than the risk free rate that would obtain in a frictionless setup, simply reflecting the conditional expectation of the stochastic discount factor.

Corporate Bonds Corporate bond values Q_t depend on default probabilities and costs of default ζ_t, as well as on the liquidity benefits they provide to households. Accordingly, corporate bond prices satisfy

$$Q_tB_{t+1}(1+\lambda_t\nu_{c,t}) = E_t\left[M_{t+1}\left(\int^{z^*_{t+1}}(1+C)B_{t+1}dF + (1-\zeta_t)\int_{z^*_{t+1}}(V_{i,t+1}+(1+C)B_{t+1})dF\right)\right], \quad (5)$$

where $\nu_{c,t} \equiv \frac{\partial}{\partial V_c}\nu(V_g, V_c)$ denotes the marginal liquidity services that corporate bonds offer to households. The first term on the right hand side denotes debt service outside default, while the second term shows that bondholders recover firm value net of default costs ζ_t after a sufficiently adverse cash flow shock. This expression highlights that corporate bonds also provide liquidity benefits to households, but possibly in different magnitudes, and different states than government bonds [16].

[16] Anecdotally, the existence of a liquidity premium in corporate bonds is consistent with the large mutual fund inflows into the corporate bond market observed after the financial crisis, which has been widely ascribed to reaching for yield within asset classes that enjoy some safe asset status, such as corporate bonds (see, e.g. Falato, Goldstein, and Hortacsu (2021))

More compactly, we can thus write the corporate bond pricing equation as

$$Q_t(1 + \lambda_t \nu_{c,t}) = E_t \left[M_{t+1} \left((1 + C) F(z^*_{t+1}) + Q_t R_{rec,t+1} \right) \right],$$

where $R_{rec,t+1}$ denotes the recovery value, that is

$$R_{rec,t+1} = (1 - \zeta_t) \frac{\int_{z^*_{t+1}} (V_{i,t+1} + (1 + C) B_{t+1}) dF}{Q_t B_{t+1}}.$$

Corporate Credit Spread To determine credit spreads, we first note that corporate bond yields can be computed as

$$\frac{1 + C}{Q_t} = \frac{1 + \lambda_t \nu_{c,t} - E_t[M_{t+1} R_{rec,t+1}]}{E_t[M_{t+1} F(z^*_{t+1})]}$$

so that comparing with the yield on a government bond with the same coupon, that is $\frac{1+\lambda_t \nu_{g,t}}{E_t[M_{t+1}]}$ gives

$$y^c_t - y^g_t = E_t[M_{t+1}] E_t[\frac{1 - F(z^*_{t+1})}{E_t[M_{t+1}]} - R_{rec,t+1}] + Cov_t[M_{t+1}, \frac{1 - F(z^*_{t+1})}{E_t[M_{t+1}]} - R_{rec,t+1}] + \lambda_t \nu_{c,t} - \lambda_t \nu_{g,t}.$$

The first term captures expected losses in default, while the second term is a default risk premium in that it captures to what extent losses arise in high marginal utility states. We note that the first term also reflects idiosyncratic default risk, while the second only captures systematic exposure. Finally, the last term captures the differential liquidity services that government, and corporate bonds, respectively, provide to households. This liquidity spread increases with the probability of liquidity shocks λ_t and the liquidity advantage of government bonds over corporate bonds, measured by the differential of the marginal values of endogenous liquidity services $\nu_{c,t} - \nu_{g,t}$. Credit spreads thus capture both a liquidity and a default component in our model.

4 Quantitative Analysis

Most of our quantitative analysis is based on model simulations. We use a global approximation technique to solve for the model policy functions. We start by describing our numerical approach along with our parameter choices and then evaluate the quantitative implications of our model.

4.1 Computation and Calibration

The possibility of default induces strong nonlinearities in payoffs, discount factor, and policies. Therefore, we use a nonlinear solution method and solve the model globally using a collocation approach. Since we face multiple state variables and the curse of dimensionality, we use Smolyak polynomials on sparse grids as the basis functions to approximate the policy functions.

In the following, we provide a brief overview of our solution method. A more detailed description of the algorithm is provided in the appendix. We start by approximating N_c control variables as functions of N_s state variables using N_p Smolyak polynomials and $N_p \times N_c$ coefficients β. There are $N_s = 6$ state variables $K_t,\ x_t,\ B_t^g,\ \varepsilon_{b,t},\ G_t/Y_t,\ Y_t/A_t$, $N_c = 5$ control variables $L_t,\ U_t,\ B_{t+1},\ Q_t,\ Q_t^G$, and $N_p = 85$ Smolyak polynomials. Choosing the approximation level of the Smolyak method to be 2, the highest order polynomial of each state variable is 4. We solve for the coefficients ι by computing the system of N_c equilibrium conditions over a grid of $N_p \times N_c$. This process involves projecting state variables one period forward, computing the implied approximation errors, and minimizing these with respect to ι. We then simulate the model and compute the approximation errors in the state space, and repeat the process until convergence.

The model is calibrated at quarterly frequency. We report our parameter choices in table 2. Regarding preference and technology parameters, such as risk aversion γ, intertemporal elasticity of substitution ψ, time discount β, leisure parameter ϑ, capital share α, and depreciation δ, we pick standard values in line with the literature. Our parameter choices for preferences imply that households have a preference for early resolution of uncertainty, so that they are concerned about shocks to long-run growth prospects. These choices are in line with the long-run risk literature pioneered in Bansal and Yaron (2004), or Drechsler and Yaron (2011), entailing a large intertemporal elasticity of substitution.

Regarding aggregate technology, the quarterly growth rate of productivity μ is 0.45% to match average trend growth in the postwar sample, with volatility σ_a set to match the volatility of consumption growth. The long run productivity has persistence ρ_a of 0.97 and shock volatility σ_x set 10% of the short run shock volatility, in line with the estimates in Croce (2014). The adjustment cost function is specified as $\Phi(\frac{I}{K}) = [\frac{a_1}{1-1/\xi_k}(\frac{I}{K})^{1-1/\xi_k} + a_2]$, where the coefficients a_1 and a_2 are chosen such that $\Phi(\frac{I}{K}) = 0$ and $\Phi'(\frac{I}{K}) = 0$ at the steady state, in line with the production-based asset pricing literature, as in Jermann (1998).

In terms of firm-level parameters, we pick the idiosyncratic shock volatility $\sigma_{z,0}$ to match the average default rate. The mean default loss ζ is set at 0.4 of the total asset value, which is at the lower bound of estimates reported in the literature. Idiosyncratic volatility exhibits mild countercyclicality governed by the parameters $\phi_{\sigma,a}$, consistent with the evidence in Chen (2010), for example. Finally, the coupon rate on corporate bonds is set at 1.5%.

The long run productivity growth effects of taxation ϕ_τ are set at 0.03. This parameter choice captures the notion that rising taxes have detrimental effects on productivity growth in the long run, consistent with the evidence in Croce, Nguyen, Raymond, and Schmid (2019). The processes for government debt and spending are chosen to match their data counterparts. The parameter κ_τ determines the degree of tax smoothing and is set to match the tax rate persistence and volatility.

We calibrate the liquidation cost φ_g, φ_c and φ_l to match bid ask spreads in government bond, corporate bond, and stock markets. The liquidity shock probability (constant in the baseline specification) λ is calibrated to the absolute deviation of the money market mutual fund flow relative to the fund size. This data moment, estimated to be 0.12, captures that around 12 percent of the money market mutual fund flows in and out on a quarterly basis. The distribution of the liquidity shock determines the turnover of government and corporate bonds. We discipline μ_ξ and σ_ξ by matching the relative turnover of treasury and corporate bonds, and the liquidity premium on treasury bills, measured by the Repo/Bill spread.

4.2 Quantitative Results

We start by assessing the overall quantitative fit of our model for liquidity and credit spreads by inspecting a wide range of credit and asset market statistics, along with macroeconomic moments. We then illustrate the basic intuition and discuss the economic mechanisms more succinctly by evaluating the relevant equilibrium policies.

4.2.1 Moments

Table 3 reports basic moments from model simulations regarding some of the main building blocks of our model. Panel A shows that our calibrated model is consistent with important aspects of the dynamics of fiscal variables. As overall government expenditure and debt dynamics are targeted through our specification of the fiscal rule, their means and volatilities match their empirical counterparts rather well. Moreover, as in the data, government expenditures exhibit countercyclical dynamics given a correlation with output growth of -0.2. On the other hand, taxes are endogenously determined through the government's budget constraint. Our model matches levels, volatilities, and persistence of taxes quite well. A quantitatively relevant account of tax dynamics is critical in our context, as taxes emerge as an endogenous source of long-run productivity risk in our model, priced in equity and, importantly, credit markets. Taken together, our model displays procyclical surplus dynamics with a realistic correlation of surplus with output growth of 0.29, a critical feature of the data, as emphasized recently by Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2019) and Jiang, Lustig, Van Nieuwerburgh, and Xiaolan (2020).

Panel B reports statistics regarding default risk in corporate credit markets. Importantly, the model rationalizes the average corporate yields spreads of around a hundred basis points observed in the data. At the same time, default rates in the model are realistically low, just as recovery rates line up well with their empirical counterparts. In spite of this low default risk, leverage ratios are well matched in the model, at around forty percent. The joint observation of high credit spreads and low leverage in the presence of significant tax advantages of debt, and low default probabilities, is often referred to as the 'credit spread puzzle' and the 'low leverage puzzle, respectively.

Our rationale builds on the recent literature on the 'credit spread puzzle' (see, for example, Chen, Collin Dufresne, and Goldstein (2009), Chen (2010), or Bhamra, Kuehn, and Strebulaev (2010)), although with a twist. In our risk-sensitive model, defaults tend to cluster in downturns, so that bondholders incur losses precisely when their marginal valuations are highest, and a fraction of spreads, namely close to twenty percent, is made up by a default premium that investors require as compensation for countercyclical losses. In contrast to the previous literature, the default premium in our model here emerges in a fully fledged general equilibrium production economy. Moreover, our model also gives rise to a novel twist, in that corporate bonds provide less valuable liquidity services to investors than government bonds. This differential liquidity benefit is priced into corporate bonds and contributes a quantitatively significant amount to spreads. Indeed, in our calibrated setting it makes up for about one fourth of the overall credit spread.

Panel C offers a more detailed investigation of the quantitative implications of the model for liquidity premia, and the dual role of safe asset supply for liquidity and risk premia more specifically. We first document a liquidity premium on government bonds of about 0.3, in line with the empirical estimates obtained in the recent literature, such as Nagel (2016). This number suggests, therefore, that yields on traded government bonds are significantly below the equilibrium risk free rate due to the liquidity services they provide. Corporate bonds also enjoy some liquidity benefits in spite of their inherent default risk, however the premium, at 0.07, is substantially smaller than the one on government bonds. Intuitively, in the context of the model, they trade with higher transaction costs in the market for liquidity services. While our model falls short of matching the turnover ratios in both government and corporate bond markets, it captures their relative magnitudes. In particular, it is quantitatively consistent with the intuitive observation that turnover in Treasury markets is substantially higher than in corporate bond markets.

Our model also captures some of the stylized facts regarding differential effects of safe asset supply on liquidity and default spreads, respectively. As demonstrated in section 2, a rising government debt supply lowers liquidity premia, but does raise default premia on corporate bonds at the same time. Our model is consistent with that observation. In particular, as reported in panel C, the regression coefficients on default spreads and liquidity spreads on the debt to GDP ratio in simulated data have positive and negative signs, respectively. Moreover, the magnitudes are roughly in the range of the empirical counterparts. In the next section, we discuss the economic mechanism underlying this quantitative result in more detail.

In panel D, we provide some quantitative evidence on the magnitude of 'crowding out' of corporate debt through the issuance of government debt. Indeed, in the data the regression coefficient of the aggregate market value of corporate debt on the government debt-to-GDP ratio is negative, consistent with the notion that government debt crowds out some of the private debt market activity. A similar pattern obtains in the model, although it is quantitatively somewhat overstated.

Our model is quantitatively broadly consistent with a wide range of stylized facts regarding aggregate fluctuations and stock returns, as table 4 shows. In particular, in spite of a realistically moderate amount of aggregate consumption risk, our model produces a significant equity premium of about five percent annually, and annual return volatility of close to seven percent. While this is to a large extent due to the exogenous and tax-based endogenous movements in long-run productivity risk, as explored in the literature previously, it obtains in spite of realistically low corporate leverage. At the same time, the model reasonably reproduces the relative volatilities of aggregate macro quantities, such as consumption, investment, and output, in the data, and is consistent with the fact that investment is significantly more volatile than consumption, a pattern that is often challenging to match in general equilibrium asset pricing models.

We provide a detailed sensitivity analysis of our quantitative results with respect to parameter choices and model specifications in Appendix C.

4.2.2 Dynamics

Beyond moments, figure 4 illustrates the dynamic properties of our model by showing empirically plausible impulse response functions, in line with those obtained in the data (figure 2). Just as in the data, expected excess returns, credit spreads, and the default risk premium rise, while liquidity premia decline with an increasing supply of safe assets as represented by a one standard deviation fiscal shock ε_b. Importantly, due to its nonlinear nature, the figure illustrates the sensitivity of the responses due to the initial level of debt, given a shock of the same size. Critically, the responses of excess returns, default spreads, and default premiums in an initial high debt state are significantly amplified relative to a more moderate debt regime, while the response of the liquidity premium is substantially muted. Accordingly, the trade-off between liquidity services and risk propagation of government debt depends on fiscal slack in a quantitatively relevant way. In particular, consistent with the empirical evidence in Table 1, in our model, liquidity benefits of government debt weaken in times of fiscal stress when risk premia rise.

Figure 5 hints at the mechanisms generating these realistic dynamics in the model by displaying the responses of key variables to the same one standard deviation fiscal shock ε_b. With rising debt, the government budget constraint naturally dictates higher tax pressure going forward, which translates into gloomier growth prospects given our specification of productivity dynamics in expression (2). These natural dynamics are accompanied by movements in conditional volatilities in that tax volatility increases, and, ultimately in general equilibrium, consumption risk. Intuitively, movements in tax volatility reflect that the real distortions stemming from elevated tax pressure further depress the tax base, so that adverse shocks have to be absorbed by even higher future taxes. Therefore tax volatility rises alongside the tax level, in line with our qualitative model discussion in the context of expression (4). Importantly, while in our general equilibrium model they are endogenously correlated, both rising tax levels and tax volatility contribute to rising consumption risk, as we show below. We refer to movements in tax pressure and conditional tax volatility attributed to changes in the government debt burden, and ultimately reflected in consumption risk, as *fiscal risks*.

Taken together, the plots thus document that in our model fiscal risks come with higher risk premia, reflected in higher credit spreads and default premia, especially so when fiscal slack is low.

We now turn to a more detailed examination of the sources and effects of fiscal risks in our model.

4.2.3 Equilibrium Fiscal Risks

We examine the sources and effects of fiscal risks through a graphical analysis of the equilibrium policy functions. In the following figures, we illustrate the policy functions of key variables with respect to government debt, holding the other state variables fixed.

Figure 6 illustrates the dependence of endogenous tax level and (conditional) volatility on government debt, reflected in rising consumption risk and fundamental output volatility. Notably, these equilibrium relationships display nonlinear patterns in that volatilities rise increasingly sharply when fiscal slack falls. Importantly, tax levels and volatility rise jointly endogenously with government debt in our model.

Both movements in levels and in conditional volatilities of taxes contribute to rising consumption risks. Figure 7 illustrates this notion. We approximately isolate independent movements in tax levels and volatilities by estimating on our simulated data a stochastic process for the tax rate that allows for stochastic volatility[17]. We then feed this exogenous tax process into the model [18]. In this setting, we plot the dependence of output and consumption volatility on both tax level and (log) tax volatility. As the figure shows, we recover quantitatively significantly and slightly nonlinearly increasing patterns in all cases. Intuitively, even in the absence of fluctuations in conditional tax volatility, at high tax levels small movements in taxes have significant effects on consumption growth[19]. Moreover, keeping the average tax level constant, movements in the conditional volatility of taxes are reflected in higher macroeconomic risk. In our full model, these effects are endogenously correlated, and reinforce each other.

Implications for Credit Spreads Figure 8 illustrates how fiscal risks affect firms' cost of borrowing by plotting fluctuations in credit market variables with respect to movements in government debt. The pricing of corporate debt in our model reflects default risk and liquidity features of cor-

[17]More precisely, we set $\tau_{t+1} = (1-\rho_\tau)\tau_\vartheta + \rho_\tau \tau_t + \sigma_t^\tau \epsilon_{t+1}$ and $\log(\sigma_t^{\tau,2}) = \lambda \log(\sigma_{t-1}^{\tau,2}) + \kappa\eta_t$. This is approximate as it allows for independent innovations in levels and volatilities, while in the full model these are endogenously correlated. We obtain estimates of an average tax of 0.32 with volatility 0.04 and persistence 0.95, and an average log tax volatility of 0.04 and persistence 0.95.

[18]In this 'auxiliary' model, taxes are a purely exogenous process, and taxes and government debt are not tied together through the government budget constraint. Everything else is kept identical to the full model.

[19]More formally, we can link consumption growth to changes in taxes, for example from the first order condition for labor supply, through $\frac{C_{t+1}}{C_t} = \frac{1-\tau_{t+1}}{1-\tau_t}\frac{w_{t+1}}{w_t}\frac{A_{t+1}}{A_t}\frac{1-L_{t+1}}{1-L_t}$. The volatility of $\frac{1-\tau_{t+1}}{1-\tau_t}$ is increasing in the average tax rate.

porate bonds. Indeed, the figure identifies the key tension at the core of our model. Intriguingly, the overall corporate credit spread is non-monotonic, and in fact U-shaped, with respect to government debt. This pattern documents succinctly the dual effects that government debt has on firms' cost of capital. While default risk and its pricing is rising with government debt, a higher supply of safe assets reduces the liquidity benefits that corporate bonds provide so that its liquidity premium falls, as the lower right panel shows. Intuitively, in the model, a higher supply of Treasuries reduces households' reliance on corporate bonds to cover liquidity shocks, so that the liquidity premium falls.

Quantitatively, in our calibration, the liquidity component dominates in episodes with low government debt and low taxes in which, accordingly, increasing safe asset supply reduces firms' cost of borrowing. On the other hand, the default component increasingly dominates when fiscal slack falls, so that issuing government debt in such times contributes to rising cost of borrowing for firms. In particular, it leads to rapidly rising costs of firms' external financing when the government's net debt burden starts exceeding fifty percent.

The contribution of default risk to credit spreads can be decomposed into two components, namely the probability of default and its pricing. Regarding the first component, rising government debt comes with increasing corporate default probabilities (top left panel) as rising and more volatile tax pressure leads to lower and more volatile revenues. This makes firms more exposed to adverse cash flow shocks that induce default in our model, and leaves more firms at the brink of bankruptcy. On top of that, regarding the pricing of default risk, the default premium, that is investors' compensation for systematic default risk, also increases with government debt, as the top right panel shows. Intuitively, a higher rate of corporate defaults and losses coincides with higher consumption risk (as shown in figure 6), so that investors ask for higher compensation in the form of a risk premium for holding bonds that default in states with high marginal utility. Ultimately thus, firms' rising borrowing costs are exacerbated through higher fiscal risks with falling fiscal slack as reflected in higher default premia.

Implications for Treasury Yields Figure 9 illustrates the dependence of the government's borrowing costs on safe asset supply. Importantly, Treasury yields rise sharply with the government debt burden (top left panel). Rising debt thus makes it harder for the government to roll over debt, and such episodes tend to coincide with slowdowns in growth and rises in volatility, as figure 10 shows.

In our model, this pattern obtains in spite of the associated increase of macroeconomic risk, which tends to exert downward pressure on interest rates through a precautionary motive. Rather, in the model, this pattern reflects the decline of the liquidity premium with rising government debt, as shown in the lower left panel. Intuitively, as the Treasury supply grows, households find it easier to absorb liquidity shocks without resorting to selling off corporate bonds at higher transaction costs or liquidating assets altogether in the model. This diminishes the liquidity benefits of additional Treasury supply, as captured by a falling liquidity premium on government bonds. Formally, this is captured by the observation that the marginal value of government bonds liquidity services in negative in expression (1), while empirically it is consistent with the prominent finding that government debt negatively predicts liquidity premia (see, for example, Krishnamurthy and Vissing-Jorgensen (2012)). When Treasuries' importance in absorbing liquidity shocks diminishes, so does trading activity and turnover in this market, as shown in the lower right panel.

When Treasury supply expands, not only do the government's borrowing costs increase, but so does their volatility. Indeed, the top right panel of figure 9 shows that the volatility of Treasury yields rises significantly with the government burden, reflecting higher macroeconomic risk associated with higher Treasury supply. Increasing safe asset supply thus also creates uncertainty about the government's future debt servicing expenses.

Implications for Growth In general equilibrium, fiscal risks spill over into the remaining variables, as figure 10 illustrates. The top panels show that not only does expected productivity growth fall with rising debt and tax risks, but growth prospects grow increasingly volatile in line with rising macroeconomic risk. Anticipating bleaker and more uncertain growth prospects, firms invest more cautiously (lower left panel) and are more reluctant to issue corporate debt to finance investment so that leverage falls (lower right panel). While in our trade-off model of capital structure tax savings from issuing debt rise with average tax pressure, so do default probabilities and credit spreads (see figure 8), ultimately rendering debt less attractive. In this sense, given the associated decline in investment and growth, our model also predicts a form of 'real crowding out'.

'r versus g' Under the label 'r vs g', a debate has recently evolved around the notion that the fiscal costs of servicing the current large stock of government debt may be low in an environment with low interest rates and stable growth. Indeed, as Blanchard (2019) argues,'the current U.S.

situation in which safe interest rates are expected to remain below growth rates for a long time, is more the historical norm than the exception'.

Our model, in which safety attributes of government debt and expected growth ('g') are jointly determined and linked through the government budget constraint in a stochastic environment, provides some perspective on this link. While, on average, our model indeed is quantitatively consistent with the recent low interest rate environment, and elevated expected growth rates[20], in our stochastic environment, the equilibrium policies imply an endogenous *joint distribution* of interest rates and growth rates. As shown above (see figures 9 and 10), both the government's borrowing costs and growth rates become increasingly volatile with a rising debt burden. Indeed, the equilibrium distribution accounts for the possibility that rising government debt can lead to episodes in which Treasury yields dwarf expected growth. As government debt rises, Treasury yields rise as well, as liquidity premiums and safety attributes decline. At the same time, the government budget constraint dictates that with a rising debt burden, tax pressure and tax volatility grows, thereby depressing expected growth. Therefore, a growing government burden can push Treasury yields and thus debt servicing costs above expected growth rates.

Figure 11 illustrates such tensions in the equilibrium distribution. It displays the difference between realized Treasury yields and expected growth rates in relation to the government debt-to-gdp ratio from the simulated ergodic distribution of the model. Indeed, Treasury yields rise with government debt, while expected growth rates decline, in line with our previous discussion. Quantitatively, in the model, when net debt goes beyond roughly seventy percent, yields exceeding expected growth become increasingly common. Such periods of elevated debt servicing costs therefore create episodes of fiscal stress, and notably, coincide with high taxes and volatility. In this sense, the safety attributes of Treasuries rapidly decline.

An alternative way of interpreting these tensions is in terms of the average duration of positive 'r minus g' spells. In other words, in the model, there is a strong link between government indebtedness, and the average duration between a negative 'r minus g' observation and the next positive 'r minus g' realization. In fact, quantitatively, we can show that in the model, that duration is strictly decreasing in the debt-to-GDP ratio. This model implication is consistent with the recent international empirical evidence in Lian, Presbitero, and Wiriadinata (2020). In turn, our estimates are disciplined by empirical evidence on links between government debt and risk

[20] In our calibration, the transversality condition is always satisfied, so that the debt-to-gdp ratio remains bounded.

premia.

Empirical Evidence A key channel in our model, illustrated in figure 6, is that in equilibrium, a higher debt burden and the corresponding higher tax pressure and tax volatility is associated with elevated macroeconomic volatility and consumption risk (bottom panels). In Table 5, we provide empirical evidence supporting this channel, at multiple horizons. In the data, we measure consumption volatility by first fitting a GARCH(1,1) model to consumption growth at the quarterly frequency, and estimating medium-term 5-year consumption volatility as the average quarterly volatility over the subsequent 20 quarters. The table documents a significantly positive correlation between fiscal variables and future consumption risks, at short and medium horizons. In particular, rising government debt is associated with higher consumption risk going forward, as are taxes, both through a level and a volatility channel, just as in the model. Furthermore, the table shows evidence that rises in government are aligned with future increases in the volatility of taxes, in line with the predictions of our model. Overall, the table adds empirical content to the main mechanisms in our model.

5 Applications

Our setting provides a natural laboratory to provide quantitative guidance on the effects of fiscal interventions involving Treasury supply. We now apply our model to evaluate a number of policy proposals that arose in recent times. Our model can speak directly to quantitative easing policies implemented recently in response to the Covid-19 crisis through corporate bond purchases by the Federal Reserve, proposals regarding government grant extensions to financially distressed firms to avoid bankruptcies, as well as to liquidity provision around financial crises such as the great recession of 2008 or fragility in corporate bond mutual funds in 2021.

5.1 Quantitative Easing through a Corporate Credit Facility

In March 2020, amidst concerns regarding impending defaults of US companies and declining liquidity in corporate credit markets in response to the Covid-19 pandemic economic crisis, the Federal Reserve announced new corporate credit facilities. The facilities' purpose was to support liquidity in credit markets and provide companies access to credit so that they are better able to maintain business operations and capacity during the pandemic. Moreover, as mutual funds have become major players in the corporate bond market [21], unprecedented outflows in the pandemic triggered concerns regarding financial fragility in corporate funding (see e.g. Falato, Goldstein, and Hortacsu (2021), or Haddad, Moreira, and Muir (2020)). Effectively, the Federal Reserve stepped in to purchase corporate debt up to the amount of 750 billions [22].

We represent these purchases in our model by focusing on a consolidated government budget constraint. In this context, purchases of corporate debt by the Federal Reserve effectively show up in the government budget constraint, as the Federal Reserve has the fiscal backing of the US Treasury. Our model therefore allows to provide some initial quantitative guidance on the macroeconomic effects of corporate credit facilities.

To provide a formal account of the government's corporate credit facility, we assume that the government purchases an amount θ_t of corporate debt, which it finances by issuing government debt. The adjusted government budget constraint now includes the excess return on the corporate bond purchase $\theta_{t-1}R_{\theta,t}$, with $R_{\theta,t} = \frac{(1+C)F(z_t^*)+Q_{t-1}R_{rec,t}}{Q_{t-1}} - \frac{1}{Q^g_{t-1}}$. Accordingly, the policy is required to satisfy the adjusted budget constraint

$$Q^g_t B^g_{t+1} = B^g_t + G_t + TR_t - T_t - \theta_{t-1}R_{\theta,t}.$$

Clearly, such a policy increases the government bond supply and decreases the public corporate bond supply. Accordingly, the household's positions in government and corporate bonds are adjusted in that

$$V_{g,t}Y_t = Q^g_t B^g_{t+1} + \theta_t, \quad \text{and} \quad V_{c,t}Y_t = Q_t B_{t+1} - \theta_t.$$

Naturally, in the context of the model, by expanding the Treasury supply, such a corporate credit facility improves liquidity and the liquidity premium declines accordingly. However, the expression also highlights that it generates fiscal risks that depend on the realization of the corporate bond returns. Indeed, by taking positions in risky corporate bonds, the government is itself exposed to incurring losses in defaulted bonds that have to be covered by issuing further debt or raising taxes. In the following, we provide quantitative effects of such state-dependent outcomes through the lens

[21] Through the lens of the model, the rise of mutual funds in the corporate bond market can be rationalized as reaching for yield when corporate bonds, as an asset class, exhibit liquidity or safety attributes, as in our expression (5). See e.g. Becker and Ivashina (2015), or Bretscher, Schmid, Sen, and Sharma (2021).

[22] See, for example, Haddad, Moreira, and Muir (2021) for a recent evaluation.

of our model by means of impulse responses. As a benchmark, we assume that the government issues debt to cover any losses.

Impulse responses We consider a one time shock θ_t to the government's corporate bond purchases unexpected by households. While households do not take into account such a policy ex ante, they respond optimally ex post. We consider a shock in the size of 5% of GDP, close to the maximum set by the Federal Reserve.

Formally, while on impact at time t the budget constraint is unaffected because the purchase of corporate bonds equals the issuance of government bonds, the debt outstanding and the liquidity change. Moreover, at time $t+1$ the budget constraint is affected by the realizations of corporate bond returns in that any gap $\theta_{t-1}R_{\theta,t}$ has to be covered by a change of $Q_t^g B_{t+1}^g$.

Figure 12, panel A, displays a first set of results. Notably, the effects of the corporate credit facility are sharply state dependent. In a good scenario, the government earns positive average excess returns commensurate with its risky position. An increase of the safe asset supply improves liquidity and reduces liquidity premia by around 5 basis points. The positive excess returns ease the fiscal burden but the magnitude is somewhat modest. In a bad scenario, in contrast, all the bonds just default at the default boundary z_{t+1}^*. In this case, the government incurs a significant loss. At the same time, an increase of the safe asset supply improves liquidity and reduces the liquidity premium by a comparable amount, which is line with the regression sensitivity of -0.8 reported previously. However, the government has to issue debt to cover the losses in period $t+2$ implying higher taxes and default spreads going forward. As panel B illustrates, these effects are significantly amplified in scenarios with little fiscal slack, such as when the government starts with a debt to GDP ratio of 80% instead of the postwar mean of around 40%. Clearly, the liquidity benefits are diminished, while the fiscal risk is substantially enhanced. Ultimately, the government may achieve its main objective to improve market liquidity, but only at the cost of creating significant fiscal risks.

5.2 Stimulus Policy through Government Grant Extensions

An alternative policy proposal to prevent bankruptcy waves and to provide stimulus to starving industries such as Airlines is to extend direct grants to companies. This amounts to a direct fiscal intervention executed by the Treasury. There is a natural implementation of this policy in our model.

A firm defaults if it is exposed to an idiosyncratic shock exceeding the default boundary, that is, if $z_{i,t} \geqslant z_t^*$. The policy consists in the government injecting funds in the amount of $(z_{i,t} - z_t^*)K_t$ into each firm that would default, to prevent it to go into bankruptcy. The total amount of grants therefore equals

$$\theta_t = \int_{z_t^*} (z_{i,t} - z_t^*) dF K_t.$$

These grants are expenditures from the government's perspective. Assuming the government finances these expenditures by issuing debt, its adjusted budget constraint becomes

$$Q_t^g B_{t+1}^g = B_t^g + G_t + TR_t - T_t + \theta_t.$$

Clearly, as before, extending grants to companies increases the government's fiscal burden creating fiscal risks, while at the same time providing liquidity to financial markets. On top of that, the government faces a non-trivial trade-off between the benefits of reducing losses in defaults and the costs of extending grants. That trade-off is highly state-dependent and depends on the expected default probability. We illustrate the trade-off by computing the costs and benefits in different states by varying the expected growth that drives the idiosyncratic volatility and default probability.

Figure 13 illustrates the results. Specifically, we plot these costs and benefits for different values of the state variable x, while keeping all other state variables at the mean. Lowering expected growth x reduces equity valuations and thus leads to elevated default probabilities, while raising x does the opposite. Both benefits and costs increase with default probabilities. Critically, however, the sensitivity is much larger for the cost. The total default loss increases with default probability slowly. In high default probability states, firms endogenously choose low leverage. In the case of a default, asset values and default losses are low for each firm. On the other hand, total grants extended are increasing much faster with the default probability. Intuitively, the grant to save each firm is similar under small or large default probabilities. Having more firms defaulting, the grant expenditures increase therefore almost linearly with the probability. Extending grants to faltering businesses and industries thus exposes the government to the risk of creating budget deficits and the need to raise financing in times of fiscal stress, creating fiscal risks and excess tax volatility going forward.

5.3 Liquidity Shocks and Crises

The financial crisis of 2008 prominently manifested itself also as a dramatic liquidity crisis as investors and financial institutions tried to liquidate assets to cover funding needs. As a consequence, liquidity spreads in financial markets were subject to sudden spikes. To give an account of that episode through the lens of our model, and to evaluate possible remedies, we now examine an extension of the benchmark specification, in which stochastic liquidity needs can give rise to liquidity crises. We use that specification to extract historical liquidity shocks that can rationalize the financial crisis, and more generally, the recent history of U.S. liquidity premia in the time series.

We introduce aggregate liquidity shocks into the model by letting the probability of being exposed to a liquidity demand shock, λ_t follow a persistent stochastic process. More specifically, we assume it follows an AR(1) process with constant volatility. Our calibration attempts to disentangle movements in liquidity spreads induced by changes in government debt supply, from pure liquidity demand shocks. To that end, we first fit an autoregressive process to the government debt to gdp ratio and extract the corresponding innovations. We the regress liquidity spreads on debt to filter out the liquidity state, to which we fit an autoregressive process and use it to extract the shocks. The implied process displays an autoregressive coefficient of 0.98.

The first set of results is displayed in figure 14. The top right panel displays the evolution of the liquidity state that we extract from the data. The top left panel shows both the historical series of the debt to gdp ratio (blue line) as well as the model implied one constructed by feeding historical shocks into the model (red line). By construction, the model fits the debt to gdp series very closely. The implied liquidity state is volatile and persistent, suggesting a significant risk surrounding investors' liquidity demand. This risk allows the model to provide a fairly realistic account of the historical evolution of U.S. liquidity spreads, as the red line in the lower left panel shows. In particular, the model captures spikes in liquidity spreads around the recent financial crisis well. The red line in the lower right panel shows the model implied evolution of credit spreads. While, very clearly, the model does not capture the volatility in corporate bond markets as the model implied spreads are much smoother than those in the data, it captures the directions of the movements relatively well, as spikes in the data coincide with spread increases in the model.

Overall, the model provides a reasonably realistic account of the recent evolution of the liquidity and default risk in U.S. bond markets. A natural question that we can address through the lens of the model is to what extent the debt policy of the U.S. Treasury affects these dynamics. We address this question next.

Counterfactuals: Liquidity-sensitive Debt policies The negative link between liquidity premia and the supply of safe assets that has been documented in the literature before and confirmed in the empirical part of this paper suggests that the debt policy of the government should affect movements in liquidity spreads. In particular, while it appears to be the standard practice of the Treasury to only let debt issuance respond to spending shocks, as considered in the baseline specification of the model, it may appear beneficial to allow it to respond to liquidity states as well in an attempt to reduce spikes in spreads. Indeed, the empirical pattern that the model reproduces, would suggest that if the government were to issue debt aggressively when liquidity demand is high, it could reduce and smooth out movements in liquidity spreads. We consider that possibility in a counterfactual in our model. Specifically, we modify the government's debt policy rule in expression (3) by allowing it not only to respond to expenditure shocks as captured by the parameter κ_τ, but also to innovations to the liquidity states captured by a parameter κ_{liq}. This is a very general representation of policies motivated by concerns regarding liquidity in financial markets, such as fragility in corporate bond funds.

The yellow lines in figure 14 show a first set of results. They represent the implied historical evolution of variables, when the government's debt issuance, counterfactually, responds to movements in liquidity demand by setting $\kappa_{liq} = 0.06$. Clearly, such a policy smoothes out fluctuations in liquidity spreads, and reduces their overall level. Historically, however, as the top left panel and the lower right panel show, this would have come along with a more volatile debt to gdp series, as well as significantly more volatile credit spreads.

Figure 15 illustrates and quantifies the real implications of the underlying trade-off. It provides sensitivity of average credit spreads and their default components, as well as average liquidity spreads and consumption risks with respect to the responsiveness of the debt policy of the government with respect to liquidity states, as captured by varying the parameter κ_{liq}. It illustrates the real fiscal cost of a more accommodating debt policy through a binding government budget constraint in that this raises tax commitments and their volatility, thereby raising credit spreads and firms' funding costs, and ultimately, consumption risk.

6 Conclusion

We empirically and theoretically examine the impact of safe asset supply through government bonds on credit markets and the macroeconomy. Our results emphasize a dual role of government debt in credit market activity. Through a *safety* channel an increase in government debt improves liquidity and lowers liquidity premia by facilitating debt rollover, thereby reducing credit spreads. Through a *risk* channel, however, we show that rising government debt creates elevated tax pressure and tax volatility, and ultimately, consumption volatility. These movements are reflected in higher risk premia and credit spreads, raising firms' cost of capital and depressing investment and growth. Our model thus allows to identify and quantify a novel fiscal risk channel associated with rising US government debt. Our results suggest that this risk channel gains in relevance in periods of fiscal stress, and sheds a cautionary perspective on recent unconventional stabilization policy and stimulus proposals.

Our dual view provides a quantitative perspective on the fiscal costs of rising public debt, and the ongoing debate on its sustainability in a low interest rate environment. Our general equilibrium model in which safety attributes of debt and growth are jointly determined in an environment with fiscal risk predicts protracted episodes during which Treasury yields dwarf expected growth. Treasury yields rise with an expanded safe asset supply as safety premia decline through a safety channel, while growth rates fall with rising tax pressure and tax risk through a risk channel. When a growing government debt burden pushes debt servicing costs above expected growth rates, public debt may rapidly become unsustainable. Our results suggest that increasing 'safe' asset supply can be quite risky, so that our risk channel effectively limits the government's ability to provide liquidity and safety services, especially in times of low fiscal slack. Our empirical evidence on risk premia provides a novel approach to disciplining the quantitative analysis.

Our model lends itself naturally to a quantitative analysis of government policies implementing debt-financed stimulus. Our results provide a quantitative perspective on the risks inherent in government-backed corporate credit facilities and corporate grant extensions, for example. It would be interesting to evaluate the effects of recent stimulus packages or corporate tax policies proposed by the Biden administration through the lens of our model. We leave this for future research.

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Table 1: Regression Analysis

	by	(t-stat)	R^2	by	(t-stat)	vol	(t-stat)	R^2
A. Level								
GZ Spread	0.71	(2.52)	0.09	0.88	(4.66)	0.63	(3.40)	0.44
Repo/Tbill	-0.67	(-4.04)	0.28	-0.65	(-4.03)	0.08	(1.25)	0.30
B. First Diff								
GZ Spread	3.56	(2.32)	0.10	3.58	(2.51)	0.08	(3.08)	0.18
Repo/Tbill	-0.85	(-1.85)	0.00	-0.84	(-1.84)	0.02	(1.23)	0.01
C. Predictive								
IG Excess Return	5.67	(1.88)	0.01	6.50	(2.17)	2.96	(2.23)	0.02
HY Excess Return	9.69	(2.35)	0.01	9.85	(2.18)	0.25	(0.09)	0.01
HY - IG	8.81	(2.43)	0.01	7.85	(1.98)	-1.49	(-0.61)	(0.01)

D. Nonlinearity

	Δby_t	(t-stat)	$\Delta by_t \times (by_t - \mu_{by})$	(t-stat)	R^2
GZ Spread	4.01	(2.68)	4.41	(2.76)	0.13
Repo/Tbill	-0.80	(-1.93)	0.50	(0.49)	0.00

The table reports estimates from OLS regressions of yield spreads and corporate bond excess returns on log debt-to-GDP ratio and stock market realized volatility.
Panel A: $spread_t = \beta_0 + \beta_1 by_t + \beta_2 vol_t + u_t$.
Panel B: $\Delta spread_t = \beta_0 + \beta_1 \Delta by_t + \beta_2 \Delta vol_t + u_t$.
Panel C: $r_{corp,t+1} - r_{f,t} = \beta_0 + \beta_1 by_t + \beta_2 vol_t + u_{t+1}$.
Panel D: $\Delta spread_t = \beta_0 + \beta_1 \Delta by_t + \beta_2 \Delta by_t \times (by_t - \mu_{by}) + u_t$.
GZ spread is the corporate bond spread in Gilchrist and Zakrajŝek (2012). Repo/Bill is the spread between general collateral repo rate (Repo) and treasury bill rate. $r_{corp,t+1} - r_{f,t}$ is the excess corporate bond return. by is the log debt-to-GDP ratio. vol is realized stock return volatility. The t-statistics are based on Newey-West standard errors. The sample is from 1973M1 to 2018M12. The sample of high yield bonds is from 1983M7 to 2018M12.

Table 2: Parameter Values

Parameter	Description	Value
A. Preferences		
β	Subjective discount factor	0.9955
ψ	Elasticity of intertemporal substitution	2.00
γ	Risk aversion	10
ϑ	Labor parameter	3.50
B. Production		
α	Capital share	0.345
δ	Depreciation rate of capital stock	0.15
ξ_k	Adjustment cost parameter	2
μ	Mean productivity growth	0.0045
σ_a	Conditional volatility	0.0113
ρ_x	Long-run persistence	0.97
σ_x	Long-run conditional volatility	0.00113
$\sigma_{z,0}$	Idiosyncratic volatility	0.20
$\phi_{\sigma,a}$	Idiosyncratic Cylicality	20
C. Financing		
C	Corporate coupon rate	0.015
ζ_0	Default loss mean	0.4
ϕ_g	Treasury transaction cost	0.001
ϕ_c	Corporate transaction cost	0.01
ϕ_l	Liquidation cost	0.03
λ	Liquidity shock arrival rate	0.12
μ_ξ	Liquidity shock size mean	0.7
σ_ξ	Liquidity shock size volatility	0.25
D. Fiscal Policy		
ϕ_τ	Long-run tax effects	0.03
μ_g	Spending constant	0.004
ρ_b	Spending persistence	0.98
σ_g	Spending volatility	0.003
μ_{tr}	Transfer constant	0.13
σ_g	Transfer volatility	0.168
μ_b	Debt constant	0.08
ρ_b	Debt persistence	0.96
κ_τ	Tax smoothing	0.93

This table summarizes the parameter values used in the benchmark calibration of the model. The table is divided into four categories: Preferences, Production, Financing, and Fiscal Policy. The model is calibrated at the quarterly frequency.

Table 3: Moments I

Variable	Model	Data
A. Fiscal		
government debt-to-GDP ratio $E[Q^g B^g/Y]$	0.47	0.39
$\sigma(Q^g B^g/Y)$	15.65	15.88
$AR1(Q^g B^g/Y)$	0.95	0.98
corporate tax rate $E[\tau]$	0.32	0.35
$\sigma(\tau)$	4.07	10.10
$AR1(\tau)$	0.95	0.97
B. Credit		
corporate bond recovery rate $E[r_{rec}]$	0.33	0.40
default rate $E[F(z)]$	1.07	1.00
leverage $E[Q_t B_{t+1}/(Q_t B_{t+1} + V_t^{ex})]$	0.40	0.40
yield spread $E[y_t^c - y_t^g]$	1.10	0.95
mean default spread	0.84	
default spread: mean default loss	0.71	
default spread: mean default premium	0.12	
first diff regression coef. of default spread on gov't debt-to-GDP	2.82	3.42
C. Liquidity		
liquidity spread $E[\nu_c - \nu_g]$	0.26	
risk-free rate/treasury bill spread $E[\nu_g]$	-0.33	-0.42
liquidity premium of corporate bond $E[\nu_c]$	-0.07	
mean government bond turnover	0.44	19.75
mean corporate bond turnover	0.14	0.85
mean ratio of government and corporate bond volume	25.35	25.05
first diff regression coef. of liquidity spread on gov't debt-to-GDP	-0.85	-0.81
regression coef. of gov't bond volume on gov't debt-to-GDP	-0.19	-1.08
D. Crowding out		
regression coef. of corporate debt-to-GDP on gov't debt-to-GDP	-0.27	-0.08

This table summarizes the moments in the data and the model. The model moments are obtained from a long sample simulation of 10,000 periods. The data sample is from 1947Q1 to 2018Q4. We report moments of fiscal variables in panel A, credit variables in panel B, liquidity moments in panel C, and crowding out in panel D. The moments are annualized.

Table 4: Moments II

Variable	Model	Data
$E[\Delta c]$	1.81	1.95
$E[r_d]$	4.09	8.18
$E[r_f]$	0.91	0.72
$E[r_d - r_f]$	3.18	7.46
$\sigma(\Delta c)$	2.52	1.60
$\sigma(\Delta y)$	3.15	1.86
$\sigma(\Delta i)$	7.79	9.52
$\sigma(r_d)$	6.85	15.44
$\sigma(r_f)$	0.60	1.22

This table summarizes the moments in the data and the model. The model moments are obtained from a long sample simulation of 10,000 periods. The data sample is from 1947Q1 to 2018Q4. We report moments of macroeconomic and return variables. The moments are annualized.

Table 5: Government Debt and Volatility

	1 quarter		5 years	
$corr(by, vol(\Delta c))$	0.16	(0.07)	0.40	(0.11)
$corr(\tau, vol(\Delta c))$	0.48	(0.08)	0.63	(0.06)
$corr(by, vol(\tau))$	0.14	(0.06)	0.39	(0.11)
$corr(vol(\Delta c), vol(\tau))$	0.66	(0.16)	0.41	(0.07)

This table shows the correlation between the log debt-to-GDP ratio, the corporate tax rate, and the consumption volatility, and the corporate tax volatility. The estimate of 1-quarter volatility is from GARCH(1,1) models. The 5-year consumption volatility is the average of the quarterly vol over the subsequent 20 quarters. The Newey-West standard errors are in the parentheses. The data sample is from 1947Q1 to 2018Q4.

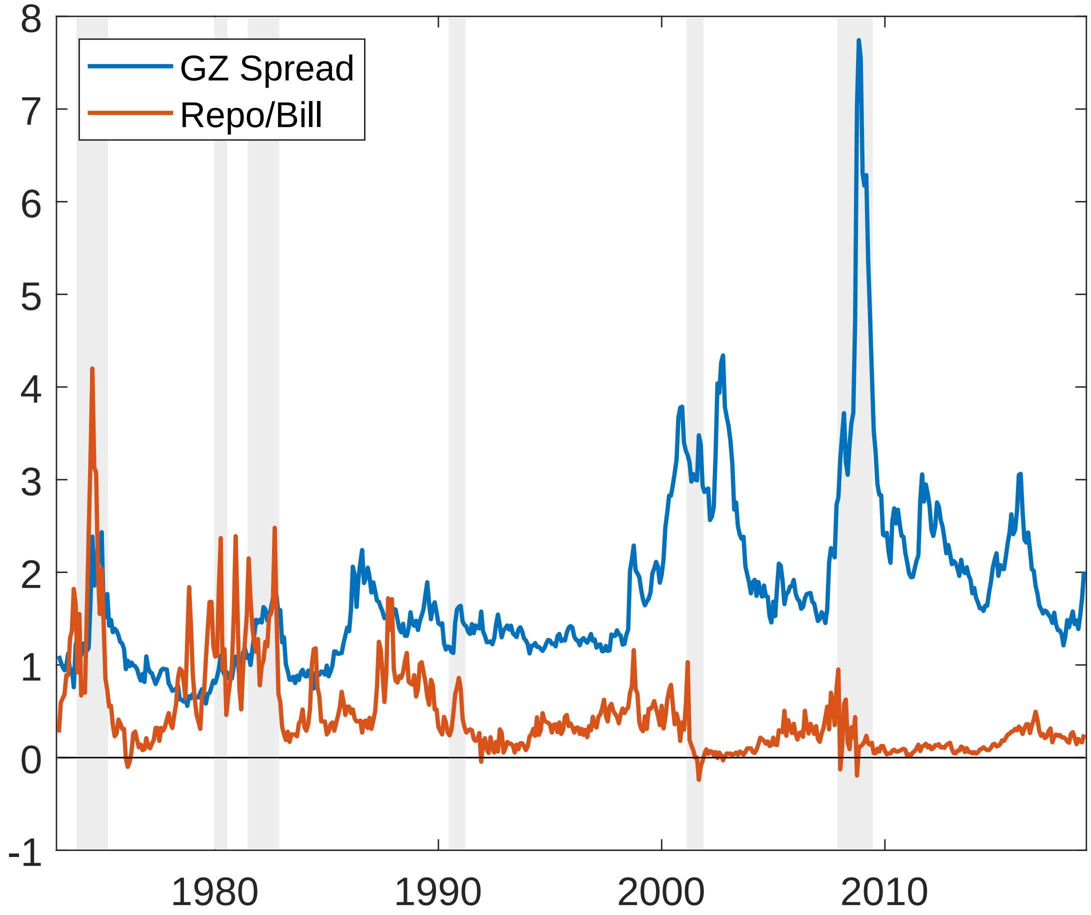


Figure 1: **Debt and Yield.** The figure plots the corporate bond spread in Gilchrist and Zakrajŝek (2012) and the spreads between general collateral repo rate (Repo) and treasury bill rate. The sample period is from 1973M1 to 2018M12.

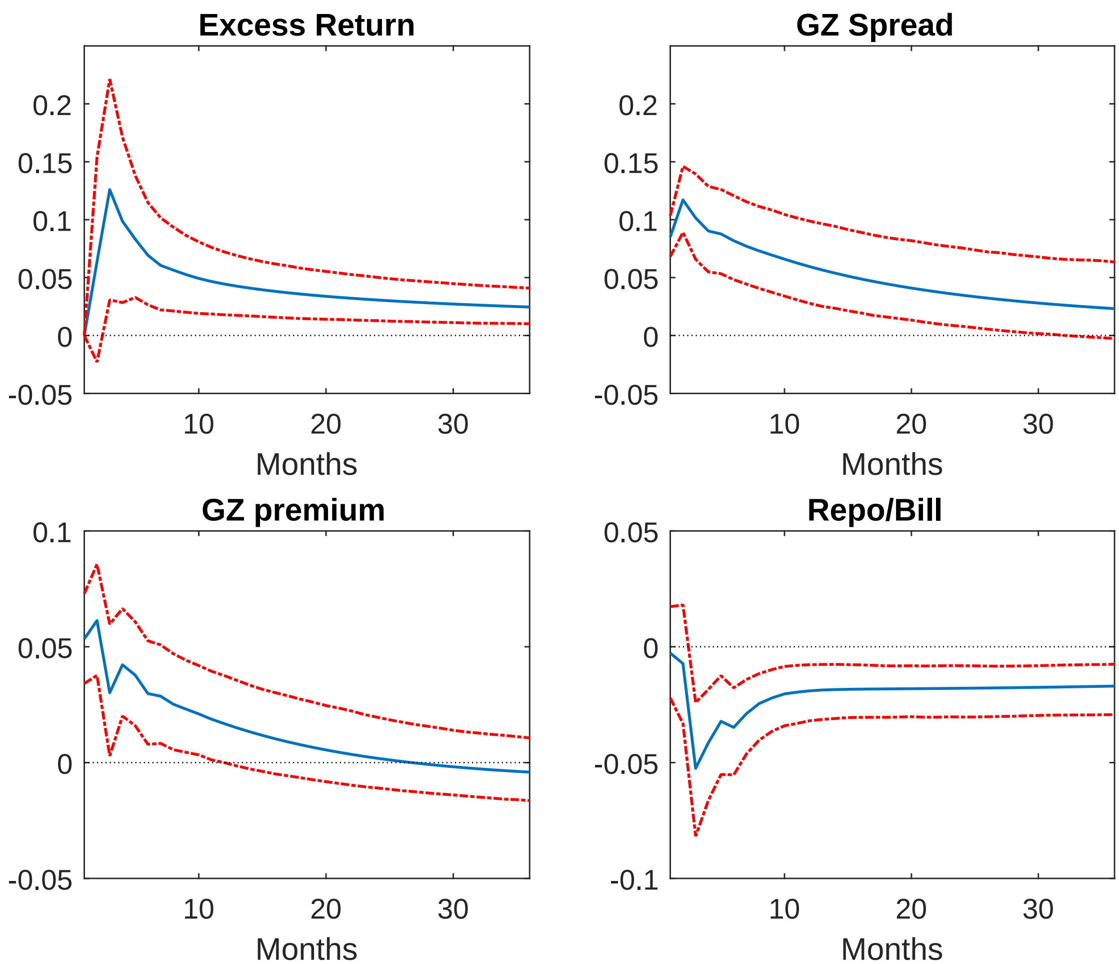


Figure 2: **Impulse Response Functions.** The figure plots the impulse response functions to a shock to the debt-to-GDP ratio, based on our estimated VAR. The VAR includes the fed funds rate (ffr_t), industrial production growth (Δip_t), stock return volatility (vol_t), corporate bond excess return (r_t^{ex}), debt-to-GDP ratio (by_t), corporate bond spread (GZ_t) and premium (GZp_t) in Gilchrist and Zakrajšek (2012), and the spreads between the general collateral repo rate and the treasury bill rate. We use a recursive identification strategy and identify orthorganalized innovations to the debt-to-GDP (the fifth variable) as a non-discretionary increase of government debt, that is, a debt shock. The sample period is from 1973M1 to 2018M12.

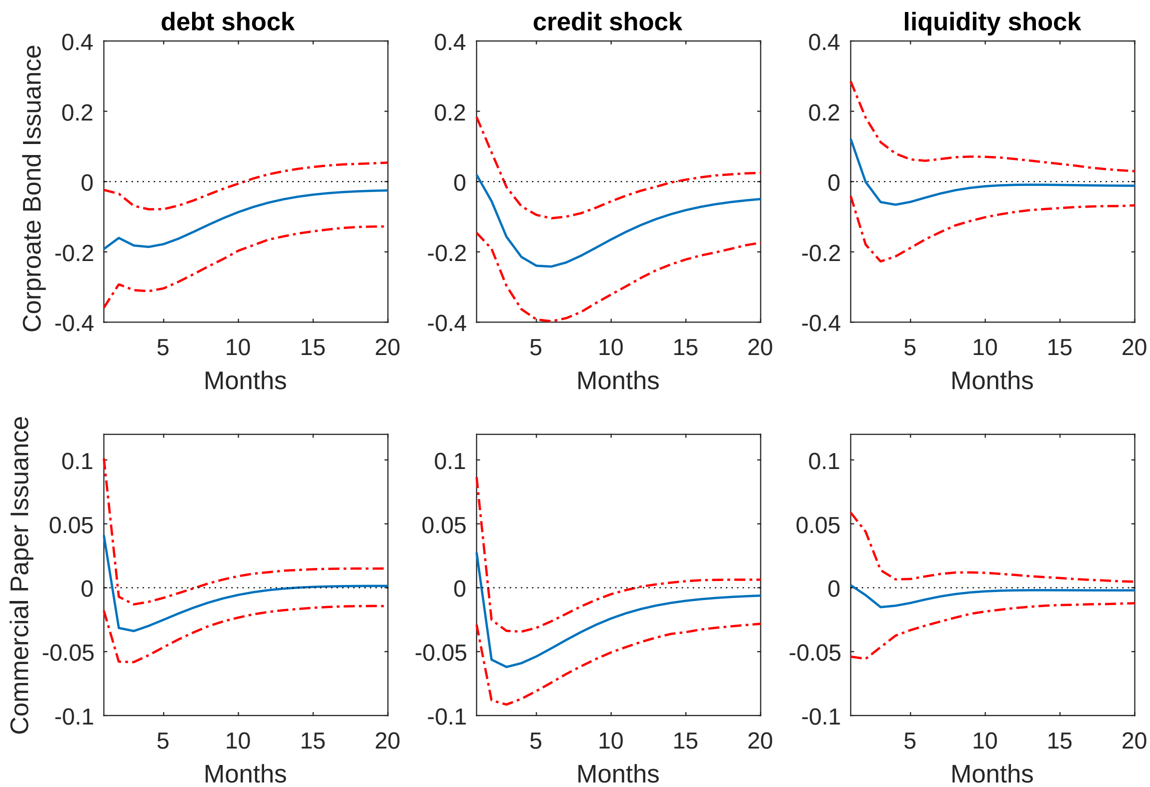


Figure 3: **Impulse Response Functions.** The figure plots the impulse response functions to a shock to the debt-to-GDP ratio, the corporate bond spread, and the liquidity spread, based on our estimated VAR. The VAR includes fed funds rate (ffr_t), real GDP growth (Δy_t), stock return volatility (vol_t), corporate bond excess return (r_t^{ex}), debt-to-GDP ratio (by_t), corporate bond spread (GZ_t) and premium (GZp_t) in Gilchrist and Zakrajšek (2012), the spreads between general collateral repo rate and treasury bill rate, and the net increases of corporate bond and commercial paper of nonfinancial corporate business, normalized by GDP. We use an recursive identification strategy and identify orthorganalized innovations to the debt-to-GDP (the fifth variable) as a non-discretionary increase of government debt, that is, a debt shock. The innovations to the corporate bond spread and the repo-bill spread are identified as a credit shock and a liquidity shock . The sample period is from 1973Q1 to 2018Q4.

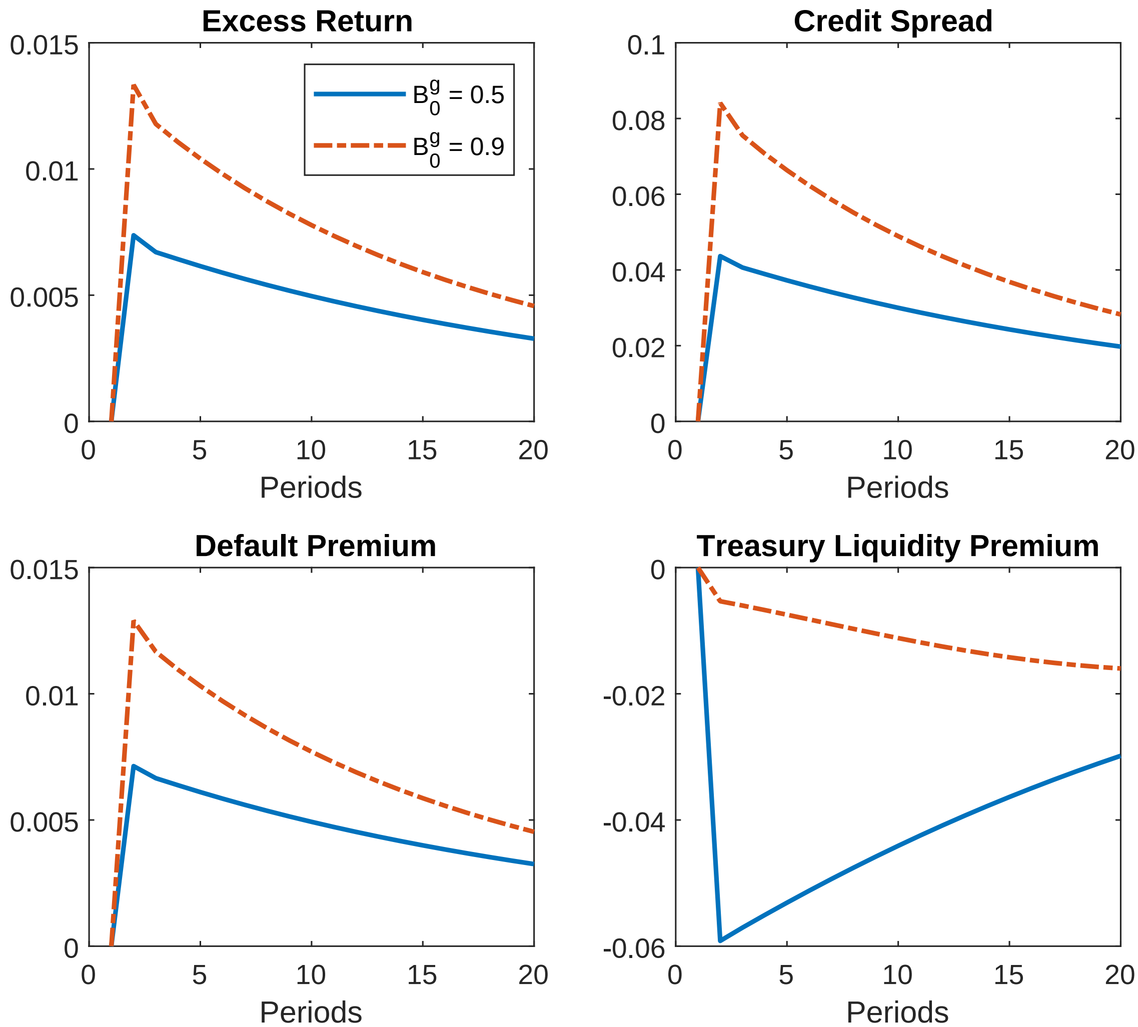


Figure 4: **Impulse Response Functions.** The figure plots the impulse response functions of expected corporate bond excess return, corporate credit spread, the credit default premium, and the liquidity premium on treasury bonds to a one-standard-deviation fiscal shock $\varepsilon_{b,t}$, in the calibrated model. The initial level of the debt B_0^g is either 0.5 or 0.9.

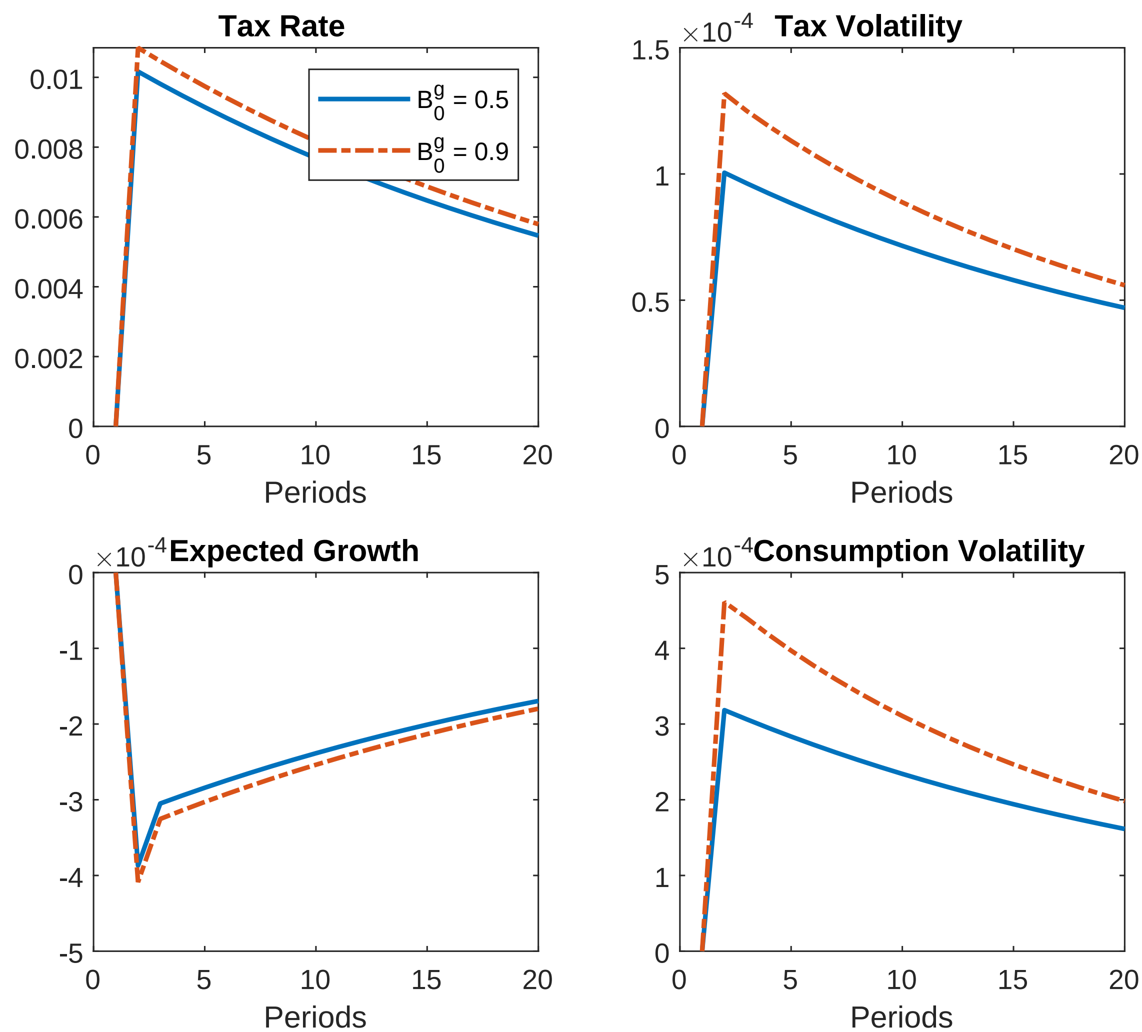


Figure 5: **Impulse Response Functions.** The figure plots the impulse response functions of the tax rate, tax volatility, the expected productivity growth, and consumption volatility to a one-standard-deviation fiscal shock $\varepsilon_{b,t}$, in the calibrated model. The initial level of the debt B_0^g is either 0.5 or 0.9.

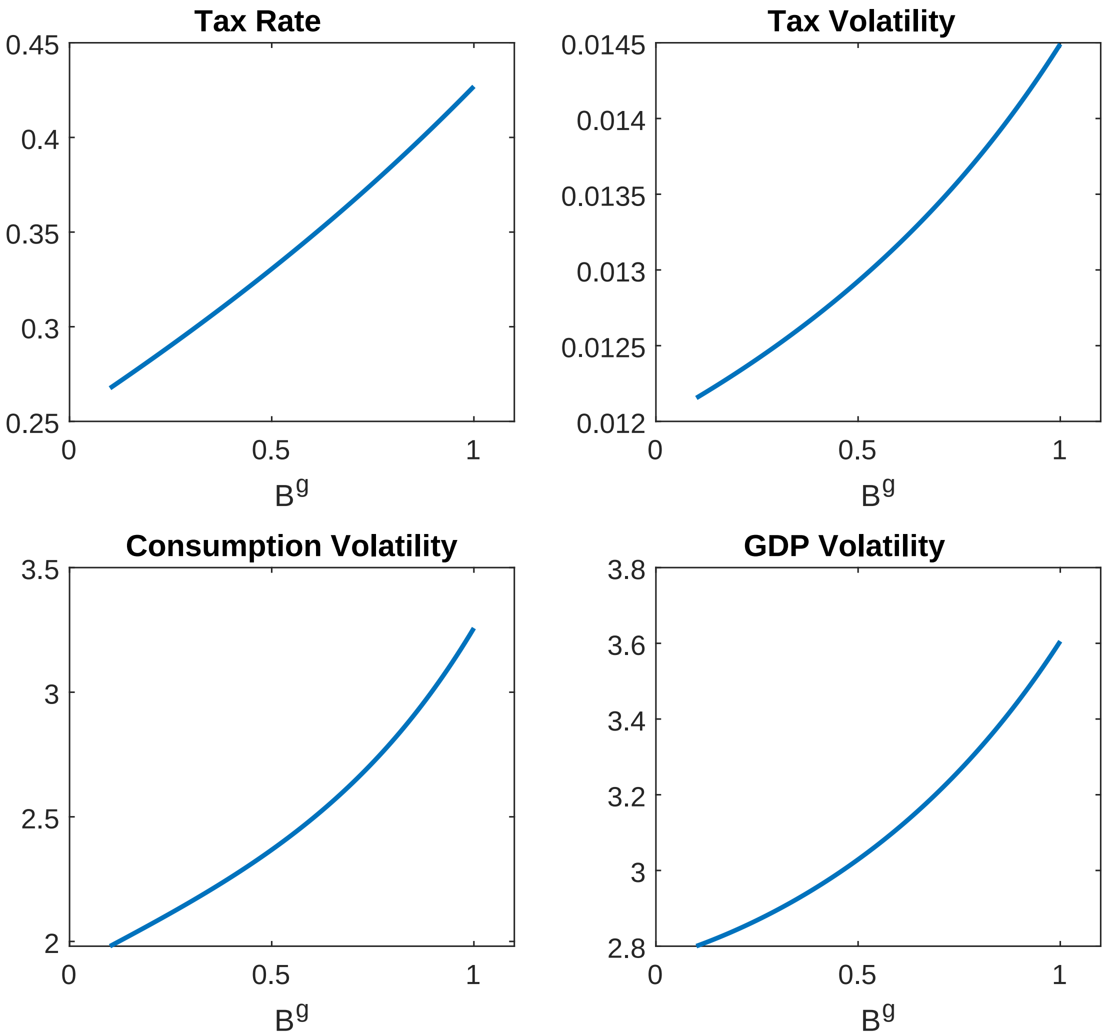


Figure 6: **Policy Functions I.** The figure plots the policy functions of the expected tax rate, the conditional volatility of tax rate, the conditional volatility of consumption growth, and the conditional volatility of GDP growth on government debt (B_g), holding other state variables at the mean.

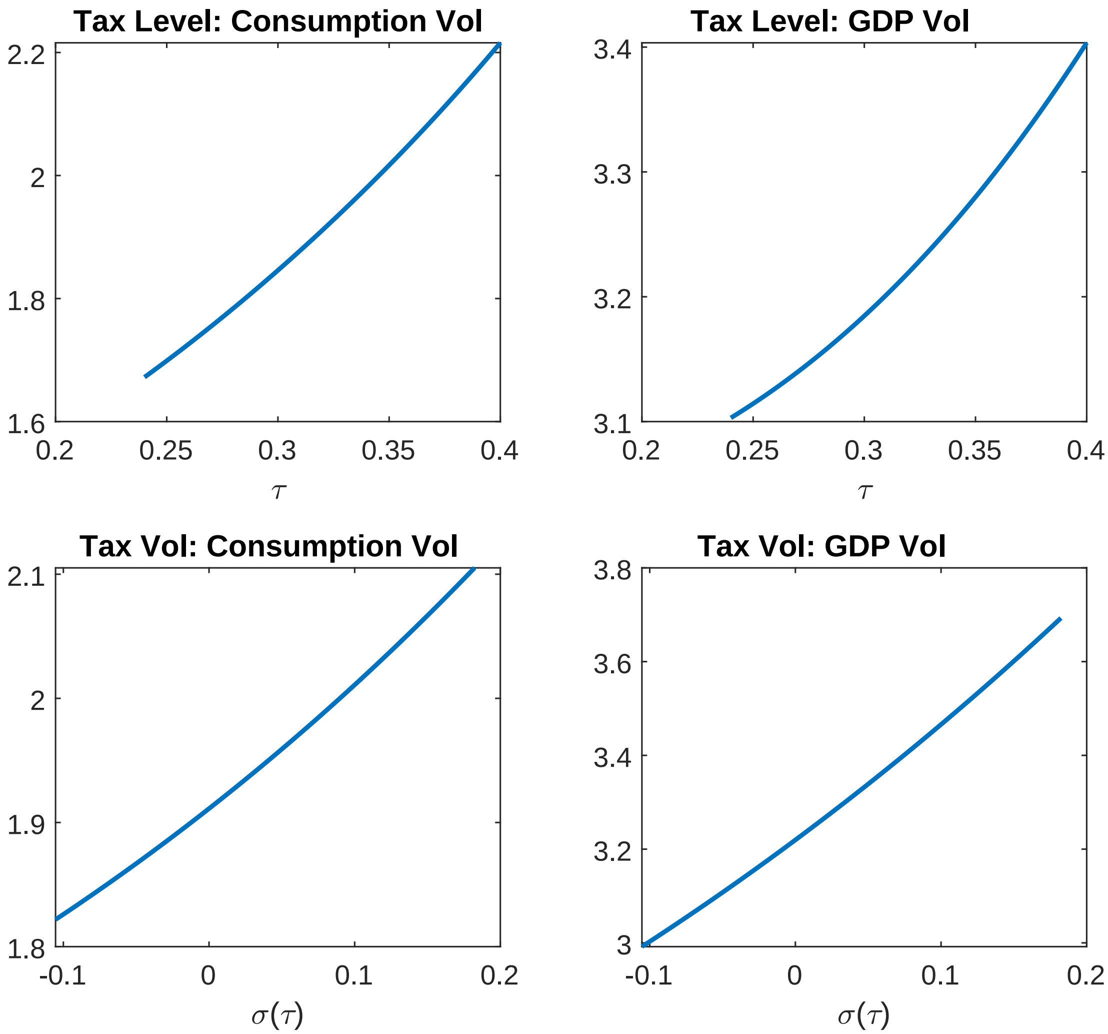


Figure 7: **Policy Functions II.** The figure plots the policy functions of the conditional volatility of consumption growth and GDP growth on the tax rate (τ) and tax volatiity ($\sigma(\tau)$), holding other state variables at the mean.

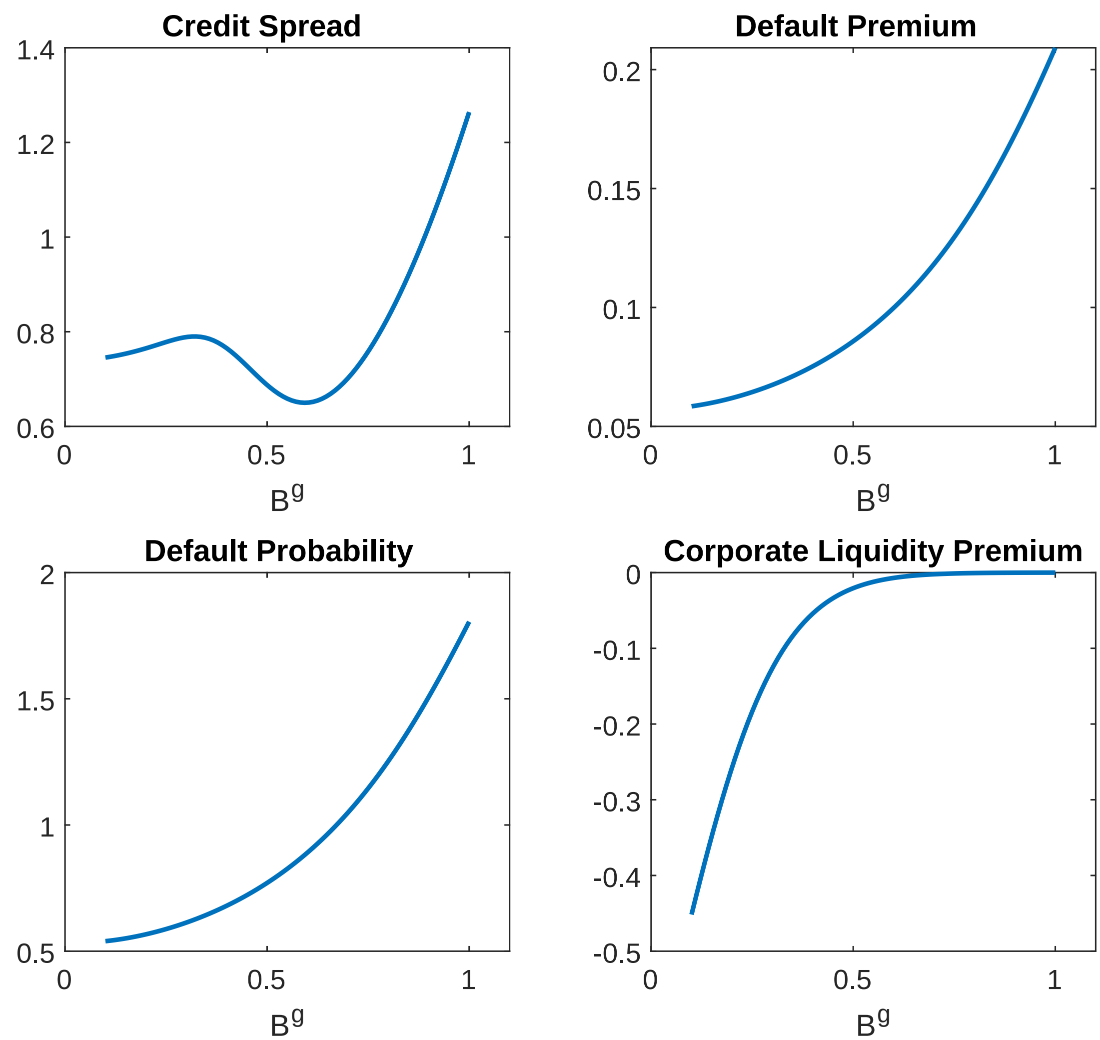


Figure 8: **Policy Functions III.** The figure plots the policy functions of credit spread, default premium, default probability, and the liquidity premium on corporate bonds on government debt (B_g), holding other state variables at the mean.

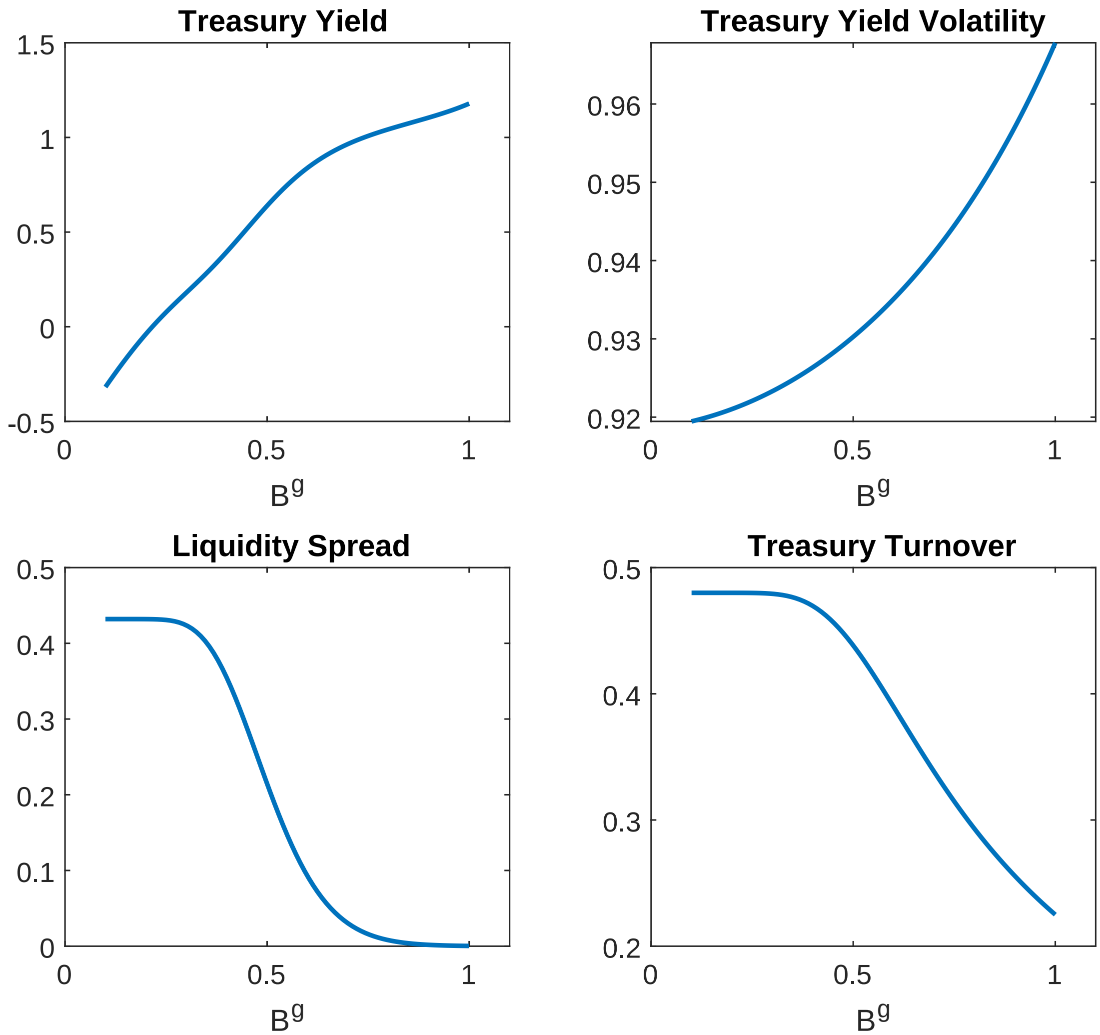


Figure 9: **Policy Functions IV.** The figure plots the policy functions of the Treasury yield, the conditional volatility of the Treasury yield in the next period, liquidity spread, and the Treasury turnover on government debt (B_g), holding other state variables at the mean.

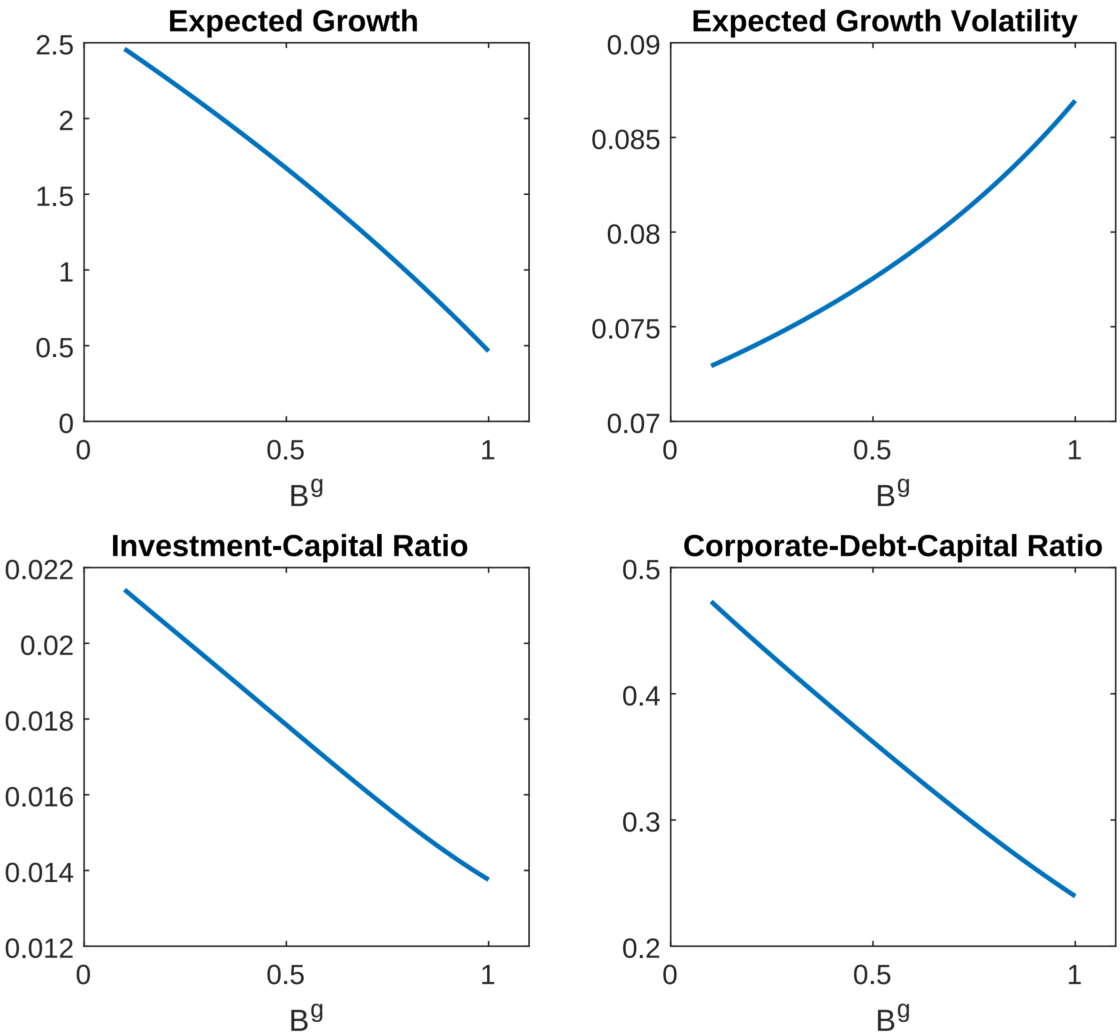


Figure 10: **Policy Functions V.** The figure plots the policy functions of the expected productivity growth, the conditional volatility of the expected productivity growth, the investment-capital ratio, and the corporate-debt-capital ratio on government debt (B_g), holding other state variables at the mean.

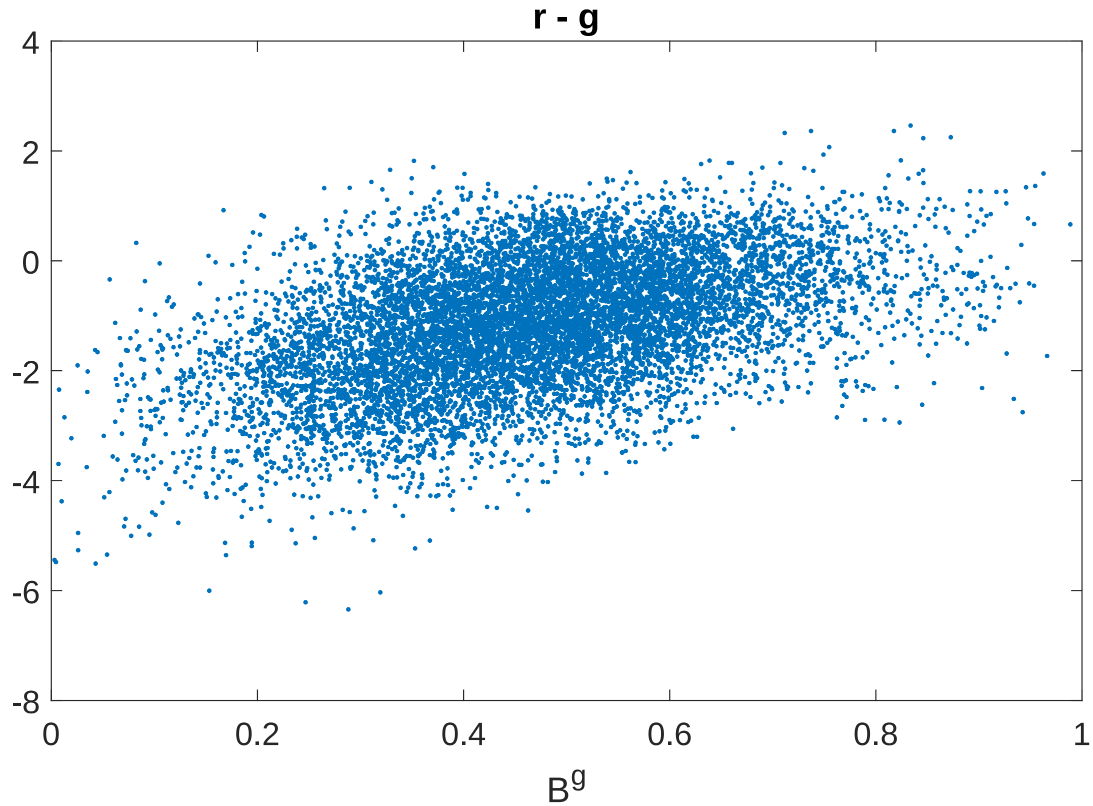
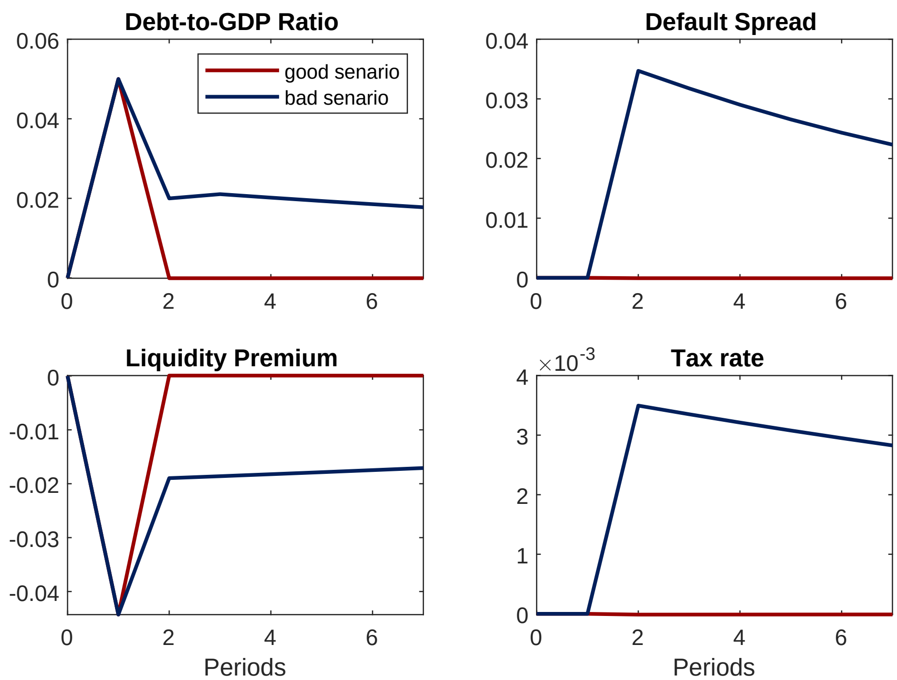


Figure 11: **Distribution of Yields and Expected Growth.** The figure plots the difference between realized Treasury yields and expected growth rates as a function of government debt from the ergodic distribution of model simulations.

Panel A



Panel B

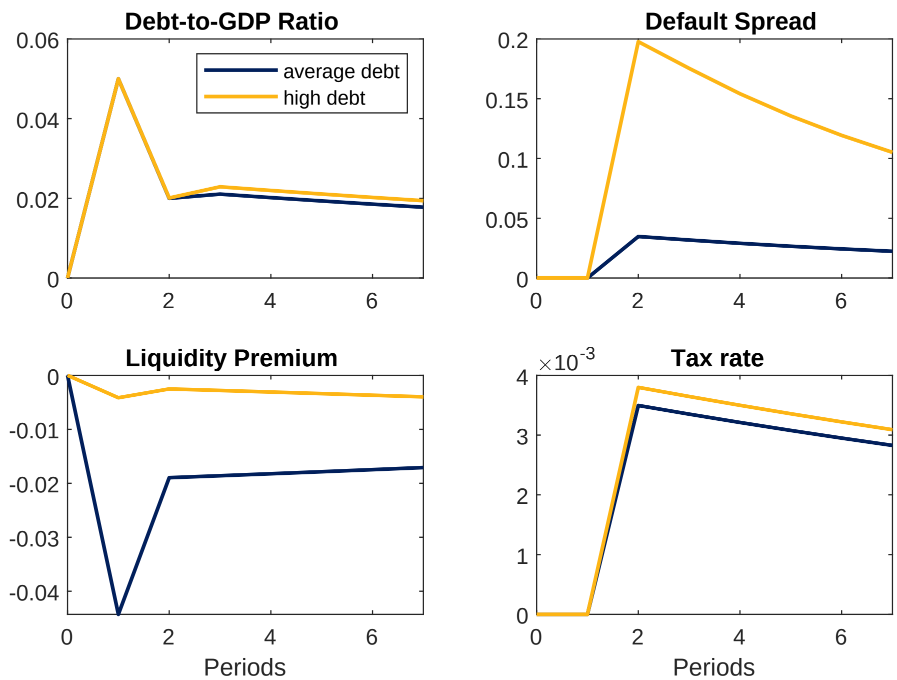


Figure 12: **Impulse Response Functions to a Corporate Bond Purchase Shock.** The figure plots the impulse response functions of the debt-to-gdp ratio, default spread, liquidity premium, and tax rate to a corporate bond purchase shock θ_t in the size of 5 percent of GDP. In a "good scenario", the government earns positive average returns. In a "bad scenario", all the bonds just default at the default boundary. "Average debt" and "high debt" indicate that the government starts with a debt-to-GDP ratio of 40 and 80 percent respectively, in a bad scenario.

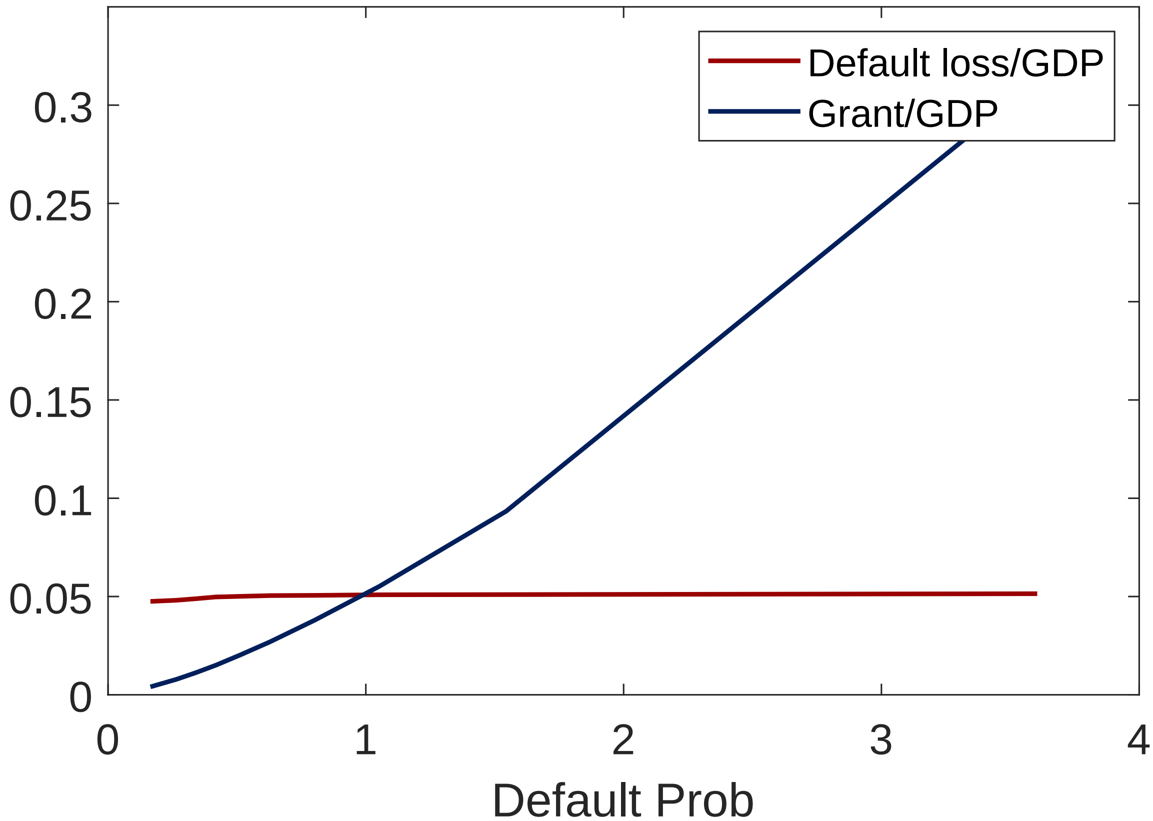


Figure 13: **Costs and Benefits of Government Grant Extensions.** The figure plots costs and benefits of government grant extensions. The current state variable x is set to vary the default probability, and other state variables are at the mean. Under different default probabilities, the figure plots the total amount of grants and the reduction of default losses over GDP.

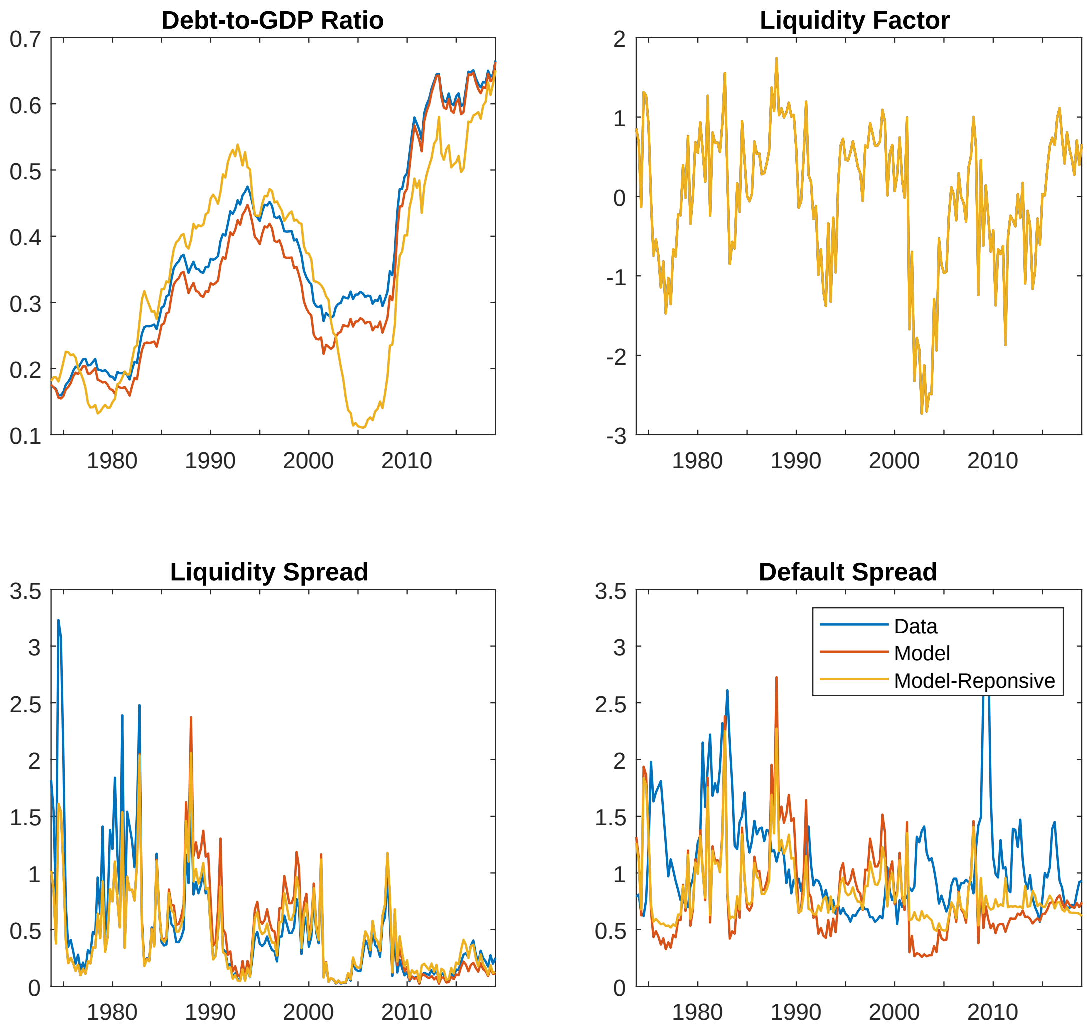


Figure 14: **Time Series of Debt, Liquidity and Spreads.** The figure plots the time series of debt-to-GDP ratio, the liquidity factor, the liquidity spread, and the credit spread in the data, in the baseline model, and in the specification of the model in which debt issuance responds to liquidity demand ($\kappa_{liq} = 0.06$).

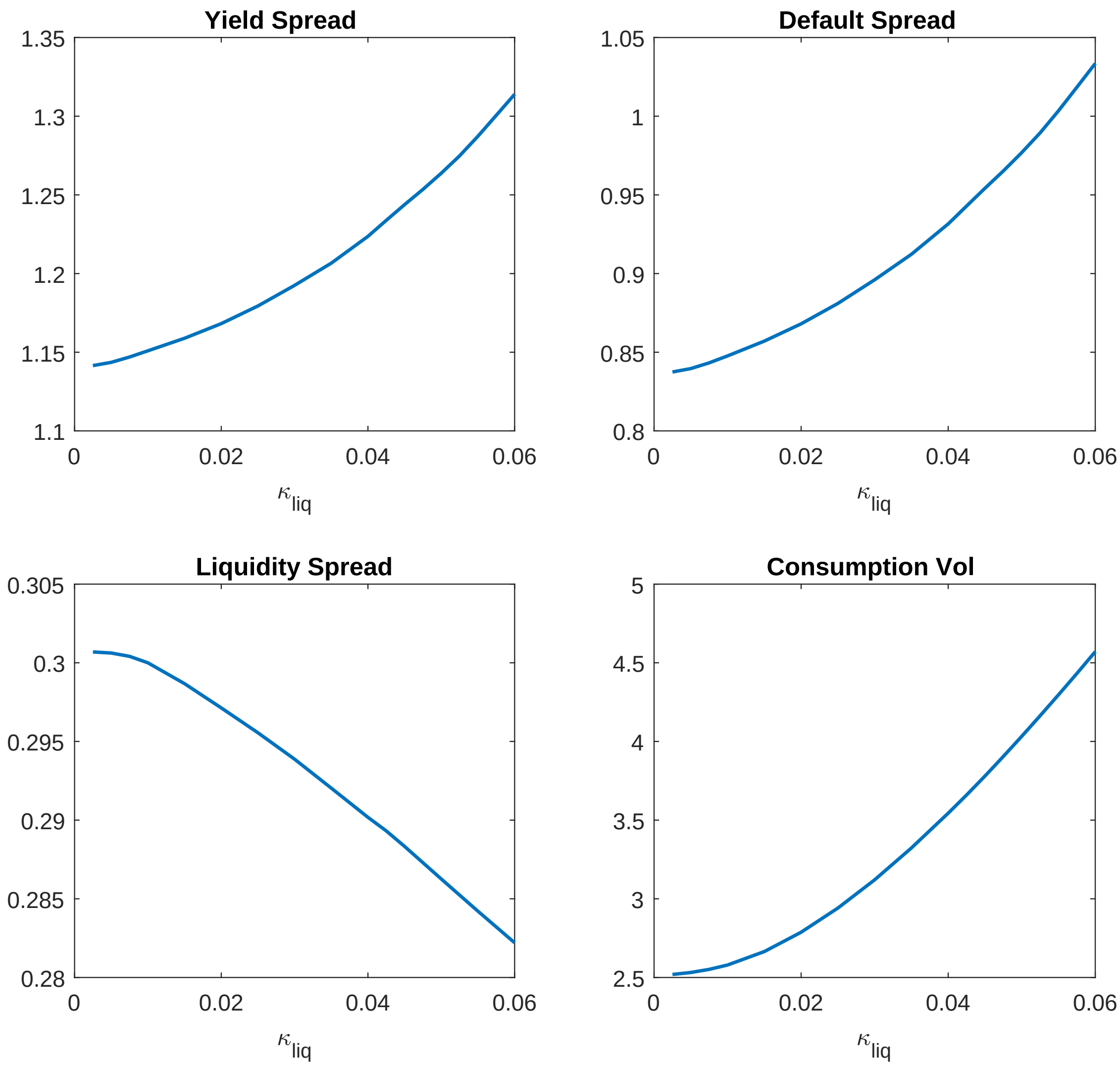


Figure 15: **Responsiveness of The Debt Policy to Liquidity Demand.** The figure plots the means of the credit spread, default spread, liquidity spread and the volatility of consumption growth in model specifications in which the debt policy have a certain degree of Responsiveness κ_{liq} to liquidity demand.

Appendix A. Computational Algorithm

This section presents a brief overview of our computational algorithm. The possibility of default induces strong nonlinearities in both payoffs and the discount factor. Therefore, we use a global, nonlinear solution method. Endogenous variables are approximated using Smolyak polynomials and solved for using projection methods.

A.1 Projection Method

We approximate N_c control variables as functions of N_s state variables using N_p Smolyak polynomials and $N_p \times N_c$ coefficients b. N_p increases with N_s.

We compute the system of N_c equilibrium conditions over a grid of $N_p \times N_c$. We solve the system of equations and obtain b.

In the benhmark case,there are 6 state variables $X = [K_t,\ x_t\ B_t^g,\ \varepsilon_{b,t},\ G_t/Y_t,\ Y_t/A_t]$ and 5 control variables $L_t,\ U_t,\ B_{t+1},\ Q_t,\ Q_t^G$. $N_s = 6$. $N_c = 5$. $N_p = 85$.

A.2 Algorithm

Step 1. Compute the policy function Given coefficients b and grid X.

Use the rescale function $\Phi : R^2 \to [-1, 1]^{N_s}$ to rescale the state variables. For example,

$$\Phi(K_t) = -1 + 2\frac{K_t - K_{min}}{K_{max} - K_{min}}.$$

Use the Smolyak basis functions $\Psi_n(X)$ to compute the policy function $\hat{f}(X; b^{(i)}) = \sum_{n=1}^{N_p} b_n \Psi_n(\Phi(X))$

$$[L_t,\ U_t,\ IB_t,\ Q_t,\ Q_t^G]' = \hat{f}(X; b^{(i)}) = \sum_{n=1}^{N_p} b_n \Psi_n(\Phi(X_n)).$$

Step 2. Compute the state variables in the next period We use the equilibrium conditions to compute the state variables:

$Y_t,\ F_t = K_t^\alpha (A_t L_t)^{1-\alpha}$

$C_t,\ F_{L,t} = \frac{(1-\nu)C_t}{\nu(1-L_t)}$

$I_t,\ Y_t = C_t + I_t$

$K_{t+1},\ K_{t+1} = (1-\delta)K_t + \Phi_k(\frac{I_t}{K_t})K_t$

The remaining state variables follow their law of motions.

Step 3. Compute approximation errors Given the Gaussian quadrature, compute conditional expectations using J integration nodes and weights, $\epsilon_{t+1,j}$ and $\omega_{t,j}$. At each node $X_{t+1,j}$, compute $U_{t+1,j}$

$$E_t[U_{t+1}^{1-\gamma}] = \sum_{j=1}^{J} \omega_{t,j} \left\{ U_{t+1,j}^{1-\gamma} \right\}.$$

Compute $L_{t+1,j}$, $Y_{t+1,j}$, $C_{t+1,j}$, $I_{t+1,j}$,$M_{t+1,j}$, $q_{k,t+1,j}$,$Q_{t+1,j}$, $K_{t+2,j}$, $B_{t+2,j}$, $V_{t+1,j}^{ex}$, $\int^{z_{t+1}^*} V_{i,t+1,j} dF$, $\frac{\partial Q_{t+1}}{\partial K_{t+1}}$,$R_{k,t+1,j}$, $z_{t+1,j}^*$, ...

Use the variables at $t+1$ and node j to compute all the expectations.

Step 4. Solve system of equations of approximation errors with respect to b

Step 5. Simulate the model and compute approximation errors in the simulated state space

A.3 Smolyak polynomials

Smolyak polynomials are a carefully-selected subset of Chebyshev polynomials. Their approximation level is μ. The maximum order of one dimension is $2^\mu + 1$. For example, the 2nd Smoyak polynomials have the highest order of 4, the same as the 4th Chebyshev polynomials. However, the number of polynomials is significantly smaller than the tensor product.

Appendix B. Data Sources

Our government debt data are from the Federal Reserve Bank of Dallas. We use the FRED database to collect the following data: Industrial Production, 3-month treasury bill rates and banker's acceptance rate. Returns on corporate bonds are obtained from the investment grade bond return index from Barclays. General collateralized Repo rates are obtained from Bloomberg. We augment the repo rate with banker's acceptance rate before 1991. The GZ spread and credit risk premium are from Simon Gilchrist's website. We collect the total outstanding and annual trading volume of government and corporate debt from the Securities Industry and Financial Markets Association. The real GDP, government spending and tax are from BEA. The corproate tax rate is measured as the ratio between taxes on corporate income and corporate profits in NIPA Table 1.14.

Appendix C. Model Sensitivity

Table 6 provides sensitivity of the basic model moments with respect to some of the parameter choices in the benchmark specification. In particular, the table illustrates the quantitative relevance of our specification of liquidity risk, exogenous long-run productivity risk and endogenous long-run productivity risk through taxes as well as countercyclical idiosyncratic risk.

Exogenous and endogenous long-run risks play important roles in determining the average equity premium and interest rates. The equity premium substantially drops in absence of these sources of risk, while short term interest rates increase. The default premium, as a source of compensation for aggregate risk, also falls quite substantially absent long-run productivity risk. The latter is also rather sensitive with respect to the specification of idiosyncratic risk, as are credit spreads more broadly. These forces altogether determine the quantitative effect of government debt on credit spreads. Similarly, the crowding out effects of government debt on corporate debt are largely driven by endogenous tax risks and countercyclical idiosyncratic risks. At the same time, while endogenous long-run tax risks with $\phi_\tau > 0$ amplify our quantitative results, the model retains significant risk premia with $\phi_\tau = 0$.

We further explore the determinants of liquidity premiums in Table 7. We perform comparative statics on four liquidity parameters: the probability of arrival λ_t , the mean μ_ξ and standard deviation σ_ξ of liquidity shocks, and transaction costs φ_g, φ_c, φ_l. In the "Low" columns, we set the parameter to be half of the value in the benchmark. We emphasize a number of observations. First, the probability λ_t acts as a scaling factor. An increase in the probability increases the liquidity premiums ν_g and ν_c, liquidity spreads and turnover proportionally. Second, an increase in the mean μ_ξ increases liquidity spreads and turnover. This is intuitive, as given larger average shocks, relatively higher funding needs have to be covered by either selling corporate bonds, or even outright liquidation. Moreover, the effect is no longer linear because of that shift of the liquidity shock distribution. The turnover ratio decreases since the fatter tail leads to a higher transaction volume and frequency in the corporate bond market. It also has a nontrivial effect on the default spread as rollover risk rises alongside. Third, an increase in the standard deviation σ_ξ

increases the liquidity premia ν_g and ν_c, as there is a higher likelihood of funding needs of a size that require transacting corporate bonds, or even liquidation. On the other hand, quantitatively, the effects on the spread and the turnover are modest, given our calibration. In this sense, second moment variation in liquidity needs is second order relative to first moment variation. Finally, transactions costs also act as a scaling factor. While an increase in transaction costs increases the spreads, it does not materially affect turnover.

Table 6: Moments III

Variable	Bench	$\lambda = 0$	$x_t = 0$	$\phi_\tau = 0$	$\phi_{\sigma,a} = 0$
A. Market					
stock return $E[r_d]$	4.09	4.09	3.55	3.67	4.03
risk-free rate $E[r_f]$	0.91	0.89	1.74	1.42	0.90
equity premium $E[r_d - r_f]$	3.18	3.20	1.81	2.25	3.13
consumption volatility $\sigma(\Delta c)$	2.52	2.55	2.33	2.62	2.52
B. Credit					
corporate bond recovery rate $E[r_{rec}]$	0.33	0.32	0.51	0.39	0.51
default rate $E[F(z)]$	1.07	1.04	0.77	1.00	0.73
leverage $E[Q_t B_{t+1}/(Q_t B_{t+1} + V_t^{ex})]$	0.40	0.39	0.41	0.40	0.42
yield spread $E[y_t^c - y_t^g]$	1.10	0.84	0.64	0.95	0.65
mean default spread	0.84	0.84	0.41	0.70	0.39
default spread: mean default loss	0.71	0.71	0.38	0.61	0.36
default spread: mean default premium	0.12	0.12	0.02	0.09	0.03
first diff regression coef. of default spread on gov't debt-to-GDP	2.82	3.05	0.87	1.08	0.55
C. Liquidity					
liquidity spread $E[\nu_c - \nu_g]$	0.26		0.24	0.25	0.26
risk-free rate/treasury bill spread $E[\nu_g]$	-0.33		-0.28	-0.32	-0.31
liquidity premium of corporate bond $E[\nu_c]$	-0.07		-0.04	-0.07	-0.05
mean government bond turnover	0.44		0.43	0.43	0.44
mean corporate bond turnover	0.14		0.12	0.13	0.13
mean ratio of government and corporate bond volume	25.35		33.28	26.64	23.43
first diff regression coef. of liquidity spread on gov't debt-to-GDP	-0.85		-0.84	-0.86	-0.86
regression coef. of gov't bond volume on gov't debt-to-GDP	-0.19		-0.22	-0.21	-0.19
D. Crowding out					
regression coef. of corporate debt-to-GDP on gov't debt-to-GDP	-0.27	-0.26	-0.24	-0.12	-0.14

This table summarizes the moments in the model. The model moments are obtained from a long sample simulation of 10,000 periods. We report moments of market variables in panel A, credit variables in panel B, liquidity moments in panel C, and crowding out in panel D. "Bench" refers to the results from the benchmark model. The sensitivity analysis sets the parameters as the column title suggests and holds other parameters as the benchmark.

Table 7: Moments IV

Variable	Bench	Low λ	Low μ_ξ	Low σ_ξ	Low $\varphi' s$
A. Credit					
corporate bond recovery rate $E[r_{rec}]$	0.33	0.33	0.32	0.33	0.33
default rate $E[F(z)]$	1.07	1.05	1.04	1.04	1.05
leverage $E[Q_t B_{t+1}/(Q_t B_{t+1} + V_t^{ex})]$	0.40	0.40	0.40	0.40	0.40
yield spread $E[y_t^c - y_t^g]$	1.10	0.96	0.95	1.08	0.96
mean default spread	0.84	0.83	0.83	0.82	0.83
default spread: mean default loss	0.71	0.71	0.71	0.70	0.71
default spread: mean default premium	0.12	0.12	0.12	0.12	0.12
first diff regression coef. of default spread on gov't debt-to-GDP	2.82	2.87	2.97	2.81	2.87
B. Liquidity					
liquidity spread $E[\nu_c - \nu_g]$	0.26	0.13	0.12	0.26	0.13
risk-free rate/treasury bill spread $E[\nu_g]$	-0.33	-0.16	-0.13	-0.29	-0.16
liquidity premium of corporate bond $E[\nu_c]$	-0.07	-0.04	-0.01	-0.03	-0.04
mean government bond turnover	0.44	0.22	0.36	0.44	0.44
mean corporate bond turnover	0.14	0.07	0.04	0.12	0.14
mean ratio of government and corporate bond volume	25.35	26.19	1560	10^7	26.19
first diff regression coef. of liquidity spread on gov't debt-to-GDP	-0.85	-0.43	-0.75	-1.03	-0.43
regression coef. of gov't bond volume on gov't debt-to-GDP	-0.19	-0.20	-0.42	-0.19	-0.20

This table summarizes the moments in the model. The model moments are obtained from a long sample simulation of 10,000 periods. We report moments of market variables in panel A, credit variables in panel B, liquidity moments in panel C, and crowding out in panel D. "Bench" refers to the results from the benchmark model. The sensitivity analysis sets the parameters in the column to be half of the value in the benchmark. In the "$\varphi' s$" columns, we change all the three transaction cost parameters φ_g, φ_c and φ_l.