Debt Maturity without Commitment*

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Abstract

This paper analyzes how sovereign risk paired with social costs of default shape the government debt maturity structure. Governments balance benefits of default induced redistribution and costs due to income losses in the wake of a default. Their choice of short- versus long-term debt issuance affects default and rollover decisions by subsequent policy makers whose price impact gives rise to revenue losses on inframarginal units of debt. When considering whether to issue additional debt of a certain maturity, the government weighs the benefit of smoothing disposable income and the cost due to these revenue losses. Consistent with the evidence, the model predicts an interior maturity structure with positive gross positions; the maturity structure shortens when debt issuance is high, output low, output volatility low, or a cross default more likely.

Keywords: Debt; maturity structure; no commitment; default.
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1 Introduction

Sovereign borrowers exert considerable effort to structure their debt maturities optimally. This is difficult to reconcile with a frictionless benchmark model in which the equilibrium

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allocation concurs with net financial positions while gross financial positions and the maturity structure are indeterminate (Modigliani and Miller, 1958; Barro, 1974). Existing theories (discussed below) point to a role of government debt maturity if the environment allows for multiple equilibria, including "bad" ones featuring a rollover crisis, or if the government cannot issue securities with explicitly state contingent payoffs. However, the predictions of these theories are not robust or not in line with the empirical evidence, leading Faraglia, Marcet and Scott (2008, p. 28) to conclude that "[w]e remain in search of a plausible theory of debt management."

In this paper, I offer an alternative explanation for borrowers' scrupulous choice of maturity, arguing that lack of commitment paired with social costs in the wake of a government default undermines the neutrality of the maturity structure. Focusing on these two factors is natural given that a large literature concerned with sovereign borrowing emphasizes the pervasiveness of limited contract enforceability and the significant social costs in the aftermath of defaults.[1] The implications of this alternative explanation turn out to be consistent with the evidence. In particular, the model predicts an interior maturity structure with positive gross positions that shortens when debt issuance is high, output low, output volatility low, or the risk of debt acceleration and cross-default high.

I consider a government issuing real non-contingent debt of various maturities to investors on the international financial market. Successive governments (or selves of the government) decide whether, and to what extent, to honor maturing debt. They also choose the level of taxation and new debt issuance to finance contemporaneous debt repayment as well as exogenous government purchases. The government's desire to redistribute from foreign bondholders to domestic taxpayers creates an incentive to default on maturing debt.[2] Counteracting this temptation is an opposing incentive to avoid the ex ante random costs of defaulting which take the form of income losses for taxpayers. Both bondholders and the government form rational expectations. The price of a debt maturity therefore reflects its expected repayment rate, and government policy is subgame perfect.

In equilibrium, the risk-adjusted returns on short- and long-term funding are identical and the equilibrium maturity structure is determined on the demand side. In particular, it is critically shaped by revenue losses on inframarginal units of debt which arise because debt issuance affects the market prices of maturities currently issued. These price effects reflect the rational expectations of investors that debt issuance changes the default and rollover choices of subsequent policy makers, in particular that higher debt issuance reduces the probability of future repayment. When considering whether to issue additional debt of a certain maturity, the government weighs the benefit of smoothing the disposable income across periods and states—a benefit that depends on the price of the maturity

[1] See Eaton and Fernandez (1995) for an overview over the literature and Reinhart and Rogoff (2004), Sturzenegger and Zettelmeyer (2006, pp. 49–52) or Panizza, Sturzenegger and Zettelmeyer (2009), among many others, for a discussion of the costs of sovereign defaults.

[2] The incentive to default might alternatively derive from the government's desire to transfer funds from the private to the public sector, in order to avoid tax distortions. Focusing on the redistributive motive is attractive for two reasons. On the one hand, conflict between interest groups indeed appears to affect governments' default decisions, see the discussion later in the text. On the other hand, abstracting from tax distortions allows to disregard a second source of time inconsistency, related to the optimal timing of taxes (Lucas and Stokey, 1983).

being issued and its state contingent equilibrium repayment rate—and the cost due to the associated revenue losses, reflecting the consequences of the government's inability to commit its successors.

To understand the implications of this tradeoff for the equilibrium maturity structure, I consider first a simplified setup that allows to derive closed-form solutions. If the hazard function of income losses in the wake of a default is non-decreasing, the cost-benefit ratio associated with the issuance of a particular debt maturity is a convex function. Accordingly, the equilibrium maturity structure is interior and unique and equilibrium policy smoothes cost-benefit ratios across available maturities, in parallel with the familiar tax (distortion) smoothing prescription (Barro, 1979; Lucas and Stokey, 1983). While the latter stipulates a Ramsey tax sequence and associated net government debt sequence that minimizes the detrimental effects of tax distortions, the maturity smoothing prescription specifies the gross positions of each maturity (and thus, net debt positions and taxes) that maximize welfare when lack of commitment is binding.

In a benchmark case with exponentially distributed income losses in the wake of debt repudiation, the cost-benefit ratio associated with each debt maturity is independent of the quantity of debt outstanding. One of the two sources of time inconsistency in the model then is shut off—debt issuance affects future debt repayment choices but not future rollover choices—and as a consequence, the smoothing prescription implies a fully balanced maturity structure.

If income losses in the wake of a default are distributed according to any other distribution guaranteeing uniqueness of the equilibrium maturity structure, then current debt issuance affects future repayment and rollover decisions. In particular, higher outstanding debt leads the cost-benefit ratio of short-term debt issuance to deteriorate, depressing such debt issuance. As a consequence, long-term debt issuance increases the amount of debt maturing in the long term by less than one-to-one. This reduces the inframarginal losses and improves the cost-benefit ratio of long-term debt, giving rise to an equilibrium maturity structure that is tilted towards the long end. Higher quantities of debt reduce this cost advantage of long-term debt, inducing a more balanced maturity structure. This has direct implications for the government's portfolio over the cycle: In periods of high marginal utility total debt issuance increases and the maturity structure shortens; in periods of low marginal utility total debt issuance decreases and the maturity structure lengthens.

Output volatility tends to lengthen the equilibrium maturity structure as well. When output is low and marginal utility high, governments find it optimal to issue more debt. Since this increases the risk of default in the future, output is positively correlated with the price of newly-issued and outstanding debt. Ex ante, long-term debt therefore provides a useful hedge for the government since its return correlates positively with output.

Debt acceleration and cross-default introduce additional feedback effects across maturities. When a default on maturing debt reduces the cost for the subsequent government to default on currently outstanding debt, then equilibrium features cross defaults with the market prices of maturing and outstanding debt collapsing simultaneously although the repayment rate on outstanding debt is chosen only later, by the subsequent government. Default choices in such an environment depend on the quantities of maturing and outstanding debt, and issuance of any maturity triggers inframarginal revenue losses across all maturities. In general, the implications for the equilibrium maturity structure are ambiguous. However, as the probability of acceleration conditional on a default on maturing debt approaches one, the cost-benefit ratio of long-term debt uniformly dominates the corresponding ratio of short-term debt, implying that the equilibrium maturity structure is concentrated on the short end.

The broad picture that emerges from the model's analytical solutions is one of an interior maturity structure with positive gross positions, in line with the empirical evidence, but in contrast with predictions from models that stress the role of the maturity structure in completing markets or avoiding rollover crises (see below). The model predicts a shortening of the maturity structure when debt issuance is high, in line with evidence summarized by Rodrik and Velasco (1999); around times of low output ("crises"), consistent with the evidence reported by Broner, Lorenzoni and Schmukler (2007); and in periods with low output volatility or high risk of cross default and acceleration.[3]

These analytical results are also reflected in the numerical solutions of the policy functions for the general setup. TBW

The model of this paper is silent about the choice of maturity structure in countries whose debt is perceived to be default-risk free.[4] In the aftermath of the recent turmoil on financial markets and the related deterioration of government budgets, the number of such countries is shrinking as the ratings of sovereign debt securities previously considered to be safe have been downgraded.[5] Credibility problems therefore are likely to bear on the maturity structure in a wide range of developing and developed economies.

Revenue losses on inframarginal units of debt, central to the mechanism at work in the paper, constitute an inherent feature of these credibility problems. Closely related to these revenue losses, previous literature has emphasized debt dilution as a consequence of lack of commitment. In particular, it has been pointed out that debt issuance reduces the value of outstanding debt and that this effect may increase governments' incentives to issue new debt ex post.[6] In contrast, the revenue losses of interest in the present paper arise with respect to contemporaneously issued debt and are fully internalized by the government seeking funding. Ex-post benefits from diluting outstanding debt therefore contrast with ex-ante costs of issuing new debt maturities, due to the social losses associated with default.

[3]According to Rodrik and Velasco (1999), "the overall debt burden (debt/GDP ratio) is positively correlated with short-term borrowing in the time-series (but not in the cross-section). One interpretation is that countries that go on a borrowing binge are forced to shorten the maturity of their external liabilities in the short run" (p. 21). According to Broner et al. (2007) "emerging economies issue relatively more short-term debt during periods of financial turmoil, and wait for tranquil times to issue longterm debt" (p. 3).

[4]Choices of debt structure in those countries appear to be affected by liquidity concerns. In the UK, for example, the Debt Management Office "argues that cost is not the only factor. There is a virtue in being predictable, and in keeping all sections of the bond market supplied with debt to trade" (*The Economist*, "Losing interest," June 14th 2008).

[5]See, for example, *The Economist*, "Rate and see," December 12th 2009.

[6]Dilution may be present even if outstanding debt is prioritized, see Bizer and DeMarzo (1992) who analyze the case where increased borrowing leads a borrower to take actions that lower the probability of repayment.

Importantly, these costs arise under entirely standard premises. For example, the assumption that debt contracts stipulate non-contingent payments and failure to make contractually specified payments triggers social losses is standard, presumably reflecting the notion that informational constraints prevent sovereign borrowers from entering into more sophisticated financial arrangements. The present paper does not address the reasons for such constraints, nor does it rationalize other central tenets in the sovereign debt literature, in particular lack of commitment. Instead, the paper maintains the standard set of assumptions and analyzes the determinants of sovereign debt maturity within their context.

Related Literature Lack of commitment and the associated difficulty to sustain borrowing take center stage in the sovereign debt literature.[7] Eaton and Gersovitz (1981) suggest that the threat of financial autarky discourages strategic default. Bulow and Rogoff (1989*b*), Grossman and Han (1999), Kletzer and Wright (2000) and Ljungqvist and Sargent (2004, ch. 19), among many others. discuss this hypothesis and the role that the set of available financial instruments plays in it. Cole and Kehoe (1998) and Sandleris (2006) argue that a sovereign default serves as a negative signal, inducing parties outside of the credit relationship to initiate actions that are costly for the government. Tabellini (1991), Dixit and Londregan (2000), Kremer and Mehta (2000), Niepelt (2004) or Guembel and Sussman (2009) argue that distributive motives can counteract a sovereign's incentive to default. More direct default costs of the type considered here are present, for example, in the models of Bulow and Rogoff (1989*a*), Bulow and Rogoff (1989*b*), Cole and Kehoe (2000), Aguiar and Gopinath (2006) and Arellano (2008).[8]

To motivate an optimal maturity structure, some authors suggest that short-term debt renders a country vulnerable to rollover crises, and that long-term debt reduces such vulnerability (Calvo, 1988; Alesina, Prati and Tabellini, 1990; Giavazzi and Pagano, 1990; Rodrik and Velasco, 1999; Cole and Kehoe, 2000). However, Chamon (2007) shows that a simple mechanism is able to eliminate the coordination failure associated with rollover crises. Phelan (2004) draws a distinction between the maturity of debt and the sequencing of debt rollovers which matters for crises. Broner et al. (2007) argue that supply side features induce emerging markets to borrow short-term in spite of the increased risk of a rollover crisis. In their model, lenders are risk averse and heavily exposed to the price risk of long-term emerging-markets debt. Higher quantities of long-term debt therefore drive up term premia and thus, the cost of long-term funding.

Lucas and Stokey (1983) characterize the Ramsey tax policy in a closed economy where the government has access to state contingent debt. They show that a complete set of maturities allows to implement the Ramsey policy even if the government can only commit to debt repayment and not to taxes. Underlying this finding are general equilibrium price effects: Deviations from the ex-ante optimal tax policy change interest rates ex post, devaluing some debt maturity positions and appreciating others. An appropriate choice of maturity structure ex ante allows the government to balance the benefits and

[7]Kydland and Prescott (1977) and Fischer (1980) discuss the government's ex-post incentive to default when taxes are distorting.

[8]See also Tirole (2006, p. 180) where a default might trigger a costly loss of social capital.

costs of a policy change ex post and thus, to sustain the Ramsey policy. Abstracting from time-consistency issues, Angeletos (2002) shows that a sufficiently rich maturity structure of non-contingent bonds may serve as a substitute for state-contingent debt in Lucas and Stokey's (1983) model (see also Gale, 1990). Shocks to government spending or productivity affect consumption and interest rates in general equilibrium and, since prices of bonds with different maturity respond differently to these price changes, an appropriate portfolio of maturities allows the government to hedge against these shocks. However, as documented by Faraglia et al. (2008), the quantitative implications of this "complete market approach" are at odds with the data. Nosbusch (2008) shows that the government may be able to get close to the complete-markets tax smoothing policy even if the set of available maturities is very small. Similar to Faraglia et al. (2008), the basic prescription for the government in Nosbusch's (2008) model is to borrow long and invest short, in contrast with the positive short- and long-term debt positions observed in the data.

Closer in spirit to the present paper, Calvo and Guidotti (1990) and Missale and Blanchard (1994) discuss the role of the maturity structure of nominal debt for the government's incentive to engineer surprise inflation. Hatchondo and Martinez (2009) analyze numerically how the duration of government debt affects debt issuance, default choices and risk premia (see also Arellano and Ramanarayanan, 2008). Finally, a large literature in corporate finance analyzes the role of commitment problems for the financial structure of firms, see Tirole (2006) for an overview and Jeanne (2004) for an application in the sovereign debt context.

Outline The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 shows how lack of commitment paired with social costs in the wake of a default introduces a role for the debt maturity structure. Sections 4 and 5 contain the analytical and numerical characterizations of the equilibrium maturity structure, respectively. Section 6 concludes.

2 Model

Time is discrete and indexed by $t = 0, 1, 2, \ldots$. The small open economy is inhabited by a representative taxpayer and a government that interacts with foreign investors. The government levies taxes, τ_t, chooses the repayment rate on maturing debt, r_t, and issues zero-coupon debt of various maturities, $\{b_{t,s}\}_{s=t+1}^{t+M}$, where the first and second subscript denotes the issuance and maturity date, respectively, and where $M < \infty$ is the maximal maturity. Debt instrument $b_{t,s}$ promises a "safe" return in period s that is, a return independent of the state of nature in that period. Vector ι_t summarizes the government's debt issuance in period t, $\iota_t \equiv (b_{t,t+1}, \ldots, b_{t,t+M})$. Without loss of generality, government spending other than debt repayment is normalized to zero.

2.1 Private Sector

Taxpayers do not save nor borrow and all government debt therefore is held by foreign investors.[9] The assumption that the sets of taxpayers and investors do not "overlap" is unimportant for the central results but simplifies the analysis; modeling a mixed rather than concentrated ownership structure of debt would require a theory of how this ownership structure is determined in equilibrium.[10]

Taxpayers have time- and state-additive preferences over consumption with strictly increasing and concave felicity function $u(\cdot)$. They discount the future according to the discount factor $\delta \in (0, 1)$ and face state-contigent pre-tax income y_t^p. Welfare of taxpayers at time t is given by

$$\mathrm{E}\left[\sum_{s \geq t} \delta^{s-t} u(y_s^p - \tau_s)|s_t, r_t, \iota_t\right],$$

where s_t denotes the state at the beginning of period t, to be specified below. Since taxpayers do not save, the government's choice of taxes (which is implied by the debt issuance and redemption policy) directly affects household consumption and welfare.

Foreign investors are competitive, risk neutral and require a riskfree interest rate equal to β^{-1} where $\beta \in (0, 1)$. In equilibrium, government debt therefore pays an expected return of β^{-1} per period.

2.2 Government

The government maximizes the welfare of taxpayers.[11] Crucially, it cannot commit its successors (or future selves). In each period t, the contemporaneous government therefore chooses debt issuance as well as the uniform (pari passu) repayment rate on all maturing debt, $b_{x,t} \equiv \sum_{s=t-M}^{t-1} b_{s,t}$. Taxes follow residually from the government's dynamic budget constraint.

2.3 Default Costs

A government default—defined as a situation where the repayment rate falls short of unity—triggers temporary income losses for taxpayers (cf. Eaton and Gersovitz, 1981; Cole

[9] Mankiw (2000) or Matsen, Sveen and Torvik (2005) analyze fiscal policy in economies with "savers" and "spenders."

[10] The government's default decision depends on the ownership structure of debt relative to the distribution of tax burdens across the population, see below. Changes in the ownership structure therefore affect the default decision ex post and thus, investment decisions ex ante.

Tabellini (1991) and Dixit and Londregan (2000) provide theories of the ownership structure of debt. They assume that households can only save in government debt (Tabellini, 1991), or that the return on the only alternative asset is household specific (Dixit and Londregan, 2000). Both assumptions are not applicable in the current context. See also Niepelt (2004).

[11] If the government maximized a weighted average of taxpayers' and investors' welfare and attached a sufficiently large weight to the welfare of investors, interior repayment rates might result, in contrast to what follows. If the government attached a strictly positive weight to the welfare of investors and if investors were risk averse, investor wealth would constitute a state variable, in contrast to what follows.

and Kehoe, 2000; Aguiar and Gopinath, 2006; Arellano, 2008). More specifically, a default in period t triggers an income loss $L_t \geq 0$ where L_t is the realization of an i.i.d. random variable with cumulative distribution function $F(\cdot)$ and associated probability density function $f(\cdot)$, $f(L) > 0$ for all $L > 0$. The government learns about the realization of L_t at the beginning of the period, before choosing its policy instruments. Pre-tax income of taxpayers is given by $y_t^p = y_t - \mathbf{1}_{[r_t<1]} L_t$ where y_t denotes the exogenous net output in the economy and $\mathbf{1}_{[x]}$ denotes the indicator function for event x.

The assumption of temporary rather than persistent income losses is motivated by two considerations. First, temporary default costs constitute a natural benchmark.[12] Second, and more importantly, the assumption of temporary losses is more plausible. In particular, permanent exclusion from trade or credit markets and other forms of long-term punishment may serve as threat points in the negotiation between a defaulting sovereign and its creditors; but such forms of long-term punishment are unlikely to be realized in equilibrium if the parties renegotiate.[13] Empirical evidence supports the notion of temporary rather than permanent default costs as well as the notion that these costs arise in the form of output losses (cf., for example, Panizza et al., 2009).[14] The assumption that L_t is distributed identically and independently over time is made to simplify notation; the assumption is relaxed at a later stage.

2.4 Cross Default and Debt Accumulation

Being unable to commit, a government cannot force its successors to pay a certain rate of return, including zero. This implies that a government may not *directly* cross default on contemporaneously outstanding debt. Indirectly, however, a cross default may arise. In particular, in period t, the random variable cd_t takes the value 1 with probability $\pi \in [0, 1]$ and the value 0 with probability $1 - \pi$. If $\mathrm{cd}_t = 1$, then a default on debt maturing in period t (carrying income losses L_t) reduces to zero the cost for subsequent governments of defaulting on debt outstanding in period t. If $\mathrm{cd}_t = 1$, a default on maturing debt therefore triggers a simultaneous devaluation of outstanding debt since future governments will always find it in their interest to completely default on that debt.[15]

The three exogenous shocks y_t, L_t and cd_t are pairwise independent of each other.

[12] The results of this paper remain valid under the assumption of permanent default costs if these costs do not interact with future debt issuance and repayment rate decisions. This is the case, for example, if the utility function is linear.

[13] Suppose, for example, that the sovereign chooses between either repaying, or not repaying and entering into a bargaining process with creditors. This process takes one period, generating income losses L_n, and results in a settlement where lenders secure a strictly positive repayment rate, $\bar{r}_n > 0$. The analysis in this paper is consistent with this interpretation although it abstracts from any safe return component on sovereign debt (as implied by $\bar{r}_n$).

[14] According to Panizza et al. (2009, p. 692), "[c]apital exclusion periods [in the wake of a default] are brief; effects on the cost of borrowing are temporary and small ... defaulting debtors have been able to issue new debt domestically (including to foreign investors) at relatively low cost. If anything, defaults appear to be deterred by the domestic collateral damage that tends to accompany debt crises".

[15] Alternatively, the cross default can be interpreted as a debt buyback at very low prices that reflect equilibrium expectations of subsequent governments' default decisions.

Let $b_{x,t,t+s}$ denote the amount of debt outstanding in period t and maturing in period $s, 0 \leq s \leq M-1$ (with $b_{x,t,t} = b_{x,t}$). The law of motion for the M debt maturities then is given by

$$b_{x,t+1,t+s} = b_{x,t,t+s}(1 - \mathbf{1}_{[r_t<1 \ \& \ \mathrm{cd}_t=1]}) + b_{t,t+s}, \ 1 \leq s \leq M. \tag{1}$$

Equation (1) states that the stock of debt outstanding in period $t+1$ and maturing in period $t+s$ is given by the debt outstanding in period t and maturing in period $t+s$ as well as the s-period-maturity debt issued in period t. However, in case of a default in period t accompanied by the realization $\mathrm{cd}_t = 1$, the former component vanishes.

The assumption of a "cross-default shock" cd_t is motivated by two considerations. First, as discussed above, it allows to reconcile the assumption of no commitment on the one hand with the equilibrium occurrence of cross default on the other. Second, the stochastic specification of cd_t captures the fact that the extent of cross default and restructuring during sovereign default episodes varies, reflecting the fact that both the sovereign and certain creditors might want to delay or prevent acceleration.[16] The latter include lenders that seek to avoid an immediate deterioration of their balance sheet as otherwise implied by mark-to-market regulation, or the government itself if it purchased the country's debt on the secondary market.[17]

2.5 Equilibrium

Apart from time (in the finite-horizon case), the economy's state is given by the realizations of the three exogenous shocks (net output, income loss in the wake of a default, and cross-default option) as well as the quantities of maturing and outstanding debt:

$$s_t = (y_t, \mathrm{cd}_t, L_t, b_{x,t}, \{b_{x,t,t+s}\}_{s=1}^{M-1}).$$

(Throughout the paper, I exclude artificial state variables of the type sustaining trigger strategies.)

Denote by $q_{t,s}(s_t, r_t, \iota_t)$ the price of debt issued in period t state s_t and maturing in period s if the government implements the policy (r_t, ι_t). All governments in period t and earlier take the price functions $\{q_{t,s}(\cdot)\}_{s=t+1}^{t+M}$ as given when choosing their policies. Define the deficit in period t as the market value of debt issued in period t,

$$d_t(s_t, r_t, \iota_t) \equiv \sum_{s=t+1}^{t+M} b_{t,s} \ q_{t,s}(s_t, r_t, \iota_t).$$

The dynamic budget constraint of the government, $\tau_t = b_{x,t}r_t - d_t(s_t, r_t, \iota_t)$, implies that period-$t$ consumption of taxpayers, c_t, is given by $c_t = y_t - \mathbf{1}_{[r_t<1]}L_t - b_{x,t}r_t + d_t(s_t, r_t, \iota_t)$.

Let $G_t(s_t)$ denote the value of the government's program conditional on the state s_t. An equilibrium is given by pricing functions $\{q_{t,s}(\cdot)\}_t$ (of s_t, r_t, ι_t), value functions $\{G_t(\cdot)\}_t$ (of s_t), and policy functions $\{r_t(\cdot), \iota_t(\cdot)\}_t$ (of s_t) such that

[16] Acceleration of bonds often requires support by creditors representing a significant share (typically 25 percent) of the outstanding bonds.

[17] See Buchheit (2009) for a discussion in the context of Ecuador's sovereign bond default.

i. conditional on the pricing functions, the value and policy functions solve

$$\begin{aligned} G_t(s_t) &= \max_{r_t \in [0,1], \iota_t} u(y_t - b_{x,t} r_t - \mathbf{1}_{[r_t<1]} L_t + d_t(s_t, r_t, \iota_t)) + \delta \mathrm{E}\left[G_{t+1}(s_{t+1}) | s_t, r_t, \iota_t\right] \\ & \quad \text{s.t. (1) for all } s_t, t; \end{aligned}$$

ii. the pricing functions reflect rational expectations by investors,

$$\begin{aligned} q_{t,t+s}(s_t, r_t, \iota_t) &= \beta^s \mathrm{E}\left[\prod_{i=t+1}^{t+s-1} (1 - \mathbf{1}_{[r_i(s_i)<1 \ \& \ \mathrm{cd}_i=1]}) r_{t+s}(s_{t+s}) | s_t, r_t, \iota_t\right] \\ & \quad \text{for all } s_t, r_t \in [0,1], \iota_t, t, 1 \leq s \leq M. \end{aligned} \tag{2}$$

Condition (2) states that in equilibrium and on average, investors earn the required rate of return. In that sense, they are insulated against the effects of government policy. Domestic taxpayers, in contrast, are heavily exposed. Their disposable income varies with r_t and ι_t because these instruments affect contemporaneous and (indirectly) future taxes. The benevolent government balances the costs and benefits of these effects of r_t and ι_t. In doing so, it is constrained by the fact that subsequent governments act ex-post optimal rather than following the ex-ante optimal Ramsey policy.

3 Analysis

I focus on the case with two maturities, $M = 2$. Short-term debt matures after one period, long-term debt after two. Accordingly, the state is given by $s_t = (y_t, \mathrm{cd}_t, L_t, b_{x,t}, b_{x,t,t+1})$.

3.1 Optimal Debt Repayment

Consider first the government's choice of repayment rate, r_t. Since the marginal cost of reducing r_t equals zero for $r_t < 1$, the optimal repayment rate equals either zero or unity, depending on the realization of s_t. In particular,

$$\begin{aligned} \text{if } \mathrm{cd}_t = 0: \quad r_t(s_t) &= \begin{cases} 1 & \text{if } L_t - b_{x,t} \geq 0 \\ 0 & \text{if } L_t - b_{x,t} < 0 \end{cases} \\ \text{if } \mathrm{cd}_t = 1: \quad r_t(s_t) &= \begin{cases} 1 & \text{if } L_t - b_{x,t} \geq \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) \\ 0 & \text{if } L_t - b_{x,t} < \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) \end{cases} \end{aligned} . \tag{3}$$

If $\mathrm{cd}_t = 0$, the choice of repayment rate does not affect the evolution of outstanding debt in equation (1). The government's repayment decision then is static, due to the temporary nature of default costs, and maximizes $y_t - b_{x,t} r_t - \mathbf{1}_{[r_t<1]} L_t + d_t(s_t, r_t, \iota_t)$.

If $\mathrm{cd}_t = 1$, in contrast, then the repayment decision is dynamic and the function $\alpha_t(y_t, b_{x,t}, b_{x,t,t+1})$ is characterized by the indifference condition

$$\begin{aligned} & u(y_t - b_{x,t} + d_t(s_t, 1, \iota_t(s_t))) + \delta \mathrm{E}[G_{t+1}(s_{t+1}) | s_t, 1, \iota_t(s_t)] \equiv \\ & u(y_t - b_{x,t} - \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) + d_t(s_t, 0, \tilde{\iota}_t(s_t))) + \delta \mathrm{E}[G_{t+1}(s_{t+1}) | s_t, 0, \tilde{\iota}_t(s_t)] \text{ if } \mathrm{cd}_t = 1. \end{aligned} \tag{4}$$

(Equilibrium debt issuance may differ depending on whether the government defaults or not, thus the distinction between $\iota_t(s_t)$ and $\tilde{\iota}_t(s_t)$.) The function $\alpha(\cdot)$ is positive if $b_{x,t}, b_{x,t,t+1} \geq 0$.[18]

Condition (3) states that a government defaults whenever the income losses L_t are relatively small. This is consistent with the notion that governments tend to default when the political costs of such a move—i.e., income losses of pivotal pressure groups—are low.[19] Governments also tend to default when economic activity is depressed (Borensztein, Levy Yegati and Panizza, 2006; Tomz and Wright, 2007). The model is consistent with this fact as well if it is slightly extended to include a direct default cost for the government in addition to the income losses for taxpayers.[20]

Corner solutions for the optimal repayment rate follow under more general assumptions about default costs than those invoked here, see the discussion in Appendix A. Interior repayment rates would arise if income losses in the wake of a default were a convex function of the default rate (implausible, as argued in Appendix A) or the government attached sufficiently strong weight to the welfare of foreign investors (implausible as well).

Equation (3) pins down expected repayment rates and thus, the rational-expectations prices of newly-issued debt given in (2). To streamline notation, let $1-F_t^{\text{cd}=0} \equiv 1-F(b_{x,t})$ denote the repayment probability in period t conditional on $\text{cd}_t = 0$; let $1 - F_t^{\text{cd}=1} \equiv 1 - F(b_{x,t} + \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}))$ denote the repayment probability in period t conditional on $\text{cd}_t = 1$; and let $1 - F_t$ denote the unconditional (on cd_t) repayment probability in period t.

Conditional on the state and policy choices in period t, the repayment probability $1 - F_{t+1}^{\text{cd}=0}$ is a fixed number while $1 - F_{t+1}^{\text{cd}=1}$ is a function of y_{t+1} if output affects $\alpha_{t+1}(y_{t+1}, b_{x,t+1}, b_{x,t+1,t+2})$. Accordingly, the price of short-term debt issued in period t equals

$$\begin{aligned} q_{t,t+1}(s_t, r_t, \iota_t) &= \beta \mathrm{E}[r_{t+1}(s_{t+1})|s_t, r_t, \iota_t] = \beta \mathrm{E}_{y_{t+1},\text{cd}_{t+1}}[1 - F_{t+1}|s_t, r_t, \iota_t] \\ &= \beta\{\pi \mathrm{E}_{y_{t+1}}[1 - F_{t+1}^{\text{cd}=1}|s_t, r_t, \iota_t] + (1-\pi)(1 - F_{t+1}^{\text{cd}=0}|s_t, r_t, \iota_t)\}, \end{aligned} \quad (5)$$

[18]To see this, note that

$$\begin{aligned} & u(y_t - b_{x,t} + d_t(s_t, 1, \iota_t(s_t))) + \delta \mathrm{E}[G_{t+1}(s_{t+1})|s_t, 1, \iota_t(s_t)] \\ \equiv\ & u(y_t - b_{x,t} - \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) + d_t(s_t, 0, \tilde{\iota}_t(s_t))) + \delta \mathrm{E}[G_{t+1}(s_{t+1})|s_t, 0, \tilde{\iota}_t(s_t)] \\ \geq\ & u(y_t - b_{x,t} - \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) + d_t(s_t, 0, \iota_t(s_t))) + \delta \mathrm{E}[G_{t+1}(s_{t+1})|s_t, 0, \iota_t(s_t)] \text{ if } \text{cd}_t = 1. \end{aligned}$$

Moreover, $d_t(s_t, 1, \iota_t(s_t)) \leq d_t(s_t, 0, \iota_t(s_t))$ if $\text{cd}_t = 1$ since outstanding debt decreases the market price of newly issued debt, see below. It follows that $-b_{x,t} \geq -b_{x,t} - \alpha_t(y_t, b_{x,t}, b_{x,t,t+1})$.

[19]Tomz (2002) documents that domestic audiences opposed the government of Argentina to suspend debt payments in 1999 but supported such action two years later. Kohlscheen (2004) documents that parliamentary democracies rarely resort to rescheduling (despite shorter office terms of their executives), presumably because domestic constituencies opposed to default are more likely to be politically influential in representative democracies. MacDonald (2003) suggests that it is precisely in countries where a default does not generate clearly identifiable winners and losers among politically influential groups where sovereign defaults have been avoided.

[20]If default triggers a cost K to the government in addition to the income losses for taxpayers, the default decision (in the case $\text{cd}_t = 0$) reduces to $r_t = 1$ iff $u(y_t - b_{x,t} + d_t) \geq u(y_t - L_t + \tilde{d}_t) - K$. Concavity of $u(\cdot)$ implies that low income levels render a default more likely.

where the subscript of the expectations operator indicates the random variables with respect to which expectations are taken.

The price of long-term debt issued in period t reflects "cross-default risk" in period $t+1$ as well as default risk in period $t+2$. In the absence of a cross-default in period $t+1$, the (discounted) conditional expected repayment rate on outstanding debt equals the price of newly-issued short-term debt in that period, due to pari passu. I therefore have

$$\begin{aligned} q_{t,t+2}(s_t, r_t, \iota_t) &= \beta^2 \mathrm{E}[(1 - \mathbf{1}_{[r_{t+1}(s_{t+1})<1 \text{ \& } \mathrm{cd}_{t+1}=1]}) r_{t+2}(s_{t+2}) | s_t, r_t, \iota_t] \\ &= \beta \mathrm{E}[(1 - \mathbf{1}_{[r_{t+1}(s_{t+1})<1 \text{ \& } \mathrm{cd}_{t+1}=1]}) q_{t+1,t+2}([s_{t+1}, r]) | s_t, r_t, \iota_t] \\ &= \beta\pi \mathrm{E}_{y_{t+1}} \left[(1 - F^{\mathrm{cd}=1}_{t+1}) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) | L_{t+1} = \infty, s_t, r_t, \iota_t \right] \\ &\quad + \beta(1-\pi) \mathrm{E}_{y_{t+1}, L_{t+1}} \left[q^{\mathrm{cd}=0}_{t+1,t+2}([s_{t+1}, r]) | s_t, r_t, \iota_t \right], \end{aligned} \tag{6}$$

where I use the short-hand notation

$$\begin{aligned} q^{\mathrm{cd}=0}_{t+1,t+2}([s_{t+1}, r]) &\equiv q_{t+1,t+2}(s_{t+1}, r_{t+1}(s_{t+1}), \iota_{t+1}(s_{t+1})) \text{ if } \mathrm{cd}_{t+1} = 0, \\ q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) &\equiv q_{t+1,t+2}(s_{t+1}, 1, \iota_{t+1}(s_{t+1})) \text{ if } \mathrm{cd}_{t+1} = 1. \end{aligned}$$

To understand the previous equalities, recall that a cross-default is averted either if $\mathrm{cd}_{t+1} = 1$ but L_{t+1} is sufficiently large or if $\mathrm{cd}_{t+1} = 0$. Moreover, if no default occurs in period $t+1$ (that is, if L_{t+1} is sufficiently large) then debt issuance is independent of the particular realization of L_{t+1} and some expectations can be conditioned on $L_{t+1} = \infty$.

In the extreme case without cross-default, $\pi = 0$, the expressions for the price functions simplify. In particular, we then have

$$\begin{aligned} q_{t,t+1}(s_t, r_t, \iota_t) &= \beta(1 - F(b_{x,t,t+1} + b_{t,t+1})), \\ q_{t,t+2}(s_t, r_t, \iota_t) &= \beta^2 \mathrm{E}_{y_{t+1}, L_{t+1}}[1 - F(b_{t,t+2} + b_{t+1,t+2}(s_{t+1})) | s_t, r_t, \iota_t]. \end{aligned}$$

Note that the price of each maturity is decreasing in its quantity. This negative dependence arises because higher debt issuance reduces the probability of repayment. For the same reason, higher inherited, outstanding debt reduces the price of short-term debt and higher expected short-term debt issuance by the subsequent government ($b_{t+1,t+2}$) reduces the price of long-term debt.

In the opposite case with certain risk of cross-default in every period, $\pi = 1$, the price functions are given by

$$\begin{aligned} & q_{t,t+1}(s_t, r_t, \iota_t) = \\ & \quad \beta \mathrm{E}_{y_{t+1}}[1 - F(b_{x,t,t+1} + b_{t,t+1} + \alpha_{t+1}(y_{t+1}, b_{x,t,t+1} + b_{t,t+1}, b_{t,t+2})) | s_t, r_t, \iota_t], \\ & q_{t,t+2}(s_t, r_t, \iota_t) = \\ & \quad \beta^2 \mathrm{E}_{y_{t+1}, y_{t+2}} [(1 - F(b_{x,t,t+1} + b_{t,t+1} + \alpha_{t+1}(y_{t+1}, b_{x,t,t+1} + b_{t,t+1}, b_{t,t+2}))) \times \\ & \quad\quad (1 - F(b_{t,t+2} + b_{t+1,t+2}(s_{t+1}) + \alpha_{t+2}(y_{t+2}, b_{t,t+2} + b_{t+1,t+2}(s_{t+1}), b_{t+1,t+3}))) | L_{t+1} = \infty, s_t, r_t, \iota_t]. \end{aligned}$$

Intuitively, when a default on short-term debt necessarily triggers a default on outstanding long-term bonds, the price of long-term debt is bounded above by β times the price of short-term debt.

I proceed in the following under the assumption that the pricing functions are differentiable in $(b_{x,t,t+1}, \iota_t)$ and the government's program well behaved, implying that the policy functions are smooth. Later, when considering special cases of the model, I verify that this is indeed the case.[21]

3.2 Optimal Debt Issuance

Issuing debt of a particular maturity has two types of effects. On the one hand, it raises revenue, in proportion to the price of the maturity. On the other hand, it affects the revenue raised from inframarginal units of debt, by changing the repayment probabilities and thus, prices of these units. This second effect is a direct consequence of the government's lack of commitment and reflects the endogeneity of subsequent debt-issuance and repayment-rate decisions.

Formally, the effect of a marginal increase in $b_{t,t+1}$ and $b_{t,t+2}$, respectively, on the deficit equals

$$\begin{aligned}
\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}} &= q_{t,t+1}(s_t, r_t, \iota_t) \underbrace{+b_{t,t+1}\frac{\mathrm{d}q_{t,t+1}(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}}}_{\mathcal{I}_{t,ss}} \underbrace{+b_{t,t+2}\frac{\mathrm{d}q_{t,t+2}(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}}}_{\mathcal{I}_{t,sl}}, \\
\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+2}} &= q_{t,t+2}(s_t, r_t, \iota_t) \underbrace{+b_{t,t+1}\frac{\mathrm{d}q_{t,t+1}(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+2}}}_{\mathcal{I}_{t,ls}} \underbrace{+b_{t,t+2}\frac{\mathrm{d}q_{t,t+2}(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+2}}}_{\mathcal{I}_{t,ll}}.
\end{aligned}$$

In the following, I denote the revenue effects on inframarginal units of debt by $\mathcal{I}_{t,\cdot}$ where the second subscript indicates the debt maturities involved. For example, $\mathcal{I}_{t,sl}$ denotes the revenue effects on inframarginal long-term debt caused by a marginal increase of short-term debt.

Negative revenue effects on inframarginal units of debt imply that the revenue a government can raise is limited. The deficit is maximized at the peak of the "debt-Laffer surface"; in an interior maximum this peak is attained if the two marginal effects on the deficit given above equal zero. (If $\delta = 0$, the government in each period aims at maximizing the deficit.)

To streamline notation, let $S_{t+1} \equiv (s_{t+1}, r_{t+1}(s_{t+1}), \iota_{t+1}(s_{t+1}))$ and define, in parallel with the short-hand notation for the pricing functions,

$$\begin{aligned}
u'([s_{t+1}, r]) &\equiv u'(y_{t+1} - b_{x,t+1}r_{t+1}(s_{t+1}) - \mathbf{1}_{[r_{t+1}(s_{t+1})<1]}L_{t+1} + d_{t+1}(S_{t+1})), \\
u'([s_{t+1}, 1]) &\equiv u'(y_{t+1} - b_{x,t+1} + d_{t+1}(s_{t+1}, 1, \iota_{t+1}(s_{t+1}))).
\end{aligned}$$

Consider the effect on the government's value function of a marginal increase in the stock of maturing debt, given by

$$\frac{\partial G_t(s_t)}{\partial b_{x,t}} = \begin{cases} -u'(y_t - b_{x,t} + d_t(S_t)) & \text{if } L_t - b_{x,t} \geq \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) \\ 0 & \text{if } L_t - b_{x,t} < \alpha_t(y_t, b_{x,t}, b_{x,t,t+1}) \end{cases}$$

[21] In general, the objective function is not concave in the amounts of debt issued, due to the option to default. In particular, two factors might undermine concavity. First, the fact that higher debt issuance reduces the probability of repayment in the future. Second, if the price function is convex, the fact that higher debt issuance implies increasingly smaller revenue losses on inframarginal units of debt.

and implying

$$\frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|s_t, r_t, \iota_t]}{\partial b_{x,t+1}} = \mathrm{E}_{y_{t+1},\mathrm{cd}_{t+1}}\left[-(1-F_{t+1})u'([s_{t+1},1])|L_{t+1}=\infty, s_t, r_t, \iota_t\right].$$

In states where the government repays, higher maturing debt reduces the government's value proportionally to taxpayers' marginal utility of consumption, due to higher taxation. Note that, while a change of $b_{x,t}$ may lead to adjustments in new debt issuance, these adjustments do not have a first-order effect on $G_t(s_t)$ since the choice of debt issuance is optimal from the perspective of the government in period t.

Consider next the effect on the government's value function of a marginal increase in the stock of outstanding debt. In case of a cross-default, this marginal effect equals zero since outstanding debt is defaulted upon anyway. Otherwise, the marginal effect is given by

$$\frac{\partial G_t(s_t)}{\partial b_{x,t,t+1}} = u'([s_t, r])\frac{\mathrm{d}d_t(S_t)}{\mathrm{d}b_{x,t,t+1}}|_{\text{direct}} + \delta\frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|S_t]}{\partial b_{x,t+1}} \text{ if } \mathrm{cd}_t = 0 \text{ or } r_t(s_t) = 1.$$

Indirect welfare effects caused by adjustments in r_t or ι_t are not of first order since the choice of repayment rate and debt issuance is optimal from the perspective of the government in period t. As a consequence, the only first-order effect of a marginal increase in $b_{x,t,t+1}$ on felicity in period t results from induced price changes and thus, revenue effects on inframarginal units of newly-issued debt. These price effects of outstanding debt are identical to the price effects of newly-issued short-term debt, implying

$$\frac{\mathrm{d}d_t(S_t)}{\mathrm{d}b_{x,t,t+1}}|_{\text{direct}} = \mathcal{I}_{t,ss} + \mathcal{I}_{t,sl} \text{ if } \mathrm{cd}_t = 0 \text{ or } r_t(s_t) = 1.$$

Accordingly

$$\begin{aligned}
&\frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|s_t, r_t, \iota_t]}{\partial b_{x,t+1,t+2}} = \\
&\quad \pi \mathrm{E}_{y_{t+1}}\left[(1-F_{t+1}^{\mathrm{cd}=1})\left\{u'([s_{t+1},1])(\mathcal{I}_{t+1,ss}+\mathcal{I}_{t+1,sl}) + \delta\frac{\partial \mathrm{E}[G_{t+2}(s_{t+2})|S_{t+1}]}{\partial b_{x,t+2}}\right\}\right. \\
&\quad\quad \left. |\mathrm{cd}_{t+1}=1, L_{t+1}=\infty, s_t, r_t, \iota_t\right] \\
&+ \quad (1-\pi)\mathrm{E}_{y_{t+1},L_{t+1}}\left[u'([s_{t+1},r])(\mathcal{I}_{t+1,ss}+\mathcal{I}_{t+1,sl}) + \delta\frac{\partial \mathrm{E}[G_{t+2}(s_{t+2})|S_{t+1}]}{\partial b_{x,t+2}}|\mathrm{cd}_{t+1}=0, s_t, r_t, \iota_t\right].
\end{aligned}$$

With these results at hand, I turn to the characterization of the debt issuance choice. Consider first the choice of short-term debt. A marginal increase in $b_{t,t+1}$ raises the government's objective by

$$u'(c_t)\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}} + \delta\frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|s_t, r_t, \iota_t]}{\partial b_{x,t+1}}$$

which can be expressed as

$$u'(c_t)(\mathcal{I}_{t,ss}+\mathcal{I}_{t,sl}) + \mathrm{E}_{y_{t+1},\mathrm{cd}_{t+1}}[(1-F_{t+1})(\beta u'(c_t) - \delta u'([s_{t+1},1]))|L_{t+1}=\infty, s_t, r_t, \iota_t]. \quad (7)$$

The marginal effect in (7) consists of two parts. On the one hand, a consumption smoothing effect, represented by the term on the right-hand side and reflecting the fact that debt issuance allows to shift consumption across time and states. By issuing one unit of short-term debt at price $\beta \mathrm{E}[(1 - F_{t+1})|s_t, r_t, \iota_t]$, the government increases the deficit by the corresponding amount and taxpayers benefit. At the same time, however, taxpayers face lower future consumption in those states in the subsequent period where the debt is repaid. This negative effect is discounted at factor δ. On the other hand, the term on the left-hand side represents the revenue effects on inframarginal units of debt.

It is important to note that the welfare effects due to changes in the repayment probability on inframarginal units of debt are confined to the revenue effects as represented in the term $u'(c_t)(\mathcal{I}_{t,ss} + \mathcal{I}_{t,sl})$ rather than, in addition, the continuation value say. To understand this result, consider for example the situation where the government issues short-term debt, $b_{t,t+1} > 0$. The implied higher stock of maturing debt in the following period induces the subsequent government to default in more states of nature; this depresses the issuance price of the debt.[22] From the perspective of the government in period $t+1$, this increased default probability does not have first-order welfare implications since the government in period $t+1$ is indifferent at the margin between repaying the debt or defaulting on it. From the perspective of the government in period t, in contrast, the increased default probability is suboptimal as it reduces the revenue raised through debt issuance *without a corresponding gain*.[23] The fact that the government in period $t+1$ does not internalize the consequences of its choice of repayment rate on its predecessor's revenue from debt issuance is at the source of the time inconsistency problem analyzed in this paper. Appendix B further discusses the welfare effects related to revenue effects on inframarginal debt, focusing on the role played by social (rather than private) losses in the wake of a default in shaping those.

Consider next the choice of long-term debt. A marginal increase in $b_{t,t+2}$ raises the government's objective by

$$u'(c_t)\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+2}} + \delta \frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|s_t, r_t, \iota_t]}{\partial b_{x,t+1,t+2}}$$

[22]For simplicity, I disregard the fact that the subsequent government may also change debt issuance. This simplification is irrelevant for the basic argument.

[23]If the government prematurely redeems outstanding long-term debt ($b_{t,t+1} < 0$), the induced response by the subsequent government runs counter to the interests of the government in period t too. For debt redemption increases the expected repayment rate in the following period and therefore raises the price at which the government buys back its bonds.

which can be expressed as

$$
\begin{aligned}
& u'(c_t)(\mathcal{I}_{t,ls}+\mathcal{I}_{t,ll}) \\
+\quad & \pi \mathrm{E}_{y_{t+1}}\left[(1-F_{t+1}^{\mathrm{cd}=1})\delta u'([s_{t+1},1])(\mathcal{I}_{t+1,ss}+\mathcal{I}_{t+1,sl})|\mathrm{cd}_{t+1}=1, L_{t+1}=\infty, s_t, r_t, \iota_t\right] \\
+\quad & (1-\pi)\mathrm{E}_{y_{t+1},L_{t+1}}\left[\delta u'([s_{t+1},r])(\mathcal{I}_{t+1,ss}+\mathcal{I}_{t+1,sl})|\mathrm{cd}_{t+1}=0, s_t, r_t, \iota_t\right] \qquad (8) \\
+\quad & \pi \mathrm{E}_{y_{t+1}}\left[(1-F_{t+1}^{\mathrm{cd}=1})\mathrm{E}_{y_{t+2},\mathrm{cd}_{t+2}}\left[(1-F_{t+2})(\beta^2 u'(c_t)-\delta^2 u'([s_{t+2},1]))|L_{t+2}=\infty, S_{t+1}\right]\right. \\
& \qquad \left. |\mathrm{cd}_{t+1}=1, L_{t+1}=\infty, s_t, r_t, \iota_t\right] \\
+\quad & (1-\pi)\mathrm{E}_{y_{t+1},L_{t+1}}\left[\mathrm{E}_{y_{t+2},\mathrm{cd}_{t+2}}\left[(1-F_{t+2})(\beta^2 u'(c_t)-\delta^2 u'([s_{t+2},1]))|L_{t+2}=\infty, S_{t+1}\right]\right. \\
& \qquad \left. |\mathrm{cd}_{t+1}=0, s_t, r_t, \iota_t\right].
\end{aligned}
$$

Parallel to (7), the marginal effect in (8) consists of a consumption-smoothing effect (represented by the last two terms) and a revenue effect on inframarginal units (represented by the first three terms). In contrast to (7), the revenue effects in (8) arise with respect to both contemporaneous and subsequent debt issuance because long-term debt issued in period t affects the price of short- or long-term debt issued in period $t+1$.

If short-term debt issuance in period $t+1$ is interior, then (7) and (8) can be combined to yield an alternative representation of (8):

$$
\begin{aligned}
& u'(c_t)(\mathcal{I}_{t,ls}+\mathcal{I}_{t,ll}) \\
+\quad & \pi \mathrm{E}_{y_{t+1}}\left[(1-F_{t+1}^{\mathrm{cd}=1})\beta(1-F_{t+2})(\beta u'(c_t)-\delta u'([s_{t+1},1]))|\mathrm{cd}_{t+1}=1, L_{t+1}=\infty, s_t, r_t, \iota_t\right] \\
+\quad & (1-\pi)\mathrm{E}_{y_{t+1},L_{t+1}}\left[\beta(1-F_{t+2})(\beta u'(c_t)-\delta u'([s_{t+1},r]))|\mathrm{cd}_{t+1}=0, s_t, r_t, \iota_t\right]. \qquad (9)
\end{aligned}
$$

The marginal effect in (9) displays in the first line the contemporaneous revenue effects on inframarginal units of debt and in the second line the consumption-smoothing effect from issuing long-term debt and redeeming it after one period at price $\beta\mathrm{E}[1-F_{t+2}|s_{t+1}, r_{t+1}, \iota_{t+1}]$. (If short-term debt is issued in period $t+1$ then the government in that period is indifferent between redeeming outstanding debt or holding on to it.) A comparison of the marginal effect of short-term debt issuance, (7), and of long-term debt issuance, (9), reveals two dimensions along which the two maturities differ. First, the two maturities have different risk characteristics. While short-term debt shifts consumption between period t and the *repayment states* in period $t+1$, long-term debt shifts consumption between period t and *all states without cross-default* in period $t+1$. Second, the two maturities generate different revenue effects on inframarginal units of debt.

To put these results into perspective, it is useful to recall the benchmark case with commitment, distinguishing between an environment with safe debt on the one hand and state-contingent debt on the other. If the government could commit its successors to honor maturing debt at face value, all $\mathcal{I}$ terms in the expressions above would be absent and all repayment probabilities would equal unity. In an interior optimum, both (7) and (9) then would reduce to the *same* condition,

$$\beta u'(y_t - b_{x,t} + d_t(s_t,1,\iota_t)) - \delta \mathrm{E}_{y_{t+1}}[u'(y_{t+1}-b_{x,t+1}+d_{t+1}(s_{t+1},1,\iota_{t+1}(s_{t+1})))|s_t,1,\iota_t] = 0,$$

indicating that the government's portfolio choice would be indeterminate. This result hinges on the fact that, due to the exogenous asset pricing kernel of foreign investors, the price of outstanding debt does not respond to shocks that affect marginal utility in the economy. If, in contrast, the price of outstanding debt were state contingent because of an endogenous asset pricing kernel, then the government's choice of maturity structure would be determinate even under commitment to non-state-contingent debt (see Gale, 1990; Angeletos, 2002).

If the government could commit its successors to honor maturing debt at state-contingent repayment rates, all $\mathcal{I}_{t,\cdot}$ and $\mathbf{1}_{[r_t(s_t)<1]}L_t$ terms in the expressions above would be absent and all repayment probabilities would correspond to the respective averages of state-contingent repayment rates chosen ex ante. The optimal maturity structure then would be determinate if the returns to maturities correlated differently with taxpayers' marginal utility, as in a standard portfolio choice problem. Absent such differences in the correlation structure, the choice of maturity structure would be indeterminate.

Summarizing, in the model of this paper, determinacy of the optimal maturity structure does not rely on an endogenous asset pricing kernel on the one hand or standard portfolio choice considerations on the other. Instead, the optimal maturity structure is determinate although the asset pricing kernel of foreign investors is exogenous and even if the correlation between the return on government debt and taxpayers' marginal utility does not differ across maturities (as is the case, for example, if taxpayers are risk neutral).

4 Equilibrium: Analytical Results

I now turn to several special cases of the model. In all of these cases, marginal utility of consumption is assumed to be a function of output only, $u'(y_t)$. The level of disposable income and thus, $b_{x,t}$ and L_t therefore do not affect the government's rollover decision in period t, $b_{t,t+1}(y_t, \mathrm{cd}_t, b_{x,t,t+1})$ and $b_{t,t+2}(y_t, \mathrm{cd}_t, b_{x,t,t+1})$. To guarantee positive debt positions, I assume $\delta \ll \beta$.[24]

The assumption about the marginal utility function is motivated by tractability considerations: If rollover choices are independent of $b_{x,t}$ and L_t then the equilibrium maturity structure can be characterized in closed form. Note that with risk neutral preferences the assumption is satisfied trivially. More generally, the assumption is satisfied approximately if variations in output have a much stronger effect on taxpayers' disposable income than policy does.

4.1 Cyclicality and Risk

In a first part, I abstract from the possibility of cross-default, $\pi = 0$, and focus on the effect of output cyclicality and volatility on the maturity structure.

Absent cross-default, the equilibrium price functions satisfy

$$\begin{aligned} q_{t,t+1}(s_t, r_t, \iota_t) &= \beta(1 - F(b_{x,t,t+1} + b_{t,t+1})) \\ q_{t,t+2}(s_t, r_t, \iota_t) &= \beta^2 \mathrm{E}_{y_{t+1}}[1 - F(b_{t,t+2} + b_{t+1,t+2}(y_{t+1}, b_{t,t+2}))|s_t, r_t, \iota_t], \end{aligned}$$

[24]The quantitative sovereign debt literature typically assumes $\delta \ll \beta$ to match the debt quotas in the data (see, for example, Aguiar and Gopinath, 2006; Arellano, 2008).

implying that revenue effects across maturities do not arise, $\mathcal{I}_{t,sl} = \mathcal{I}_{t,ls} = 0$. The effect on the government's objective of a marginal increase in $b_{t,t+1}$ therefore reduces to

$$-u'(y_t)b_{t,t+1}\beta f(b_{x,t+1}) + (1 - F(b_{x,t+1}))\mathrm{E}_{y_{t+1}}\left[\beta u'(y_t) - \delta u'(y_{t+1})|s_t\right].$$

If the hazard function $H(L) \equiv f(L)/(1 - F(L))$ is non-decreasing, as assumed in the following, then this marginal effect equals zero for a unique, positive quantity of short-term debt issuance,

$$b_{t,t+1}(y_t, b_{x,t,t+1}) = H(b_{x,t+1})^{-1}\mathrm{E}_{y_{t+1}}\left[1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}|s_t\right] > 0 \tag{10}$$

with $-1 < \frac{\partial b_{t,t+1}(y_t, b_{x,t,t+1})}{\partial b_{x,t,t+1}} \leq 0$.

The equilibrium level of short-term debt issuance equalizes marginal costs and benefits. The latter are given by the net utility gain from borrowing an amount corresponding to the price of the marginal unit of debt. This gain is high if taxpayers prefer early consumption, $\delta < \beta$, or if marginal utility is high relative to expected future marginal utility, $u'(y_t) > \mathrm{E}[u'(y_{t+1})|s_t]$. The marginal costs, on the other hand, are given by the marginal-utility weighted revenue losses on inframarginal units of debt.

The assumption that $H(L)$ be non-decreasing is a natural one. On the one hand, many distribution functions typically used in economic applications satisfy this assumption.[25] On the other hand, the assumption has the plausible implication that the revenue losses on inframarginal units of debt, $b_{t,t+1}\beta f(b_{x,t+1})$, relative to the revenue gains from the marginal unit of debt, $\beta(1 - F(b_{x,t+1}))$, are convex in $b_{t,t+1}$. This does not only imply that equilibrium short-term debt issuance is unique but also that this issuance responds negatively to the amount of debt outstanding, $b_{x,t,t+1}$, and that the function $b_{x,t,t+1} + b_{t,t+1}(b_{x,t,t+1})$ is strictly increasing in $b_{x,t,t+1}$.

Two special cases merit particular emphasis. The first case refers to the exponential distribution function whose hazard function is constant, $H(L) = \lambda$, implying that short-term debt issuance is independent of the quantity of outstanding debt,

$$b_{t,t+1}(y_t) = \lambda^{-1}\mathrm{E}_{y_{t+1}}\left[1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}|s_t\right].$$

Intuitively, the revenue losses on inframarginal units of debt relative to the revenue gain from the marginal unit are a function of newly-issued debt only in this case. The quantity of newly-issued debt therefore is independent of the amount of debt outstanding. This implies, in turn, that short-term debt issuance does not affect the rollover decision of the

[25] Examples of distribution functions with increasing hazard functions include uniform, normal, exponential, logistic, extreme value, Laplace, power, Weibull, gamma, chi-squared, chi, or beta distributions (see, e.g., Bagnoli and Bergstrom, 2005).

If L_t is distributed according to an exponential distribution, $F(L) = 1 - \exp(-\lambda L)$, then the hazard function is constant, $H(L) = \lambda$.

If L_t is distributed according to a Weibull distribution, $F(L) = 1 - \exp(-L^{\lambda}), \lambda > 1$, then the hazard function is strictly increasing, $H(L) = \lambda L^{\lambda-1}$; moreover, for $1 \leq \lambda \leq 2$, the hazard function is concave, and for all $\lambda > 1$, $H'(L)^2 - H(L)H''(L) > 0$.

subsequent government. One source of time-inconsistency in the model therefore is shut down if $H(L)$ is constant.

The second special case refers to the Weibull distribution with parameter $\lambda = 2$ whose hazard function is given by $H(L) = 2L$. With Weibull distributed losses, short-term debt issuance does depend on the quantity of outstanding debt but the parametric assumption $\lambda = 2$ renders the dependence analytically tractable,

$$b_{t,t+1}(y_t, b_{x,t,t+1}) = -\frac{b_{x,t,t+1}}{2} + \frac{1}{2}\sqrt{b_{x,t,t+1}^2 + 2\mathrm{E}_{y_{t+1}}\left[1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}|s_t\right]}.$$

Note that under the assumption of Weibull distributed losses (as with any strictly increasing hazard function), debt issuance choices by a government affect both repayment and rollover decisions by its successor. In contrast to the case with exponentially distributed losses the general model therefore captures two sources of time-inconsistent behavior. Note also that the maturity structure will generally vary with shocks to output.

Returning to the general case of a non-decreasing hazard function, observe for future reference that the function $b_{t,t+1}(y_t, b_{x,t,t+1})$ is convex if the hazard function satisfies a second-order criterion. In particular, $\partial^2 b_{t,t+1}(y_t, b_{x,t,t+1})/(\partial b_{x,t,t+1})^2 \geq 0$ if and only if the following condition is satisfied:

(C) The function $2H'(L)^2 - H(L)H''(L) \geq 0$, for example because the hazard function is concave.

Both the exponential and Weibull distribution functions satisfy condition (C). If condition (C) holds strictly, then the function $b_{t,t+1}(y_t, b_{x,t,t+1})$ is strictly convex.

Turning to long-term debt issuance, the effect on the government's objective of a marginal increase in $b_{t,t+2}$ is given by

$$-u'(y_t)b_{t,t+2}\beta^2\mathrm{E}_{y_{t+1}}\left[f(b_{x,t+2})\left(1 + \frac{\partial b_{t+1,t+2}(y_{t+1}, b_{t,t+2})}{\partial b_{x,t+1,t+2}}\right)|s_t\right] \\ + \mathrm{E}_{y_{t+1}}\left[(1 - F(b_{x,t+2}))(\beta^2 u'(y_t) - \delta\beta u'(y_{t+1}))|s_t\right]$$

where $b_{x,t+2} = b_{t,t+2} + b_{t+1,t+2}(y_{t+1}, b_{t,t+2})$. If the partial derivative in the first line does not decrease too quickly (as is guaranteed by condition (C)) then this marginal effect equals zero for a unique, positive quantity of long-term debt that only depends on output,

$$b_{t,t+2}(y_t) = \frac{\mathrm{E}_{y_{t+1}}\left[(1 - F(b_{x,t+2}))\left(1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}\right)|s_t\right]}{\mathrm{E}_{y_{t+1}}\left[f(b_{x,t+2})\left(1 + \frac{\partial b_{t+1,t+2}(y_{t+1},b_{t,t+2})}{\partial b_{x,t+1,t+2}}\right)|s_t\right]} > 0. \tag{11}$$

Summarizing, we have the following preliminary result:

Lemma 1. *Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$, $\delta \ll \beta$ and the hazard function is weakly increasing. There exists an equilibrium in which the policy functions $b_{t,t+1}(s_t)$ and $b_{t,t+2}(s_t)$ do not depend on $b_{x,t}$ or L_t. If the hazard function satisfies condition (C), then the maturity structure in this equilibrium is unique.*

The equilibrium characterized in the Lemma is the only equilibrium that arises in a finite horizon economy, including the limit with the number of periods approaching infinity. This follows from a straightforward backward induction argument. In the subsequent discussion, I focus on this type of equilibrium.

I now characterize the equilibrium maturity structure in more detail. To build intuition, consider first the case of a constant hazard function, $H(L) = \lambda$, and suppose that output follows a deterministic process. The two marginal effects (when set equal to zero) then reduce to the first-order conditions

$$\begin{aligned} b_{t,t+1}(y_t)\lambda &= 1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}, \\ b_{t,t+2}(y_t)\lambda &= 1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}, \end{aligned}$$

implying that the equilibrium maturity structure is *fully balanced* at all times. Intuitively, with a constant hazard function, the revenue losses on inframarginal units of debt relative to the revenue gain on the marginal unit are independent across maturities and convex. The quantities of the two maturities therefore are determined independently of each other and the equilibrium policy "smoothes maturities" or more specifically, the convex losses associated with them for parallel reasons as those driving Barro's (1979) "tax-smoothing" prescription. Summarizing, we have the following result:

Proposition 1. Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$ and $\delta \ll \beta$. If the hazard function is constant and y_t deterministic then the unique equilibrium maturity structure is fully balanced. Debt issuance is high when $u'(y_t)$ is high.

The benchmark result of a fully balanced maturity structure hinges on the feature that the revenue losses on inframarginal units of debt relative to the revenue gain on the marginal unit are independent across maturities. With a strictly increasing hazard function, this independence disappears because long-term debt issuance affects short-term debt issuance in the subsequent period as is evident from the term $\left(1 + \frac{\partial b_{t+1,t+2}(y_{t+1}, b_{t,t+2})}{\partial b_{x,t+1,t+2}}\right)$ in the expression for the marginal effect of long-term debt issuance.

Consider the equilibrium in an environment with constant output. In such an equilibrium, $b_{t-1,t+1} = b_{t,t+2} \equiv b_{\text{long}}$ and $b_{t,t+1} = b_{t+1,t+2} \equiv b_{\text{shrt}}$ and the two first-order conditions read

$$\begin{aligned} b_{\text{shrt}} H(b_{\text{shrt}} + b_{\text{long}}) &= 1 - \frac{\delta}{\beta}, \\ b_{\text{long}} H(b_{\text{shrt}} + b_{\text{long}}) \left(1 + \frac{\partial b_{\text{shrt}}(y, b_{\text{long}})}{\partial b_{x,t+1,t+2}}\right) &= 1 - \frac{\delta}{\beta}. \end{aligned}$$

Since the partial derivative in the second equation is negative, the equilibrium maturity structure is *tilted towards long-term* debt, $b_{\text{shrt}} < b_{\text{long}}$. Underlying this result is the fact that short-term debt issuance responds negatively to the quantity of outstanding debt. As a consequence, long-term debt issuance increases the amount of debt maturing in the long run by less than one-to-one while short-term debt issuance increases the amount of debt maturing in the short run by one-to-one. Long-term debt issuance therefore has a smaller price impact, rendering it "cheaper" from the government's perspective.

If the partial derivative in the second equation is strictly increasing (that is, if the inequality in condition (C) holds strictly) then the tilt towards long-term debt becomes smaller as the total amount of debt issued increases. *Higher debt quotas therefore go hand in hand with a shortening* of the maturity structure, in line with the evidence cited earlier (Rodrik and Velasco, 1999). Summarizing, we have the following result:

Proposition 2. Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$ and $\delta \ll \beta$. If the hazard function is strictly increasing, satisfies condition (C) and y_t is constant then the unique equilibrium maturity structure is tilted towards long-term debt. If condition (C) holds strictly, higher debt quotas go hand in hand with a shortening of the maturity structure.

Consider next the equilibrium in a cyclical environment with output alternating between the values y^h and y^l, $y^l \leq y^h$. We know from Proposition 1 that the maturity structure is time invariant in such an environment if the hazard function $H(L)$ is constant. I therefore directly concentrate on the case where the hazard function is strictly increasing. If condition (C) is satisfied, the equilibrium maturity structure is characterized by the equations

$$\begin{aligned}
b_{\text{shrt}}(y^h, b_{\text{long}}(y^l))H[b_{\text{shrt}}(y^h, b_{\text{long}}(y^l)) + b_{\text{long}}(y^l)] &= 1 - \frac{\delta u'(y^l)}{\beta u'(y^h)}, \\
b_{\text{shrt}}(y^l, b_{\text{long}}(y^h))H[b_{\text{shrt}}(y^l, b_{\text{long}}(y^h)) + b_{\text{long}}(y^h)] &= 1 - \frac{\delta u'(y^h)}{\beta u'(y^l)}, \\
b_{\text{long}}(y^h)H[b_{\text{shrt}}(y^l, b_{\text{long}}(y^h)) + b_{\text{long}}(y^h)]\left(1 + \frac{\partial b_{\text{shrt}}(y^l, b_{\text{long}}(y^h))}{\partial b_{x,t,t+1}}\right) &= 1 - \frac{\delta u'(y^l)}{\beta u'(y^h)}, \\
b_{\text{long}}(y^l)H[b_{\text{shrt}}(y^h, b_{\text{long}}(y^l)) + b_{\text{long}}(y^l)]\left(1 + \frac{\partial b_{\text{shrt}}(y^h, b_{\text{long}}(y^l))}{\partial b_{x,t,t+1}}\right) &= 1 - \frac{\delta u'(y^h)}{\beta u'(y^l)}
\end{aligned}$$

and the effects summarized in Proposition 2 come into play.[26] Due to the negative partial derivatives in the first-order conditions characterizing long-term debt issuance, the maturity structure is tilted towards long-term debt. This effect is relatively weaker in times of *high marginal utility* where higher debt issuance is associated with a *shortening of the maturity structure*, in line with the evidence (Broner et al., 2007).

This result can be proved under the assumption that L is distributed according to a Weibull distribution with parameter $\lambda = 2$, $H(L) = 2L$. Define $m_i(y; \mu)$ as the equilibrium ratio of short- and long-term debt issuance in the ith period of the cycle where output takes the value y and the ratio of marginal utilities is given by $\mu \equiv u'(y^l)/u'(y^h) \geq 1$. The following result can then be proved:

[26] An alternative source of time variation in the maturity structure relates to changes of the function $H(\cdot)$ over time. A priori, it is not clear how such changes should correlate with output and marginal utility.

Proposition 3. Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$ and $\delta \ll \beta$. If the hazard function $H(L) = 2L$ and y_t follows a two-period cycle then the unique equilibrium maturity structure shortens in periods where marginal utility is high. In particular, $\frac{\partial m_1(y^h;1)}{\partial \mu} < 0 < \frac{\partial m_2(y^l;1)}{\partial \mu}$.

Importantly, this finding does not hinge on the fact that the length of the cycle and the maturity of long-term debt coincide. In fact, it can be shown that a parallel result holds for a three-period cycle with marginal utility given by $u'(y^h)$ during the first two periods of the cycle and $u'(y^l) \geq u'(y^h)$ during the third:

Proposition 4. Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$ and $\delta \ll \beta$. If the hazard function $H(L) = 2L$ and y_t follows a three-period cycle then the unique equilibrium maturity structure shortens towards periods where marginal utility is high. In particular, $\frac{\partial m_1(y^h;1)}{\partial \mu} < \frac{\partial m_2(y^h;1)}{\partial \mu} < 0 < \frac{\partial m_3(y^l;1)}{\partial \mu}$.

Figure 1 illustrates how debt issuance and government cash flows vary over the three-period cycle in the absence of default.[27] If output is constant such that $\mu = 1$, then debt issuance and cash flow is constant as well; cash flows are negative due to impatience, $\delta < \beta$. As the relative scarcity of resources in the third period increases (reflected by a rise in μ) the debt policy becomes more cyclical, with the maturity structure shortening towards the end of the cycle. In the last period of the cycle where resources are scarcest, the cash flow is least negative because the government issues the most debt.

Finally, consider the equilibrium implications of stochastic output. If output is random, the probability distribution of possible output realizations in the subsequent period affects debt issuance, see equations (10) and (11). As far as short-term debt issuance is concerned, the implications of output risk are confined to the fact that the *expected* marginal rate of substitution between current and subsequent consumption determines the benefit of debt issuance. With respect to long-term debt issuance, output risk additionally introduces insurance considerations. To see this, it is instructive to rewrite (11) as

$$b_{t,t+2}(y_t) = \frac{\mathrm{E}_{y_{t+1}}\left[1 - F(b_{x,t+2})|s_t\right]\mathrm{E}_{y_{t+1}}\left[1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}|s_t\right] + \mathrm{Cov}_{y_{t+1}}\left[1 - F(b_{x,t+2}), 1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}|s_t\right]}{\mathrm{E}_{y_{t+1}}\left[f(b_{x,t+2})\left(1 + \frac{\partial b_{t+1,t+2}(y_{t+1}, b_{t,t+2})}{\partial b_{x,t+1,t+2}}\right)|s_t\right]}.$$

The first term on the right-hand side of this expression represents the average consumption smoothing benefit from the marginal unit of debt relative to the cost due to revenue losses on inframarginal units. The second term reflects the normalized insurance benefit.

If the price of outstanding debt in period $t+1$ (which is proportional to $1 - F(b_{x,t+2})$) covaries negatively with marginal utility in that period (and therefore positively with the term $1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}$), then long-term debt provides useful insurance benefits and, ceteris paribus, more of it is issued. Whether the price actually covaries negatively with marginal

[27] The figure is drawn for $\beta = 0.95$.

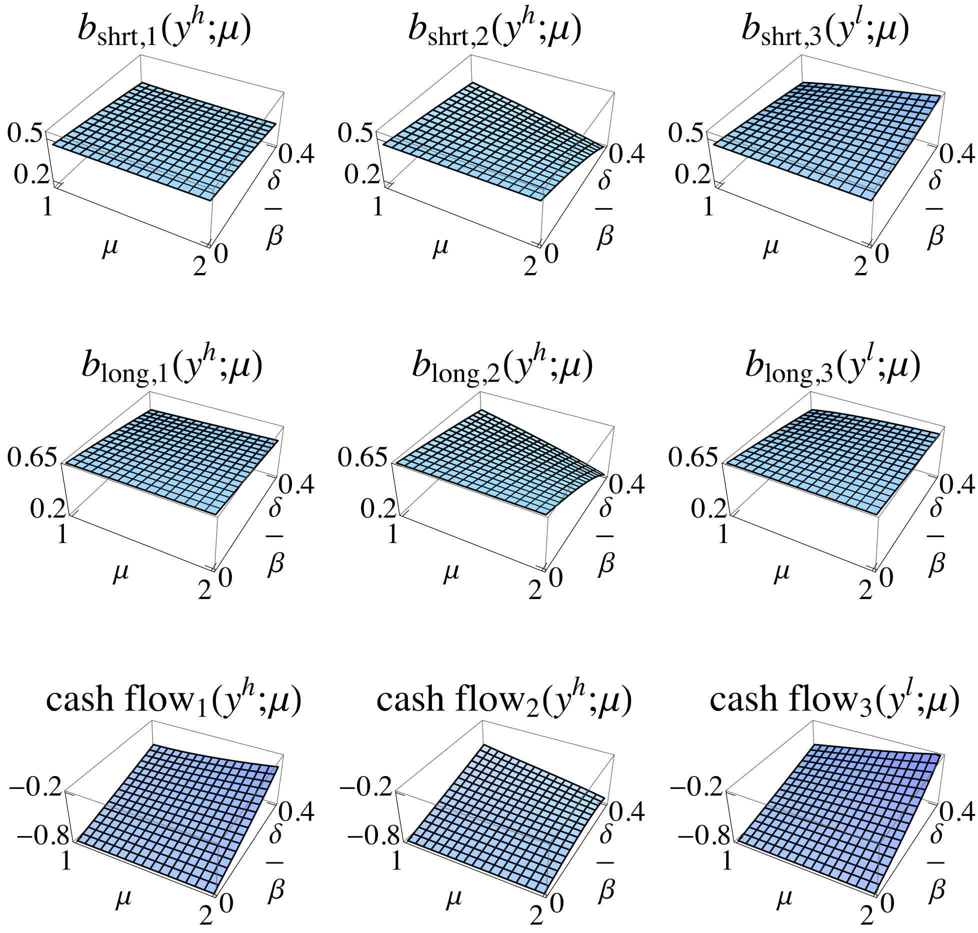

Figure 1: Government debt issuance and cash flows (in the absence of default) over a three-period cycle, $H(L) = 2L$

utility depends on the covariance between marginal utility and short-term debt issuance. If this latter covariance is positive, as to be expected, then long-term debt serves as a hedge.

Consider the case of a constant hazard function. The expectation and covariance terms then simplify[28] and (11) reduces to

$$\begin{aligned}
b_{t,t+2}(y_t) &= \lambda^{-1} \frac{\mathrm{E}_{y_{t+1}}\left[\exp(-\lambda(b_{t+1,t+2}(y_{t+1})))\left(1-\frac{\delta u'(y_{t+1})}{\beta u'(y_t)}\right)|s_t\right]}{\mathrm{E}_{y_{t+1}}\left[\exp(-\lambda(b_{t+1,t+2}(y_{t+1})))|s_t\right]} \\
&= b_{t,t+1}(y_t) + \lambda^{-1} \frac{\mathrm{Cov}_{y_{t+1}}\left[\exp(-\lambda(b_{t+1,t+2}(y_{t+1}))), \left(1-\frac{\delta u'(y_{t+1})}{\beta u'(y_t)}\right)|s_t\right]}{\mathrm{E}_{y_{t+1}}\left[\exp(-\lambda(b_{t+1,t+2}(y_{t+1})))|s_t\right]},
\end{aligned}$$

where the second equality follows from (10) (with $H(L) = \lambda$ due to exponentially distributed losses). Equation (10) implies that short-term debt issuance covaries positively with contemporaneous marginal utility and thus, that the covariance term in the above expression for long-term debt issuance is positive. As a consequence, long-term debt issuance exceeds short-term debt issuance, and increasingly so for high covariance.

Proposition 5. *Suppose that marginal utility in period t is a function of y_t only, $\pi = 0$ and $\delta \ll \beta$. If the hazard function is constant and y_t stochastic, then the unique equilibrium maturity structure is tilted towards the long end.*

4.2 Cross-Default

I now introduce the possibility of cross-default, $\pi > 0$, abstracting from output risk. From (5) and (6), the equilibrium price functions are given by

$$\begin{aligned}
q_{t,t+1}(s_t, r_t, \iota_t) &= \beta\pi(1-F_{t+1}^{\mathrm{cd}=1}) + \beta(1-\pi)(1-F_{t+1}^{\mathrm{cd}=0}), \\
q_{t,t+2}(s_t, r_t, \iota_t) &= \beta\pi(1-F_{t+1}^{\mathrm{cd}=1})q_{t+1,t+2}^{\mathrm{cd}=1}([s_{t+1}, 1]) + \beta(1-\pi)q_{t+1,t+2}^{\mathrm{cd}=0}([s_{t+1}, r]).
\end{aligned}$$

The possibility of cross-default introduces "cross-revenue effects," $\mathcal{I}_{t,sl}, \mathcal{I}_{t,ls} \neq 0$. Intuitively, short-term debt issuance drives up the risk of default in the subsequent period; but such a default does not only affect maturing debt but also, if $\mathrm{cd}_{t+1} = 1$, outstanding debt. At the same time, long-term debt issuance drives up the risk of default on maturing and outstanding debt in the subsequent period if $\mathrm{cd}_{t+1} = 1$. Formally,

$$\begin{aligned}
\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}} &= q_{t,t+1}(s_t, r_t, \iota_t) - b_{t,t+1}\left(\beta\pi f_{t+1}^{\mathrm{cd}=1} + \beta(1-\pi)f_{t+1}^{\mathrm{cd}=0}\right) \\
&\quad - b_{t,t+2}\left(\beta\pi f_{t+1}^{\mathrm{cd}=1} q_{t+1,t+2}^{\mathrm{cd}=1}([s_{t+1}, 1])\right), \\
\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+2}} &= q_{t,t+2}(s_t, r_t, \iota_t) - b_{t,t+1}\left(\beta\pi f_{t+1}^{\mathrm{cd}=1} \frac{\partial\alpha_{t+1}(y_{t+1}, b_{x,t+1}, b_{t,t+2})}{\partial b_{x,t+1,t+2}}\right) \\
&\quad - b_{t,t+2}\left(\beta\pi f_{t+1}^{\mathrm{cd}=1} \frac{\partial\alpha_{t+1}(y_{t+1}, b_{x,t+1}, b_{t,t+2})}{\partial b_{x,t+1,t+2}} q_{t+1,t+2}^{\mathrm{cd}=1}([s_{t+1}, 1]) - \Omega_{t+1}\right)
\end{aligned}$$

[28] If L is distributed exponentially with parameter λ, then $1 - F(b_1 + b_2) = (1 - F(b_1)) \exp(-\lambda b_2)$ and $f(b_1 + b_2) = f(b_1) \exp(-\lambda b_2) = \lambda(1 - F(b_1)) \exp(-\lambda b_2)$.

where $\Omega_{t+1} < 0$.[29]

From (4), an interior solution for short-term debt issuance (as assumed in the following and verified later) implies[30]

$$\frac{\partial \alpha_t(y_t, b_{x,t}, b_{x,t,t+1})}{\partial b_{x,t,t+1}} = \beta \mathrm{E}[1 - F_{t+1}|\mathrm{cd}_t = 1, s_t, r_t, \iota_t] = q^{\mathrm{cd}=1}_{t,t+1}([s_t, 1]).$$

Moreover, $q_{t,t+2}(s_t, r_t, \iota_t) = q_{t,t+1}(s_t, r_t, \iota_t) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) + \Phi_t$ where $\Phi_t \geq 0$ and $\Phi_t = 0$ if $\pi = 1$.[31]

Consider the effect on the government's objective of issuing $u'(y_t)^{-1}$ units of short-term debt and $(u'(y_t) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]))^{-1}$ units of long-term debt, respectively. The former,

$$\begin{aligned} q_{t,t+1}(s_t, r_t, \iota_t) \left(1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}\right) - b_{t,t+1} \left(\beta \pi f^{\mathrm{cd}=1}_{t+1} + \beta(1-\pi) f^{\mathrm{cd}=0}_{t+1}\right) \\ - b_{t,t+2} \left(\beta \pi f^{\mathrm{cd}=1}_{t+1} q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1])\right), \end{aligned}$$

differs from the latter,

$$\begin{aligned} \left(q_{t,t+1}(s_t, r_t, \iota_t) + \frac{\Phi_t}{q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1])}\right) \left(1 - \frac{\delta u'(y_{t+1})}{\beta u'(y_t)}\right) - b_{t,t+1} \left(\beta \pi f^{\mathrm{cd}=1}_{t+1}\right) \\ - b_{t,t+2} \left(\beta \pi f^{\mathrm{cd}=1}_{t+1} q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) - \frac{\Omega_{t+1}}{q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1])}\right), \end{aligned}$$

in three respects. First, long-term debt raises more revenue on the marginal unit of debt than short-term debt unless $\pi = 1$ (in which case both maturities raise the same revenue on the marginal unit) because the price of long-term debt accounts for the possibility of repayment in the long term if a cross-default in the short term is avoided. Second,

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[29] We have

$$\Omega_{t+1} = \beta \pi (1 - F^{\mathrm{cd}=1}_{t+1}) \frac{\partial q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1])}{\partial b_{x,t+1,t+2}} + \beta(1-\pi) \frac{\partial q^{\mathrm{cd}=0}_{t+1,t+2}([s_{t+1}, r])}{\partial b_{x,t+1,t+2}}.$$

[30] Differentiating (4) with respect to $b_{x,t,t+1}$ yields

$$u'([s_t, 1])(\mathcal{I}_{t,ss} + \mathcal{I}_{t,sl}) + \delta \frac{\partial \mathrm{E}[G_{t+1}(s_{t+1})|s_t, r_t, \iota_t]}{\partial b_{x,t,t+1}} = -u'([s_t, 0]) \frac{\partial \alpha_t(y_t, b_{x,t}, b_{x,t,t+1})}{\partial b_{x,t,t+1}} \text{ s.t. } \mathrm{cd}_t = 1.$$

From the first-order condition for $b_{t,t+1}$, the left-hand side equals $-u'([s_t, 1])\beta \mathrm{E}[1 - F_{t+1}|\mathrm{cd}_t = 1, s_t, r_t, \iota_t]$.

[31] We have

$$\begin{aligned} q_{t,t+2}(s_t, r_t, \iota_t) &= (q_{t,t+1}(s_t, r_t, \iota_t) - \beta(1-\pi)(1 - F^{\mathrm{cd}=0}_{t+1})) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) \\ &\qquad + \beta(1-\pi) q^{\mathrm{cd}=0}_{t+1,t+2}([s_{t+1}, r]) \\ &= q_{t,t+1}(s_t, r_t, \iota_t) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) \\ &\qquad - \beta(1-\pi) \left((1 - F^{\mathrm{cd}=0}_{t+1}) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) - q^{\mathrm{cd}=0}_{t+1,t+2}([s_{t+1}, r])\right) \\ &\equiv q_{t,t+1}(s_t, r_t, \iota_t) q^{\mathrm{cd}=1}_{t+1,t+2}([s_{t+1}, 1]) + \Phi_t. \end{aligned}$$

long-term debt generates higher revenue losses on inframarginal units of long-term debt, reflecting the fact that long-term debt issuance increases the default likelihood in the long-term, conditional on no default occuring in the short term. Finally, long-term debt generates lower revenue losses on inframarginal units of short-term debt since long-term debt issuance does not increases the default risk in the short term if $\mathrm{cd}_{t+1} = 0$.

If $\pi = 1$, the first and last difference vanish while the second remains in place (Ω_{t+1} remains strictly negative). As a consequence, short-term debt *always dominates* long-term debt if $\pi = 1$.[32]

Proposition 6. Suppose that marginal utility in period t is a function of y_t only, $\pi = 1$ and $\delta \ll \beta$. If y_t is deterministic then short-term debt dominates long-term debt.

5 Equilibrium: Numerical Results

TBW

6 Conclusion

TBW

A Alternative Specifications of Social Costs

Corner solutions for the optimal repayment rate follow under more general assumptions about the income losses in the wake of a default. Consider for example the case where income losses are proportional to L_t and the *default rate*,

$$\mathrm{losses}_t = (1 - r_t)L_t.$$

The optimal repayment choice then is identical to the one given in the text.

Consider next the situation where income losses are proportional to L_t and the total *amount* defaulted upon,

$$\mathrm{losses}_t = (1 - r_t)b_{x,t}L_t.$$

The optimal repayment rate then varies with L_t but does not depend on the amount of maturing debt, rendering such a specification unattractive.

Consider next the situation where income losses are a *concave* function of the amount defaulted upon, for example

$$\mathrm{losses}_t = [(1 - r_t)b_{x,t}]^{1/2}L_t$$

or

$$\mathrm{losses}_t = \mathbf{1}_{[r_t<1]}L_t + k(1 - r_t)b_{x,t},\ 0 < k < 1.$$

[32]If $b_{t,t+1} \leq 0$ then short-term debt dominates only weakly.

Again, the optimal repayment rate then equals either unity or zero since the total cost from debt repayment and income losses is a concave function of the default rate.

If income losses are a *convex* function of the amount defaulted upon, for example

$$\text{losses}_t = [(1 - r_t)b_{x,t}]^2 L_t,$$

then the equilibrium repayment rate is no longer discrete. However, convexity of income losses appears less plausible than the previously discussed specifications, for at least two reasons. First, most notions of income losses are consistent with concave costs: The marginal cost of defaulting on the first 5 percent of debt exceeds the one from defaulting on the following 5 percent. Second, convex income losses would lead governments to *always* default at least partially, in contrast with the empirical evidence.

B Social Costs and the Incentive to Dilute

In this section, I analyze how the assumption of social costs in the wake of a default shapes the government's rollover decision. I focus on the case where the government issues short-term debt only and π equals zero. Recall from the text that, in this case,

$$\frac{\mathrm{d}d_t(s_t, r_t, \iota_t)}{\mathrm{d}b_{t,t+1}} = \beta \left(1 - F(b_{x,t+1}) \underbrace{- b_{t,t+1} f(b_{x,t+1})}_{\mathcal{I}_{t,ss}} \right)$$

while the marginal effect of short-term debt issuance on the government's objective is given by

$$u'(y_t - \min[b_{x,t}, L_t] + d_t(s_t, r_t, \iota_t))\beta\mathcal{I}_{t,ss} + (1 - F(b_{x,t+1})) \times \\ (\beta u'(y_t - \min[b_{x,t}, L_t] + d_t(s_t, r_t, \iota_t)) - \delta \mathrm{E}[u'(y_{t+1} - b_{x,t+1} + d_{t+1}(s_{t+1}, r_{t+1}, \iota_{t+1}))|s_t])\,.$$

Consider an alternative setup without social costs in the wake of a default. Assume as before that the government either fully repays the maturing debt or suffers a cost L_t. In contrast to the main model, however, suppose now that this cost corresponds to a *transfer* to bondholders rather than a social loss. One can interpret this modified setting as a situation where the realization of L_t determines the bargaining power of bondholders vis-a-vis the government. According to this interpretation, bondholders can successfully press for full repayment if the realization of L_t is high. If the realization of L_t falls short of the maturing debt, however, bondholders must concede and settle for a reduced repayment equal to L_t.

In this modified setup, the repayment rate in period t is given by

$$r_t(s_t) = \begin{cases} 1 & \text{if } L_t \geq b_{x,t} \\ \frac{L_t}{b_{x,t}} & \text{if } L_t < b_{x,t} \end{cases}$$

and the expected repayment rate features a new component that accounts for payments in the partial default case:

$$\mathrm{E}\left[r_{t+1}(s_{t+1})|s_t\right] = 1 - F(b_{x,t+1}) + \underbrace{\frac{1}{b_{x,t+1}} \int_0^{b_{x,t+1}} L_{t+1} \mathrm{d}F(L_{t+1})}_{\text{new term}}\,.$$

Accordingly, the marginal effect of debt issuance in period t on the deficit in that period changes to

$$\begin{aligned}\frac{\mathrm{d}d_t(s_t,r_t,\iota_t)}{\mathrm{d}b_{t,t+1}} &= \beta\left(1-F(b_{x,t+1})-b_{t,t+1}f(b_{x,t+1})\right) \\ &\quad +\underbrace{\beta\left(b_{t,t+1}f(b_{x,t+1})+\frac{1}{b_{x,t+1}}\int_0^{b_{x,t+1}} L_{t+1}\mathrm{d}F(L_{t+1})\left(1-\frac{b_{t,t+1}}{b_{x,t+1}}\right)\right)}_{\text{new terms}}.\end{aligned}$$

The presence of transfers rather than social costs introduces three marginal effects in addition to those present in the main model. First, the increase in $b_{t,t+1}$ raises more revenue because newly-issued debt is *partially* repaid in some states, as reflected in the term $\frac{1}{b_{x,t+1}}\int_0^{b_{x,t+1}} L_{t+1}\mathrm{d}F(L_{t+1})$. Second, as reflected in the term $b_{t,t+1}f(b_{x,t+1})$, an increase in $b_{t,t+1}$ raises the probability of *partial* repayment of the newly-issued debt at the critical income loss, $b_{x,t+1}$. Finally, the increase in $b_{t,t+1}$ causes revenue losses on newly-issued inframarginal debt, $-\frac{b_{t,t+1}}{b_{x,t+1}^2}\int_0^{b_{x,t+1}} L_{t+1}\mathrm{d}F(L_{t+1})$, because it reduces the repayment rate in case of *partial* default.

The second of these additional effects cancels with the loss on inframarginal debt that is already present in the main model. Intuitively, the revenue gain due to more likely, partial repayment exactly compensates for the revenue loss due to less likely, full repayment. On net, the marginal effect on the deficit therefore amounts to $\beta(1-F(b_{x,t+1}))+\beta\frac{1}{b_{x,t+1}}\int_0^{b_{x,t+1}} L_{t+1}\mathrm{d}F(L_{t+1})\left(1-\frac{b_{t,t+1}}{b_{x,t+1}}\right)$. If $0<b_{x,t,t+1}<b_{x,t+1}$ such that debt is outstanding and the government issues additional debt, then this marginal effect exceeds $\beta(1-F(b_{x,t+1}))$ because debt issuance effectively redistributes collateral from outstanding to newly-issued debt, in contrast with the situation in the main model.

The government's program in period t is unchanged relative to the original setup, except for the modified expression characterizing the deficit. (From the government's point of view, it is irrelevant whether income losses in period $t+1$ correspond to transfers to bond holders rather than social losses.) The effect of a marginal increase in $b_{t,t+1}$ therefore equals

$$\begin{aligned}&u'(y_t-\min[b_{x,t},L_t]+d_t(s_t,r_t,\iota_t))\beta\frac{1}{b_{x,t+1}}\int_0^{b_{x,t+1}} L_{t+1}\mathrm{d}F(L_{t+1})\frac{b_{x,t,t+1}}{b_{x,t+1}}+(1-F(b_{x,t+1}))\times \\ &\left(\beta u'(y_t-\min[b_{x,t},L_t]+d_t(s_t,r_t,\iota_t))-\delta\mathrm{E}[u'(y_{t+1}-b_{x,t+1}+d_{t+1}(s_{t+1},r_{t+1},\iota_{t+1}))|s_t]\right),\end{aligned}$$

reflecting the same consumption-smoothing effect as in the main model (in the second line), but modified revenue losses on inframarginal units of debt (in the first line). Without social costs in the wake of a default as they are present in the original setup, the government therefore has an incentive to dilute outstanding debt.

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