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Abstract

This paper extends the baseline framework used in recent quantitative studies of sovereign default by assuming that the government can borrow using long-duration bonds. This contrasts with previous studies, which assume the government can borrow using bonds that mature after one quarter. We show that, when we assume that the government issues bonds with a duration similar to the average duration of sovereign bonds in emerging economies, the model generates an interest rate that is substantially higher and more volatile than the one obtained assuming one-quarter bonds. This narrows the gap between the predictions of the model and the data, which indicates that the introduction of long-duration bonds may be a useful tool for future research about emerging economies. Our analysis is also relevant for the study of other credit markets.

JEL classification: F34, F41.

Keywords: Sovereign Default, Endogenous Borrowing Constraints, Bond Duration, Debt Dilution, Markov Perfect Equilibrium.

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E-mails: JuanCarlos.Hatchondo@rich.frb.org; leo14627@gmail.com. The views expressed herein are those of the authors and should not be attributed to the IMF, its Executive Board, or its management, the Federal Reserve Bank of Richmond, or the Federal Reserve System.

1 Introduction

Business cycles in small emerging economies differ from those in developed economies. Emerging economies feature interest rates that are higher, more volatile, and countercyclical (interest rates are usually acyclical in developed economies). Additionally, they have higher output volatility, higher volatility of consumption relative to income, and more countercyclical net exports (see Aguiar and Gopinath (2007), Neumeyer and Perri (2005), and Uribe and Yue (2006)). Because of the high volatility and countercyclicality of the interest rate in emerging economies, a state-dependent interest rate schedule is usually considered a key ingredient in any model designed to explain the cyclical behavior of aggregate quantities and prices in these economies. In this respect, some studies assume an exogenous interest rate schedule.[1] Others present models with microfoundations for the interest rate schedule based on the risk of default. This is the approach taken by recent quantitative studies of sovereign default, which extend the framework proposed by Eaton and Gersovitz (1981).[2] The setup studied in our paper belongs to the second class of models.

As in previous studies of sovereign default, we analyze a small open economy that receives a stochastic endowment stream of a single tradable good. The government's objective is to maximize the expected utility of private agents. Each period, the government makes two decisions. First, it decides whether to default on previously issued debt. Second, the government decides how much to borrow or save. The government can borrow (save) by issuing (buying) non-contingent bonds that are priced by risk-neutral investors. The cost of defaulting is represented by an endowment loss that is incurred in the default period.

The main difference between our paper and previous studies is that, while previous quantitative studies assume that sovereign bonds mature after one quarter, we assume that the gov-

[1] See, for instance, Aguiar and Gopinath (2007), Neumeyer and Perri (2005), Schmitt-Grohé and Uribe (2003), and Uribe and Yue (2006).

[2] See, for instance, Aguiar and Gopinath (2006), Arellano (2008), Arellano and Ramanarayanan (2008), Bai and Zhang (2006), Benjamin and Wright (2008), Cuadra and Sapriza (2006, 2008), D'Erasmo (2008), Eyigungor (2006), Hatchondo et al. (2006, 2007, 2009), Lizarazo (2005, 2006), Mendoza and Yue (2008), and Yue (2005). These models share blueprints with the models used in quantitative studies of household bankruptcy—see, for example, Athreya (2002), Athreya et al. (2007a,b), Chatterjee et al. (2007a), Chatterjee et al. (2007b), Li and Sarte (2006), Livshits et al. (2008), and Sánchez (2008).

ernment issues bonds that pay an infinite stream of coupons until a default is declared. We also assume that coupon payments promised in a bond decrease at a constant rate. Our assumptions allow us to introduce long-duration debt instruments in a simple and tractable way—the number of state variables is independent of the duration—and to match the average duration in the data by calibrating the rate at which coupon payments decrease.[3]

We solve the model both assuming that the government issues one-quarter bonds (as in previous studies), and assuming that the government issues bonds with an average duration of four years—similar to the average duration in emerging economies, as documented by Cruces et al. (2002) and Cunningham et al. (2001). We show that the mean and the standard deviation of the interest rate in our simulations of the model increase significantly when we increase the bond duration. Depending on our parameterization of the cost of defaulting, the mean spread—the difference between the bond yield and the risk-free interest rate—increases from less than 0.12% to more than 2.73%. The standard deviation of the spread increases from less than 0.06% to more than 0.27%. This narrows the gap between the predictions of the model and the data. Furthermore, assuming four-year bonds instead of one-quarter bonds does not damage the ability of the model to replicate other salient features of emerging economies. Thus, introducing long-duration bonds seems to be a useful tool for future research about these economies.

1.1 Related literature

As we mentioned above, the introduction of long-duration bonds enhances our ability to account for the behavior of the spread in emerging economies. Aguiar and Gopinath (2006) document the difficulties in accounting for the spread behavior of the standard sovereign default model with one-period bonds. In fact, their model with shocks to the endowment level generates a mean spread that is below the mean spread generated by the baseline model with one-period bonds studied in this paper. Several studies explore mechanisms to improve the quantitative performance of sovereign default models in terms of the spread behavior. Below, we discuss some of these mechanisms that rely on making the interest rate at which the government can

[3] The duration of a bond corresponds to the number of periods that it takes to recover the initial investment in the bond. Copeland and Weston (1992) present a thorough discussion of the concept of bond duration.

borrow less responsive to changes in borrowing levels.

Arellano (2008) succeeds in presenting a quantitative model with one-period bonds that generates a higher mean spread (3.58%) by assuming a cost of defaulting that is more sensitive to endowment shocks than the one we assume (and the ones assumed by Aguiar and Gopinath (2006) and other studies). However, in her model, when economic conditions are good, the spread generated by the model is close to zero, which is not observed in the data—see Figure 5 in Arellano (2008). Our findings suggest that introducing long-duration bonds could help in generating positive spread levels even in periods of high income. When economic conditions are good and the probability of default in the next period is small, the long-duration-bond spread may be significantly above zero because lenders anticipate a higher default probability in more distant periods.

Chatterjee and Eyigungor (2009) study how long-duration bonds can improve the spread behavior generated by a model of sovereign default that uses the cost of defaulting assumed in Arellano (2008). They calibrate their model to obtain an average spread of 8.8% with long-duration bonds and show that, using one-period bonds (and the same calibration), the average spread declines to 0.4%. Their model also departs from ours by assuming a minimum consumption shock. They explain that this shock helps find a numerical solution. In addition, they provide a characterization of equilibrium with long-duration bonds and find that an equilibrium zero-profit bond price function exists and is decreasing with respect to the borrowing level.

Arellano and Ramanarayanan (2008) also study a model of sovereign default with long-duration bonds and with the cost of defaulting assumed in Arellano (2008). They discuss how the optimal maturity structure changes over the business cycle. They find that, in the data, when interest rate spreads rise, debt maturity shortens and the spread on short-term bonds is higher than on long-term bonds. They document how their model can account for these observations. In their simulations of a model with both two-year and ten-year bonds, the mean spread is 6.58% for two-year bonds and 6.25% for ten-year bonds.

Mendoza and Yue (2008) also show that in a sovereign default model the mean spread is higher when the sensitivity of the output cost of defaulting to the productivity shock is increased. They study sovereign defaults in a production economy with TFP shocks and an endogenous output cost of defaulting. In their benchmark simulations, the mean spread is 2.4%. When they shut down their endogenous output cost of defaulting and replace it with the (exogenous) output cost assumed by Aguiar and Gopinath (2006), the mean spread in the simulations decreases to 0.5%. Mendoza and Yue (2008) discuss how this fall in the mean spread is explained in part by the lower sensitivity of the output cost to the state assumed by Aguiar and Gopinath (2006).

Hatchondo et al. (2009) show that introducing political risk into a standard sovereign default framework may help in generating a higher spread (see also D'Erasmo (2008)). In the presence of political turnover between governments with different discount factors, the mean spread is 6.3%. Without political turnover, the model generates a mean spread between 0.3% and 1.5%, depending on the government's patience. Political shocks make the interest rate at which the government can borrow less responsive to changes in borrowing levels.

Benjamin and Wright (2008) show that a model with debt renegotiation can generate higher spreads during the renegotiation period than in the pre-default period, as observed in the data. Both in their model and in the data, the market value of sovereign bonds declines after the sovereign declares a default. However, in their simulations, pre-default spread levels are lower than in the data. Pouzo (2008) conducts a similar exercise and reports an average spread of 1% for pre-default simulation samples and 119% for renegotiation-period samples.

The rest of the article proceeds as follows. Section 2 introduces the model. Section 3 presents the recursive formulation of the model. Section 4 discusses the parameter values used to solve the model. Section 5 presents the results. Section 6 discusses robustness. Section 7 concludes.

2 The model

The basic framework in this paper follows previous work that extends the sovereign default model presented by Eaton and Gersovitz (1981) in order to study its quantitative performance. The main difference between the model we present and the baseline framework is that our model allows us to introduce long-duration bonds.

2.1 The environment

There is a single tradable good. The economy receives a stochastic endowment stream of this good y_t, where

$$\log(y_t) = (1-\rho)\,\mu + \rho \log(y_{t-1}) + \varepsilon_t,$$

with $|\rho| < 1$, and $\varepsilon_t \sim N\left(0, \sigma_\epsilon^2\right)$.

The government's objective is to maximize the present expected discounted value of future utility flows of the representative agent in the economy, namely

$$E\left[\sum_{t=0}^{\infty} \beta^t u\left(c_t\right)\right],$$

where β denotes the subjective discount factor and the utility function is assumed to display a constant coefficient of relative risk aversion, denoted by σ. That is,

$$u\left(c\right) = \frac{c^{(1-\sigma)} - 1}{1-\sigma}.$$

Each period, the government makes two decisions. First, it decides whether to default, which implies repudiating all current and future debt obligations contracted in the past. The default cost is represented by an endowment loss of $\phi\left(y\right)$ in the default period. Second, the government decides the number of bonds that it purchases or issues in the current period.

We assume that a bond issued in period t promises an infinite stream of coupons, which decreases at a constant rate δ. In particular, a bond issued in period t promises to pay one unit of the good in period $t+1$ and $(1-\delta)^{s-1}$ units in period $t+s$, with $s \geq 2$. The coupon structure assumed in this paper can also be interpreted as if the debt issued by the government consisted of a portfolio of zero-coupon bonds of different maturities, where the portfolio weights decline geometrically with maturity.

We assume that each period the government can choose any debt level for the following period, anticipating that the price at which it can issue or purchase bonds is such that lenders make zero profits in expectation.[4] Note that, with long-duration bonds, this implies that the

[4]There are several borrowing games that would lead to government borrowing opportunities like the ones described above. For instance, it could be assumed that each period, the government conducts the following

government can repurchase the bonds it issued in previous periods at the zero-profit price in the same way it can issue bonds at the zero-profit price.[5] Lenders can borrow or lend at the risk-free rate r, and have perfect information regarding the economy's endowment.

Following recent quantitative studies of default risk, we assume that the government cannot commit to future default and borrowing decisions. Thus, one may interpret this environment as a game in which the government making the default and borrowing decisions in period t is a player who takes as given the default and borrowing strategies of other players (governments) who will decide after t. In contrast, if the government could commit to future default and borrowing decisions, it would internalize the effect of period-t decisions in every period before t.

We solve the model using the Markov Perfect Equilibrium concept. That is, we assume that in each period, the government's equilibrium default and borrowing strategies depend only on payoff relevant state variables.

2.2 Discussion of assumptions

First, note that the coupon structure we assume allows us to consider debt with durations longer than one period without increasing the dimensionality of the state space. The government default and issuance decisions in period t are influenced by its debt obligations for that period and by its current debt obligations for every future period. Since we assume that bonds issued in all previous periods promise a sequence of coupons that decrease at the same constant rate, current coupon obligations are sufficient to predict the stream of future debt obligations derived from past issuances.

In contrast, alternative strategies to model long-duration bonds could imply an increase in the dimensionality of the state space. For instance, suppose that the government issues zero-

auction: First, the government announces how many bonds it wants to issue or purchase. Then, each lender offers the government a price at which he is willing to buy the bonds the government is issuing or to sell the bonds the government wants to purchase. The government then chooses the lenders with whom it will perform the transaction. Finally, the transaction is performed and the current-period borrowing game ends.

[5] In our simulations with four-year bonds ($\delta = 4.5\%$), depending on the parameterization of the cost of defaulting, the government repurchases debt issued in previous periods only in between 0% (with $\phi(y) = 0.5y$) and 0.007% (with $\phi(y) = 0.1y$) of the periods (when the model is simulated for 750,000 periods). That is, in almost every period, the government does not want its coupon payment obligations to decrease at a rate higher than $\delta = 4.5\%$ per quarter.

coupon bonds that mature n periods ahead. In period t, the default and issuance decisions would depend on the bonds issued between period $t-n$ and period $t-1$, which would determine the government's debt obligations from period t to period $t+n-1$. Thus, generally, in order to solve the model, one would need to keep track of n state variables. Similarly, if one assumes that bonds promise an infinite sequence of coupons that decrease at a constant rate but allows this rate to be different for bonds issued in different periods, one would have to keep track of the history of past issuances. Thus, it would not be possible to summarize all future payment obligations with one state variable.

In our framework, the law of motion of coupon payment obligations follows a simple formulation. Let b denote the number of outstanding coupon claims at the beginning of the current period, and b' denote the number of outstanding coupon claims at the beginning of next period. A negative value of b implies that the government was a net issuer of bonds in the past. Let d denote the current-period default decision. We assume that d is equal to 1 if the government defaulted in the current period and is equal to 0 if it did not. Let i denote the current-period issuance level. Then,

$$b' = b(1-\delta)(1-d) - i \tag{1}$$

represents the law of motion for coupon payment obligations. For example, if the government chooses $b' = (1-d)(1-\delta)b$, it is neither issuing nor buying bonds. That is, the number of coupons that will mature next period is solely determined by past debt issuances and the current default decision. If the government chooses $b' < (1-d)(1-\delta)b$, it is issuing new bonds, and if $b' > (1-d)(1-\delta)b$, the government is purchasing bonds. Note that the law of motion in equation (1) resembles the law of motion of capital in the neoclassical growth model.

The assumed coupon structure also allows us to calibrate the bond duration, which in our framework depends on δ. We use the Macaulay definition of duration.[6] According to this definition, the duration of a bond is equal to the weighted sum of future payment dates, where

[6]Empirical studies and credit rating agencies use measures of duration of sovereign bonds based on this definition. See, for example, Cruces et al. (2002) and Cunningham et al. (2001).

each date is weighted by the relative importance of the payments due at that date:

$$D \equiv \sum_{s=1}^{\infty} s \frac{C_s \left(1+r^*\right)^{-s}}{q},$$

where D denotes the duration of a bond that promises a coupon C_s at date s and has a price q, and r^* denotes the constant per-period yield delivered by the bond.[7] The Macaulay duration of a bond with the coupon structure we assume is given by

$$D = \frac{1+r^*}{\delta + r^*}. \tag{2}$$

Equation (2) shows that δ can be calibrated to obtain a desired bond duration. Note also that the one-period bond model is a particular case of our framework: it corresponds to $\delta = 1$, which implies a duration of one period according to equation (2).

It should be emphasized that in our model the maturity structure of sovereign debt is fixed and cannot be changed by the government. Our goal is to show that abandoning the one-period bond assumption can enhance the ability of the model to explain the behavior of interest rates in emerging economies. Analyzing how the government chooses the optimal maturity structure of sovereign debt is an interesting topic but is beyond the scope of this paper.

Although we assume perpetual bonds because it allows us to have a tractable framework, it should be mentioned that perpetual bonds are commonly used, mainly by banks but also by some governments. The best known examples of perpetual government bonds are consols issued by the British government in the eighteenth century. Other examples of perpetual sovereign bonds exist but, in general, issuances of perpetual government bonds are rare.

The assumption that default triggers an output loss is standard and intends to capture the disruptions in economic activity caused by a default decision. It has been argued that a sovereign default increases the borrowing cost of domestic firms and, thus, it reduces output. Using micro-level data, Arteta and Hale (2008) find that sovereign debt crises are systematically accompanied by a large decline in foreign credit to domestic private firms. This could be the case because

[7] That is, r^* satisfies

$$q = \sum_{s=1}^{\infty} C_s \left(1+r^*\right)^{-s}.$$

a sovereign default may induce investors to believe that there is a higher risk of expropriation or bad economic conditions and, therefore, it may reduce firms' net worth and their ability to borrow (see Sandleris (2006) and the references therein). IMF (2002), Kumhof (2004), and Kumhof and Tanner (2005) discuss how financial crises that lead to severe recessions follow a sovereign default. Similarly, Kaminsky and Reinhart (1999) show that currency devaluations in developing countries tend to cause banking problems. Kobayashi (2006) presents a model in which a shock that disturbs the payments system causes a decrease in aggregate productivity. Mendoza and Yue (2008) study the link between sovereign-default risk and output.

We do not assume that countries can be excluded from capital markets after a default episode. Wright (2005) discusses how in the past three decades the sovereign debt market has become more competitive and explains how an increase in competition (number of creditors) may diminish creditors' ability to coordinate and punish defaulting countries by excluding them from capital markets (see also Athreya and Janicki (2006), Cole et al. (1995), Hatchondo et al. (2007), and Wright (2002)). Hatchondo et al. (2009) discuss how defaults and subsequent difficulties in market access can be jointly explained by the presence of political turnover. Empirical studies suggest that once variables such as the quality of policies and institutions are used as controls, market access is not significantly influenced by past default decisions (see, for example, Eichengreen and Portes (2000), Gelos et al. (2004), and Meyersson (2006)). Hatchondo et al. (2007) solve a baseline model of sovereign default with and without the exclusion punishment—the framework analyzed in that paper closely resembles the framework studied in Aguiar and Gopinath (2006)—and show that eliminating the exclusion punishment does not significantly affect the mean spread and the spread volatility generated by the model.

Two final remarks about the cost of defaulting are in order. First, to gain tractability, we assume that the cost of defaulting lasts for only one period, although the negative effects of a sovereign default on the defaulting country's economic activity seem to last for more than one quarter. As explained in Hatchondo et al. (2007), when defaulting countries are not assumed to be excluded from capital markets, assuming that the output loss triggered by a default could last for more than one period would increase the dimensionality of the state space: it would require keeping track of the current accumulated default punishment. Hatchondo et al. (2007) study a framework similar to the one considered in this paper and show that the predictions of the model do not seem to be affected by whether it is assumed that the output loss lasts for one period or for a stochastic number of periods.

Second, assuming that the cost of defaulting is too sensitive to the output level may lead to counterfactual implications with respect to the responsiveness of default decisions to output. Tomz and Wright (2007) document that the correlation between default decisions and output levels is negative but moderate. They also show that, in a baseline model of sovereign default, almost all default episodes take place in periods of low output. Independently of the debt duration assumed, this is also the case in our model. This counterfactual implication could be avoided by assuming that the dynamics in the model are not solely driven by endowment shocks. For instance, Hatchondo et al. (2009) show how, as suggested by Tomz and Wright (2007), introducing political risk helps generate a moderate correlation between default decisions and output levels. For the sake of simplicity and transparency, we follow previous studies that focus on a model in which dynamics are only driven by endowment shocks.

3 Recursive formulation

Let $V(b, y)$ denote the government's value function at the beginning of a period, that is, before the default decision is made. Let $\tilde{V}(d, b, y)$ denote its value function after the default decision has been made. Let $F(y' \mid y)$ denote the conditional cumulative distribution function of the next-period endowment y'. For any bond price function $q(b', y)$, the function $V(b, y)$ satisfies the following functional equation:

$$V(b, y) = \max_{d \epsilon \{0,1\}} \{d\tilde{V}(1, b, y) + (1-d)\tilde{V}(0, b, y)\}, \tag{3}$$

where

$$\tilde{V}(d, b, y) = \max_{b' \leq 0} \left\{ u(c) + \beta \int V(b', y') F(dy' \mid y) \right\}, \tag{4}$$

and

$$c = y - d\phi(y) + (1-d)b - q(b', y)\left[b' - (1-d)(1-\delta)b\right].$$

The bond price that satisfies lenders' zero-profit condition is given by the following functional equation:

$$q^{ZP}(b', y) = \frac{1}{1+r} \int [1 - h(b', y')] F(dy' \mid y) + \frac{1-\delta}{1+r} \int [1 - h(b', y')] \; q^{ZP}(g(h(b', y'), b', y'), y') F(dy' \mid y), \quad (5)$$

where $h(b, y)$ and $g(d, b, y)$ denote the future default and borrowing rules that lenders expect the government to follow. The default rule $h(b, y)$ is equal to one if the government defaults, and is equal to zero otherwise. The function $g(d, b, y)$ determines the number of coupons that will mature next period. The first term in the right-hand side of equation (5) equals the expected value of the next-period coupon payment promised in a bond. The second term in the right-hand side of equation (5) equals the expected value of all other future coupon payments, which is summarized by the expected price at which the bond could be sold next period. Note that the second term is equal to zero with one-period bonds ($\delta = 1$).

Equations (3)-(5) illustrate that the government finds its optimal current default and borrowing decisions taking as given its future default and borrowing decision rules $h(b, y)$ and $g(d, b, y)$. In equilibrium, the optimal default and borrowing rules that solve problems (3) and (4) must be equal to $h(b, y)$ and $g(d, b, y)$ for all possible values of the state variables.

Definition 1 *A Markov Perfect Equilibrium is characterized by*

1. a set of value functions $\tilde{V}(d, b, y)$ and $V(b, y)$,
2. a default rule $h(b, y)$ and a borrowing rule $g(d, b, y)$,
3. a bond price function $q^{ZP}(b', y)$,

such that:

(a) given $h(b, y)$ and $g(d, b, y)$, $V(b, y)$ and $\tilde{V}(d, b, y)$ satisfy functional equations (3) and (4) when the government can trade bonds at $q^{ZP}(b', y)$;

]

Risk aversion	σ	2
Interest rate	r	1%
Output autocorrelation coefficient	ρ	0.9
Standard deviation of innovations	σ_ϵ	2.7%
Mean log output	μ	(-1/2)σ_ϵ^2
Output loss	λ	10%, 20%, 50%
Discount factor	β	0.95
Duration	δ	1, 0.045

Table 1: Parameter values.

(b) given $h(b, y)$ and $g(d, b, y)$, the bond price function $q^{ZP}(b', y)$ offered to the government satisfies lenders' zero-profit condition implicit in equation (5); and

(c) the default rule $h(b, y)$ and borrowing rule $g(d, b, y)$ solve the dynamic programming problem defined by equations (3) and (4) when the government can trade bonds at $q^{ZP}(b', y)$.

4 Parameterization

The model is solved numerically using value function iteration and interpolation.[8] Table 1 presents the parameterization used in this paper.

We assume a coefficient of relative risk aversion of 2, which is within the range of accepted values in studies of real business cycles. A period in the model refers to a quarter. The risk-free

[8]We use linear interpolation for endowment levels and spline interpolation for asset positions. The algorithm finds two value functions, $\tilde{V}(1, b, y)$ and $\tilde{V}(0, b, y)$. Convergence in the equilibrium price function $q^{ZP}(b', y)$ in equation (5) is assured. As discussed by Krusell and Smith (2003), there is typically a problem of multiplicity of Markov perfect equilibria in infinite-horizon economies. In order to avoid this problem, we solve for the equilibrium of the finite-horizon version of our economy, and we increase the number of periods of the finite-horizon economy until value functions and bond prices for the first and second periods of this economy are sufficiently close. We then use the first-period equilibrium objects as the infinite-horizon-economy equilibrium objects.

interest rate is set equal to 1%. As in Hatchondo et al. (2009), the parameter values that govern the endowment process are chosen so as to mimic the behavior of GDP in Argentina from the fourth quarter of 1993 to the third quarter of 2001. The parameterization of the output process is similar to the parameterization used in other studies that consider a longer sample period (see, for instance, Aguiar and Gopinath (2006)).

As in previous studies (see, for example, Aguiar and Gopinath (2006)), we assume that the loss in output triggered by a default is represented by a function $\phi(y) = \lambda y$. We present results for three values for λ, which allows us to show that the value of λ does not affect the main conclusion of the paper: the mean and the standard deviation of the spread are substantially higher when governments can issue bonds with a duration similar to the one observed in emerging economies instead of a duration of one quarter.

We assume a relatively low value for the discount factor. However, the value we assume is higher than the ones assumed in previous studies with a cost of defaulting similar to the one in this paper (for instance, Aguiar and Gopinath (2006) assume $\beta = 0.8$). Low discount factors may be a result of political polarization in emerging economies (see Amador (2003) and Cuadra and Sapriza (2008)).

We present results for two values of δ. When $\delta = 1$, bonds have a duration of one quarter, which is the case analyzed in previous studies. When $\delta = 0.045$, bonds have an average duration of 4.12 years when $\lambda = 0.5$ (durations are similar for the other values of λ we study). Cruces et al. (2002) report that the average duration of Argentinean bonds included in the EMBI index was 4.13 years in 2000. This duration is not significantly different from what is observed in other emerging economies. Using a sample of 27 emerging economies, Cruces et al. (2002) find an average duration of 4.77 years with a standard deviation of 1.52. In Section 6, we solve the model for alternative values of δ and show that the mean and standard deviation of the spread increase monotonically with the debt duration.

5 Results

This section discusses the ability of the model to replicate some stylized facts about the macroeconomic behavior of emerging economies. We simulate the model for a number of periods that allows us to extract 500 samples of 32 consecutive periods before a default. Except for the computation of default frequencies, which are computed using all the simulation data, we focus on samples of 32 periods because we want to compare the artificial data generated by the model with Argentine data from the fourth quarter of 1993 to the third quarter of 2001.[9] In order to facilitate the comparison of simulation results with the data, we only consider simulation sample paths where the last default was declared at least two periods before the beginning of each sample.

Table 2 reports moments in the data and in our simulations.[10] The moments reported in the table are chosen so as to evaluate the ability of the model to replicate distinctive business cycle properties of emerging economies. Relative to developed economies, emerging economies feature higher, more volatile and countercyclical interest rates; a higher volatility of consumption relative to income; and more countercyclical net exports. The trade balance (TB) is expressed as a fraction of output (Y). The interest rate spread (R_s) is expressed in annual terms.[11] The logarithm of income and consumption are denoted by y and c, respectively. The standard deviation of x is denoted by $\sigma(x)$ and is reported in percentage terms. The coefficient of correlation between x and z is denoted by $\rho(x, z)$. Moments are computed using detrended series. Trends are computed using the Hodrick-Prescott filter with a smoothing parameter of $1,600$.

[9] The qualitative features of this data are also observed in other sample periods and in other emerging markets (see, for example, Aguiar and Gopinath (2007), Neumeyer and Perri (2005), and Uribe and Yue (2006)). The only exception is that in the data we consider, the volatility of consumption is slightly lower than the volatility of income, while emerging market economies tend to display a higher volatility of consumption relative to income.

[10] The data for output, consumption, and trade balance were obtained from the Argentinean Finance Ministry. The spread before the first quarter of 1998 is taken from Neumeyer and Perri (2005), and from the EMBI Global after that. The average duration in the data is the one reported by Cruces et al. (2002).

[11] Let

$$r^* = \frac{1}{q^{ZP}(b', y)} - \delta$$

denote the per-period constant yield implied by a bond price $q^{ZP}(b', y)$. The annualized spread is given by $R_s = \left(\frac{1+r^*}{1+r}\right)^4 - 1$.

		$\lambda = 10\%$		$\lambda = 20\%$		$\lambda = 50\%$	
	Data	$\delta = 1$	$\delta = 0.045$	$\delta = 1$	$\delta = 0.045$	$\delta = 1$	$\delta = 0.045$
Average duration	4.13	0.25	4.07	0.25	4.08	0.25	4.12
$E(R_s)$	**7.44**	**0.12**	**3.01**	**0.11**	**2.93**	**0.12**	**2.73**
$\sigma(R_s)$	**2.51**	**0.03**	**0.27**	**0.04**	**0.29**	**0.06**	**0.33**
$\sigma(y)$	3.17	3.12	3.07	3.05	3.06	3.15	3.07
$\sigma(c)$	2.98	3.21	3.13	3.27	3.23	3.66	3.45
$\sigma(TB/Y)$	1.35	0.20	0.12	0.38	0.26	0.85	0.56
$\rho(c, y)$	0.97	1.00	1.00	0.99	1.00	0.98	0.99
$\rho(TB/Y, y)$	-0.69	-0.46	-0.58	-0.48	-0.60	-0.50	-0.64
$\rho(R_s, y)$	-0.65	-0.93	-0.86	-0.86	-0.86	-0.77	-0.86
$\rho(R_s, TB/Y)$	0.56	0.76	0.83	0.86	0.85	0.93	0.88
Debt/output		0.09	0.10	0.18	0.21	0.44	0.51
Defaults per 100 years		0.12	3.02	0.11	2.92	0.12	2.72

Table 2: Business cycle statistics. The second column is computed using data from Argentina from 1993 to 2001. Other columns report the mean of the value of each moment in 500 simulation samples.

Table 2 shows that the mean and the standard deviation of the spread are higher with four-year bonds ($\delta = 0.045$) than with one-quarter bonds ($\delta = 1$). It also shows that introducing four-year bonds does not limit the ability of the model to replicate other features of the data: Other statistics reported in the table are similar when computed with one-period bonds and four-year bonds. Differences in the behavior of the spread are also apparent in Figure 1, which shows the combinations of income realizations and spread levels in the simulations of the model with one-quarter and four-year bonds for $\lambda = 0.5$ (the figure would look similar for other values of λ).

In order to shed light on the government's optimal choices, we next discuss the Euler equation that determines these choices. In order to simplify the notation, we do not write consumption, default, and future borrowing as functions of the state variables. Let $\tilde{b} \equiv (1-d)(1-\delta)b$ denote

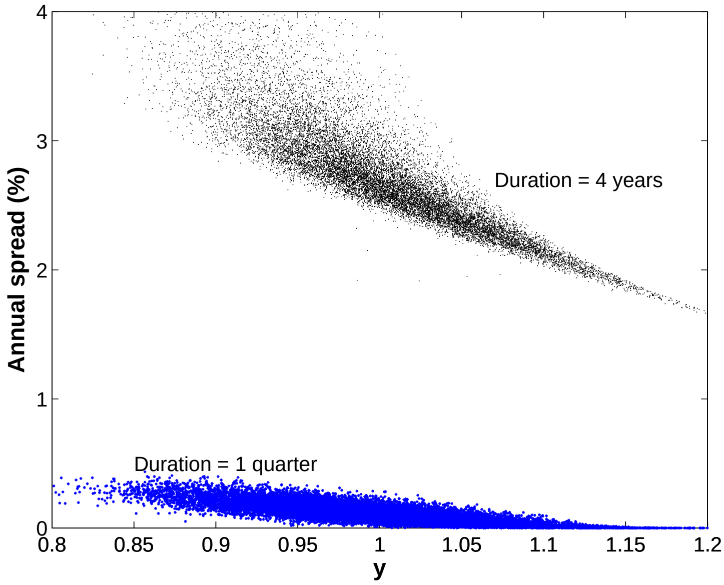

Figure 1: Endowment realizations and equilibrium spread levels in economies with one-quarter and four-year bonds, for $\lambda = 0.5$. The plot shows 500 samples of 32 periods before a default episode.

the interim number of next-period coupon obligations. We use $f_j(x_1, ..., x_n)$ to denote the first-order derivative of the function f with respect to the argument x_j. The Euler equation is given by

$$u_1(c)q^{ZP}(b', y) = \beta \int u_1(c')(1-d')[1+q^{ZP}(b'', y')(1-\delta)]F(dy' \mid y) - u_1(c)q_1^{ZP}(b', y)(b' - \tilde{b}). \quad (6)$$

The left-hand side of equation (6) represents the marginal benefit of borrowing. By issuing one extra bond today, the government can increase current consumption by $q^{ZP}(b', y)$ units. The right-hand side of equation (6) represents the marginal cost of borrowing. The first term in the right-hand side represents the "future cost of borrowing." By borrowing more, the government decreases future consumption in states where a default is not declared. The second term in the right-hand side represents the "current cost of borrowing." By borrowing more, the government decreases the issuance price of every bond it issues in the current period, which in turn decreases current consumption.

As discussed in the literature on debt dilution, default risk and the government's inability to commit to future borrowing levels introduce incentives to overborrow and therefore pay higher spreads.[12] An increase in the current borrowing level raises the default probability on all outstanding debt, and thus, it decreases the market value of all outstanding debt—debt dilution occurs. As one can see in the current cost of borrowing in equation (6), when issuing bonds, the government only internalizes as a cost the dilution of the value of current bond issuances. It does not internalize the cost of diluting the value of bonds issued in past periods. With one-period bonds, when the government decides its current borrowing level, the outstanding debt level is zero (either because the government has honored its debt obligations at the beginning of the period or because it has defaulted on them). Thus, the government does not have the option to dilute previously issued debt. The introduction of long-duration bonds incorporates into the model the incentives to overborrow discussed in the literature about debt dilution, which in turn induce the government to pay higher spreads.

Note that the introduction of long-duration bonds also reduces the fraction of debt that would need to be rolled over in a given period in order to keep the debt level constant (this fraction is equal to δ). This tends to reduce the current cost of borrowing by decreasing current issuances ($b' - \tilde{b}$ in equation (6)). With one-quarter bonds, in each period in which the government does not default, it has to pay back its entire debt stock. This leads to relatively high issuance volumes. In contrast, with four-year bonds, the government only rolls over a small fraction of its debt. Consequently, the decrease in the issuance price in the current cost of borrowing $q_1^{ZP}(b', y)$ is weighted by a smaller number (a smaller issuance volume).

Figure 2 illustrates that, with one-quarter bonds, low debt levels command a spread that is close to zero.[13] In contrast, with four-year bonds, even if the government chooses low debt levels, spread levels would be substantially above zero. For low debt levels, the probability of a default in the next period is close to zero. With one-period bonds, this implies an expected recovery rate close to one—i.e., the fraction of the loan lenders expect to recover is close to one.

[12] See, for instance, Bi (2006), Bizer and DeMarzo (1992), Detragiache (1994), Hatchondo and Martinez (2007), Kletzer (1984), Sachs and Cohen (1982), and Tirole (2002).

[13] The figure presents the spread that renders lenders zero profits in expectation as a function of the face value of next-period debt—defined as the present value of future payment obligations discounted at the risk-free rate, $\frac{b'}{\delta+r}$. We construct the figure assuming $\lambda = 0.5$, but the shape of the graphs are similar for lower values of λ. The main difference is that the zero-profit spread curve starts increasing sharply at lower borrowing levels when λ takes lower values. This is reflected in the relationship between λ and the debt-to-output ratios in Table 2.

With long-duration bonds, it is still true that, when the government chooses a debt level close to zero, the probability of a default in the next period is negligible. However, equilibrium default probabilities in other future periods are significantly above zero and, therefore, the expected recovery rate on current issuances is significantly lower than one. Suppose for example that the government is issuing long-duration debt for the first time. No matter how small the first issuance is, lenders would anticipate an expected recovery rate lower than one because they can forecast future issuance behavior. This implies that the government does not have the choice to issue small amounts at the risk-free rate.[14]

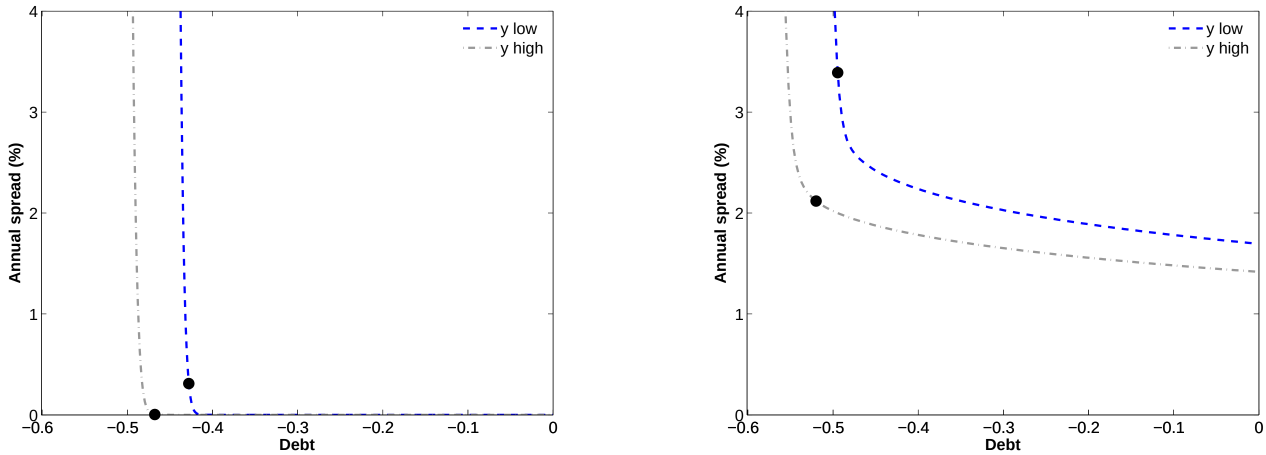

Figure 2: Menu of combinations of spreads and next-period debt levels ($\frac{b'}{\delta+r}$) from which the government can choose. The left (right) panel is obtained assuming bonds with a duration of one quarter (four years). The solid dots illustrate the optimal decision of a government that inherits a debt level equal to the average debt observed in our simulations for each bond duration. The low (high) value of y corresponds to an endowment realization that is one standard deviation below (above) the unconditional mean.

Next, we discuss why introducing long-duration bonds allows the model to generate a higher spread volatility. Figure 2 shows that with four-year bonds, the menu of interest rates available to the government is more sensitive to the current endowment realization than with one-period bonds. This is the case because lower income levels today imply lower expected income levels in future periods and, thus, make lenders anticipate higher default probabilities in future periods (recall that with long-duration bonds, the interest rate spread depends on default probabilities

[14]This finding resembles the result in environments where the borrower does not have within-period commitment to exclusive borrowing contracts (see, for example, Bizer and DeMarzo (1992) and Hatchondo and Martinez (2007)).

in every future period, not just in the next period). When four-year bonds are assumed, the higher sensitivity of the menu of zero-profit interest rates to the endowment leads the government to choose spread levels that are more sensitive to income (see the dots in Figure 2) and, thus, it leads to a higher spread volatility. Furthermore, since with long-duration bonds per-period issuance levels are lower, the government may be more willing to choose debt levels that are on the steep section of the interest rate schedule.

Table 2 also shows that the face value of debt ($\frac{b'}{\delta+r}$) is higher with four-year bonds than with one-quarter bonds. There are two reasons for this. First, as explained before, the government is only concerned about the effect of current-period issuances on the price of these issuances, which constitute a small fraction of the total debt level when we assume four-year bonds. This induces the government to choose a higher debt burden. Second, for any given debt burden, the higher default probability obtained with four-year bonds implies a higher face value of debt. The possibility of a government default implies that the actual debt burden is lower than the face value of future coupon obligations.

It should also be mentioned that the introduction of long-duration bonds may allow models of sovereign default to account for both debt levels and debt service levels in the data. With one-period bonds, debt levels are very close to debt service levels. Thus, studies that target debt service levels generate debt levels that are too low compared with the data. In contrast, studies that target debt levels generate debt service levels that are too high compared with the data. With long-duration bonds, if the bond duration and the spread in the model match the data, targeting the mean debt level is equivalent to targeting the mean debt service level.

In addition, Table 2 illustrates how equilibrium debt levels generated by the model are close to the cost of defaulting. For instance, if we assume that the cost of defaulting is 10% (50%) of output, the mean debt level generated by the model is 9% (44%) of output with one-quarter bonds and 10% (51%) with four-year bonds.[15]

Table 2 also shows that the mean annual spread generated by the model is almost identical to

[15] We do not parameterize the model to replicate debt levels in the data. The reason for this is that debt levels generated by the baseline model of sovereign default are difficult to compare with debt levels in the data. In the model, the government cannot borrow and save at the same time, the recovery rate on debt in default is zero, and all debt is held by foreigners.

the default frequency (number of defaults in 100 years). This is not surprising because we assume that sovereign bonds are priced by risk-neutral lenders and the recovery rate in case of default is zero. We do not contrast the default probability generated by the model with the one in the data because it is difficult to obtain a precise measure of the latter. First, default episodes are low frequency events and, therefore, a large sample size is necessary to obtain precise estimates of the default probability. Second, there are disagreements about what constitutes a sovereign default. Third, the default probability may change over time for a variety of reasons such as changes in the structure of international capital markets or in the probability distribution of shocks that hit the economy. For instance, the environment under which Argentina borrowed from international markets and the tradeoffs involved in default decisions during the last two decades might have been quite different from the environment and tradeoffs in place 200 years ago.

Finally, we find that the ex-ante welfare of domestic agents is optimized at low duration levels. Figure 3 illustrates the consumption compensation that would leave domestic agents indifferent between living in an economy with one-quarter bonds and living in an economy with a bond duration larger than one quarter. A positive number implies that agents are worse off in the economy with one-quarter bonds. The figure corresponds to cases where the initial debt level is equal to zero and $\lambda = 0.5$. The graph considers three levels of initial income: the unconditional mean and two standard deviations above and below the unconditional mean. The graph shows that ex-ante welfare is optimized at a value of δ close to 0.85, which implies an average duration of 0.29 years. The availability of long-duration bonds helps transfer resources to states in which consumption is more valuable. However, at larger debt durations those gains are dwarfed by the losses raised by the lack of commitment to future borrowing and default decisions. In economies with longer-duration bonds, the higher default frequency implies that the country pays the cost of defaulting more often, which is detrimental to welfare. If we assume bonds with $\delta = 0.045$ instead of one-quarter bonds, agents lose between 0.14% and 0.18% of consumption, depending on their initial income.

Thus, this paper clearly identifies a motive for issuing shorter-term debt: shorter-duration debt decreases the default frequency by weakening debt-dilution incentives. Of course, there are other tradeoffs between issuing long- and short-term debt that are not present or do not play a significant role in this paper (for a discussion of these tradeoffs see, for example, Alfaro and Kanczuk (2007), Arellano and Ramanarayanan (2008), Bi (2006), Broner et al. (2007), and Niepelt (2008)).

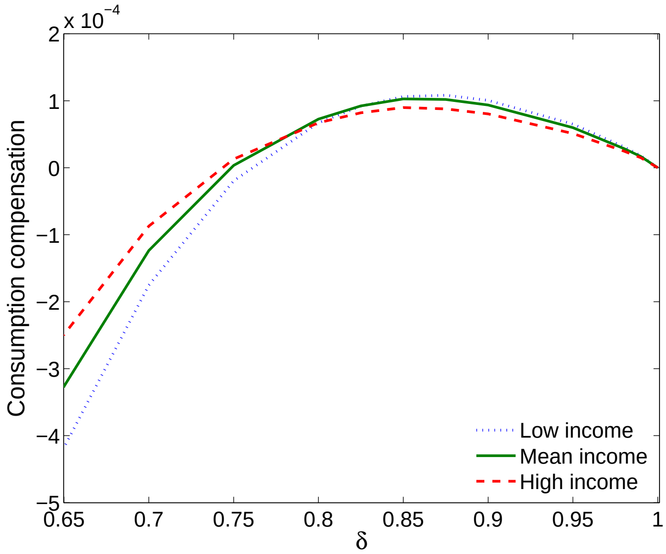

Figure 3: Consumption compensation (in percentage terms) that makes domestic agents indifferent between the economy with one-quarter bonds and economies with other bond durations. The figure was constructed assuming that the initial debt level is equal to zero. A low (high) initial income corresponds to an income realization that is two standard deviations below (above) the mean income.

6 Robustness

The previous section describes the main result of the paper, namely that the introduction of long-duration bonds significantly enhances the ability of a standard sovereign default model to account for the mean and standard deviation of the spread observed in the data. In this section, we show that our findings are robust to changes in the bond duration and to the cost of defaulting assumed for the experiment presented in Section 5.

First, we show that our findings are not an artifact of the specific values of δ used in our baseline parameterization. We solve the model for alternative values of δ and, for each value, we compute the average debt duration using the interest rate implicit in the equilibrium bond price and the mean and standard deviation of the spread observed in simulations. The results are summarized in Figure 4, which illustrates how the mean and standard deviation of the spread increase monotonically with the average debt duration.

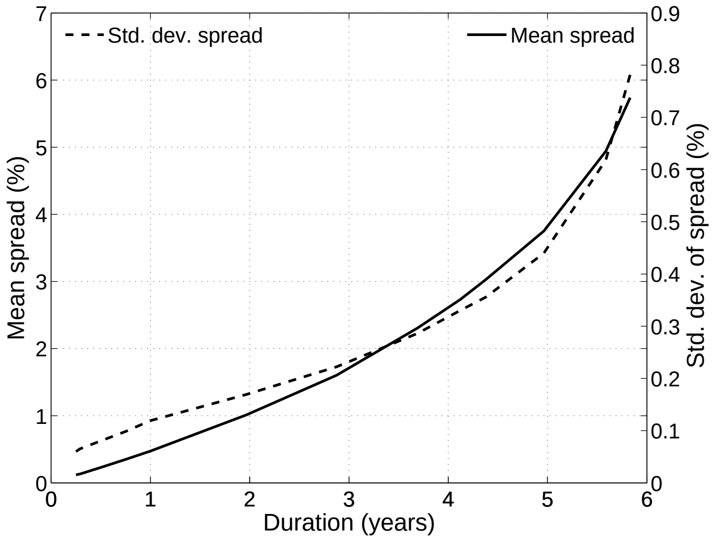

Figure 4: Simulated mean spread and standard deviation of the spread as functions of the average debt duration in the simulations.

Our findings are also robust to changes in the cost of defaulting. In order to illustrate this point, we replace our cost of defaulting with the cost of defaulting assumed in Aguiar and Gopinath (2006), and we solve the modified model. That is, we assume that i) the country is excluded from capital markets in the default period and then faces a constant probability of reentry into capital markets equal to 10% in every future period, and ii) the country loses 2% of its endowment in each period it remains excluded. All remaining parameter values are the same as in our benchmark parameterization. We solve the modified model and find that the mean spread in the simulations increases from 0.04% in the economy with one-quarter bonds to 0.86% in the economy with four-year bonds (these statistics are computed exactly as those reported in Table 2, but with the additional restriction that the chosen samples do not contain periods where the country is excluded from capital markets). The standard deviation of the spread increases from 0.008% in the economy with one-quarter bonds to 0.07% in the economy with four-year bonds. These magnitudes are lower than the ones presented in Table 2, but the relative changes across different bond durations are similar. Differences in the mean and standard deviation of the spread across models are explained by differences in the sensitivity of the cost of defaulting to the endowment level (see Section 1.1). Our findings indicate that the latter may not significantly affect the sensitivity of the spread behavior to debt duration.

7 Conclusions

We present an extended version of the baseline model of sovereign default that allows us to study economies where the government issues long-duration bonds. We show that when the model is parameterized to display a bond duration similar to the one observed in the data, the mean and the standard deviation of the interest rate are substantially larger than when one-quarter bonds are assumed. Replicating the behavior of domestic interest rates is an important goal in studies of emerging economies. Our results narrow the gap between the predictions of the baseline model and the data, indicating that the extended model may be a useful tool for future research.

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