Debt dilution and sovereign default risk*

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Abstract

We propose a sovereign default framework that allows us to quantify the importance of debt dilution for the level and volatility of the interest rate spread paid by sovereigns to compensate lenders for default risk. We find that debt dilution accounts for almost 82% of the mean spread and 71% of the spread volatility in the simulations of a baseline model. Even without commitment to future repayment policies and without contingency of sovereign debt obligations, if the sovereign could eliminate the dilution problem, the number of defaults per 100 years in our simulations decreases from 3.10 with debt dilution to 0.42 without debt dilution. This occurs in spite of dilution accounting for only 11% of the mean debt level. Our analysis is also relevant for the study of other credit markets where the debt dilution problem could appear.

JEL classification: F34, F41.

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1 Introduction

Understanding the behavior of interest rates in emerging economies is a central issue in academic and policy discussions. Neumeyer and Perri (2005) and Uribe and Yue (2006) argue that the level and volatility of interest rates in emerging economies may play a significant role in accounting for the distinctive features of business cycle dynamics observed in these economies.[1] Mendoza and Yue (2008) show how, in a sovereign default model, aggregate income shocks are amplified through changes in the default premium and thus in domestic interest rates.

What accounts for high and volatile interest rates in emerging economies? This paper contributes to answering this question.

We propose a measure of the effects of debt dilution on sovereign default risk and thus, on interest rate spreads—differences between sovereign bond yields and the risk-free interest rate. We measure these effects through the lens of a baseline sovereign default framework à la Eaton and Gersovitz (1981), similar to the ones used in recent studies.[2] We impose discipline to our quantitative exercise by calibrating the baseline model (with debt dilution) to match the mean and the standard deviation of the interest rate spread in the data.

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, it decides how much to borrow or save. The government can borrow (save) by issuing (buying) non-contingent long-duration bonds, as in Hatchondo and Martinez

[1]Interest rates in emerging economies are higher and more volatile than in developed economies, interest rates are countercyclical in emerging economies and procyclical or acyclical in developed economies, and emerging economies feature higher output volatility, more countercyclical net exports, and higher consumption volatility than income volatility (see, for example, Aguiar and Gopinath (2007), Alvarez et al. (2009), Boz et al. (2008), Neumeyer and Perri (2005), and Uribe and Yue (2006)).

[2]See, for instance, Aguiar and Gopinath (2006), Arellano (2008), Arellano and Ramanarayanan (2010), Bai and Zhang (2006), Benjamin and Wright (2008), Borri and Verdelhan (2009), Boz (2009), Cuadra et al. (forthcoming), Cuadra and Sapriza (2006, 2008), Chatterjee and Eyigungor (2009), D'Erasmo (2008), Hatchondo and Martinez (2009), Hatchondo et al. (2007, 2009, 2010), Lizarazo (2005, 2006), Mendoza and Yue (2008), Sandleris et al. (2009), and Yue (forthcoming). These models share blueprints with the models used in 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).

(2009).[3] The cost of defaulting is represented by an endowment loss that is incurred in the default period.

There are three features of this framework that imply inefficiencies that could be important in accounting for the equilibrium levels of debt and sovereign default risk. First, the government cannot commit to its future repayment policy. Second, bond payments are not contingent to income shocks. Third, the government can borrow from multiple lenders and the debt claims of existent debt holders are not contingent to future debt issuances. These three features represent characteristics of sovereign debt in reality and are standard in sovereign debt models.

In financial contracting theory, the third feature of sovereign debt markets described above is referred to as the nonexclusivity problem or debt dilution problem.[4] This problem (henceforth, debt dilution) has received considerable attention both in academic and policy discussions—see, for example, Bizer and DeMarzo (1992), Bolton and Jeanne (2009), Borensztein et al. (2004), Detragiache (1994), Eaton and Fernandez (1995), Kletzer (1984), Niepelt (2008), Sachs and Cohen (1982), Tirole (2002), and the references therein.[5] As in previous work, we study the effects of debt dilution in the presence of the other two features mentioned above (the lack of commitment to future repayment policies and the lack of contingency of sovereign debt).[6]

The standard modeling approach for the study of debt dilution is to focus on the effect

[3]With one-period bonds, when the government decides its current borrowing level, the outstanding debt level is zero (either because the government honored its debt obligations at the beginning of the period or because it defaulted on them). Thus, the government does not have the option to dilute the value of debt it issued in previous periods.

[4]Bolton and Jeanne (2009) discuss how the debt dilution problem can be endogenized as the result of monitoring costs.

[5]Although we often refer to the debt dilution *problem*, allowing for debt dilution may be beneficial because it could help complete markets. Saravia (forthcoming) shows that this is a theoretical possibility. We find that, in our environment, there is a small benefit from controlling debt dilution. We also argue that the standard sovereign default model with risk-neutral lenders and a pure-exchange economy is likely to underestimate this benefit.

[6]Bolton and Jeanne (2009) argue that it is somewhat of a puzzle that the overwhelming majority of sovereign debts are not GDP indexed. Indexing debt payments to GDP appears to be feasible, desirable, and relatively immune to manipulation (see also Borensztein and Mauro (2004), Durdu (2009), and Sandleris et al. (2009)). Bolton and Jeanne (2009) also argue that sovereigns willingness to repay has many other determinants besides domestic GDP. Tomz and Wright (2007) show that these other determinants play an important role as predictors of sovereign defaults. For instance, Alfaro and Kanczuk (2005), Cole et al. (1995), Hatchondo et al. (2009), and Guembel and Sussman (2009) discuss how sovereign defaults may be triggered by changes in political circumstances. Richer models that incorporates determinants of sovereign default other than GDP would feature market incompleteness even with GDP-indexed bonds. We follow the most common approach of assuming that GDP shocks are the only shock in the economy and that sovereign debt contracts are not GDP-indexed.

of seniority clauses in debt contracts. However, it is well known that seniority may not fully eliminate debt dilution and, therefore, comparing equilibria with and without seniority may not be equivalent to comparing equilibria with and without debt dilution (see, for example, Bizer and DeMarzo (1992)). Furthermore, in a model in which the duration of sovereign bonds matches the one observed in the data, imposing a full seniority structure would require a large number of state variables, which would make difficult to solve the model. Our first contribution is to propose a modification of the baseline default model that forces the borrower to internalize all the effects of new borrowing on bond prices without increasing the dimensionality of the state space: We assume that before issuing debt, the borrower must obtain permission from existing bondholders, and can compensate them for the dilution of the value of their debt implied by new issuances.[7]

In addition, while the debt dilution studies mentioned above suggest that dilution may be an important source of inefficiencies in debt markets, they do not quantify the effects of debt dilution.[8] Our second contribution is to provide a measure of the effects of debt dilution on the levels of sovereign debt and default risk based on the comparison of simulation results obtained in the baseline model and in the model without dilution. We find that, even without commitment to future repayment policies and without contingency of sovereign debt, if the sovereign could eliminate debt dilution, the number of default per 100 years decreases from 3.10 with debt dilution to 0.42 without debt dilution. That is, the dilution problem accounts for 71% of the default risk in the simulations of the baseline model. In the model, default risk is reflected in the interest rate spread. The mean spread in the simulations decreases from 7.38 to 0.57. The standard deviation of the spread decreases from 2.45 with debt dilution to 0.72 without debt

[7]Note that we capture the decline in the price of existing bonds that results from the increase in the default probability implied by new issuances, and this would not be captured with the seniority approach. Suppose there is seniority and, in case of default, the recovery rate of a senior bond is not affected by the issuance of a junior bond (because the value of the collateral in the senior bond is not affected by the junior issuance). The probability of a default on the senior bond may still be affected by the junior issuance (see, for example Bizer and DeMarzo (1992)). Therefore, even in the presence of seniority, the price of the senior bond may still be affected by the junior issuance and thus the debt dilution problem may persist.

[8]Bi (2006) presents a quantitative analysis of a model with one and two-quarter bonds. She studies the effects of making earlier issuances senior to new issuances. She finds that this decreases the default frequency but increases the mean debt level (perhaps because the endogenous borrowing constraint in the model is relaxed by making earlier issuances less risky).

dilution. We also find that this occurs in spite of dilution accounting for only 1% of the mean debt level in the simulations of the baseline model.

The rest of the article proceeds as follows. Section 2 introduces the model. Section 3 presents the results. Section 4 concludes and discusses possible extensions.

2 The model

We first discuss the baseline model with debt dilution and later introduce a modification to this model that allows us to eliminate debt dilution.

2.1 The baseline environment

We follow previous work that extends the sovereign default model presented by Eaton and Gersovitz (1981) in order to study its quantitative performance.

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 γ. That is,

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

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. We follow most recent studies of sovereign default by assuming that the recovery rate is zero. The default cost is represented by an endowment loss in the default period that, as in Chatterjee and Eyigungor (2009), takes the form of a quadratic loss function $\phi(y) = d_0 y + d_1 y^2$.

Second, the government decides the number of bonds that it purchases or issues in the current period. We allow for long-duration bonds as in Hatchondo and Martinez (2009), Chatterjee and Eyigungor (2009), and Arellano and Ramanarayanan (2010). Long-duration bonds are essential for the study of intertemporal debt dilution. As Hatchondo and Martinez (2009), 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 $s \geq 2$.[9]

It should be emphasized that δ is a fixed parameter of the model, it is not allowed to change over time, and it is not chosen by the government. This allows us to study long-duration bonds without increasing the dimensionality of the state space. If one allows the government to choose a different value of δ each period, one would have to keep track of how many bonds the government has issued for each possible value of δ. For instance, Arellano and Ramanarayanan (2010) study a version of this model in which the government can choose to issue bonds with two possible values of δ, which requires to keep track of two state variables to determine the government's liabilities.

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 satisfies a no-arbitrage condition. 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 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.

[9]The Macaulay duration of a bond with the coupon structure we assume is given by

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

where r^* denotes the constant per-period yield delivered by the bond.

Finally, the transaction is performed and the current-period borrowing game ends. Lenders can borrow or lend at the risk-free rate r, and have perfect information regarding the economy's endowment.

Motivated by several studies that document that the risk premium is an important component of sovereign spreads and that a significant fraction of the spread volatility in the data is accounted for by volatility in the risk premium (see, for example, Borri and Verdelhan (2009), Broner et al. (2007), Longstaff et al. (2007), and González-Rozada and Levy Yeyati (2008)), we assume that bond prices satisfy a no arbitrage condition in which the stochastic discount factor $M(y', y)$ takes the form $M(y', y) = exp(-r - \alpha\varepsilon' - 0.5\alpha^2\sigma_\epsilon^2)$. This formulation is a special case of the discrete-time version of the Vasicek one-factor model of the term structure (see Vasicek (1977) and Backus et al. (1998)) and allows us to introduce risk premium in a tractable way. As in Arellano and Ramanarayanan (2010), we assume that the risk premium depends on the income shock in the borrowing economy. A more plausible alternative is one in which the lenders' valuation of future payments is not perfectly correlated with the endowment in the borrower's economy and in which the risk-free interest rate r is also subject to shocks. The advantage of the formulation used in this paper is that it avoids introducing another state variable to the model. Hatchondo et al. (2010) discuss the computation cost of obtaining accurate solutions in models of sovereign default with one-period bonds and Chatterjee and Eyigungor (2009) explain how the computation cost increases when long-duration bonds are assumed.

As in 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. We focus on Markov Perfect Equilibrium. That is, we assume that in each period, the government's equilibrium default and borrowing strategies depend only on payoff relevant state variables. As discussed by Krusell and Smith (2003), there may be 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.

2.1.1 Recursive formulation of the baseline framework

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 $V(b, y)$ 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:

$$V(b, y) = \max_{d\epsilon\{0,1\}} \{d\tilde{V}(1, b, y) + (1 - d)\tilde{V}(0, b, y)\}, \tag{2}$$

where

$$\tilde{V}(d, b, y) = \max_{b' \leq 0} \left\{ u(c) + \beta \int V(b', y') F(dy' \mid y) \right\}, \tag{3}$$

and

$$c = y - d\phi(y) + (1 - d)b - q(b', y)\left[b' - (1 - d)(1 - \delta)b\right]. \tag{4}$$

The bond price that satisfies the no-arbitrage condition is given by the following functional equation:

$$q(b', y) = \frac{1}{1+r} \int M(y', y)\left[1 - h(b', y')\right] F(dy' \mid y) + \frac{1-\delta}{1+r} \int M(y', y)\left[1 - h(b', y')\right] \, q(g(h(b', y'), b', y'), \tag{5}$$

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.

Equations (2)-(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 (2) and (3) 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 $q(b', y)$,

such that:

(a) given $h(b, y)$ and $g(d, b, y)$, $V(b, y)$ and $\tilde{V}(d, b, y)$ satisfy functional equations (2) and (3) when the government can trade bonds at $q(b', y)$;

(b) given $h(b, y)$ and $g(d, b, y)$, the bond price function $q(b', y)$ offered to the government satisfies the no-arbitrage condition given by 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 (2) and (3) when the government can trade bonds at $q(b', y)$.

2.2 A model without debt dilution

In this section, we propose a modification to the model presented in Section 2.1 that will allow us to study an economy without debt dilution and, in turn, measure the effects of debt dilution on the levels of borrowing and default risk. In the baseline model presented in Section 2.1, the debt dilution problem arises as follows. An increase in the current borrowing level increases the probability of a default on previously issued debt and, thus, it decreases the market value of this debt—debt dilution occurs. Each period, the government borrows without internalizing the cost of diluting the value of debt issued in past periods. Lenders anticipate the effect of future borrowing on the probability of a default on the debt they buy and require to be compensated for future debt dilutions through a higher bond yield. Thus, the government could benefit from eliminating debt dilution in future periods because this would reduce the interest rate at which it can borrow in the current period.

In order to eliminate debt dilution, we force the government to internalize capital losses that existent debt holders incur when the government issues new debt. We assume that, before issuing debt, the government must obtain authorization from existing bondholders, and that the government can compensate them for the dilution of the value of their debt implied by new issuances. In particular, suppose that after the government announces how many bonds it wants to issue, it can offer to pay a compensation for each existing bond if bondholders do not oppose to the new issuances. Then, if existing bondholders choose to approve the government's debt issuance, the government pays the compensation and issue new bonds as in the baseline model presented in Section 2.1. Otherwise, the government does not issue (or buys back) bonds in the current period.

It should be mentioned that implementing this mechanism may not be as difficult as one may first think. On the one hand, obtaining the approval of all existing bondholders for new debt issuances may be difficult. On the other hand, asking for the approval of a representative bondholder or an institution representing the interest of bondholders (e.g. an investment bank) could suffice. Majority clauses could also be used. Bolton and Jeanne (2009) discuss how an institution could be assigned the task of facilitating sovereign debt restructuring. In a similar manner, such institution could be responsible for approving government's proposals of new debt issuances.

2.2.1 Recursive formulation of the framework without debt dilution

As before, let $q(b', y)$ denote the price a sovereign bond. Let $\tilde{b} \equiv (1-d)(1-\delta)b$ denote the interim number of next-period coupon obligations. Suppose the government issues $\tilde{b} - b' > 0$ bonds. If the holder of a government bond chooses not to allow the government to issue new bonds, the price of his bond would be $q(\tilde{b}, y)$. Otherwise, the price would be $q(b', y)$ and he could be compensated for new debt issuances. Consequently, the minimum compensation a bondholder would accept in exchange for allowing the government to issue $\tilde{b} - b'$ bonds is $q(\tilde{b}, y) - q(b', y)$. This is the compensation the government would offer in equilibrium. The resources obtained by the government when issuing $\tilde{b} - b'$ bonds equal $(\tilde{b} - b')q(b', y) + \tilde{b}[q(\tilde{b}, y) - q(b', y)]$.

In addition, we assume that, as in Section 2.1, when the government wants to buy back its bonds, it does so at the secondary-market price $q(b', y)$.[10] Suppose the bond price is higher when the debt level is lower because the default probability is increasing with respect to the debt level (as is always the case in this paper and in previous quantitative studies of sovereign default). The equilibrium bond price is given by

$$\begin{aligned} q(b', y) \quad = \quad & \frac{1}{1+r} \int M(y', y) \left[1 - h\left(b', y'\right)\right] F\left(dy' \mid y\right) \\ & + \frac{1-\delta}{1+r} \int M(y', y) \left[1 - h\left(b', y'\right)\right] \max\left\{0, q(b'(1-\delta), y') - q(g(h(b', y'), b', y'), y')\right\} F\left(dy' \mid y\right) \\ & + \frac{1-\delta}{1+r} \int M(y', y) \left[1 - h\left(b', y'\right)\right] q(g(h(b', y'), b', y'), y') F\left(dy' \mid y\right). \qquad (6) \end{aligned}$$

The first term of the right-hand side of equation (6) represents the expected value of the next-period coupon payment. The second term represents the expected compensations bond holders would receive if the government issues new debt. This compensation implies that lenders price sovereign bonds anticipating that the value of their investment will not be diluted by new debt issuances. The third term represents the expected next-period value of a bond. Consequently,

[10] Alternatively, we could have assumed that the government receives a compensation from lenders when it buys back debt in the same way it compensates lenders when it issues debt. That is, lenders could make transfers to the government when there is a debt buyback. Our assumption allows us to focus on the debt dilution problem discussed in the literature without introducing the effects of other mechanisms.

without debt dilution, the government's budget constraint reads

$$c = y - d\phi(y) + (1-d)b + q(b', y)(\tilde{b} - b') + \tilde{b}\max\{0, q(\tilde{b}, y) - q(b', y)\}. \tag{7}$$

The last term of the right-hand side of equation (7) represents the government's compensation to existing bondholders for the issuance of new debt. Replacing equations (4) and (5) by equations (6) and (7) in the dynamic programming problem described in Section 2.1.1 describes the problem without debt dilution.

It should be noticed that the resources the government obtains from borrowing in our model without dilution are the same resources it would obtain when dealing with an *exclusive* lender. Suppose all government debt is held by a lender who is the only one who can buy bonds from the government. If this lender chooses not to buy more debt from the government, the end-of-period value of its debt holdings would be $-\tilde{b}q(\tilde{b}, y)$. If he buys $\tilde{b} - b'$ bonds from the government, the end-of-period value of his debt holdings would be $-b'q(b', y)$. Thus, the exclusive lender is willing to buy $\tilde{b} - b'$ bonds from the government for $\tilde{b}q(\tilde{b}, y) - b'q(b', y)$, which is equal to the amount the government obtains when issuing bonds while compensating existing bond holders: $(\tilde{b} - b')q(b', y) + \tilde{b}[q(\tilde{b}, y) - q(b', y)]$. This illustrates how with the mechanism we propose, the government's borrowing opportunities resemble the opportunities it would have with an *exclusive* lender, and how one can think about debt dilution as a nonexclusivity problem.

Another way of thinking about our model without debt dilution is to assume that before issuing debt the government must buy back all previous issuances at the market price that would be observed if new debt is not issued in the current period. Suppose this is the case and the government wants to issue debt (i.e., $b' < \tilde{b}$ and, therefore, $q(b', y) < q(\tilde{b}, y)$). Then, the government's budget constraint reads

$$c = y - d\phi(y) + (1-d)b + \tilde{b}q(\tilde{b}, y) - b'q(b', y) \tag{8}$$

and is equivalent to the government's budget constraint in equation (7).

3 Results

In this section we compare the predictions of the model with and without debt dilution. First, in order to illustrate how in our model without debt dilution the government internalizes the effect of current borrowing on the price of previous issuances, we compare the first-order condition that characterizes the government's borrowing decision with and without debt dilution. To simplify the notation, we do not write consumption, default, and future borrowing as functions of the state variables. 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 first-order condition for the model with dilution is given by

$$u_1(c)q(b', y) = \beta \int V_1(b', y') F(dy' \mid y) - u_1(c)q_1(b', y)(b' - \tilde{b}). \tag{9}$$

The left-hand side of equation (9) represents the marginal benefit of borrowing. By issuing one extra bond today, the government can increase current consumption by $q(b', y)$ units. The right-hand side of equation (9) 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 expected future consumption. 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.

Suppose that, without debt dilution, the bond price is decreasing in the debt level (as we find it is the case for the parameterization we study) and that the government chooses to issue bonds ($b' < \tilde{b}$), as it is the case in 92% of the periods in our simulations. Then, the first-order condition for the model without dilution is given by

$$u_1(c)\hat{q}(b', y) = \beta \int \hat{V}_1(b', y') F(dy' \mid y) - u_1(c)\hat{q}_1(b', y)b', \tag{10}$$

where $\hat{V}$ and $\hat{q}$ denote the equilibrium value and bond price functions without debt dilution.

The comparison of equations (9) and (10) shows how our modification to the baseline model allows us to eliminate the debt dilution problem. In equation (9), the debt dilution represented by the change in the bond price $q_1(b', y)$ in the "current cost of borrowing" is weighted by new issuances $(b' - \tilde{b})$ only. This illustrates how in the baseline model the government chooses its issuance level without internalizing the dilution of the value of the debt issued in previous periods. In contrast, equation (10) shows that with our modification to the baseline model, the debt dilution represented by the change in the bond price $\hat{q}_1(b', y)$ in the "current cost of borrowing" is weighted by the entire debt stock b'. This illustrates how in the modified model the government chooses its issuance level internalizing the dilution of the value of the debt issued in previous periods. This is natural since the government has to compensate debt holders by the dilution of the debt value implied by its current-period issuances. Next, we discuss the quantitative effects of debt dilution.

3.1 Calibration

Following Hatchondo et al. (2010), we solve the model numerically using value function iteration and interpolation.[11] Table 1 presents the calibration we use, which target similar statistics to the ones targeted in other studies of sovereign default.

For the borrower, 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 interest rate is set equal to 1%. 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, following Hatchondo et al. (2009). 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)).

With $\delta = 3.41\%$, bonds have an average duration of 4.19 years in the simulations of the baseline model. 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.

We calibrate the discount factor, the output cost (two parameter values), and the parameter

[11] 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 $q(b', y)$ is also assured.

Risk aversion (lender)	σ	2
Interest rate	r	1%
Output autocorrelation coefficient	ρ	0.9
Standard deviation of innovations	σ_ϵ	2.7%
Mean log output	μ	$(-1/2)\sigma_\epsilon^2$
Discount factor	β	0.969
Duration	δ	0.0341
Default cost	d_0	0.69
Default cost	d_1	1.01
Pricing kernel	α	4

Table 1: Parameter values.

of the pricing kernel targeting a mean spread of 7.4, a standard deviation of the spread of 2.5, and a mean debt level of 28% of the mean quarterly output, in the pre-default samples of our simulations (the definition of these samples is presented below), and a default frequency of three defaults per one hundred years. The targets for the spread distribution are taken from the spread behavior observed before the 2001 Argentine default (see below). Even though it is not clear what are the values in the data for the mean debt level and the default frequency one should target, we choose to target these values because they have received attention in the literature, they are clearly influenced by our model parameter values, and they will influence the welfare gains from eliminating dilution. For the period we studied, Chatterjee and Eyigungor (2009) targets a mean level of unsecured sovereign debt of 70%. Since our model is a model of external debt and Sturzenegger and Zettelmeyer (2006) estimates that 60% of the debt Argentina defaulted on was held by residents, we choose to target a mean debt level that is 40% of the value targeted by Chatterjee and Eyigungor (2009). We target a frequency of three defaults per 100 years because that is the value used as reference in previous quantitative studies (see, for example, Arellano (2008) or Aguiar and Gopinath (2006)). We will discuss how our results are influenced by the mean debt level and default frequency we choose to target. The discount factor value we assume is higher than the ones assumed in previous studies (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)).

3.2 Simulation results

This section discusses quantitative effects of debt dilution. In order to do so, it presents simulation results from the models with and without debt dilution. To facilitate the comparison of our results with the ones in previous studies, we report results for pre-default simulation samples, as these studies do. 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 compare the artificial data generated by the model with Argentine data from the fourth quarter of 1993 to the third quarter of 2001.[12] In order to facilitate the comparison of simulation results with the data, we only consider simulation sample paths in which 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.[13] The moments reported in the table are chosen so as to illustrate 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 rate; a higher volatility of consumption relative to income; and more countercyclical net exports. The trade balance (TB) is expressed

[12]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), Alvarez et al. (2009), Boz et al. (2008) 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.

[13]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. We do not report the debt level and the default frequency in the data because, as argued in Hatchondo and Martinez (2009), we believe that debt levels generated by the baseline model of sovereign default are difficult to compare with debt levels in the data, and that it is difficult to obtain a precise measure of default frequencies.

as a fraction of output (Y). The interest rate spread (R_s) is expressed in annual terms.[14] 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 $1,600$. Table 2 also reports the mean debt market value computed as the mean b divided by δ plus the mean equilibrium interest rate, and the mean debt face value computed as the mean b divided by $\delta + r$.

	Data	With debt dilution	Without debt dilution
Defaults per 100 years	3.00	3.10	0.42
Mean debt (market value)		0.20	0.18
Mean debt (face value)	0.28	0.28	0.18
$E(R_s)$	7.44	7.38	0.57
$\sigma(R_s)$	2.51	2.45	0.72
$\sigma(y)$	3.17	3.03	3.36
$\sigma(c)$	2.98	3.14	4.06
$\sigma(TB/Y)$	1.35	0.26	0.85
$\rho(c, y)$	0.97	1.00	0.99
$\rho(TB/Y, y)$	-0.69	-0.49	-0.73
$\rho(R_s, y)$	-0.65	-0.80	-0.63
$\rho(R_s, TB/Y)$	0.56	0.70	0.80

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 in the simulations of our baseline model, as in the ones in previous studies

[14]Let

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

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

and in the data, consumption and income are highly correlated, the consumption volatility is higher than the income volatility, and spread and trade balances are countercyclical. The model also matches well the moments we choose to target in order to impose discipline to our measurement exercise (the default frequency, the mean debt level, and the mean and standard deviation of the spread). With this in mind, we concentrate on the main question this paper intends to answer: What are the quantitative effects of the debt dilution problem?

Table 2 shows that the number of default per 100 years decreases from 3.10 in the baseline to 0.42 without debt dilution. That is, we find that debt dilution accounts for 86% of the default risk in the simulations of the baseline model. Eliminating dilution decreases the mean spread in the simulations from 7.38% to 0.57%. That is, debt dilution accounts for 92% of the spread paid by the sovereign. Recall that reducing default risk allows the sovereign to pay a lower risk premium. The table also shows that dilution implies a large increase in default risk in spite of implying only a negligible amount of overborrowing. The mean face value of outstanding bonds decreases by 34%. But most of this decline is explained by the lower interest rate in the simulations of the model without debt dilution: The mean market value of outstanding bonds decreases only by 11%. Next, we explain how, even for the same borrowing level, the government would be forced to pay a significantly higher interest rate when it cannot commit not to dilute the value of previous issuances. In particular, we shall explain that when the risk of dilution is present, choosing negligible default risk is not an option for the government.

In order to shed light on how the debt dilution problem influences equilibrium allocations, Figure 1 presents the implied spread demanded by lenders 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, $\frac{b'}{\delta+r}$. This function defines the set of combinations of spreads and next-period debt levels that the government can choose from. The figure also presents the combination of spread levels and next-period debt chosen by the government.

For the baseline model, the left panel of Figure 1 illustrates how the government cannot borrow paying spreads close to zero. 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. However, the expected recovery rate—i.e., the fraction of the

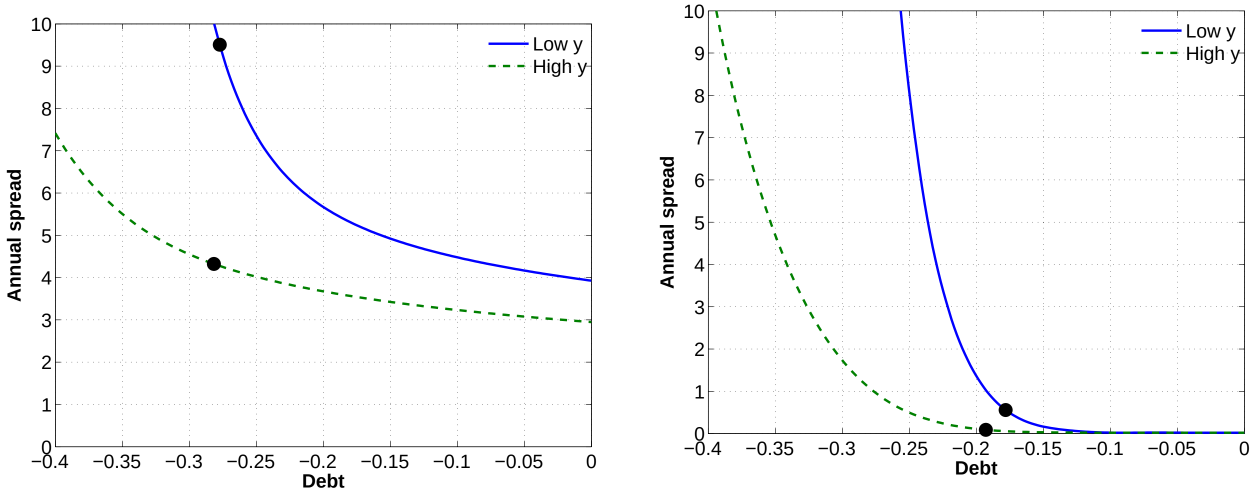

Figure 1: Menu of combinations of spreads and next-period debt levels ($\frac{b'}{\delta+r}$) from which the government can choose. The left panel corresponds to the baseline case. The right panel corresponds to the case with compensations to bondholders for debt dilution. In each case, solid dots illustrate the optimal decision of a government that inherits a debt level equal to the average debt observed in our simulations for that case. The low (high) value of y corresponds to an endowment realization that is one standard deviation below (above) the unconditional mean.

loan lenders expect to recover—is significantly away from one because lenders anticipate positive default probabilities in future periods. For instance, the left panel of Figure 1 shows that, as one would expect, the government chooses to take significant default risk (i.e., to pay high spreads) in bad times, when it needs to borrow more. Suppose, for example, that the government is issuing 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.

In contrast, the right panel of Figure 1 illustrates how eliminating debt dilution gives the government the opportunity to borrow paying spreads close to zero. The figure shows that, even in bad times, the government will choose to keep the default probability close to zero and, therefore, to pay spreads close to zero. The intuition behind this finding is straightforward. One may think about the government as choosing the default probability in each period—choosing to issue more debt is equivalent to choosing a higher default probability. The government's commitment to compensating bondholders for any debt dilution it creates reduces incentives to choose higher default probabilities in bad times because this would imply compensating bondholders for the corresponding decline in their bonds value. In our quantitative exercise, the government never wants to pay significant compensations to bondholders. That is, when the government overcomes the debt dilution problem, it never chooses to take significant default risk. Consequently, the standard deviation of the spread decreases from 2.45 with debt dilution to 0.72 without debt dilution.

3.3 Welfare costs of debt-dilution

Figure 2 illustrates that the ex-ante welfare gain that domestic agents experience after moving from an economy with long-duration bonds and dilution to an economy with long-duration bonds without dilution is around 0.10% of consumption. The figure corresponds to cases where the initial debt level is equal to zero. In the absence of commitment, the possible gains that agents enjoy from diluting debt in some states are compensated by the higher cost of borrowing and the higher frequency of default crisis.

However, one may want to take the welfare implication with a grain of salt. The model presented in the paper focuses on an economy without production in which interest rates cannot affect factors allocation. The developing of a sovereign default framework that accommodates effects of interest rates on factors allocation is the subject of ongoing research (see, for example, Mendoza and Yue (2008)). An interesting extension of our analysis would be to study the implications of the debt dilution problem in such a framework and evaluate the welfare cost of debt dilution.

3.3.1 One-period bonds vs. long-duration bonds without debt dilution

An alternative model without debt dilution is the commonly used one-period bond model. With one-period bonds, there is no room for intertemporal debt dilution because when the government decides its borrowing level, the outstanding debt level is zero (either because the government honored its debt obligations at the beginning of the period or because it defaulted on them). Table 3 presents simulation results obtained assuming one-period bonds ($\delta = 1$). In order to

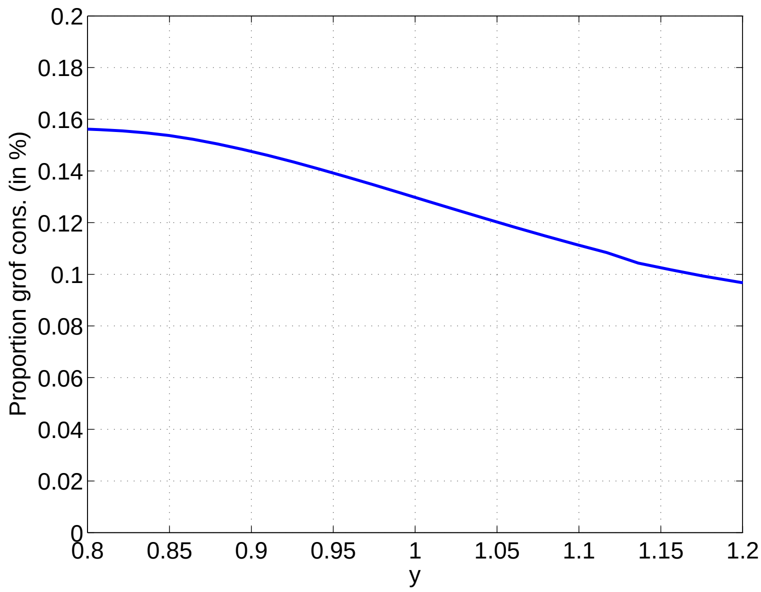

Figure 2: Consumption compensation (in percentage terms) that makes domestic agents indifferent between living in an economy with or without dilution and long-duration bonds. The figure was constructed assuming that the initial debt level is equal to zero. A positive number means that agents prefer the economy without dilution.

facilitate comparisons, we report again the statistics obtained with our model with long-duration bonds and without debt dilution ($\delta = 0.0341$). The table shows that simulation results obtained with one-period bonds differ from those obtained with our model without debt dilution.

One-period bonds and long-duration bonds without debt dilution are different assets. In order to shed more light on the different allocations observed in the two economies without dilution, Figure 3 presents the no-arbitrage spread curves and the government optimal choices for these two economies. Consider first the case of a sufficiently negative income shock in the economy with long bonds. For this case, the government chooses not to issue debt. When income is sufficiently low, it does not pay off to issue new debt because the revenue raised by new debt issuances is not enough to compensate existing bondholders for diluting the value of their bonds.[15] Furthermore, it is not optimal to buy back debt because consumption is already low. Consequently, the optimal strategy for the government is to just pay off current coupon

[15]When income is sufficiently low that the initial debt level lays on the decreasing part of the revenue function $-q(b', y)b'$, choosing $b' < b(1-\delta)$ would be a bad deal because $-q(b', y)b' < q(b(1-\delta), y)b(1-\delta)$.

	$\delta = 0.0341$	$\delta = 1$
Defaults per 100 years	0.42	0.23
Mean debt (market value)	0.18	0.19
Mean debt (face value)	0.18	0.19
$E(R_s)$	0.57	0.45
$\sigma(R_s)$	0.72	0.45
$\sigma(y)$	3.36	3.11
$\sigma(c)$	4.06	3.82
$\sigma(TB/Y)$	0.85	1.09
$\rho(c, y)$	0.99	0.97
$\rho(TB/Y, y)$	-0.73	-0.53
$\rho(R_s, y)$	-0.63	-0.73
$\rho(R_s, TB/Y)$	0.80	0.90

Table 3: Business cycle statistics without debt dilution.

obligations. Even though the government does not issue new debt, the spread for existing debt can be significantly high.

In the economy with one-period bonds, however, the government does not have the option to partially amortize the debt: the government has to pay off all outstanding debt obligations (or default on them) before it issues new debt. When the government issues new debt it will never want to reach the decreasing section of the revenue curve, so for sufficiently low income realizations, the spread in the economy with one-period bonds is lower than the spread in the economy with long-duration bonds and no dilution. In fact, the higher mean and standard deviation of the spread observed in the economy with long-duration bonds and no dilution is due to the high spread levels observe in periods of exceptionally low income levels (typically preceding a default).

Besides, our setup without debt dilution and long-duration bonds provides partial insurance against moderately negative income shocks. Recall that, in that setup, we assume that lenders

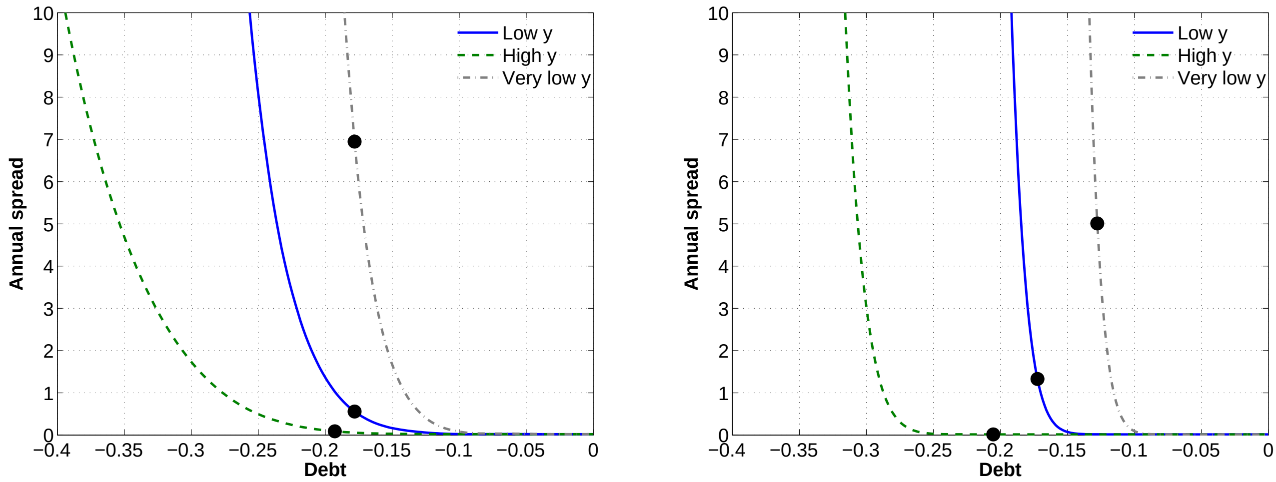

Figure 3: Menu of combinations of spreads and next-period debt levels ($\frac{b'}{\delta+r}$) from which the government can choose. The left panel corresponds to the case of long-duration bonds without debt dilution. The right panel corresponds to the case of one-period bonds. In each case, solid dots illustrate the optimal decision of a government that inherits a debt level equal to the average debt observed in our simulations for that case. The low (high) value of y corresponds to an endowment realization that is one standard deviation below (above) the unconditional mean.

are compensated for the effect of new issuances in bond prices, but not for declines in the bond price implied by the worsening of economic conditions (see equation (7)). Thus, the government's debt obligation (the cost of buying back its debt) are increasing in income. In contrast, with one-period bonds, the government's debt obligations are not contingent on the income realization. This explains why the governments borrowing needs after encountering a moderately negative income shock are larger in the one-period-bond version of the model than in the model with long-duration bonds and without debt dilution.

4 Conclusions

We proposed an extension of a baseline sovereign default framework à la Eaton and Gersovitz (1981) that allowed us to study the case in which the sovereign eliminates debt dilution. We found that debt dilution accounts for almost 100% of the default risk in the simulations of the baseline model. That is, even without commitment to future repayment policies and without contingency of sovereign debt, if the sovereign could eliminate debt dilution, it would almost eliminate default risk.

The default risk implied by debt dilution is reflected in higher interest rate spreads for sovereign bonds. For emerging economies, previous studies find evidence of a significant effect of interest rate spreads on productivity (through the allocation of factors of production), and of a significant role of interest rate spreads in the amplification of shocks to these economies (see, for example, Mendoza and Yue (2008), Neumeyer and Perri (2005), and Uribe and Yue (2006)). In the light of these findings, our results indicate that the welfare cost of debt dilution may be large and that, therefore, countries that pay high sovereign spreads may gain from committing to rules that attenuate debt dilution.

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