

# Sovereign Debt Tolerance with Potentially Permanent Costs of Default\*

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October 2023

Preliminary: please do not circulate

## Abstract

We investigate the effect of uncertainty about the nature of output costs of sovereign default on debt tolerance. While the theoretical literature assumes output losses lasting until market access is restored, the empirical evidence points to persistent effects, and output may not return to its pre-default trend. We include such uncertainty in a model of sovereign default and find that it can significantly boost equilibrium debt levels. We also consider a government which is averse to this type of uncertainty and seeks robust decision rules. We calibrate the model to match evidence on the output trajectory around debt restructuring episodes and infer output costs of about the size found in the empirical literature, alongside significant uncertainty about their permanence and a strong desire for robustness.

## JEL Classification

**Keywords** Sovereign debt, default, debt tolerance, permanent costs, robustness

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\*The views expressed herein are those of the authors and should not be attributed to the IMF, its Executive Board, or its management. Zhuo Chen provided excellent research assistance.

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## INTRODUCTION

A fundamental question in the sovereign debt literature, and one to which Rogoff made substantial contributions, is what supports debt repayments. In the absence of international enforcement of sovereign debts, costs of default, actual and perceived, physical and reputational, determine how much debt can be sustained as well as the terms at which countries borrow.

This paper focuses on how the possibility of permanent scarring effects of a default heightens the ex-ante costs of restructuring. Motivated by the lack of conclusive empirical evidence one way or the other, we consider uncertainty about how permanent such costs are. We draw implications for the amount of sustainable debt in equilibrium and find that the possibility of permanent costs has a large impact on debt tolerance (Reinhart, Rogoff, and Savastano, 2003), especially when combined with realistic risk attitudes for the debtor country.

In two influential papers, Bulow and Rogoff (1989a) show the limits of reputation and exclusion alone to sustain otherwise unenforceable payments on sovereign debt. Bulow and Rogoff (1989b) propose the inclusion of other costs affecting the economy, such as direct sanctions interfering with trade. The idea that countries sustain debt because defaults entail costs for the real economy still underpins most of the literature on sovereign debt, even if their source has shifted away from sanctions.<sup>1</sup> Costs can also involve broader general reputational spillovers affecting the rest of the economy, as in Cole and Kehoe (1998). Most models in the theoretical literature assume an output cost of default which lasts until credit market access is restored. At the same time, the empirical literature has estimated output growth costs that tend to be concentrated around the restructuring episode.

It is well documented that economic growth declines around the time of restructurings or defaults (Borensztein and Panizza, 2009) but the exact nature of such costs is not so clear. Subsequent studies with different methodologies (De Paoli et al., 2009; Asonuma et al., 2023; Farah-Yacoub et al., 2022; Cerra and Saxena, 2008) find growth slowdowns following a debt restructuring, some of which are quite persistent.

In practice, countries go to great lengths to remain current on their debts. If anything, they tend to wait until restructurings come “too late” (IMF, 2013), which suggests large perceived costs of restructurings, even though we do not observe much in the way of direct punishments, certainly not in the magnitude of the defaulted debt.

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<sup>1</sup>For surveys of the literature on sustainable public debt and sovereign default, see the handbook chapters by Aguiar and Amador (2014), Aguiar, Chatterjee, Cole, and Stangebye (2016), D’Erasmus, Mendoza, and Zhang (2016), and Martinez, Roch, Roldán, and Zettelmeyer (2023).

We evaluate the effect of potentially permanent costs within a sovereign default framework à la [Eaton and Gersovitz \(1981\)](#) with trend growth combined with uncertainty about the type of costs associated with default. In the model, a government chooses whether to repay its debt without knowing if defaulting would trigger a transitory or permanent decline in output. Moreover, we consider a government who does not fully trust its prior about the probability of a transitory cost and seeks robust decision rules as in [Hansen and Sargent \(2001\)](#).<sup>2</sup>

To obtain decision rules which are robust to different, unidentified misspecifications of its prior on the output cost persistence, the government entertains plausible distortions of it and evaluates each action’s payoff under the worst one, the so-called worst-case model. While robustness is in general technically equivalent to risk-sensitive Epstein-Zin preferences ([Anderson, Hansen, and Sargent, 2003](#)), we leverage the flexibility of robustness to emphasize aversion towards uncertainty about the permanence of default costs in particular.<sup>3</sup>

These departures from the canonical model allow us to match reduced-form evidence on the trajectory of output following a debt restructuring. Our calibration identifies a degree of robustness and a probability of permanent costs which contribute to an increase of about a third in debt tolerance. Making the costs permanent for sure leads to an increase in debt tolerance of almost a half relative to fully transitory costs. Conceptually, a higher probability of permanent costs and a higher degree of robustness both contribute to debt tolerance, but with different implications for the observed output trajectory following a typical default. Finally, we also find that the robust government sustains higher levels of debt (as if permanent costs were more likely) but does not default less often.

The remainder of the paper is organized as follows. Section 2 discusses some of the possible costs associated with a restructuring and reviews the findings from the empirical literature on the costs of default. Section 3 presents the model and Section 4 describes its calibration. Section 5 discusses the equilibrium and quantitative results of the model. Section 6 concludes.

## 2. OUTPUT LOSSES AND OTHER COSTS AROUND RESTRUCTURINGS

The empirical literature estimates sizable impacts of defaults on economic activity, but deciding whether such effects are permanent is a statistically daunting task. [Borensztein and Panizza \(2009\)](#) estimate a 2.6 percentage point decline in growth in the first year of the episode, but that ef-

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<sup>2</sup>Robustness is also featured in [Pouzo and Presno \(2016\)](#) and [Roch and Roldán \(2023\)](#) in the context of sovereign debt, but on the lender side.

<sup>3</sup>For a discussion of robustness to “structured uncertainty,” see [Hansen and Sargent \(2015\)](#)

fect (on growth) is short lived with no statistically significant effect on lagged variables. [Levy Yeyati and Panizza \(2011\)](#) also find in quarterly data that much of the contraction actually takes place before the default event in question. [Asonuma and Trebesch \(2016\)](#) show that restructurings that take place preemptively before payments are missed tend to be quicker and have better growth outcomes than those that take place after a default. [Asonuma et al. \(2023\)](#) estimate local projections on the level of log GDP relative to pre-crisis trend to investigate the persistence of a level effect. The adverse effects tend to be mild and temporary for preemptive restructurings, but large and persistent for restructurings involving a default (which historically has been the case in most restructurings). They estimate GDP to remain 4 percent below its pre-crisis trend five years after the default, which suggests these losses are not reversed.<sup>4</sup> [Farah-Yacoub et al. \(2022\)](#) use synthetic controls to estimate the economic and social costs of default on a long historical sample. They estimate a cumulative 8.4 percentage point gap within the first three years, with substantial scarring effects even after a decade.

Most of the literature has focused on external debt restructurings. One notable exception is Reinhart and Rogoff (2008), which show that the output decline after domestic restructurings is much larger than for external ones. Domestic debt restructurings were relatively rare during the 1980s and early 1990s, but have become more common as countries have started to rely more on domestic financing ([IMF, 2021](#)). Domestic restructurings can more directly lead to major financial disruption which can by itself entail significant output costs ([Pérez, 2018](#)).

There is a wide range of outcomes following a debt restructuring. Some countries do experience mild and temporary declines, while for others the impact is deeper and more protracted. A few even experience a growth acceleration. Figure 1 plots the evolution of the log of GDP relative to the pre-restructuring trend for different countries experiencing an external debt restructuring.<sup>5</sup> The left panel covers EMs and the right one, Low-Income Countries (LICs).<sup>6</sup> Each line traces the evolution of a country from 5 years prior to its restructuring to 10 years afterwards. When there are multiple restructurings within that time frame, we code the event based on the first restructuring (e.g. if a country restructures in 1982 and then again in 1987, the lines would plot the time from 1977 to 1992). The log GDP series is detrended using a linear time trend based on the 5 years prior to the restructuring.<sup>7</sup> Hence by construction, the series hovers around zero

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<sup>4</sup>Most sources of catch-up growth such as pent-up demand should have already materialized in that horizon

<sup>5</sup>The events are based on the [Asonuma and Trebesch](#) dataset which includes both restructurings that take place after payments are missed (default) as well as distressed exchanges that take place preemptively prior to payments being missed. The latter is less frequent, but has become relatively more common over time.

<sup>6</sup>We define these two groups based on whether they are covered by the IMF-World Bank LIC Debt Sustainability Framework or the one for market access countries. The sample is listed in the Appendix.

<sup>7</sup>A linear trend is preferable to using more sophisticated filters, such as HP, which would use observations after

prior to the restructuring, but can deviate significantly after that event.

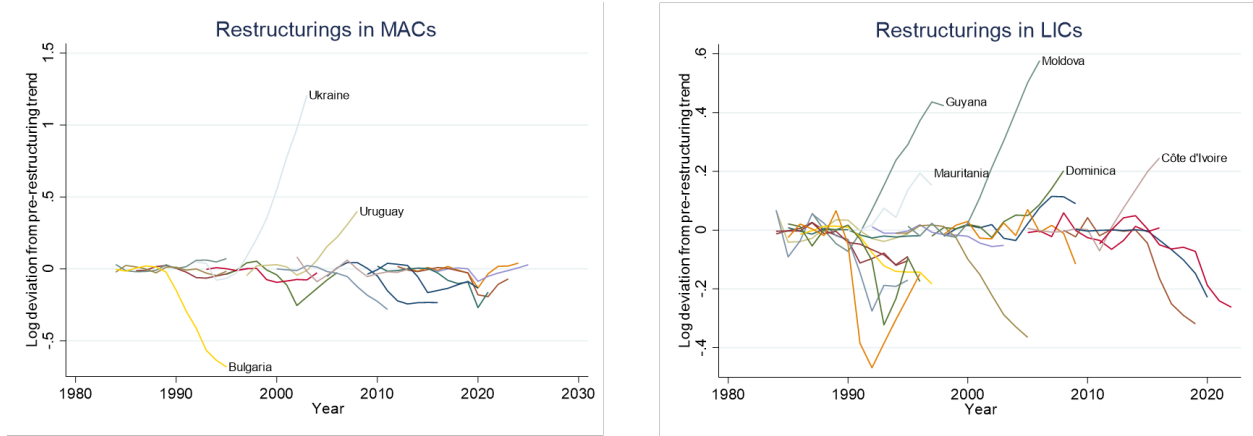


FIGURE 1: GROWTH OUTCOMES AROUND DEBT RESTRUCTURINGS

There are fundamental differences between EM and LIC restructurings, especially in the historical sample. The official sector plays a much larger role in LICs, and many of those countries remained deeply insolvent until their debt crisis was eventually resolved as part of the Heavily Indebted Poor Countries (HIPC) initiative. HIPC, combined with the Multilateral Debt Relief Initiative (MDRI) provided deep debt writedowns (enough to bring debt down to 150 percent of exports, sometimes even less). This helps explain the weak performance of LICs prior to the late 1990s/early 2000s, and their relatively strong performance afterwards. For that reason, we focus our attention on the sample of EMs, as shown in Figure 1A.

The growth performance of EMs tends to be weaker following restructurings, which were much more common in the 1980s, as expected. There are several cases where GDP remains well below pre-crisis trends, reflecting the severity of that systemic event and the long time it took for its eventual resolution. It is also worth noting that external financial conditions were particularly unfavorable at that time (due to very high U.S. interest rates), and that many of the affected countries had deep structural problems (for example, very closed economies particularly in Latin America). From the 1990s onwards, we see relatively fewer restructuring episodes. We still see quite a few cases where GDP remains below trend, but there are also a number of cases where the lines remain closer to zero (which again, indicates the pre-crisis trend) or where the initial decline starts to revert sooner. There were a number of important innovations in the debt restructuring technology over time, including the adoption of Collective Action Clauses (CACs) on bonds and eventually enhanced CACs which allowed aggregation of votes across series (making it more

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the crisis to inform its trend. One alternative could be to use one-sided filters using only backward-looking data, but for the purposes of this illustration a simple linear trend suffices.

difficult for a creditor to hold out when there was widespread support from other creditors to a restructuring). IMF (2020) takes stock of developments in sovereign debt restructurings involving the private-sector creditors and notes that compared with previous periods, recent restructurings have generally proceeded smoothly and quicker, and were more likely to be preemptive.

On balance, the output costs are substantial in the historical sample. There are a number of steps a debtor can take to minimize those costs, such as collaboratively engaging with creditors towards restructuring before payments are missed. But there are many things beyond the debtor's control, and restructurings are inherently complicated processes. Thus, even these costs have come down in expectation, there is still a tangible risk that things could go wrong and the costs turn out to be large. That cost can be further amplified by the risk and ambiguity aversion of the debtor, and help sustain more debt in equilibrium.

## 2.1 *Other costs*

Our focus has been on credit market exclusion combined with output costs, since these are easier to directly map into a model. As Bulow and Rogoff (1989a), Bulow and Rogoff (1989b), and Rogoff (2022) point out, credit exclusion in itself cannot yield a large enough cost to sustain observed levels of debt, which is why researchers tend to combine it with direct costs on productivity or income. But there are other potential sources of costs.

Direct sanctions have been proposed as another channel that could help sustain debt. Such punishments could translate into a decline in output, financial exclusion, and depending on the nature of the sanctions have a direct effect on welfare over and beyond the decline in output. In practice, we do not observe much in the way of such punishments on debtors. Even high profile cases of litigation involving asset seizures involve sums that are nowhere near the order of magnitude of the debt claims. The main example of a successful and disruptive litigation is Argentina vs NML Capital, where a 2014 ruling prevented the debtor from repaying the restructured bonds (from its 2001 default) without repaying the litigants in full. Such litigation can enforce credit market exclusion as a punishment (since it discourages new credit by interfering with repayments to new creditors). The debtor settled with that holdout creditor in 2016. Since then, New York courts have clarified that the decision to repay some creditors but not others in and of itself does not breach the contractual clause that underpinned NML's strategy. And that successful strategy will become increasingly difficult to pursue as enhanced CACs become more widespread. In almost all cases, litigants were not able to seize assets or disrupt ongoing restructurings (IMF, 2020).

It is possible that direct sanctions do not play a significant role because borrowers do follow procedures and norms that have come to be expected during a debt restructuring. Debtors typically ask only for the relief needed to restore sustainability with reasonable buffers, and most restructurings take place in the context of an IMF-supported program to facilitate the adjustment (and where a debt sustainability analysis informs the envelope of relief needed to restore sustainability based on the feasible adjustment.) In practice, even debtors that take a fairly adversarial position with respect to their creditors follow these norms and are eager to bring the restructuring to a close. This is illustrated by the fact that if anything, restructurings tend to deliver “too little” relief (IMF, 2013; Asonuma and He, 2023). EM bond restructurings are rarely associated with significant face-value reductions, with much of the net present value relief coming from the rescheduling of debt at a moderate interest rate (significantly lower than the country would face if it were to issue new debt in the absence of a restructuring).

If countries were to deviate from these norms, e.g. ask for significant relief where it is not needed, they would likely face stronger pressures from the international community. But it is hard to test such hypothesis in the absence of counterfactuals. Even if such considerations play a role in practice, we still have the question of what costs can sustain debt relative to the choice of restructuring following established norms.

### 3. MODEL

**Resources** The economy receives an endowment stream following a stochastic process with trend and cycle components

$$Y_t = \exp(z_t)\Gamma_t \tag{1}$$

with

$$\begin{aligned} z_t &= \rho z_{t-1} + \sigma_z \varepsilon_t^z \\ \log(\Gamma_t) &= \log(\Gamma_{t-1}) + \log(g_t) \end{aligned}$$

where  $\varepsilon_t^z \stackrel{iid}{\sim} \mathcal{N}(0, 1)$  and  $\log(g_t) \stackrel{iid}{\sim} \mathcal{N}(0, \sigma_g)$ .

We normalize variables by  $\Gamma_t$  and denote normalized values with lowercase. For example,  $y_t = Y_t/\Gamma_t = \exp(z_t)$  and the utility function satisfies

$$u(C) = \frac{C^{1-\gamma}}{1-\gamma} = \Gamma^{1-\gamma} \frac{(C/\Gamma)^{1-\gamma}}{1-\gamma} = \Gamma^{1-\gamma} u(c)$$

which implies a normalization constant  $\Gamma_t^{1-\gamma}$  for the value functions, as laid out in more detail in Appendix A. We keep the formulation for the trend  $\Gamma$  as parsimonious as possible since its

only purpose is to enable possibly permanent costs of default, which would manifest as ex-post decreases in  $\Gamma$ .

**Assets** The government borrows from international lenders in the form of a defaultable bond which promises to pay a noncontingent stream of geometrically-decaying coupons as in [Leland \(1998\)](#), [Hatchondo and Martinez \(2009\)](#), and [Chatterjee and Eyigungor \(2012\)](#). A bond issued in period  $t$  pays  $(1 - \rho)^{s-1} \kappa$  units of the good in period  $t + s$ , which effectively makes a one-period-old bond a perfect substitute of  $(1 - \rho)$  units of newly-issued debt. The coupon rate  $\kappa = r + \rho$ , where  $r$  is the international risk-free rate, is chosen so that the price of a bond that is expected to never default is  $q^* = 1$ .

Upon default, the government loses access to international capital markets and faces a loss of output. There is uncertainty about whether this loss of output is permanent or transitory, as well as about the length of the exclusion period.

**Government** The government is benevolent and makes choices on a sequential basis to maximize the utility of a representative household with preferences given by

$$V_t = \mathbb{E}_t \left[ \sum_{s=0}^{\infty} \beta^s (u(C_{t+s}) + \varepsilon_{t+s}) \right] = \mathbb{E}_t \left[ \sum_{s=0}^{\infty} \beta^s \Gamma_{t+s}^{1-\gamma} (u(c_{t+s}) + \varepsilon_{t+s}) \right] \quad (2)$$

where  $\mathbb{E}$  denotes the expectation operator,  $C_t$  represents the household's consumption,  $\beta$  is a discount factor, and  $\varepsilon$  is a preference shock for default or repayment.<sup>8</sup>

While the government is not in default, it chooses whether to repay the debt and attains a value

$$v(b, z, g) = \max \{ v_R(b, z, g) + \epsilon_R, v_D(z, g) + \epsilon_D \} \quad (3)$$

where the  $\epsilon$ 's follow a Type 1 Extreme Value distribution as in [Chatterjee et al. \(2018\)](#), yielding

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<sup>8</sup>We follow [Dvorkin et al. \(2021\)](#) and introduce preference shocks for repayment and default to improve the numerical convergence of the algorithm used to solve the model. As is also common, we keep their variance small to ensure that they do not modify the quantitative properties of the model. However, plausible stories to microfound a meaningful inclusion of such shocks include shifting political preferences, developments in domestic debt markets or in the banking system, or changes in the external borrowing terms faced by private firms. [Fourakis \(2023\)](#) uses preference shocks to obscure the actions taken by two possible 'types' of the government and thus enable a signalling dimension to government borrowing, default, and renegotiation.



familiar closed forms for  $v(b, z, g)$  and the (ex-post) default probability  $\mathcal{P}(b, z, g)$

$$\begin{aligned} v(b, z, g) &= \chi \log (\exp(v_D(z, g)/\chi) + \exp(v_R(b, z, g)/\chi)) \\ \mathcal{P}(b, z, g) &= \frac{\exp(v_D(z, g)/\chi)}{\exp(v_D(z, g)/\chi) + \exp(v_R(b, z, g)/\chi)} \end{aligned}$$

If the government chooses the repay the debt, it can access capital markets and issue new debt  $h$  (because of the normalization, the indebtedness state variable for the next period  $b' = h/g'$ ), so that

$$\begin{aligned} v_R(b, z, g) &= \max_h u(c) + \beta \mathbb{E} [(g')^{1-\gamma} v(h/g', z', g') \mid z] \\ \text{subject to } c + \kappa b &= y(z) + q(h, z, g)(h - (1 - \rho)b) \end{aligned} \quad (4)$$

If the government chooses to default, it loses access to international capital markets, which it recovers with a constant hazard  $\psi$ . While it is excluded, the borrowing economy suffers a loss of output  $\varphi(Y)$ . Upon default, a shock  $k \in \{T, P\}$  determines whether the loss of output is transitory or permanent, which happen with probability  $p$  and  $1 - p$ , respectively, independent of the rest of the state vector. We assume that all debt is destroyed after a default<sup>9</sup> for tractability and to more readily compare with other results in the literature. The expected value of default is

$$v_D(z, g) = p v_D^T(z, g) + (1 - p) \left( \frac{g - \varphi}{g} \right)^{1-\gamma} v_D^P(z, g - \varphi) \quad (5)$$

where the normalization constant differs in the case of a permanent default cost and

$$v_D^k(z, g) = u(y(z) - 1_{(k=T)}\varphi) + \beta \mathbb{E} [(g')^{1-\gamma} (\psi v(0, z', g') + (1 - \psi) v_D^k(z', g')) \mid z] \quad (6)$$

**Lenders** Bonds issued by the government are purchased by deep-pocketed, risk-neutral foreign investors who equate the expected return of the debt to their cost of funds  $r$ , yielding a debt price

$$q(h, z, g) = \frac{1}{1 + r} \mathbb{E} [(1 - \mathcal{D}(h/g', z', g'))(\kappa + (1 - \rho)q(h', z', g')) \mid z] \quad (7)$$

where  $\mathcal{D}$  denotes the government's default policy expected by lenders.

**Observation** The dependence of all value functions on  $g$  is *only* mediated by the renormalization term  $\left( \frac{g - \varphi}{g} \right)^{1-\gamma}$  which appears in the value of default  $v_D$ . A particular but fairly standard specification of the default cost allows us to avoid having to carry  $g$  as a state variable.

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<sup>9</sup>In practice, restructurings tend to involve substantial recovery rates. [Meyer, Reinhart, and Trebesch \(2022\)](#) estimate an average recovery above 50 in a long historical sample. Adding a recovery rate of that magnitude would reduce the benefits of restructuring, and hence help support more debt in equilibrium. But a positive recovery rate should not interact with the forces we highlight in this model.

**Linear costs** We assume that default costs are linear in output so that  $\varphi(Y) = \Delta Y$ . This reduces the formulation of the value of default to

$$\begin{aligned} v_D(z) &= p v_D^T(z) + (1-p)(1-\Delta)^{1-\gamma} v_D^P(z) \\ v_D^k(z) &= u(y(z)(1 - 1_{(k=T)}\Delta)) + \beta \mathbb{E} \left[ (g')^{1-\gamma} (\psi v(0, z') + (1-\psi) v_D^k(z')) \mid z \right] \end{aligned} \quad (8)$$

Furthermore, in order to have the same magnitude of default costs when they are permanent and transitory, we set costs to  $\varphi(Y) = \Delta Y = \varepsilon^z \Delta \Gamma$  or  $y \Delta \Gamma$  when they are transitory and to  $\varphi(Y) = \Delta Y = \varepsilon^z \Gamma_{-1} g \Delta$  when they are permanent. In other words, when costs are transitory we obtain consumption  $y(1-\Delta)$  and when they are permanent we obtain  $g_T = g(1-\Delta)$ . In this case, using also the *iid* assumption for  $g$ , the Bellman equations describing the government's problem become

$$\begin{aligned} v_R(b, z) &= \max_h u(c) + \beta \mathbb{E} \left[ (g')^{1-\gamma} v(h/g', z') \mid z \right] \\ \text{subject to } c + \kappa b &= y(z) + q(h, z)(h - (1-\rho)b) \\ v_D(z) &= p v_D^T(z) + (1-p)(1-\Delta)^{1-\gamma} v_D^P(z) \\ v_D^k(z) &= u(y(z)(1 - 1_{(k=T)}\Delta)) + \beta \mathbb{E} \left[ (g')^{1-\gamma} (\psi v(0, z') + (1-\psi) v_D^k(z')) \mid z \right] \end{aligned} \quad (9)$$

where the term  $(1-\Delta)^{1-\gamma}$  in the definition of  $v_D$  reflects the renormalization and also

$$q(h, z) = \frac{1}{1+r} \mathbb{E} \left[ (1 - \mathcal{D}(h/g', z'))(\kappa + (1-\rho)q(h', z')) \mid z \right]$$

### 3.1 Model with robust preferences

There are four shocks in the model,  $\varepsilon^z$  and  $g$  for the endowment process, the reentry to international markets after a default, and whether the costs of defaulting are permanent or transitory.<sup>10</sup> We assume that, while the true stochastic processes governing these shocks are unknown, all agents in the economy take the descriptions above to be approximating models. While foreign lenders trust the approximating model and use it to compute the expectation in (7), the government does not. The government is instead concerned about potential misspecification of these processes and seeks robust decision rules. We represent such doubts and objectives with *multipplier preferences* (Hansen and Sargent, 2001) which capture ambiguity aversion with a single parameter. In this framework, robust decision rules emerge from confronting the decision maker with an ‘evil agent’ alter-ego. This fictitious, auxiliary agent chooses a worst-case model to minimize the decision maker’s utility for each possible choice of action. Critically, the evil agent faces

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<sup>10</sup>The preference shocks  $(\varepsilon_R, \varepsilon_D)$ , which are only introduced for numerical purposes, are assumed not to be subject to potential misspecification.

an entropy cost  $\frac{1}{\theta}$  which only allows it to pick distortions from the approximating model (worst-case models) which are difficult to statistically distinguish from it. When the marginal cost of this relative entropy is infinite, we recover the standard rational-expectations decision maker. In what follows, we refer to the inverse of the marginal cost of relative entropy,  $\theta$ , as the robustness parameter.

Moreover, the government potentially places different degrees of trust in its model for the endowment process, which is observed continuously, and in its model for the default costs, which are observed infrequently. We therefore denote as  $\theta_s$  and  $\theta_c$  the two robustness parameters for evaluating expectations involving  $(z', g')$  and  $k$ , respectively. Finally, we assume that the government does not doubt the stochastic process for reentry to markets after a default. While it is difficult to empirically determine whether output eventually catches up to its pre-default trend, exclusion periods are generally better understood (see [Cruces and Trebesch, 2013](#)).<sup>11</sup>

With multiplier preferences, the government's problems and value functions are<sup>12</sup>

$$\begin{aligned} v_R(b, z) &= \max_h u(c) - \beta \frac{1}{\theta_s} \log \left( \mathbb{E} \left[ \exp \left( -\theta_s (g')^{1-\gamma} v(h/g', z') \right) \mid z \right] \right) \\ \text{subject to } c + \kappa b &= y(z) + q(h, z)(h - (1 - \rho)b) \end{aligned} \quad (10)$$

$$v_D(z) = -\frac{1}{\theta_c} \log \left( p \exp \left( -\theta_c v_D^T(z) \right) + (1 - p) \exp \left( -\theta_c (1 - \Delta)^{1-\gamma} v_D^P(z) \right) \right) \quad (11)$$

and

$$v_D^k(z) = u(y(z)(1 - 1_{(k=T)}\Delta)) - \beta \frac{1}{\theta_s} \log \left( \mathbb{E} \left[ \exp \left( -\theta_s (g')^{1-\gamma} (\psi v(0, z') + (1 - \psi) v_D^k(z')) \right) \mid z \right] \right) \quad (12)$$

## 4. CALIBRATION

### 4.1 Output trajectories around restructuring episodes

We summarize the evidence on output costs of restructuring by computing deviations of output around debt restructuring episodes from a pre-restructuring trend in the [Asonuma and Trebesch \(2016\)](#) dataset. We purposefully abstract from causality. Instead, our approach is to parametrize the model to ensure that it generates the same correlations we find in the data. This allows us to

<sup>11</sup>[Fourakis \(2023\)](#) provides a model of signalling to understand the response of interest rates after market access has been recovered.

<sup>12</sup>For more details about how multiplier preferences yield a Bellman equation of the form of (10), see Appendix B.

indirectly infer the underlying causal parameters determining the size and persistence of default costs.

We consider a panel of market-access countries (MACs) which have had a sovereign restructuring event in 1990-2020 for which data on external debt, standing in international capital markets, GDP, and spreads are all available for at least 10 years previous to the default event. For each restructuring episode occurring at time  $t$  in country  $i$ , we construct a pre-restructuring trend for output by regressing log output in years  $t - j$ , for  $1 \leq j \leq 6$ , against a linear function of time

$$\log Y_{i,t-j} = \alpha_{it} + \beta_{it}(t - j) + \epsilon_{itj} \quad (13)$$

We then use this pre-restructuring trend to obtain fitted values  $\hat{Y}_{i,t+k}$  and compare realized output  $Y_{i,t+k}$  against this trend at horizon  $k$ . We focus on horizons  $k = 1$  and 5 and take the median across all episodes. We complement these calculations with values for external debt (as share of GDP) and spreads, taken as averages between  $t - 10$  and  $t - 5$ .

Table 1 summarizes our results, which we later use as calibration targets for the model presented in Section 3. The output deviation is sensitive to how the trend is defined, as the loss may be spread over many years and some of the decline relative to trend may take place in the run-up to the restructuring. We are therefore careful to estimate the same statistics in the model-generated data. We recover the structural causal cost-of-default parameters by matching the output deviations, while the overall output trajectory can be used for validation of the model. Finally, as all debt in the model is external, we compute a target for external-debt-to-GDP ratio.<sup>13</sup>

TABLE 1: CALIBRATION TARGETS

Description	Calculation	Value
Output deviation, 1-year horizon, %	$Y_{t+1}/\hat{Y}_{t+1} - 1$	8.27
Output deviation, 5-year horizon, %	$Y_{t+5}/\hat{Y}_{t+5} - 1$	7.6
Average external debt-to-GDP ratio, %	$\overline{B_{t-j}/Y_{t-j}}$	23.4
Average spread, bps	$\overline{Spread_{t-j}}$	793

<sup>13</sup>This number is lower than the headline debt-to-GDP ratio at which most countries tend to experience sovereign debt defaults.

## 4.2 Baseline calibration with robustness

We parametrize our model at a quarterly frequency. We externally set most parameters to obtain a calibration to Argentina 1993Q1–2001Q4 as is standard in models of sovereign default. We assume that the government places full trust in its approximating model for the income process, so  $\theta_s = 0$ . This leaves us the sovereign’s discount factor  $\beta$ , the level of default costs  $\Delta$ , the probability of a transitory cost  $p$  (under the approximating model), and the two robustness parameters  $(\theta_s, \theta_c)$ . We set these parameters to match the local projections for output at 1 and 5 years after a default event, relative to a pre-default trend, as well as the average level of spreads and the average debt-to-GDP ratios while in repayment. Table 2 summarizes our parametrization.

TABLE 2: BASELINE PARAMETER VALUES

Externally calibrated		
	Parameter	Value
Sovereign’s risk aversion	$\gamma$	2
Preference shock scale parameter	$\chi$	0.01
Risk-free interest rate	$r$	0.01
Robustness parameter: income shocks	$\theta_s$	0
Duration of debt	$\rho$	0.05
Reentry probability	$\psi$	0.0385
Income autocorrelation coefficient	$\rho_z$	0.9484
Standard deviation of $y_t$	$\sigma_z$	0.02
Internally calibrated		
	Parameter	Value
Sovereign’s discount factor	$\beta$	0.9007
Default cost	$\Delta$	0.0425
Probability of transitory shock	$p$	0.3972
Robustness parameter: default costs	$\theta_c$	6.667

To assess the match to the moments from Table 1, we generate simulated data from the model<sup>14</sup> and filter it through the same procedure used for the sample of EM default episodes. The calibrated model matches those patterns closely, as shown in Table 3. We note that our structural estimate for the costs of default ( $\Delta = 4.25\%$ ) falls well within the range of empirical estimates of the causal

<sup>14</sup>We take 2000 simulations of 250 years in each case.

effect, and quite close to the value found by [Asonuma et al. \(2023\)](#) which controls for a number of variables as well as the endogeneity of the choice of restructuring.

TABLE 3: MODEL FIT

	Data	Model
Output deviation, 1-year horizon, %	8.27	9.06
Output deviation, 5-year horizon, %	7.6	7.45
Average external debt-to-GDP ratio, %	23.4	22.1
Average spread, bps	793	800

Figure 2 plots the entire trajectories for output around default events in the data and model, with a shaded area indicating the interquantile range in the data. The model-generated dynamics match the data counterparts well, especially taking into account that the (annual) data reflects some time-averaging relative to our quarterly model. Both data and model exhibit a slight acceleration of output in the run-up to the default (between years -5 and -2) followed by a series of negative shocks starting around 1.5 years before the default. Both model and data then show a slow recovery in the years following the episode.

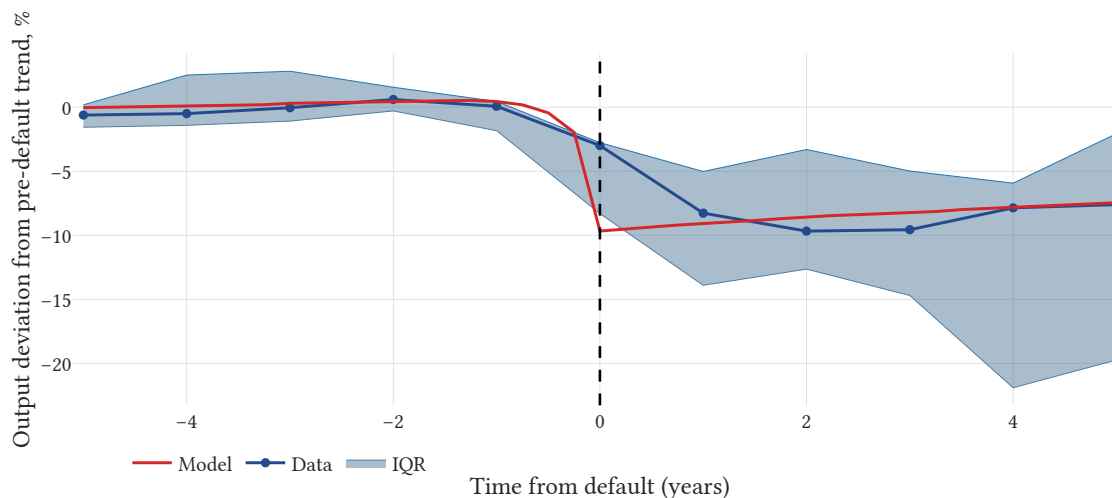


FIGURE 2: OUTPUT TRAJECTORIES AROUND DEFAULTS

## 5. EQUILIBRIUM AND QUANTITATIVE RESULTS

### 5.1 Actual and perceived persistence of default costs

Figure 3 shows simulation results at the baseline parametrization, varying the probability  $p$  that default costs are transitory and the robustness parameter affecting this particular source of uncertainty  $\theta_c$ . We solve and simulate the economy for each combination of  $(p, \theta_c)$  and report the average debt-to-GDP ratio  $B/Y$  and the default frequency, both in yearly terms.

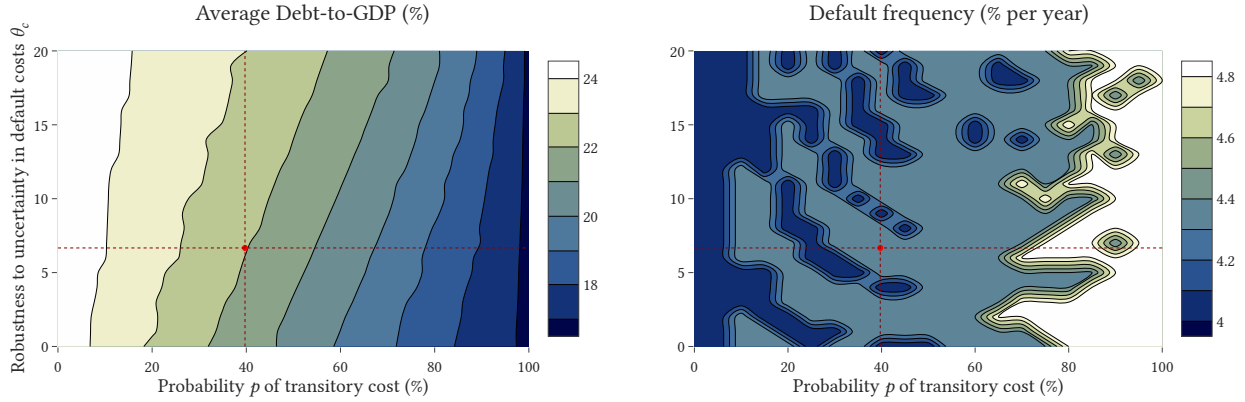


FIGURE 3: DEBT TOLERANCE VARYING  $p$  AND  $\theta_c$

*Note:* Red dots denote the baseline calibration.

When the shock is more likely to be permanent, or the government has greater misspecification concerns, the left panel of Figure 3 shows that the economy sustains larger levels of debt. Robustness has a larger impact when the underlying uncertainty about the permanence of costs is greater (i.e. when  $p$  is closer to 50%). Conversely, if  $p$  is close to 0 or 1, the government may distrust its assessment of  $p$  but is quite convinced about the nature of costs, one way or the other. In the left panel of Figure 3, the average debt responds little to changes in  $\theta_c$  for  $p$  close to the extremes and much more for intermediate values of  $p$ . Our calibrated value for  $p$  is about 40% which is squarely in the range where robustness has more quantitative bite. Compared to a parametrization in which the government is convinced that the cost is transitory ( $p = 1$ , the standard case in the literature), the average level of debt increases by about a third. At our baseline calibration, making the cost permanent for sure results in an increase of about 40-45%.

The right panel reveals that the default frequency is less sensitive to either of these parameters, and especially insensitive to the degree of robustness. Increasing  $\theta_c$  produces a slight decrease in the default frequency which is mostly obscured by noise from the simulation and numerical solution of the model. Shifting the cost from certainly permanent to certainly transitory only

increases the default frequency by about 20%. Thus, most of the increase in perceived costs of default (both through actual persistence and robustness) translates into additional borrowing. The debtor government uses the extra ‘credibility’ afforded by the higher default costs to sustain higher levels of indebtedness, rather than keeping debt the same and facing the costs of default less frequently.

## 5.2 The effect of robustness

To better understand the effect of robustness on the government’s decisions, we compute some expectations under the equilibrium worst-case model, the distortion which represents the government’s misspecification concerns. Let the *distorted expectation* of random variable  $X$  at information set  $\mathcal{F}$  be the objective expectation of the product of  $X$  with a likelihood ratio

$$\tilde{\mathbb{E}}[X \mid \mathcal{F}] = \mathbb{E} \left[ \frac{\exp(-\theta v)}{\mathbb{E}[\exp(-\theta v) \mid \mathcal{F}]} X \mid \mathcal{F} \right] \quad (14)$$

As compared to an expectation taken with the objective probability measure (the approximating or baseline model), the distorted expectation magnifies the likelihood of states for which the government’s utility, measured by the value function  $v$ , is low. This procedure results in endogenously pessimistic beliefs which sustain robust decision-making. The role of the robustness parameter  $\theta$  can also be clearly understood from (14). A larger value for  $\theta$  means larger misspecification concerns on the part of the government, and consequently a more distorted expectation. Conversely, as  $\theta \rightarrow 0$ , misspecification concerns vanish and the distorted expectation converges back to the objective one.

We focus on how robustness amplifies the perceived probability of a permanent cost of default. Because this variable  $k \in \{P, T\}$  is only realized after a default has taken place, the appropriate value function to use in (14) is  $v_D^k$ ,<sup>15</sup> with the renormalization factor  $(1 - \Delta)^{1-\gamma}$  in case the cost is permanent. Letting  $\tilde{p}(z)$  denote the distorted probability that the cost is transitory (i.e.  $k = T$ ) at state  $z$ ,

$$\tilde{p}(z) = \tilde{\mathbb{E}}[1_{(k=T)} \mid z] = \mathbb{E} \left[ \frac{\exp(-\theta v_D^k(z)(1 - 1_{(k=P)}\Delta)^{1-\gamma})}{\mathbb{E}[\exp(-\theta v_D^k(z)(1 - 1_{(k=P)}\Delta)^{1-\gamma})]} 1_{(k=T)} \mid z \right]$$

Figure 4 shows that the government’s misspecification concerns make it act as if the probability of a permanent cost of default was larger by a factor of about a quarter. Moreover, the distortion is larger when current income is lower, as a higher likelihood of default naturally makes the government more concerned about misspecification of the consequences of default.

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<sup>15</sup>In other words, the value function at the information set corresponding to the fact that a default has taken place (and the current state is  $z$ ) is  $v_D^k(z)$



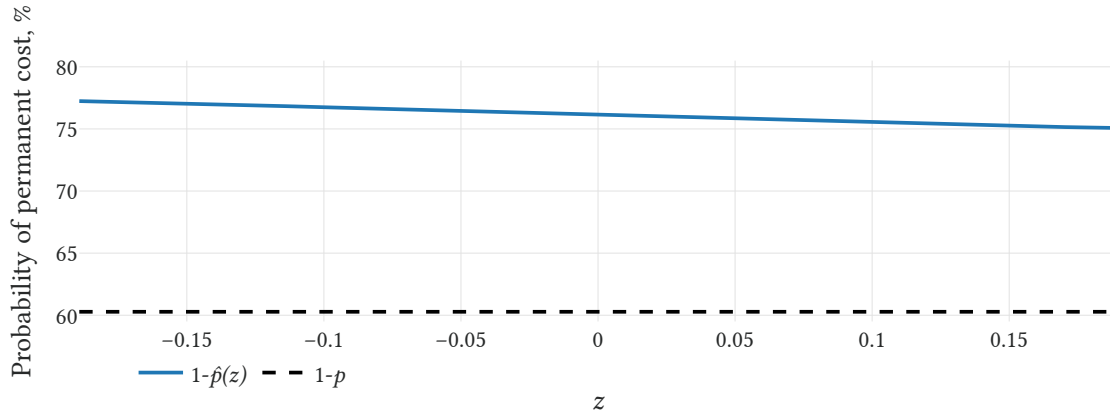


FIGURE 4: WORST-CASE PROBABILITY OF A TRANSITORY COST,  $\tilde{p}$

Figure 5 illustrates the relationship between borrowing terms faced by the government and the costs of default, actual and perceived, it faces. For a moderate level of debt (but in the region where spreads start to increase), spreads decrease when the shock is more likely to be permanent. They also decrease when the government has stronger misspecification concerns. As before, the power of robustness is dampened when the government is more certain about the nature of costs (i.e. when  $p$  is closer to 0 or 1).

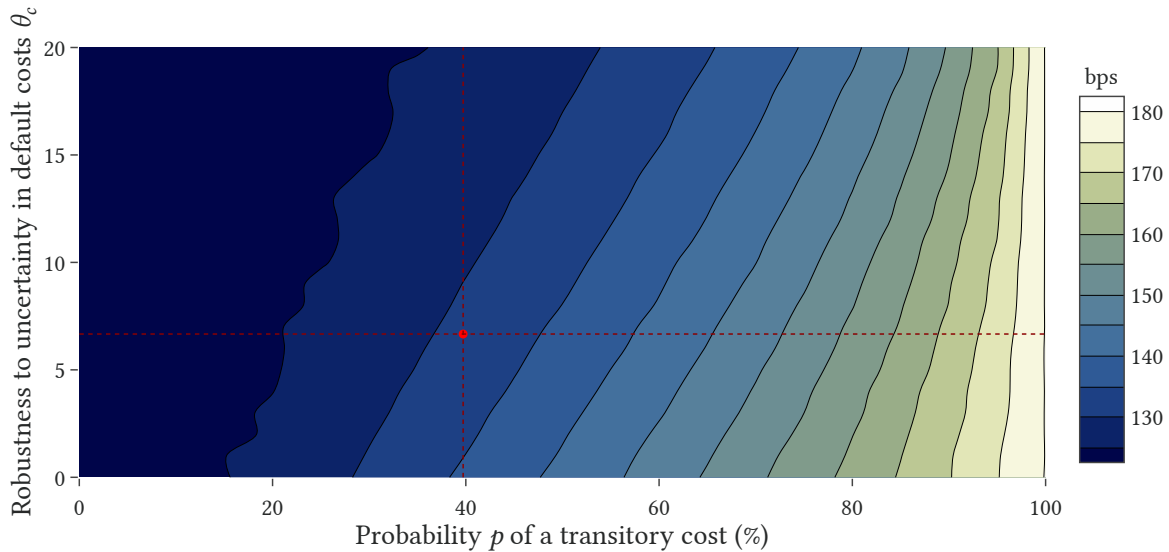


FIGURE 5: SPREADS ON GOVERNMENT DEBT

*Note:* spreads computed at mean income and debt at 15% of income in each case, red dots denote the baseline calibration

### 5.3 Model detection-error probabilities

As is common in the robustness literature, we compute model detection-error probabilities (DEP) to help inform and discipline our choice of  $\theta_s$  and  $\theta_c$ .<sup>16</sup> When the government follows robust decision rules, it does so by computing an auxiliary worst-case model. The DEP captures the probability that an agent, with a limited amount of data, mistakes data generated by one of the models as coming from the other one. A DEP of 50% means that the baseline and worst-case models are observationally equivalent while a DEP of 0 means that an agent can perfectly distinguish both models. A high DEP suggests that the amount of misspecification implicit in the distorted model is plausible and validates the decision maker's desire for robustness. Typically, in the robust control literature, acceptable values for DEP are of 20% or above (Barillas et al., 2009). Our choices of  $\theta_c$  stay well within this constraint suggesting we rely on reasonable amounts of probability distortions.<sup>17</sup>

Figure 6 plots the model detection-error probability for different values of the objective probability  $p$  of a transitory cost, as a function of the choice of the robustness parameter  $\theta_c$ .

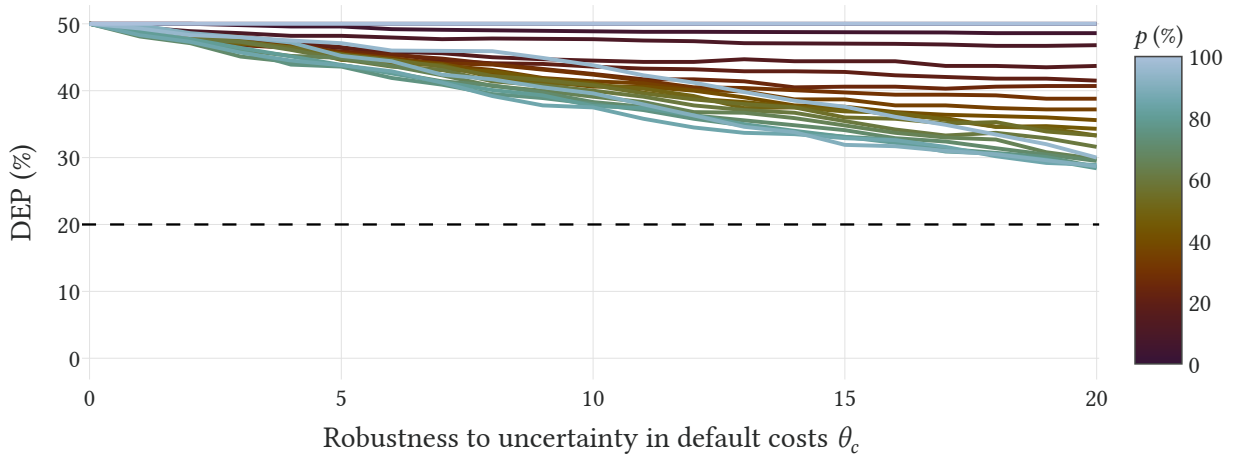


FIGURE 6: DEBT AND DEPs FOR DIFFERENT PRIOR PROBABILITIES OF A TRANSITORY COST

For a given baseline probability  $p$  of a permanent shock, increasing robustness leads to higher

<sup>16</sup>Although as of this writing we only consider changes in  $\theta_c$ .

<sup>17</sup>We compute model detection-error probabilities as the probability of misclassifying a 60-year sample (which is more than the length of quarterly data for GDP for most EMs), after a 500-period burn-in to draw from the ergodic distribution, over 2000 repetitions. We compute in each repetition the likelihood  $L(x | M)$  of data  $x$  being generated by model  $M$  for the approximating model  $A$  and for the (endogenous) worst-case model  $W$ . We then compute the probability of misclassification as the average between  $\mathbb{P}(L(x | A) > L(x | W) | W)$  and  $\mathbb{P}(L(x | W) > L(x | A) | A)$ .

levels of debt sustained in equilibrium. The government sustains these higher levels of debt because the worst-case model arising from the government’s robustness concerns features a larger probability of permanent costs (Figure 3). This feature also makes it more easily distinguishable from the baseline model. Indeed, Figure 6 shows that the DEP decreases with the robustness parameter  $\theta_c$ . Moreover, as  $p$  grows towards 1, there is more scope to distort beliefs in a pessimistic way. The more the cost looks transitory, the more there is to fear that it is permanent. This leads to lower values for the DEP when  $p$  is large, holding robustness constant. However, our choice of  $\theta_c$  always lies above the usual 20% cutoff in the robustness literature.

## 6. CONCLUDING REMARKS

This paper shows how the potential permanence of output costs following a debt restructuring can significantly amplify a country’s willingness to repay its debt and, hence, its debt capacity. Debt tolerance with permanent output costs can be almost one half larger than with purely transitory costs. In practice, decision makers are unlikely to have a clear picture of how permanent these costs are, similarly to researchers in sovereign debt. Aversion to this ambiguity boosts debt tolerance, by making the government treat costs as perhaps being more persistent. Both channels have received little attention in the literature but, as our results suggest, they may be key drivers of debt tolerance.

We find that the persistence of output costs, and the uncertainty surrounding it, has a sizable effect on debt tolerance, but perhaps not as much as one would have expected. We parametrize the model to an exclusion period of 6.5 years on average, following widely used estimates from [Cruces and Trebesch \(2013\)](#). The additional impact of making the cost permanent after the exclusion period is limited by the discounting of a relatively impatient borrower, which is also a common feature of calibrated sovereign debt models. With a more patient borrower (or a counterfactually shorter exclusion period), permanent default costs would boost debt tolerance even more. This interaction could be a key driver of what explains differences in debt tolerance across countries (e.g. “graduation” effects), and is something that could be explored in future work.

The focus of this paper, like much of the literature, has been on external debt. Domestic debt restructurings can be much more disruptive, given the implications for domestic financial stability, which can potentially lead to much larger and protracted output costs relative to an external debt restructuring. Modeling domestic debt introduces complications to the model, but would be an interesting direction for future work, and where both channels proposed could have an even larger amplifying impact on debt tolerance.

## REFERENCES

- AGUIAR, M. AND M. AMADOR (2014): “Sovereign Debt,” *Handbook of International Economics*, 4, 647–87.
- AGUIAR, M., S. CHATTERJEE, H. COLE, AND Z. STANGEBYE (2016): “Quantitative Models of Sovereign Debt Crises,” *Handbook of Macroeconomics*, 2B, 1697–1755, chapter 21.
- ANDERSON, E. W., L. P. HANSEN, AND T. J. SARGENT (2003): “A Quartet of Semigroups for Model Specification, Robustness, Prices of Risk, and Model Detection,” *Journal of the European Economic Association*, 1, 68–123.
- ASONUMA, T., M. CHAMON, A. ERCE, AND A. SASAHARA (2023): “Costs of Sovereign Defaults: Restructuring Strategies and the Credit-Investment Channel,” Mimeo.
- ASONUMA, T. AND C. HE (2023): ““Too Little” Sovereign Debt Restructurings,” Mimeo.
- ASONUMA, T. AND C. TREBESCH (2016): “Sovereign Debt Restructurings: Preemptive or Post-Default,” *Journal of the European Economic Association*, 14, 175–214.
- BARILLAS, F., L. HANSEN, AND T. SARGENT (2009): “Doubts or Variability?” *Journal of Economic Theory*, 144, 2388–2418.
- BORENSZTEIN, E. AND U. PANIZZA (2009): “The Costs of Sovereign Default,” *IMF Staff Papers*, 56, 683–741.
- BULOW, J. AND K. ROGOFF (1989a): “Sovereign Debt: Is to Forgive to Forget?” *American Economic Review*, 79, 43–50.
- (1989b): “A Constant Recontracting Model of Sovereign Debt,” *Journal of Political Economy*, 97, 155–178.
- CERRA, V. AND S. C. SAXENA (2008): “Growth Dynamics: The Myth of Economic Recovery,” *American Economic Review*, 98, 439–57.
- CHATTERJEE, S., D. CORBAE, J.-V. RIOS-RULL, AND K. DEMPSEY (2018): “A Theory of Credit Scoring and the Competitive Pricing of Default Risk,” 2018 Meeting Papers 550, Society for Economic Dynamics.
- CHATTERJEE, S. AND B. EYIGUNGOR (2012): “Maturity, Indebtedness, and Default Risk,” *American Economic Review*, 102, 2674–99.

- COLE, H. AND P. KEHOE (1998): “Models of Sovereign Debt: Partial versus General Reputations,” *International Economic Review*, 39, 55–70.
- CRUCES, J. J. AND C. TREBESCH (2013): “Sovereign Defaults: The Price of Haircuts,” *American Economic Journal: Macroeconomics*, 5, 85–117.
- DE PAOLI, B., G. HOGGARTH, AND V. SAPORTA (2009): “Output costs of sovereign crises: some empirical estimates,” Bank of England working papers 362, Bank of England.
- D’ERASMO, P., E. MENDOZA, AND J. ZHANG (2016): “Quantitative Models of Sovereign Debt Crises,” *Handbook of Macroeconomics*, 2B, 2493–2597, chapter 32.
- DVORKIN, M., J. M. SÁNCHEZ, H. SAPRIZA, AND E. YURDAGUL (2021): “Sovereign Debt Restructurings,” *American Economic Journal: Macroeconomics*, 13, 26–77.
- EATON, J. AND M. GERSOVITZ (1981): “Debt with Potential Repudiation: Theoretical and Empirical Analysis,” *The Review of Economic Studies*, 48, 289–309.
- FARAH-YACoub, J. P., C. M. H. GRAF VON LUCKNER, R. RAMALHO, AND C. M. REINHART (2022): “The Social Costs of Sovereign Default,” Policy Research Working Paper Series 10157, The World Bank.
- FOURAKIS, S. (2023): “Sovereign Default and Government Reputation,” Mimeo.
- HANSEN, L. P. AND T. J. SARGENT (2001): “Robust Control and Model Uncertainty,” *American Economic Review*, 91, 60–66.
- (2015): “Four types of ignorance,” *Journal of Monetary Economics*, 69, 97–113.
- HATCHONDO, J. C. AND L. MARTINEZ (2009): “Long-duration bonds and sovereign defaults,” *Journal of International Economics*, 79, 117–125.
- IMF (2013): “Sovereign Debt Restructuring - Recent Developments and Implications for the Fund’s Legal and Policy Framework,” available at: [https://www.imf.org/-/media/Websites/IMF/imported-full-text-pdf/external/np/pp/eng/2013/\\_042613.ashx](https://www.imf.org/-/media/Websites/IMF/imported-full-text-pdf/external/np/pp/eng/2013/_042613.ashx), IMF Policy Papers.
- (2020): “The International Architecture for Resolving Sovereign Debt Involving Private-Sector Creditors—Recent Developments, Challenges, And Reform Options,” available at: <https://www.imf.org/-/media/Files/Publications/PP/2020/English/PPEA2020043.ashx>, IMF Policy Paper No. 2020/043.

- (2021): “Issues in Restructuring of Sovereign Domestic Debt,” available at: <https://www.imf.org/-/media/Files/Publications/PP/2021/English/PPEA2021071.ashx>, IMF Policy Paper No. 2021/071.
- LELAND, H. E. (1998): “Agency Costs, Risk Management, and Capital Structure,” *Journal of Finance*, 53, 1213–1243.
- LEVY YEYATI, E. AND U. PANIZZA (2011): “The elusive costs of sovereign defaults,” *Journal of Development Economics*, 94, 95–105.
- MARTINEZ, L., F. ROCH, F. ROLDÁN, AND J. ZETTELMEYER (2023): “Sovereign Debt,” in *The Research Handbook of Financial Markets*, ed. by R. S. Gürkaynak and J. H. Wright, Edward Elgar Publishing, chap. 17, 378–405.
- MEYER, J., C. M. REINHART, AND C. TREBESCH (2022): “Sovereign Bonds since Waterloo,” *The Quarterly Journal of Economics*, 137.
- PÉREZ, D. (2018): “Sovereign Debt, Domestic Banks and the Provision of Public Liquidity,” mimeo, NYU.
- POUZO, D. AND I. PRESNO (2016): “Sovereign Default Risk and Uncertainty Premia,” *American Economic Journal: Macroeconomics*, 8, 230–66.
- REINHART, C., K. ROGOFF, AND M. A. SAVASTANO (2003): “Debt Intolerance,” *Brookings Papers on Economic Activity*, 34, 1–74.
- ROCH, F. AND F. ROLDÁN (2023): “Uncertainty Premia, Sovereign Default Risk, and State-Contingent Debt,” *Journal of Political Economy Macroeconomics*, 1, 334–370.
- ROGOFF, K. (2022): “Issues in the theory of sovereign debt and post-covid workouts,” *Journal of Policy Modeling*, 44, 804–811.

## A. NORMALIZATION DETAILS

We normalize all variables by  $\Gamma_t$ , denote normalized values with lowercase, and notice that  $y_t = \exp(z_t)$  and

$$u(C) = \frac{C^{1-\gamma}}{1-\gamma} = \Gamma^{1-\gamma} \frac{(C/\Gamma)^{1-\gamma}}{1-\gamma} = \Gamma^{1-\gamma} u(c)$$

so in a typical Bellman equation we can guess and verify (denoting  $h = B'/\Gamma$ ) forms like  $V\Gamma^{\gamma-1} = v$

$$\begin{aligned} V(B, z, \Gamma) &= \max_{B'} u(C) + \beta \mathbb{E} [V(B', z', \Gamma')] \\ V(B, z, \Gamma) &= \max_{B'} \Gamma^{1-\gamma} u(c) + \beta \mathbb{E} [V(B', z', \Gamma')] \\ \Gamma^{\gamma-1} V(B, z, \Gamma) &= \max_{B'} u(c) + \beta \mathbb{E} \left[ (\Gamma')^{\gamma-1} (\Gamma/\Gamma')^{\gamma-1} V(B', z', \Gamma') \right] \\ v(b, z, g) &= \max_h u(c) + \beta \mathbb{E} [(g')^{1-\gamma} v(b'(h, g'), z', g')] \\ v(b, z, g) &= \max_h u(c) + \beta \mathbb{E} [(g')^{1-\gamma} v(b'(h, g'), z', g')] \end{aligned}$$

while for the budget constraint we have

$$\begin{aligned} C + \kappa B &= Y + q(B' - (1 - \rho)B) \\ c + \kappa b &= y + q(B'/\Gamma - (1 - \rho)b) \\ c + \kappa b &= y + q(b'(\Gamma'/\Gamma) - (1 - \rho)b) \\ c + \kappa b &= y + q(b'g' - (1 - \rho)b) \end{aligned}$$

This budget constraint makes it clear that  $h = b'g'$  (simply substituting  $h = B'/\Gamma$  in line 2) or  $b'(h, g') = h/g'$ .

For the value of default we have, for  $g^C(g, z) = g - \varphi$  and  $\Gamma^C = \Gamma_0 g^C(g, z)$ , where  $\Gamma = \Gamma_0 g$

$$\begin{aligned} V_D(z, \Gamma) &= pV_D^T(z, \Gamma) + (1 - p)V_D^P(z, \Gamma^C) \\ (\Gamma)^{\gamma-1} V_D(z, \Gamma) &= p(\Gamma)^{\gamma-1} V_D^T(z, \Gamma) + (1 - p)(\Gamma)^{\gamma-1} V_D^P(z, \Gamma^C) \\ (\Gamma)^{\gamma-1} V_D(z, \Gamma) &= p(\Gamma)^{\gamma-1} V_D^T(z, \Gamma) + (1 - p)(\Gamma_0 g)^{\gamma-1} V_D^P(z, \Gamma^C) \\ v_D(z, g) &= p v_D^T(z, g) + (1 - p)(\Gamma_0 g^C(g, z) g / g^C(g, z))^{\gamma-1} V_D^P(z, \Gamma^C) \\ v_D(z, g) &= p v_D^T(z, g) + (1 - p) \left( \frac{g}{g^C(g, z)} \right)^{\gamma-1} \underbrace{(\Gamma_0 g^C(g, z))^{\gamma-1}}_{=\Gamma^C} V_D^P(z, \Gamma^C) \\ v_D(z, g) &= p v_D^T(z, g) + (1 - p) \left( \frac{g}{g - \varphi} \right)^{\gamma-1} v_D^P(z, g - \varphi) \end{aligned}$$

## B. ROBUSTNESS

For a technical exposition of robustness, see [Hansen and Sargent \(2001\)](#). Less formally, consider a decision maker facing a state (vector)  $x$  with a (trusted) law of motion  $\mu(x' | x, c)$  and a Bellman equation of the form

$$v(x) = \max_c u(c) + \beta \int v(x') \mu(x' | x, c) dx'$$

To include doubts about the law of motion  $\mu$  and guard against misspecification, the decision maker seeks an action that would perform reasonably well if the true law of motion was instead *any*  $\mu'$ . The alternative is left unidentified but could be any probability distribution that is difficult to distinguish statistically from  $\mu$ . To obtain an action that performs well under all possible  $\mu'$ , the decision maker enlists the help of an auxiliary evil agent who chooses a probability distortion  $m$  that minimizes the utility given the action  $c$  chosen. By behaving in this pessimistic way (each action is evaluated according to the distortion that yields the lowest utility), the decision maker obtains lower bounds for each action.

Finally, in order to only allow distortions that are difficult to identify from data, the evil agent faces a cost for the relative entropy of the original model  $\mu$  and the distorted one, the so-called worst-case model  $m\mu$ . The inverse marginal cost of relative entropy,  $\theta$ , determines how robust the resulting decision will be. The decision maker takes into account the reaction of the evil agent and solves

$$\begin{aligned} v(x) = \max_c \min_{m \geq 0} u(c) + \beta \int v(x') m(x') \mu(x' | x, c) dx' + \frac{1}{\theta} \text{ent}(m\mu, \mu) \\ \text{subject to } \int m(x') \mu(x' | x, c) dx' = 1 \end{aligned}$$

The solution to the minimization problem yields a worst-case model  $\hat{m}(x') \propto \exp(-\theta v(x'))$ . As [Hansen and Sargent \(2001\)](#) show, plugging in the worst-case model yields the robust Bellman equation

$$v(x) = \max_c u(c) + \frac{1}{-\theta} \beta \int \exp(-\theta v(x')) \mu(x' | x, c) dx'$$