

# Efficient Sovereign Debt Management: The Role of History, Maturity, Buyback and Default<sup>\*</sup>

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October 10, 2022

## Abstract

This paper identifies the role of past history, maturity, buyback and default in the context of constrained efficient sovereign borrowing. I derive a market economy in which a sovereign borrower trades non-contingent bonds of different maturities with a foreign lender. The borrower is relatively impatient and lacks commitment. I show that the market economy cannot implement the Planner's constrained efficient allocation through defaults but instead by changes in maturity and debt buybacks. Moreover, as the lender must enforce those buybacks, the implementation often requires history-dependent strategies. Nevertheless, interpreting the impatient borrower as a short-run player, small perturbations in the payoff of the market participants rule out any other strategies than Markov ones. In this case, the Planner's allocation can only be approximated by the market economy through Markov debt management policies. Developing economies present evidence of such approximation albeit with different policies and outcome.

**Keywords:** sovereign debt, limited enforcements, Markov, history

**JEL Classification:** D82, E61, F34, F41, C72, C73

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<sup>\*</sup>I am indebted to my advisors, Ramon Marimon and Alexander Monge-Naranjo, for their advice, encouragement and support. I would like to thank Dirk Krueger and seminar participants at the University of Pennsylvania and the BSE Summer Forum for helpful suggestions and comments. All remaining errors are my own.

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# 1 Introduction

The sovereign debt management of developing economies has three main features. First and foremost, the better part of those economies default on their liabilities. Defaults last several years and are associated with output contractions as well as substantial debt reliefs.<sup>1</sup> Second, developing economies rely more extensively on short-term debt during debt crises. This comes from the increasing term premium which shifts the issuance towards shorter maturities.<sup>2</sup> Third, developing economies conduct debt buybacks to repurchase part of their debt on the market. Even though such events have become rare in the last few years, they are usually very costly and ineffective in reducing indebtedness.<sup>3</sup> The question that arises is whether such debt management policies are efficient? I analyze the role of each of the above policies in attaining or approximating the constrained efficient sovereign borrowing.

I consider an environment in which a foreign lender owns a production technology in a small open economy, provides the capital input and buys bonds issued by a sovereign government (i.e. the borrower). Conversely, the sovereign government takes the decision on behalf of the small open economy, runs the production technology and issues non-contingent defaultable bonds of different maturities. In addition, domestic production is subject to persistent growth shocks. In this set-up, I introduce two frictions: the government is relatively impatient and cannot commit to repay the lender.

Relying on trigger strategies, I show that it is possible to sustain many different equilibria in this environment. I first focus on Markov equilibria to derive history-invariant debt management policies. I consider the case in which the lender inhibits the government's default incentives and the case in which it does not. I subsequently provide foundations for the use of Markov strategies. Particularly, interpreting the impatient government as a short-run player, I show that Markov strategies are in fact the only strategies robust to small and independent perturbations in payoffs. Secondly, I derive the debt management policies emanating from an optimal contract. Such policies correspond to the best achievable outcome in this environment but are usually highly history dependent.

To analyze the Markov debt management policies, I consider two types of Markov equilibria. The first one is a version of [Arellano and Ramanarayanan \(2012\)](#) with growth shocks and endogenous default cost. The lender does not inhibit default incentives and prices bonds accordingly. Default provides some form of state contingency and pushes the maturity towards the short end during debt crises. In the second Markov equilibrium, the lender introduces

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<sup>1</sup>For default duration and haircuts, see [Cruces and Trebesch \(2013\)](#) and [Asonuma and Trebesch \(2016\)](#). For default rates, see [Tomz and Wright \(2007\)](#), [Reinhart and Rogoff \(2009\)](#) and [Tomz and Wright \(2013\)](#).

<sup>2</sup>See [Arellano and Ramanarayanan \(2012\)](#), [Broner et al. \(2013\)](#) and [Bai et al. \(2017\)](#).

<sup>3</sup>See [Bulow and Rogoff \(1988, 1991\)](#) and [Cohen and Verdier \(1995\)](#).

a borrowing limit which can be made state-contingent with the help of costly buyback programs. The borrowing limit prevents defaults while allowing for risk sharing as in [Alvarez and Jermann \(2000\)](#). I show that this second equilibrium is Pareto superior demonstrating the inefficiency of default in generating risk sharing. I finally provide foundations for the use of Markov strategies. Interpreting the impatient government as a short-run player, I show that only Markov equilibria are robust to small and independent perturbations in payoffs ([Bhaskar et al., 2012](#)). The argument is that the lender conditions its actions on a past event only if the government does so and *vice versa*. Thus, conditioning on the past is only possible if both parties keep track of the entire history of play. As a result, there are two extremes: both parties either build on the entire history or do not at all.

To analyze the constrained efficient debt management policies, I first derive an optimal contract between the borrower and the lender. The Planner accounts for a borrower’s participation constraint and keeps track of the binding constraint through a co-state variable – i.e. the relative Pareto weight – which is sufficient statistics for the history of the play ([Marcet and Marimon, 2019](#)). The optimal contract determines the constrained efficient allocation. It features production distortion and state-contingent debt relief. Particularly, when the relative Pareto weight is sufficiently high, the punishment of autarky is a real threat. The contract can therefore sustain the productivity-maximizing level of capital. Otherwise, the threat of autarky fades. As a result, the Planner reduces the level of capital to relax the participation constraint. It never finds optimal to set capital to zero, though.

I then implement the constrained efficient allocation in the sovereign debt market economy. Given that the Planner never distorts capital to zero, defaults – which imply markets exclusion – cannot implement the constrained efficient allocation. Instead, the government adapts the maturity structure of its portfolio and conducts costly debt buybacks. The buyback implicitly introduces state contingency in the bond contract. It occurs at some very specific points in time implying that the price of long-term bonds evolves according to the likelihood of a buyback in the future. This in turns generates the term structure necessary to mimic the state contingency in liabilities of the optimal contract.

The implementation of the constrained efficient allocation might not generally rely on Markov strategies. The reason behind this is that buybacks are costly for the borrower. Thus, the lender has to enforce them. I show that in a Markov equilibrium, such enforcement is possible only if the borrower does not hold any assets and buybacks are not too costly. In this situation, the lender can threaten the borrower with a sudden stop on debt if the buyback does not occur as planned. However, such threat ceases to be credible as soon as the borrower possesses some assets or the buyback becomes too onerous. I find that, to replicate the constrained efficient allocation, the borrower needs to hold short-term assets

unless buybacks are uncommonly costly. As a result, Markov strategies fail to implement the Planner’s allocation under empirically plausible buyback rates.

The Markov equilibrium with default incentives is well suited for positive inquiries. I therefore calibrate it to match moments of the Argentine economy over the period 1970-2019. The calibrated model fits well the data and features defaults episodes in which indebtedness increases with respect to output and maturity shortens. Conversely, during restructurings, the level of debt remains substantial and the maturity lengthens. In addition, I show that the Markov equilibrium without default incentives shares similarities with Brazil which has not defaulted since the 1980s and conducted official buyback programs since the 2000s.

I then compare the Markov equilibria with the implementation of the optimal contract through various simulation exercises. In general, consumption is less volatile and corresponds to a lower share of output, while investment is more volatile in the constrained efficient allocation compared to the two Markov allocations. I find important welfare gains for the borrower to rely on buybacks instead of defaults. In light of this, I show that the Markov equilibrium without default incentives is quantitatively the closest to the constrained efficient allocation. This is consistent with the fact that Brazil’s economic performance has been stronger than Argentina’s in the last few decades.

The paper combines elements of the literature on sovereign defaults with elements of the literature about optimal contracts and their implementation. The literature on sovereign defaults assumes that markets are incomplete and agents follow Markov strategies ([Eaton and Gersovitz, 1981](#); [Aguiar and Gopinath, 2006](#); [Arellano, 2008](#)).<sup>4</sup> There, the borrower has access to only non-contingent claims and can obtain limited state contingency through defaults. My study is the closest to [Arellano and Ramanarayanan \(2012\)](#) and [Niepelt \(2014\)](#) given that I adopt two bonds with different maturities and to [Mendoza and Yue \(2012\)](#) given that the default cost is endogenous.<sup>5</sup> I contribute to this literature in two ways. First, I show that the reliance on defaults to obtain state contingency is inefficient. Second, I provide foundations for the use of Markov strategies interpreting the assumption of impatience as evidence of bounded memory and then applying the result of [Bhaskar et al. \(2012\)](#).

On a similar note, this paper relies on costly buybacks as a way to implement the constrained efficient allocation. It therefore relates to the seminal contribution of [Bulow and Rogoff \(1988, 1991\)](#) who document that buybacks are suboptimal as they increase the recovery value per unit of bond and therefore fail to reduce indebtedness.<sup>6</sup> Similarly, [Aguiar et al. \(2019\)](#) find that buybacks are costly as they shift the maturity structure and therefore

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<sup>4</sup>See also [Aguiar and Amador \(2014\)](#) and [Aguiar et al. \(2016\)](#).

<sup>5</sup>See also [Bohn \(1990\)](#) and [Barro \(1995\)](#) for earlier work on optimal debt structure.

<sup>6</sup>Building on this, [Cohen and Verdier \(1995\)](#) show that buybacks are effective only if they remain secret.

affect the default risk.<sup>7</sup> In opposition, [Rotemberg \(1991\)](#) shows that buybacks can be advantageous to all parties as they lower the bargaining costs. Moreover, [Acharya and Diwan \(1993\)](#) find that buybacks provide a positive signal about the borrower’s willingness to repay. My analysis goes in this direction as it emphasises the necessity and efficiency of buybacks.

The paper derives the optimal contract between a lender and a borrower and therefore relates to the seminal contributions of [Kehoe and Levine \(1993, 2001\)](#) and [Thomas and Worrall \(1994\)](#) who considered the case of limited enforcement, as well as [Thomas and Worrall \(1990\)](#), [Atkeson \(1991\)](#) and [Kocherlakota \(1996\)](#) who added moral hazard. My study accounts for limited enforcements similar to [Aguiar et al. \(2009\)](#). It is close to [Kehoe and Perri \(2002\)](#) and [Restrepo-Echavarria \(2019\)](#) as it relies on the approach of [Marcet and Marimon \(2019\)](#) with the difference that I implement the contract in a market economy.<sup>8</sup>

The paper therefore addresses the literature on optimal contract’s implementation. Unlike [Aguiar et al. \(2019\)](#) and [Müller et al. \(2019\)](#), my implementation does not generally rely on Markov strategies. On the one hand, [Aguiar et al. \(2019\)](#) account for multiple maturities but consider a Planner’s problem which does not take into consideration the legacy creditors in the objective function, unlike my Planner problem. On the other hand, [Müller et al. \(2019\)](#) use preemptive restructurings and GDP-linked bonds to mimic the return of Arrow securities, whereas I rely on the term structure. An alternative to this approach is [Dovis \(2019\)](#) who develop an implementation through partial default and an active debt maturity management. He builds on [Angeletos \(2002\)](#) and [Buera and Nicolini \(2004\)](#) who show that one can replicate the state-contingency of Arrow securities using non contingent bonds of different maturities. Unlike [Alvarez and Jermann \(2000\)](#) who assume a high sophistication of the financial market, his implementation relies on a high sophistication of the market participant’s strategies building on the entire history of play. My implementation is the closest to [Dovis \(2019\)](#) with the difference that I rely on debt buybacks without default and haircuts. Moreover, I connect my implementation with the Markov allocation. Especially, as buybacks need to be enforced, I explain why and when history dependence matters.

The paper is organized as follows. I describe the economic environment in Section 2. Subsequently, I introduce the market economy and derive the set of sustainable equilibria in Section 3. I present the Markov debt management policies in Section 4. Thereafter, I derive the constrained efficient debt management policies in Section 5. The calibration and quantitative analyses are in Section 6. Finally, I conclude in Section 7.

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<sup>7</sup>Furthermore, [Aguiar et al. \(2022\)](#) show that buybacks are rare as they only occur when there are no uncertainty surrounding debt auctions.

<sup>8</sup>The other difference is that I adopt a capital depreciation rate of 1 which facilitates the equilibrium computation. See [Koepl et al. \(2014\)](#) for a contracting problem with capital and enforcement costs.

## 2 Environment

Consider a small open economy over infinite discrete time  $t = \{0, 1, \dots\}$  with a single homogenous good. The small open economy is populated by a benevolent government and a large number of homogenous households which own domestic firms, while a foreign lender invests in the small open economy.<sup>9</sup>

The risk neutral lender discounts the future at rate  $\frac{1}{1+r}$ . It equips the small open economy with a production technology,  $F(\hat{k}, l)$ , to produce goods and provides the capital input,  $\hat{k}$ , at price  $p$ , which depreciates at rate  $\delta = 1$ . Domestic households provide the labor input,  $l$ . In addition, the lender trades bonds with the government.

The representative domestic household discounts the future at rate  $\beta < \frac{1}{1+r}$ . Preference over consumption is represented by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(\hat{c}_t),$$

where  $\hat{c}_t$  corresponds to the consumption at time  $t$ . The instantaneous utility function takes the CRRA form,  $u(\hat{c}_t) = \frac{\hat{c}_t^{1-\sigma}}{1-\sigma}$ , where  $\sigma > 0$  is the coefficient of relative risk aversion.

The government is benevolent and takes the decision on behalf of the small open economy. It can tax the payment of capital made by the domestic firms at rate  $\tau_t \in [0, 1]$ . Thus, the household's after-tax income is given by

$$\hat{y}(z_t, p_t, \hat{k}_t, \tau_t) := z_t F(\hat{k}_t, l_t) - p_t(1 - \tau_t)\hat{k}_t.$$

Domestic households are endowed with one unit of labor in each period.<sup>10</sup> I therefore denote  $f(\hat{k}) \equiv F(\hat{k}, 1)$ . The production technology has constant returns to scale, is continuous, increasing,  $f_{\hat{k}}(\hat{k}) > 0$ , concave,  $f_{\hat{k}\hat{k}}(\hat{k}) < 0$ , satisfies the Inada condition,  $\lim_{\hat{k} \rightarrow 0} f_{\hat{k}}(\hat{k}) = \infty$ , and  $f(0) > 0$ . The fact that  $f(\hat{k})$  is concave implies that the production technology displays decreasing returns to scale with respect to  $\hat{k}$ . This means that there exists a level  $\hat{k}^*(z)$  which maximizes the net production such that  $z f_{\hat{k}}(\hat{k}^*(z)) = p$ .

Domestic production is subject to a shock  $z_t$ . The law of motion is given by  $z_t = g_t z_{t-1}$  where  $g_t$  represents the growth rate at time  $t$ . Growth takes value on the discrete set  $G \equiv \{g_L, g_H\}$  with  $0 < g_L < 1 < g_H$  and follows a Markov chain of order one with  $\pi(g_{t+1}|g_t)$  corresponding to the probability of drawing  $g_{t+1}$  at date  $t+1$  conditional on drawing  $g_t$  at  $t$ . I further assume that shocks are persistent meaning that  $\pi(g|g) > 0.5$  for all  $g \in G$ .

<sup>9</sup>The present environment is similar to the one of [Quadrini \(2004\)](#), [Aguiar et al. \(2009\)](#) and [Dovis \(2019\)](#).

<sup>10</sup>As in [Aguiar et al. \(2009\)](#) and [Dovis \(2019\)](#), I combine the income of households and government together. Households provide labor inelastically and receive lump sum transfers from the government.

Finally, to ensure the economy converges to a meaningful steady state,  $(\frac{g_H}{g_L})^{-\sigma} > \beta(1+r)$  and  $\beta(1+r)g^{-\sigma} \leq 1$  for all  $g \in G$ .

The government has access to bonds with two different maturities. On the one hand, there is a one-period – i.e. short-term – bond,  $\hat{b}_{st}$ , with unit price  $q_{st}$ . On the other hand, there is a perpetual – i.e. long-term – bond,  $\hat{b}_{lt} \leq 0$ , with unit price  $q_{lt}$ , which pays a coupon of one every period (Hatchondo and Martinez, 2009). I denote debt as a negative asset meaning that  $\hat{b}_j < 0$  denotes a debt, while  $\hat{b}_j > 0$  denotes an asset for all  $j \in \{st, lt\}$ . The government can hold short-term assets but not long-term assets. The financial market is incomplete as bonds do not discriminate the returns across  $g$ .

The government can conduct *official* buybacks on the long-term bond at a specific price  $q_{lt}^{bb} = \frac{1}{r^{bb}}$  with  $r^{bb} < r$ .<sup>11</sup> Conversely, it can conduct *unofficial* buybacks in which it retires part of its debt at the market price,  $q_{lt} < q_{lt}^{bb}$ , without prior notice.<sup>12</sup> In both cases, the prospective value of long-term debt is such that  $\hat{b}'_{lt} \geq \hat{b}_{lt}$ .

I assume that the government cannot commit to repay the lender. If the government defaults, it loses access to the capital and bond market. It subsequently consumes  $\hat{c}(z) = zf(0) > 0$  but can regain access to the markets with a fixed probability  $\lambda$ . The default cost is therefore endogenous as it entirely relates to markets access. Collecting all the assumptions,

**Assumption 1** (General Settings). *The risk neutral lender discounts at rate  $\frac{1}{1+r}$ . The risk averse government has a utility function  $u(\hat{c}_t) = \frac{\hat{c}_t^{1-\sigma}}{1-\sigma}$  with  $\sigma > 0$  and discounts at rate  $\beta < \frac{1}{1+r}$ . The growth shock  $g \in G \equiv \{g_L, g_H\}$  follows an Markovian process of order one with  $0 < g_L < 1 < g_H$ ,  $(\frac{g_H}{g_L})^{-\sigma} > \beta(1+r)$ ,  $\pi(g|g) > 0.5$  and  $\beta(1+r)g^{-\sigma} \leq 1$  for all  $g \in G$ . The foreign production technology is continuous, increasing, concave, satisfies the Inada condition,  $\lim_{\hat{k} \rightarrow 0} f_{\hat{k}}(\hat{k}) = \infty$ , and  $f(0) > 0$ . Capital depreciates at rate  $\delta = 1$ .*

The timing of actions is the following. At the beginning of each period  $t \geq 0$ , the growth shock,  $g_t$ , realizes and the lender provides  $\hat{k}_t$ . Subsequently, domestic production takes place, capital depreciates and the government determines the debt repayment – including potential *official* buybacks – and the tax  $\tau_t$ . Conditional on repaying, a bond auction determines  $\hat{b}_{st,t+1}$  and  $\hat{b}_{lt,t+1}$ .<sup>13</sup> Note that, if  $\hat{b}_{st,t+1} > 0$ , the lender is in fact a short-term borrower and is the one auctioning to raise resources.

I present in the main text the detrended version of the model. I detrend the different variables by dividing them by  $z_{t-1}$ . For instance, I denote  $c_t$  as the detrended form of  $\hat{c}_t$  such that  $c_t = \frac{\hat{c}_t}{z_{t-1}}$ . Note that given the assumed utility form,  $u(\hat{c}_t) = z_{t-1}^{1-\sigma} u(c_t)$ .

<sup>11</sup>The fact that *official* buybacks are settled above the risk-free price is consistent with the evidence that buybacks are costly for sovereign borrowers (Bulow and Rogoff, 1988, 1991).

<sup>12</sup>This is what Cohen and Verdier (1995) call a secret buyback.

<sup>13</sup>This timing rules out self-fulfilling debt crises (Ayres et al., 2018).



### 3 The Market Economy

In this section, I define the set of sustainable equilibrium outcome in the market economy following the approach of [Abreu \(1988\)](#) and [Chari and Kehoe \(1990\)](#). The state space accounts for the entire history of play. Using the reversion to the worst equilibrium, it is possible to sustain many different equilibrium outcomes.

#### 3.1 The Government's problem

Define  $D_t \in \{0, 1\}$  as the government's default policy at time  $t$ . If  $D_t = 0$ , the government repays, while if  $D_t = 1$ , it defaults. Similarly, define  $M_t \in \{0, 1\}$  as the government's *official* buyback policy at time  $t$ . If  $M_t = 1$ , the government officially buys its debt back, while if  $M_t = 0$ , it does not.

In addition, define the set of government's choices as  $\mathcal{G}_t = \{D_t, M_t, b_{st,t+1}, b_{lt,t+1}, \tau_t\}$  and the government's strategy as  $\sigma_b$ . Furthermore, let  $h^t = (h^{t-1}, g_t, p_t, k_t, \mathcal{G}_t)$  denote the history up to time  $t$  taking the initial debt  $b_{st,0}$  and  $b_{lt,0}$  as well as capital  $k_0$  as given. Due to the specific timing of actions, further define the history of the lender and the government for debt as  $h_l^t = (h^{t-1}, g_t, p_t, k_t, \mathcal{G}_t)$  and  $h_b^t = (h^{t-1}, g_t, p_t, k_t)$ , respectively. I also define the history of capital as  $h_k^t = (h^{t-1}, g_t, p_t)$ .

In the case in which the government decides to repay (i.e.  $D_t = 0$ ), it determines its consumption and prospective borrowing given the realization of the history  $(h_b^t, g_t)$ . In the case of no *official* buyback (i.e.  $M_t = 0$ ), the budget constraint in detrended form reads

$$c_t + q_{st}(h_b^t, \mathcal{G}_t)g_t b_{st,t+1} + q_{lt}(h_b^t, \mathcal{G}_t)(g_t b_{lt,t+1} - b_{lt,t}) = y(g_t, p_t, k_t, \tau_t) + b_{st,t} + b_{lt,t}.$$

There is no restriction on the issue of long-term debt meaning that the government can potentially conduct *unofficial* buybacks. Conversely, in the case of an *official* buyback (i.e.  $M_t = 1$ ), budget constraint is given by

$$c_t + q_{st}(h_b^t, \mathcal{G}_t)g_t b_{st,t+1} + q_{lt}(h_b^t, \mathcal{G}_t)g_t b_{lt,t+1} = y(g_t, p_t, k_t, \tau_t) + b_{st,t} + b_{lt,t}(1 + q_{lt}^{bb}) \wedge b_{lt,t+1} \geq b_{lt,t}.$$

The government retires the current long-term bond,  $b_{lt,t}$ , at  $q_{lt}^{bb} = \frac{1}{r^{bb}}$  with  $r^{bb} < r$  and issues new long-term debt such that  $b_{lt,t+1} \geq b_{lt,t}$ . Conversely, if the government decides to default (i.e.  $D_t = 1$ ), it gets excluded from the markets and consumes the after-tax income

$$c_t = y(g_t, p_t, k_t, \tau_t).$$

Due to the specific timing of capital, the government enjoys  $k_t \geq 0$  in the first period of



autarky and then  $k_t = 0$ . The outstanding debt is restructured with probability  $\lambda$ . Upon restructuring, the government can regain access to the market. In this case,

$$c_t + q_{st}(h_b^t, \mathcal{G}_t)g_t b_{st,t+1} + q_{lt}(h_b^t, \mathcal{G}_t)g_t b_{lt,t+1} = y(g_t, p_t, 0, \tau_t) + W_t \left[ 1 + \frac{1+r}{r} \right].$$

Once the government paid the recovery value  $W_t[1 + \frac{1+r}{r}]$ , there is no remaining liabilities left. Again, due to the specific timing of actions, the government regains access to the capital market after the debt restructuring.

After any history  $(h_b^t, g_t)$ , the optimal strategy of the government,  $\sigma_b$ , is the solution of

$$W^b(h_b^t, g_t) = \max_{\mathcal{G}_t = \{b_{st,t+1}, b_{lt,t+1}, \tau_t, D_t, M_t\}} u(c_t) + \beta g_t^{1-\sigma} \mathbb{E} \left[ W^b(h_b^{t+1}, g_{t+1}) \middle| h_b^t, \mathcal{G}_t \right], \quad (1)$$

subject to the budget constraint.

### 3.2 Sustainable equilibria

This subsection aims at defining and characterizing the set of sustainable equilibria. The lender is competitive meaning that in expectations it makes zero profit. The price of one unit of bond can therefore be separated into two parts: the return when the government decides to repay and the recovery value when the government defaults. The price per unit of bond of maturity  $j$  for all  $j \in \{st, lt\}$  is given by,

$$q_j(h^t) = \mathbb{E} \left[ (1 - D(h^{t+1}))q_j^P(h^{t+1}) + D(h^{t+1})q_j^D(h^{t+1}) \middle| h_b^t, \mathcal{G}_t \right]. \quad (2)$$

If the government decides to default, the recovery value for all  $j \in \{st, lt\}$  is

$$q_j^D(h^t) = \frac{1}{1+r} \mathbb{E} \left[ (1 - \lambda)q_j^D(h^{t+1}) + \lambda \frac{W_t \frac{1+r}{1+r-\mathbb{I}_{j=lt}}}{b_{j,t}} \middle| h_b^t, \mathcal{G}_t \right],$$

where  $\mathbb{I}_{j=lt}$  is an indicator function taking value one if  $j = lt$  and zero otherwise. If the government restructures its debt, the lender receives  $\frac{W_t \frac{1+r}{1+r-\mathbb{I}_{j=lt}}}{b_{j,t}}$  per unit of bond issued. Conversely, if it does not restructure, the government does not disburse anything now, but in present value it pays  $q_j^D(h^{t+1})$ .

In case of repayment, the price depends on the maturity structure and the *official* buyback decision. For the one-period bond,

$$q_{st}^P(h^t) = \frac{1}{1+r},$$

while for the long-term bond,

$$q_{lt}^P(h^t) = \frac{1}{1+r} \mathbb{E} \left[ 1 + (1 - M(h^{t+1}))q_{lt}(h^{t+1}) + M(h^{t+1})q_{lt}^{bb} \middle| h_b^t, \mathcal{G}_t \right],$$

where  $q_{lt}^{bb} = \frac{1}{r^{bb}}$  with  $r^{bb} < r$  is the *official* buyback rate. Having properly determined the price, I can define the a sustainable equilibrium in the market economy.

**Definition 1** (Sustainable Equilibrium). *Given  $\{b_{j,0}\}_{j \in \{st,lt\}}$  and  $k_0$ , a sustainable equilibrium in this environment consists of*

- *Strategy for the government,  $\sigma_b$ .*
- *Policy for the firm's capital,  $k$ .*
- *Price schedule for capital,  $p$ , and for bonds,  $q_{st}$  and  $q_{lt}$ .*

*such that*

1. *Taking  $p$ ,  $q_{st}$  and  $q_{lt}$  as given,  $\sigma_b$  is the solution to (1).*
2. *Taking  $p$  as given, the choice of capital by domestic firms is such that*

$$\mathbb{E} \left[ u_c(c(h_b^t, g_t))(gf_k(k(h^t)) - p(h^t)) \middle| h_k^t \right] = 0. \quad (3)$$

3. *Taking  $\sigma_b$  as given, the price of capital is consistent with*

$$\max_{k_t} \mathbb{E} \left[ p(1 - \tau(h_b^t, g_t))k_t - k_t \middle| h^t \right]. \quad (4)$$

4. *The price of bonds satisfy (2).*

Following the approach of [Abreu \(1988\)](#) and [Chari and Kehoe \(1990\)](#), I characterize the set of outcomes that can be sustained in equilibrium using reversion to the worst equilibrium. The following lemma shows that permanent autarky is the worst equilibrium outcome.

**Lemma 1** (Worst Equilibrium Outcome). *In this environment, the worst possible outcome is permanent autarky which can be supported as an equilibrium.*

*Proof.* See Appendix [E](#) □

Keeping track of the entire history of play, I can sustain many different equilibrium outcome relying on trigger strategies. I now focus on two specific types of equilibria: Markov equilibria which do not build on past histories and the constrained efficient equilibrium which generally relies on past histories and is the best achievable outcome in this environment.

## 4 Markov Debt Management

In this section, I derive the Markov debt management policies. I consider the optimal debt management with and without default incentives. I finally provide foundation for the use of Markov strategies by the market participants.

### 4.1 Markov equilibrium with default incentives

Markov equilibria rely on memoryless strategies conditioned on the state which only encodes payoff-relevant information (Maskin and Tirole, 2001). In this environment, the payoff-relevant state is  $\Omega \equiv (g, b_{st}, b_{lt})$ . All Markov equilibria are sustainable equilibria as they restrict the information set to  $\Omega_t \subset h^t$  for any  $t > 0$ .<sup>14</sup> However, the opposite is not true.

The Markov equilibrium with default incentives is a version of Arellano and Ramarayanan (2012) with growth shock and endogenous default cost. The government's overall beginning of the period value is given by

$$V(\Omega) = \max_{D \in \{0,1\}} \left\{ (1-D)V^P(\Omega) + DV^D(g) \right\}, \quad (5)$$

where  $V^P$  and  $V^D$  correspond to the value of repayment and default, respectively. Under repayment, the government chooses whether to conduct *official* buybacks. Thus

$$V^P(\Omega) = \max_{M \in \{0,1\}} \left\{ (1-M)V^{NB}(\Omega) + MV^B(\Omega) \right\}, \quad (6)$$

where  $V^B$  and  $V^{NB}$  are the values under *official* buyback and no *official* buyback, respectively. If the government decides to officially repurchase its long-term debt,

$$\begin{aligned} V^B(\Omega) &= \max_{\tau, b'_{st}, b'_{lt}} u(c) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} [V(\Omega')] \\ \text{s.t.} \quad &c + q_{st}(g, b'_{st}, b'_{lt})gb'_{st} + q_{lt}(g, b'_{st}, b'_{lt})gb'_{lt} = y(g, p, k, \tau) + b_{st} + b_{lt}(1 + q_{lt}^{bb}), \\ &b'_{lt} \geq b_{lt}. \end{aligned}$$

Conversely, under no *official* buyback,

$$\begin{aligned} V^{NB}(\Omega) &= \max_{\tau, b'_{st}, b'_{lt}} u(c) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} [V(\Omega')] \\ \text{s.t.} \quad &c + q_{st}(g, b'_{st}, b'_{lt})gb'_{st} + q_{lt}(g, b'_{st}, b'_{lt})(gb'_{lt} - b_{lt}) = y(g, p, k, \tau) + b_{st} + b_{lt}. \end{aligned}$$

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<sup>14</sup>See Definition E.5 in Appendix E for a formal definition of a Markov equilibrium.

Under default, the government is excluded from the capital and bond markets. It subsequently needs to restructure its debt. The value under default is given by

$$V^D(g) = \max_{\tau} u(y(g, p, k, \tau)) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} \left[ (1 - \lambda) V^D(g') + \lambda V^E(g') \right], \quad (7)$$

and the value upon restructuring corresponds to

$$\begin{aligned} V^E(g) &= \max_{\tau, b'_{st}, b'_{lt}} u(c) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} \left[ V(\Omega') \right] \\ \text{s.t.} \quad &c + q_{st}(g, b'_{st}, b'_{lt}) g b'_{st} + q_{lt}(g, b'_{st}, b'_{lt}) g b'_{lt} = y(g, p, 0, \tau) + W \left[ 1 + \frac{1+r}{r} \right]. \end{aligned}$$

To avoid redundancy with the previous section, the pricing equations and the equilibrium definition are presented in Appendix A.

The government is tempted to tax capital only in the case of default. It therefore sets  $\tau = 1$  if  $D(\Omega) = 1$  as it loses access to the capital market in the next period. However, it sets  $\tau = 0$  if  $D(\Omega) = 0$  as any tax on capital would directly reduce the small open economy's output. It does not internalize the fact that more  $k$  raises the value of autarky. The lender therefore provides  $k$  such that  $gf_k(k) = 1$  if  $D(\Omega) = 0$  and  $k = 0$  otherwise.

In terms of debt management, this equilibrium concept is the closest to what is observed in most developing economies. On the one hand, defaults arise when growth is low ([Arellano and Ramanarayanan, 2012](#)). This is true even in the case of endogenous default cost as the level of capital is the lowest when  $g_L$  realizes. However, unlike defaults, *official* buybacks do not arise on equilibrium path. The government does not internalize the impact of *official* debt repurchase on the bond price. *Official* buybacks therefore never occur as they only incur costs to the borrower. *Unofficial* buybacks can arise on equilibrium path, though. On the other hand, maturity shortens during debt crises. The repayment of long-term debt is laddered through multiple periods which implies a greater default risk than the short-term debt. As a result, close to default, the long-term debt price drastically drops which encourages shorter maturity ([Arellano and Ramanarayanan, 2012](#)).<sup>15</sup> Thus, defaults coupled with the maturity structure provides some form of state contingency.

In Section 5, I use the value under default as the optimal contract's outside option. Thus, the Markov equilibrium with default incentives represents the reference point for comparing the different equilibria analyzed in this paper.

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<sup>15</sup>As shown by [Niepelt \(2014\)](#), this result is also a consequence of the fact that a default implicates both the long-term and the short-term debt.

## 4.2 Markov equilibrium without default incentives

I now consider the Markov equilibrium without default incentives. The aim is to introduce an endogenous borrowing constraint that ensures no default on equilibrium path. I consider two types of constraints: a non-contingent and a contingent one. The former is defined as

$$b'_{st} + b'_{lt} \geq \min_{g' \in G} \left\{ (b'_{st} + b'_{lt}) : V^P(\Omega') = V^D(g') \right\}. \quad (8)$$

This limit ensures that the government is never able to accumulate a level of debt for which a default would be optimal. This is what [Zhang \(1997\)](#) defines as a no-default borrowing constraint.

The above constraint is relatively unsophisticated, though. Especially, it does not allow for much risk sharing. With the market structure at hand, it is possible to create some state contingency through *official* buybacks. However, since agents rely on Markov strategies, I cannot condition *official* buybacks on the history of play. Instead, I consider a simple rule stating that such debt repurchase occur only when  $g = g_H$ . Formally,

$$M(\Omega) = \begin{cases} 1 & \text{if } g = g_H. \\ 0 & \text{else} \end{cases}$$

Given this, the long-term debt becomes a pseudo Arrow security as it pays out more in the high growth state than in the low growth state.<sup>16</sup> With this, I can define an endogenous borrowing limit in the form of

$$\begin{aligned} b'_{st} + b'_{lt}[1 + q_{lt}(g_L, b''_{st}, b''_{lt})] &\geq \mathcal{B}(g_L), \\ b'_{st} + b'_{lt}[1 + q_{lt}^{bb}] &\geq \mathcal{B}(g_H), \end{aligned} \quad (9)$$

where the borrowing limit is defined such that

$$\begin{aligned} V^P(g_L, b'_{st}, b'_{lt}) &= V^D(g_L) \quad \text{for all } b'_{st} + b'_{lt}[1 + q_{lt}(g_L, b''_{st}, b''_{lt})] = \mathcal{B}(g_L). \\ V^P(g_H, b'_{st}, b'_{lt}) &= V^D(g_H) \quad \text{for all } b'_{st} + b'_{lt}[1 + q_{lt}^{bb}] = \mathcal{B}(g_H). \end{aligned}$$

The definition of the endogenous borrowing limit is the one of [Alvarez and Jermann \(2000\)](#). It plays the same role as (8) with the difference that it allows for some risk sharing between the two growth states.<sup>17</sup>

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<sup>16</sup>I could have conditioned the *official* buyback on a specific portfolio of debt too. However, it is not clear *ex ante* whether such portfolio is attained with positive probability on equilibrium path.

<sup>17</sup>With the above *official* buyback policy and the fact that  $q_{lt}^{bb} > \frac{1}{r}$ , in equilibrium,  $q_{lt}(g_H, b_{st}, b_{lt}) =$

The buyback policy implies that  $b'_{lt} \geq b_{lt}$  whenever  $g = g_H$ . Hence, long-term debt holdings reduce as growth is high. Conversely, there are no direct restrictions on the holdings of short-term debt except that (9) has to hold. Note further that, as there is no default on equilibrium path,  $k = k^*(g)$ .

Provided that the lender has commitment, it will be the agent capable of implementing and enforcing the above borrowing constraints. In the case of non-contingent borrowing limit, the lender simply provides bonds as long as (8) holds. The same holds true for the state-contingent borrowing limit with the additional requirement that the government implements the appropriate buyback policy. Nevertheless, as the borrower does not internalize the price effect of *official* buybacks, the lender needs to enforce those. In a Markov equilibrium, enforcement should be contingent on  $\Omega$  only. To show how this can be achieved, I first define a borrowing Markov equilibrium.

**Definition 2** (Borrowing Markov Equilibrium). *Define  $h_{st}(\Omega) = b'_{st}$  and  $h_{lt}(\Omega) = b'_{lt}$  as the short-term and long-term bond policy, respectively. A borrowing Markov equilibrium is such that  $h_{st}(\Omega) \leq b_{st}$  and  $h_{lt}(\Omega) \leq b_{lt}$  for all  $\Omega$ .*

Given this definition, the lender can enforce *official* buybacks in a Markov borrowing equilibrium if there are no short-term assets and *official* buybacks are not too costly.

**Lemma 2** (Official Buyback Enforcement). *Under Assumption 1, if and only if  $b_{st} < 0$  and  $r > r^{bb} \geq \frac{(1+r)r}{1+2r}$ , official buybacks are enforceable in a borrowing Markov equilibrium.*

*Proof.* See Appendix E □

The rationale behind this result is that the lender is the second mover. Hence, it can threaten the government not to roll over debt if the above buyback policy is violated. Obviously, this threat is credible only if the borrower does not possess any assets and *official* buybacks are not too costly. This result can be interpreted as the standard no-saving argument of Bulow and Rogoff (1989) applied to *official* buybacks.

Lemma 2 imposes strong requirements for *official* buybacks to be enforceable with Markov strategies. As one will see in Section 5, the implementation of the constrained efficient allocation might violate such conditions, justifying the use of history-dependent strategies.

Besides this, I can show that the Markov equilibrium with a state-contingent no-default constraint is a better borrowing equilibrium than the one with default incentives.<sup>18</sup>

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$q_{lt}(g_H) > q_{lt}(g_L) = q_{lt}(g_L, b_{st}, b_{lt})$  for all  $(b_{st}, b_{lt})$ .

<sup>18</sup>Given that there is no proper dilution in the Markov equilibrium without default risk, it is not guaranteed that this equilibrium is superior to the one with default risk when Definition 2 is not satisfied.

**Proposition 1** (Superior Markov Equilibrium). *Under Assumption 1,  $b_{st} < 0$  and  $r > r^{bb} \geq \frac{(1+r)r}{1+2r}$ , the government (lender) is weakly (strictly) better off in the Markov borrowing equilibrium without default incentives than in the one with.*

*Proof.* See Appendix E □

The borrowing Markov equilibrium without default incentives is therefore Pareto superior. The rationale behind this proposition is the following. First, the government cannot do worse than the Markov equilibrium with default incentives given that (9) holds. Second, as the buyback price is above the risk-free price and there is no default on equilibrium path, the lender's value is strictly greater here than in the previous Markov equilibrium. Hence, buybacks provide a better source of risk sharing than defaults. The analysis in Section 5 later confirms this point and explains why this is the case.

### 4.3 Foundation of Markov equilibria

In light of section 3, the Markov equilibrium is a relatively unsophisticated equilibrium concept as it does not build on past history. However, interpreting the government as a short-run player, I show that small perturbations in the payoff of both market participants rule out any equilibria except Markov ones.<sup>19</sup> In other words, under bounded memory of at least one of the market participants, Markov equilibria are the only equilibria surviving small and independent idiosyncratic utility shocks.

Given that  $\beta(1+r) < 1$ , the government is relatively more impatient than the lender. This assumption is standard in the literature on sovereign debt. Not only it is necessary to obtain empirically plausible debt ratios, it is also a property inherited from the general equilibrium analysis and the martingale convergence theorem. In addition, impatience has implications in terms of political economy. It is reduced form for the fact that governments are subject to re-elections and might lose office with positive probability (Alesina and Tabellini, 1990). In this situation, the government can be interpreted as a short-term player whose recollection of past actions is bounded.<sup>20</sup> In other words, the memory of the government's memory goes back to a certain number of periods  $\mathcal{T} < \infty$ .

Besides the boundedness of the government's memory, I introduce a small perturbation in the existing environment. Following Bhaskar et al. (2012) and Angeletos and Lian (2021), in each period  $t$ , a utility shock  $\epsilon_{\varrho_{b,t}}$  and  $\epsilon_{\varrho_{l,t}}$  with  $\epsilon > 0$  is drawn for the government and the lender, respectively. It has compact support  $P_i \subset \mathbb{R}^{|A_i|}$  with absolutely continuous

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<sup>19</sup>I consider here that the lender is a long-run player. However this is without loss of generality. The result holds as long as at most one market participant has unbounded memory.

<sup>20</sup>See also Levy and Razin (2021) who explain political polarization through short-term memory.



density  $\mu_{P_i} > 0$  where  $|A_i|$  is the cardinality of the choice set of market participant  $i \in \{b, l\}$ . Moreover, it is independently distributed across market participants, histories and other shocks. If the market participant  $i \in \{b, l\}$  chooses a particular action, say  $d \in A_i$ , its utility is augmented by  $\epsilon \varrho_{i,t}^d$ . For instance, the instantaneous utility of the government taking action  $d$  (e.g. default) is given by  $u(c_t) + \epsilon \varrho_{b,t}^d$ . Finally, utility shock  $\epsilon \varrho_{i,t}$  is privately observed by market participant  $i \in \{b, l\}$ .

**Assumption 2** (Perturbed Bounded Memory). *The government's memory is bounded to  $\mathcal{T} \in (0, \infty)$  periods in the past. Plus, in each  $t$ , a utility shock  $\epsilon \varrho_{i,t}$  with  $\epsilon > 0$  is drawn from the compact support  $P_i \subset \mathbb{R}^{|A_i|}$  with absolutely continuous and i.i.d. density  $\mu_{P_i} > 0$  for each  $i \in \{b, l\}$ . The utility shock is additive, privately observed and depends on the action taken.*

Given this functional form, the case considered in Section 3 corresponds to  $\epsilon = 0$  and  $\mathcal{T} = \infty$ . The case of perturbed bounded memory boils down to what happens when  $\epsilon > 0$  but arbitrarily small and  $\mathcal{T} < \infty$ . It means that (a) the government does not recall all the past history and (b) market participants have imperfect knowledge of the other participant's fundamentals. The presence of the privately observed shock – albeit small and independent – coupled with the short-sightedness of the government prevent both participants to rely on past history. This causes all non-Markov equilibria to unravel.

**Proposition 2** (Foundation of Markov equilibria). *Under Assumption 2, all non-Markov equilibria unravel.*

*Proof.* See Appendix E □

The rationale behind that result follows Bhaskar (1998) and Bhaskar et al. (2012). Suppose the lender conditions its action at time  $t$  on a payoff-irrelevant past event, then the government must also condition on this past event. In equilibrium, such conditioning is only possible if both the lender and the government keep track of the entire history of play. In other words, the knowledge of past values of  $\varrho_b$  is necessary for the lender to appropriately reward or punish the government. Similarly, the government needs to know the previous values of  $\varrho_l$  to appropriately respond. Thus, all history-dependent equilibria unravel as soon as those utility shocks are unobserved and  $\mathcal{T}$  is finite.

This result has two main consequences. First, I am left with two extremes: both parties either build on the entire (infinite) history of play or do not at all. Second, the constrained efficient allocation can often only be approximated by means of Markov strategies. This relates to Maskin and Tirole (2001) who show that there always exists a Markov equilibrium in the vicinity of the unperturbed initial equilibrium. In view of this, in Section 6, I quantitatively assess how close Markov equilibria are from the constrained efficient allocation.

## 5 Constrained Efficient Debt Management

This section presents the constrained efficient debt management policies. I first derive the optimal contract by means of the Lagrangian approach (Marcet and Marimon, 2019) and subsequently characterize the underlying constrained efficient allocation before implementing it the market economy.

### 5.1 The optimal contract

In what follows I derive the optimal contract which has to account for limited enforcement in repayment. The participation constraint deals with the fact that the borrower can always break the contract and opt for autarky (Thomas and Worrall, 1994). Denoting  $g^t$  as the history of realized value of  $g$  at time  $t$ , it must hold that for all  $t$  and  $g^t$

$$\sum_{j=t}^{\infty} \beta^{j-t} \sum_{g^j} \pi(g^j|g_t) \mathcal{G}_j(g_t) u(c(g^j)) \geq V^D(g_t, k_t), \quad (10)$$

with  $\mathcal{G}_t(g_0) \equiv (g_0 g_1 \cdots g_{t-1})^{1-\sigma} = \prod_{i=0}^{t-1} g_i^{1-\sigma}$ . If the borrower breaks the contract, the government is sent to autarky for some time but can regain access to the market with probability  $\lambda$  and resume the Markov equilibrium with default incentives.  $V^D(g_t, k_t)$  therefore corresponds to the value of default in the Markov equilibrium given by equation (7). Note that I write  $V^D(g_t, k_t)$  instead of  $V^D(g_t)$  to make explicit the dependence on  $k_t$ . As a result, the participation constraint ensures that the borrower's value of remaining in the contract is at least as large as the value of opting out.

Given the above constraint, the optimal contract between the borrower and the lender in sequential form is the result of

$$\begin{aligned} & \max_{\{k(g^t), c(g^t)\}_{t=0}^{\infty}} \mu_{b,0} \sum_{t=0}^{\infty} \beta^t \sum_{g^t} \pi(g^t|g_0) \mathcal{G}_t(g_0) u(c(g^t)) + \mu_{l,0} \sum_{t=0}^{\infty} \left( \frac{1}{1+r} \right)^t \sum_{g^t} \pi(g^t|g_0) \prod_{i=0}^{t-1} g_i T(g^t) \\ & \text{s.t.} \quad \sum_{j=t}^{\infty} \beta^{j-t} \sum_{g^j} \pi(g^j|g_t) \mathcal{G}_j(g_t) u(c(g^j)) \geq V^D(g_t, k_t), \\ & \quad T(g^t) = g_t f(k(g^t)) - c(g^t) - k(g^t), \quad \forall g^t, t \\ & \quad \text{with } \mu_{b,0} \text{ and } \mu_{l,0} \text{ given.} \end{aligned}$$

The given weights  $\mu_{b,0}$  and  $\mu_{l,0}$  are the initial non-negative Pareto weights assigned by the Planner to the borrower and the lender, respectively.

The Planner allocates capital and consumption to maximize the lender's and the bor-

rower's weighted utility subject to the resource constraint and the participation constraint. The above maximization problem combines the utility function  $u(\cdot)$  with the production function  $f(\cdot)$  and therefore might not be convex.

**Assumption 3** (Convexity). *Define the optimal level of capital  $k^*(g)$  such that  $gf_k(k^*(g)) = 1$  and  $h := gf(k) - k$  for  $k \in [0, k^*(g)]$  with  $h^*(g) = gf(k^*(g)) - k^*(g)$ . Let  $K(h)$  denote the inverse mapping from  $[0, h^*(g)]$  to  $[0, k^*(g)]$  such that  $k = K(h)$ . For all  $g \in G$ ,  $u(gf(k(h)))$  is convex in  $h$  for  $h \in [0, h^*(g)]$ .*

Following, [Aguilar et al. \(2009\)](#), Assumption 3 ensures that there is no need for randomization whenever the curvature of  $u(\cdot)$  and  $f(\cdot)$  is not too pronounced.

I now derive the recursive formulation of the above maximization problem. Following [Marcet and Marimon \(2019\)](#), I rewrite the sequential problem as a saddle-point Lagrangian problem,

$$\begin{aligned}
\mathcal{SP} \quad & \min_{\{\gamma(g^t)\}_{t=0}^\infty} \max_{\{k(g^t), c(g^t)\}_{t=0}^\infty} \sum_{t=0}^\infty \beta^t \sum_{g^t} \pi(g^t|g_0) \mu_{b,t}(g^t) \mathcal{G}_t(g_0) u(c(g^t)) \\
& + \sum_{t=0}^\infty \left( \frac{1}{1+r} \right)^t \sum_{g^t} \pi(g^t|g_0) \mu_{l,t}(g^t) \prod_{i=0}^{t-1} g_i T(g^i) \\
& + \sum_{t=0}^\infty \beta^t \sum_{g^t} \pi(g^t|g_0) \gamma(g^t) \left[ \mathcal{G}_t(g_0) u(c(g^t)) - V^D(g_t, k_t) \right] \\
\text{s.t.} \quad & T(g^t) = g_t f(k(g^t)) - c(g^t) - k(g^t), \\
& \mu_{b,t+1}(g^t) = \mu_{b,t}(g^t) + \gamma(g^t), \\
& \mu_{l,t+1}(g^t) = \mu_{l,t}(g^t), \quad \forall g^t, t \\
& \text{with } \mu_{b,0}(g_0) \equiv \mu_{b,0} \text{ and } \mu_{l,0}(g_0) \equiv \mu_{l,0} \text{ given.}
\end{aligned}$$

In this formulation,  $\beta^t \pi(g^t|g_0) \mathcal{G}_t(g_0) \gamma(g^t)$  is the Lagrange multiplier attached to the participation constraint of the borrower at time  $t$ . The above formulation of the problem defines two new co-state variables,  $\mu_{b,t}(g^t)$  and  $\mu_{l,t}(g^t)$ , which are the temporary non-negative Pareto weights the Planner attributes to the borrower and the lender, respectively. These variables are initialized at the original Pareto weights and subsequently become recursive.

Following [Ábrahám et al. \(2019\)](#), I further simplify the above problem. I define the relative Pareto weight of the borrower as

$$x_t(g^t) = \frac{\mu_{b,t}(g^t)}{\mu_{l,t}(g^t)},$$

Given the non-negativity and boundedness of the Lagrange multipliers,  $x \in X \equiv [\underline{x}, \bar{x}]$  with  $\underline{x} \geq 0$  and  $\bar{x} < \infty$ .<sup>21</sup> Defining  $\eta \equiv \beta(1+r) \leq 1$  and  $\nu(g^t) \equiv \frac{\gamma(g^t)}{\mu_{b,t}(g^t)}$ , the law of motion of the different relative Pareto weight is given by

$$x_{t+1}(g^t) = (1 + \nu(g^t))g_t^{-\sigma}\eta x_t \text{ with } x_0 = \frac{\mu_{b,0}}{\mu_{l,0}}$$

With this normalization,  $\nu(g^t)$  represents the multiplier attached to the participation constraint. Following [Marcet and Marimon \(2019\)](#), the state vector for the problem reduces to  $(g, x)$  and the Saddle-Point Functional Equation is given by

$$FV(g, x) = \mathcal{SP} \min_{\nu(g)} \max_{k(g), c(g)} x \left[ (1 + \nu(g))u(c(g)) - \nu(g)V^D(g, k) \right] \quad (11)$$

$$\begin{aligned} & + T(g) + \frac{1}{1+r}g \sum_{g'} \pi(g'|g)FV(g', x') \\ \text{s.t. } & T(g) = gf(k(g)) - c(g) - k, \\ & x'(g) = (1 + \nu(g))g^{-\sigma}\eta x \quad \forall g. \end{aligned} \quad (12)$$

The value function takes the form of

$$\begin{aligned} FV(g, x) &= xV^b(g, x) + V^l(g, x), \text{ with} \\ V^b(g, x) &= u(c(g)) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} [V^b(g', x')], \\ V^l(g, x) &= T(g) + \frac{1}{1+r}g \mathbb{E}_{g'|g} [V^l(g', x')]. \end{aligned}$$

I obtain the optimal consumption and capital policies by taking the first-order conditions of problem (11) with regard to respectively  $c$  and  $k$

$$u_c(c(g)) = \frac{1}{x(1 + \nu(g))} \quad \text{and} \quad gf_k(k(g)) - 1 = \nu(g)u_c(gf(k(g)))gf_k(k(g))x.$$

In terms of consumption, the binding participation constraint of the borrower (i.e.  $\nu > 0$ ) induces an increase in consumption.

Regarding capital, the economy does not reach the production-maximizing level of capital  $k^*(g)$  as long as the participation constraint binds in  $g$ . Furthermore, the more this constraint binds, the more distorted is capital.

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<sup>21</sup>I later show that setting  $\underline{x} \geq 0$  this is without loss of generality as the continuation of an efficient allocation is itself efficient.

## 5.2 Equilibrium properties

I characterize the main properties of the contract. I first determine the Pareto frontier in this environment. I subsequently present how the contract provides risk sharing across states. Finally, I show how the contract's allocation can be implemented as a sustainable equilibrium in the market economy. Additional characterization can be found in Appendix B.

**Proposition 3** (Efficiency). *Under Assumptions 1 and 3, for all  $x \in X$ , the utility possibility frontier is strictly increasing and the autarkic allocation is not optimal.*

*Proof.* See Appendix E □

The proposition is made of two parts. First, autarky (i.e.  $k = 0$ ) is not optimal. Due to the Inada conditions on the production function, there are strictly positive gains from trade between the borrower and the lender. This means that defaults – which imply markets exclusion – cannot implement the Planner's constrained efficient allocation.

Second, the proposition states that the optimal contract is constrained efficient which makes it the best achievable outcome in this environment. Hence, the debt management policies that I later derive from the optimal contract are the (constrained) efficient ones.

The following proposition defines the main properties of the constrained efficient allocation. The contract features production distortions and risk sharing.

**Proposition 4** (Constrained Efficient Allocation). *Under Assumptions 1 and 3, the allocation is such that*

- I. (Production). *There exists a level of relative Pareto weight  $x^*(g)$  such that  $k(g, x) = k^*(g)$  for  $x \geq x^*(g)$  and  $x^*(g_H) > x^*(g_L)$ . Conversely, for all  $x, \tilde{x} \in X$  with  $x^*(g) > x > \tilde{x}$ ,  $0 < k(g, \tilde{x}) < k(g, x) < k^*(g)$ .*
- II. (Risk-Sharing).  *$c(g_L, x) \leq c(g_H, x)$  and  $x'(g_L, x) \leq x'(g_H, x)$  for all  $x$  with equality when  $x \geq x^*(g_H)$ .*
- III. (Liabilities).  *$V^l(g_L, x) < V^l(g_H, x)$  for all  $x$ .*

*Proof.* See Appendix E □

Part I of the above proposition states that the production-maximizing level of capital  $k^*(g)$  such that  $gf_k(k^*(g)) = 1$  is attained only if the relative Pareto weight,  $x$ , is above a certain threshold. Capital distortion is a consequence of binding participation constraint (10). As this constraint depends on the level of capital in the economy, the Planner finds optimal to reduce  $k$  to relax it and to provide risk sharing to the extent possible. It continues

to decrease  $k$  as long as  $x$  decreases but never finds optimal to set  $k = 0$ . This mechanism is absent in the Markov equilibria as the borrower does not internalize the impact of  $k$  on the default incentives.

Part II states that the Planner always provides risk sharing to the extent possible. Equalization of consumption is possible whenever the borrower's participation constraint ceases to bind. Otherwise, the Planner provides more consumption and a greater continuation value when the high growth state realizes.

Part III relates to the liabilities of the borrower. In this environment,  $T(g)$  corresponds to the borrower's current account balance. Hence, the net present value of the lender corresponds to the net foreign asset position in the contract.<sup>22</sup> A positive value  $V^l(g, x)$  therefore indicates that the borrower owes money to the lender and in that logic the greater is this value the greater is the liabilities towards the lender. The proposition states that the liabilities increase when  $g$  is high. This implies that the Planner adopts a state-contingent policy as it provides debt relief in low growth states. This state contingency will be replicated through *official* buybacks in the market economy.

Having determined the constrained efficient allocation, I now characterize the steady state of the optimal contract. The long-term contract is characterized by an ergodic set of relative Pareto weights. The term ergodic refers to the fact that the relative Pareto weights in this set are aperiodic and recurrent with non-zero probability. In other words, the economy will move around the same set of relative Pareto weights over time and over histories.

**Proposition 5** (Steady State). *A steady state is defined by an ergodic set of relative Pareto weights  $x \in [x^{lb}, x^{ub}] \subset X$ . Under Assumptions 1 and 3, it holds that  $x'(g_H, x^{ub}) = x^{ub}$  and  $x'(g_L, x^{lb}) = x^{lb}$  and*

I. *If  $\eta g_L^{-\sigma} = 1$ , then  $x^{lb} = x^{ub} < x^*(g_H)$ .*

II. *If  $\eta g_L^{-\sigma} < 1$ , then  $x^{lb} < x^{ub} < x^*(g_H)$ .*

*Proof.* See Appendix E □

The proposition states that whenever the borrower is sufficiently patient (i.e.  $\eta g_L^{-\sigma} = 1$ ), the steady state does not display any dynamic. Conversely, whenever the borrower is relatively impatient (i.e.  $\eta g_L^{-\sigma} < 1$ ), the steady state is dynamic. Note however that when the contract hits one of the bounds, history becomes irrelevant. For instance, after a sufficiently long series of  $g_L$  ( $g_H$ ), the contract hits  $x^{lb}$  ( $x^{ub}$ ). It then stays there until  $g_H$  ( $g_L$ ) realizes

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<sup>22</sup>In the balance of payments statistics, this object is the net international investment position.

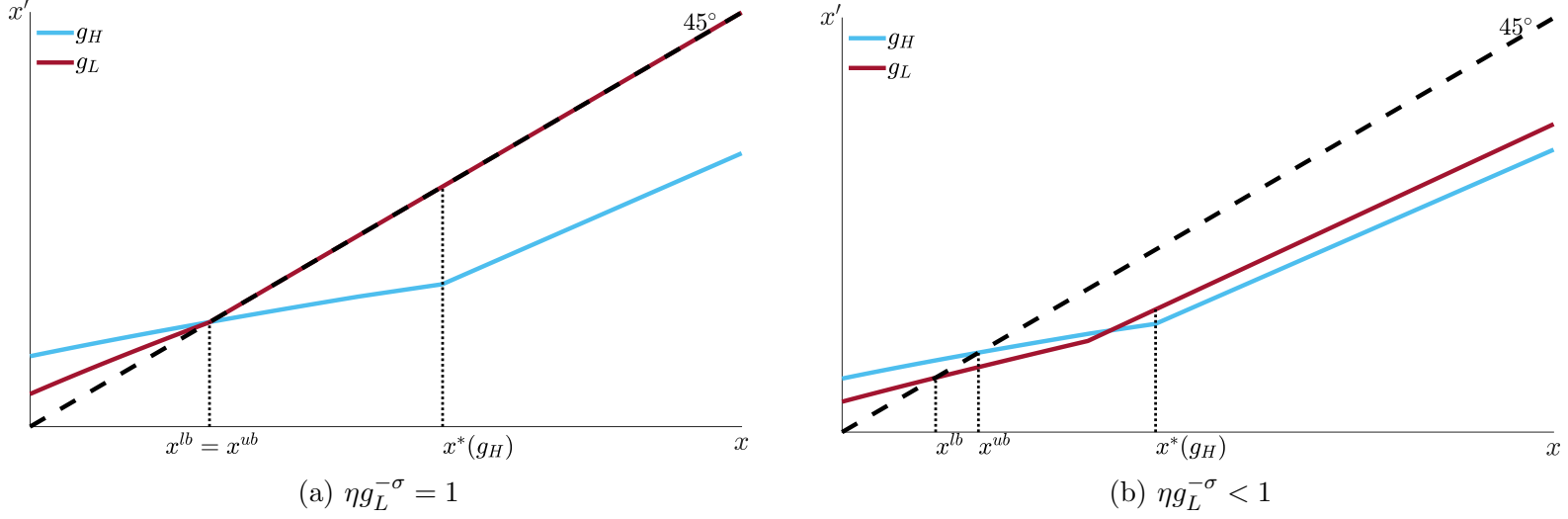


Figure 1: Steady State Dynamic

and that irrespective of the past history. The bounds of the ergodic set represent therefore regions of amnesia in the contract. Figure 1 illustrates each of the two steady states.<sup>23</sup>

### 5.3 Equilibrium implementation

Having derived and characterized the constrained efficient allocation, I am now interested in implementing the optimal contract as a sustainable equilibrium in the market economy presented in Section 3. Obviously, to replicate the constrained efficient allocation, the following conditions have to be met.

**Lemma 3** (Conditions for Implementation). *Given  $\{b_{j,0}\}_{j \in st,lt}$  and  $k_0$ , an equilibrium allocation  $\{D(g^t), M(g^t), c(g^t), k(g^t), \tau(g^t), b_{st}(g^t), b_{lt}(g^t)\}$  with prices  $\{q_{st}(g^t), q_{lt}(g^t), p(g^t)\}$  implements a constrained efficient outcome if and only if it satisfies the resource constraint, the participation constraint, (10), together with the budget constraint, the bond pricing equation, (2), the capital policy, (3), and the capital pricing equation, (4).*

*Proof.* See Appendix E □

In light of tis lemma, I construct a sustainable equilibrium in the market economy that implements the constrained efficient allocation.

**Proposition 6** (Implementation). *Under Assumptions 1 and 3, given a constrained efficient allocation, a sustainable equilibrium exists that implements it.*

<sup>23</sup>In Figure 1, the law of motion related to the high growth shock is above the one related to the low growth shock. This is possible only when  $(\frac{g_H}{g_L})^{-\sigma} > \beta(1+r)$ . Moreover,  $\beta(1+r)g^{-\sigma} \leq 1$  ensures that the law of motions eventually crosses the 45° line.



*Proof.* See Appendix E □

The implementation works as follows. The government conducts *official* buybacks when the economy hits the upper bound of the ergodic set. As this bound is reached after a sufficiently long series of high growth shocks, this buyback policy generates a specific term structure in which high growth shocks are related to relatively larger long-term bond prices than low growth shocks, while the short-term bond price remains unchanged. Given this, I can equalize the value of debt in the contract,  $V^l(g, x)$ , with the value of the debt in the market economy,  $b_{st} + b_{lt}[1 + q_{lt}]$ , for each  $(g, x)$ . As I have two growth states and two bonds, this gives a system of two equations with two unknowns which has a unique solution for each  $x$  given the specified term structure.

The implementation following Proposition 6 has many features in terms of past history, maturity, default, debt buyback, borrowing and spread:

- *History dependence.*

From (E.1) and (E.2) in Appendix E, the short-term and long-term holdings at the *official* buyback are respectively

$$\begin{aligned}\bar{b}_{st}(x) &= \frac{V^l(g_H, x)[1 + q_{lt}] - V^l(g_L, x)[1 + q_{lt}^{bb}]}{(q_{lt} - q_{lt}^{bb})}, \\ \bar{b}_{lt}(x) &= -\frac{V^l(g_H, x) - V^l(g_L, x)}{(q_{lt} - q_{lt}^{bb})}.\end{aligned}$$

From Proposition 4 Part III, it holds that  $V^l(g_H, x) > V^l(g_L, x)$  meaning that  $b_{lt} < 0$  by application of Lemma E.5. However, it is not guaranteed that  $b_{st} < 0$ . Particularly,  $b_{st}$  can be negative only if  $q_{lt}^{bb}$  is very large with respect to  $q_{lt}$ . I later show quantitatively that this requires  $r^{bb}$  to be strictly lower than  $\frac{(1+r)r}{1+2r}$ .<sup>24</sup>

Thus, Lemma 2 does not generally apply. In other words, *official* buybacks might not automatically be enforced by Markov strategies. Trigger strategies are more often than not necessary, which puts the implementation at the mercy of Proposition 2.

- *No default.*

The implementation does not rely on defaults. As previously shown, the Planner never finds optimal to distort capital to zero. This means that there is no proper markets exclusion, even when the contract hits the borrower's participation constraint. It is therefore not possible to interpret the borrower's binding constraint as a default

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<sup>24</sup>Based on the calibration in section 6, I would need  $r^{bb}$  to be at least 30 times lower than  $\frac{(1+r)r}{1+2r}$  to get  $b_{st} < 0$  at the point of buyback.

*stricto sensu* in my environment. Other studies however do. For instance, [Müller et al. \(2019\)](#) and [Restrepo-Echavarria \(2019\)](#) view the borrower’s binding constraint as a form of preemptive restructuring which does not trigger market exclusion. Nonetheless, [Asonuma and Trebesch \(2016\)](#) show that even preemptive restructurings are followed by some periods of market exclusion.

If defaults were “excusable” in the sense of [Grossman and Van Huyck \(1988\)](#), then the binding constraint could be interpreted as such. Nevertheless, this concept has little empirical relevance.

– *Costly buybacks.*

I consider that the government conducts *official* buybacks when it hits the upper bound of the ergodic set – i.e.  $x = x^{ub}$ . Moreover, buybacks are costly. In light of this, could *official* buybacks occur in the lower bound of the ergodic set – i.e.  $x = x^{lb}$  – at a discount? The answer is negative. To reach the lower point of amnesia, the relative Pareto weight needs to decrease which means the government’s indebtedness increases. This goes against the idea of a debt repurchase which aims at reducing indebtedness. In addition, buybacks at discount rates are a form of default. As discussed previously, the point in which  $x = x^{lb}$  cannot be interpreted as such.

Unlike defaults, buybacks are an efficient source of risk sharing. Defaults entail cost for both the lender and the borrower, while *official* buybacks are solely costly for the latter. A default is therefore not renegotiation proof as both contracting parties would be better off avoiding this event *ex post*.

My argument goes against [Bulow and Rogoff \(1988, 1991\)](#) in the sense that costly buybacks are necessary to implement the constrained efficient allocation. Nevertheless, in my analysis, it is true that *official* buybacks are completely ineffective in reducing the government’s indebtedness. In fact, when  $x = x^{ub}$ ,  $b'_{lt} = b_{lt}$  which means that indebtedness remains unchanged.

– *Endogenous borrowing limits.*

The bounds of the ergodic set implicitly define endogenous borrowing and lending limits. On the one hand, when the borrower hits  $x^{lb}$ , borrowing remains the same every period as long as  $g_L$  realizes. Similarly, when the borrower hits  $x^{ub}$ , no additional lending takes place as long as  $g_H$  realizes. The borrowing limit attached to  $x^{lb}$  ensures that the borrower has no incentive to default. On the other hand, the lending limit attached to  $x^{ub}$  naturally arises due to impatience.

– *Negative spread.*

Given the buyback rate and the absence of defaults, the long-term bond spread is negative. This is a feature that one finds in other implementations such as the one of [Alvarez and Jermann \(2000\)](#). The mechanism at work is different, though. In my case, the negative spread enables to mimic the state-contingency in the contract provided that defaults do not arise on equilibrium path (i.e. no positive spread). In the case of [Alvarez and Jermann \(2000\)](#), the negative spread restricts the trade of state-contingent securities in a two-sided limited enforcement problem when the participation constraint of the lender binds ([Krueger et al., 2008](#)).

## 6 Quantitative Analysis

This section starts with the calibration of the Markov equilibrium with default incentives to Argentina. It then assesses the fit of the model to the data and shows that the Markov equilibrium without default incentives shares similarities with Brazil. Subsequently, it compares the two Markov equilibria with the constrained efficient allocation. Particularly, it gauges the goodness of Markov equilibria in approximating the constrained efficient debt management policies. Finally, it compares the implementation of Section 5 with an alternative one.

### 6.1 Calibration

I calibrate the Markov equilibrium with default incentives as it corresponds to the workhorse model in the literature on sovereign debt and defaults. The calibration aims at matching some specific moments of the Argentine economy over the period 1970-2019. Table 1 summarizes each parameter.

As exposed in Section 2, the utility function takes the CRRA form with a coefficient of relative risk aversion of  $\sigma$ . From the growth literature, I adopt  $\sigma = 1$ . In addition, in accordance with Assumption 1, the production function is CES

$$F(k, l) = \left[ \alpha k^{\frac{\phi-1}{\phi}} + (1 - \alpha) l^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}},$$

where  $\alpha$  represents the capital share and  $\phi$  the CES parameter. The value of  $1 - \alpha$  is set to the average labor income share in Argentine estimated by [Frankema \(2010\)](#) and is close to the standard value of 0.7 adopted in the literature on emerging economies ([Mendoza and Yue, 2012](#); [Restrepo-Echavarria, 2019](#)). The CES parameter is  $\phi = 1.4$  to match the share of investment in GDP and is within the range of admissible values in the business cycle

Table 1: Calibration

Parameter	Value	Description	Targeted Moment
A. Based on Literature			
$\sigma$	1.00	Risk aversion	
B. Direct Measure from the Data			
$\pi(g_H g_H)$	0.58	Probability staying high state	GDP per capita growth
$\pi(g_L g_L)$	0.62	Probability staying low state	
$g_H$	1.06	High state	
$g_L$	0.96	Low state	
$1 - \alpha$	0.63	Labor share	Labor income share
$r$	0.03	Risk-free rate	10-year real US treasury rate
C. Based on Model solution			
$\beta$	0.75	Discount factor	Debt-to-GDP ratio
$\phi$	1.40	CES production	Investment-to-GDP ratio
$W$	-0.04	Recovery value of debt	Average Spread
$\lambda$	0.08	Probability re-accessing market	Default rate

literature on emerging economies.

The Markov chain comes from the estimation of [Ayres et al. \(2019\)](#) for Argentina from 1980 to 2017 based on GDP per capita growth. I set the discount factor to  $\beta = 0.75$  to match the average external debt-to-GDP ratio of 29.8%. This discount rate corresponds to a quarterly discounting above 0.93 and ensures I obtain a Markov borrowing equilibrium. Besides this, the risk-free rate is  $r = 0.03$  which corresponds to the average 10-year treasury rate minus PCE inflation ([Dvorkin et al., 2021](#)).

According to [Reinhart and Rogoff \(2009\)](#) and [Cruces and Trebesch \(2013\)](#), Argentina defaulted 8 times between 1816 and 2022 which gives a 3.9% default rate. This is larger than the usual 3% considered in the literature ([Tomz and Wright, 2007, 2013](#)). The probability of re-accessing the market is 0.08 to match the Argentine default rate, while the repayment in restructuring,  $W$  is determined such that the model matches the average (Embig) spread.

Finally, there is one parameter left to calibrate: the buyback rate  $r^{bb}$ . However, as the government in the Markov equilibrium with default incentives does not internalize the impact of buybacks on the bond price, no *official* buyback happens on equilibrium path. I therefore set  $r^{bb} = \frac{(1+r)r}{1+2r}$  which is the limit imposed by Lemma 2.

## 6.2 Numerical results

This subsection presents the result of the calibration. It gauges the fit of the model with respect to the data for both targeted and non targeted moments. It also compares the outcome of the Markov allocation with default incentives (MA), without default incentives (MAND) and the constrained efficient allocation (CEA) together.

The upper part of Table 2 present the fit of the MA with respect to the Argentine economy

Table 2: Targeted and Non-Targeted Moments

A. Targeted Moments				
Variable	Argentina	MA	MAND	CEA
$i/y$	14.50	15.23	28.56	21.78
$b/y$	43.70	47.97	11.85	54.31
Spread	8.92	9.24	-1.53	-1.50
Default rate	3.88	3.30	0	0
B. Non-Targeted Moments				
Variable	Argentina	MA	MAND	CEA
$c/y$	75.80	102.80	46.36	52.82
$tb/y$	1.60	-2.82	53.64	25.41
$\sigma(c)/\sigma(y)$	1.16	1.44	11.23	0.66
$\sigma(i)/\sigma(y)$	3.09	0.24	0.19	2.13
$\sigma(tb/y)/\sigma(y)$	1.03	5.08	4.23	0.85
$\sigma(spread)/\sigma(y)$	5.02	0.78	0.00	0.01
$\rho(c, y)$	0.91	0.04	0.94	0.26
$\rho(i, y)$	0.89	0.94	0.11	0.48
$\rho(tb/y, y)$	-0.53	0.53	-0.93	0.52
$\rho(spread, y)$	-0.68	0.38	-0.49	-0.08

*Note:* For the volatilities and correlation statistics, I filter the simulated data through the HP filter with a smoothness parameter of 1600.

in terms of targeted moments. It also reports the result of the CEA and the MAND. As one can see, the MA replicates relatively well the main features of the Argentine economy in terms of investment, spreads, defaults and indebtedness.

The lower part of Table 2 present the fit of the MA in terms of non-targeted business-cycle moments. In general the fit is poor. This is because I only consider 2 growth states meaning that I rule out tail events. The MA is related to a too large (low) volatility of consumption (investment). The trade balance in the MA admits a deficit and is pro-cyclical unlike the data. The model also cannot match the volatility of spread. It however generates an empirically plausible correlation between investment and output.

The MAND and the CEA achieve better risk sharing than the MA. In the latter, consumption corresponds to a lower share of output and is less volatile. Investment corresponds to a larger share of output, correlates less with output and is more volatile. Finally, the bond spread is negative given that defaults do not arise on equilibrium path and *official* buybacks exceed the risk-free price. The same holds true for the MAND with the exception of a greater (lower) consumption (investment) volatility than in the MA.

Table 3 depicts the underlying debt structure of the Markov equilibrium and the CEA. Two points deserve to be noted. First, the MA replicates well the data as maturity shortens during debt crises, while indebtedness relative to GDP increases. Second, during a restructuring, the maturity lengthens and the level of debt does not substantially decreases. In

Table 3: Debt Structure

	Mean $b$ (percent of $y$ )	Mean $b$ in $g_H$ (percent of $y$ )	Mean $b$ in default (percent of $y$ )	Mean $b$ in restructuring (percent of $y$ )
Argentina	43.7	40.2	51.8	51.0
MA	48.0	46.5	62.4	26.7
MAND	11.9	13.0	-	-
CEA	54.3	54.2	-	-
	Mean $b_{st}/b$ (percent)	Mean $b_{st}/b$ in $g_H$ (percent)	Mean $b_{st}/b$ in default (percent)	Mean $b_{st}/b$ in restructuring (percent)
Argentina	18.9	18.2	20.2	14.8
MA	44.8	41.8	46.3	43.1
MAND	90.1	91.3	-	-
CEA	66.5	66.5	-	-
	$\rho(b_{st}, y)$	$\rho(b_{st}, spread)$	$\rho(b_{lt}, y)$	$\rho(b_{lt}, spread)$
Argentina	-0.04	0.30	0.03	-0.01
MA	-0.69	0.06	-0.55	-0.13
MAND	-0.98	0.00	0.00	0.00
CEA	-0.40	0.03	0.40	-0.19

opposition, in both the CEA and the MAND, maturity remains stable in the high growth state. Nonetheless, while in the CEA, indebtedness decreases when  $g_H$  realizes, the opposite holds true in the MAND.

The MAND displays similarities with Brazil. First and foremost, Brazil has not defaulted since the 1980s, whereas Argentina roughly defaulted 3 times since the 1980s with the most recent episode being in 2019. Second, Brazil conducted an official buyback program from 2006 to 2015. Plus, debt repurchases were the largest when GDP growth was high.<sup>25</sup> Third, in terms of economic fundamentals, Brazil record a lower average debt ratio (29.8%), a greater average investment ratio (20.8%) and a lower average spread (4.6%) than Argentina for the period 1970 to 2019. One can see such differences when comparing the MA with the MAND in Table 2 despite adopting the same calibration.

### 6.3 Policy functions

In this section, I present the different policy functions relevant for my analysis. I start with the CEA and then shift to the MA and MAND. The main focus is to see how debt evolves between the different equilibria.

Figure 2 depicts the main policy functions related to the optimal contract. The law of motion of the relative Pareto weight is consistent with the fact that  $\eta g_L^{-\sigma} < 1$ . In that logic, the steady state of the contract is not degenerate and is located around  $x = 0.29$  and  $x = 0.33$ . Besides this, capital is distorted for low values of  $x$ . However, as soon as  $x$

<sup>25</sup>See <https://www.gov.br/tesouronacional/en/federal-public-debt/external-market/buyback-program>.

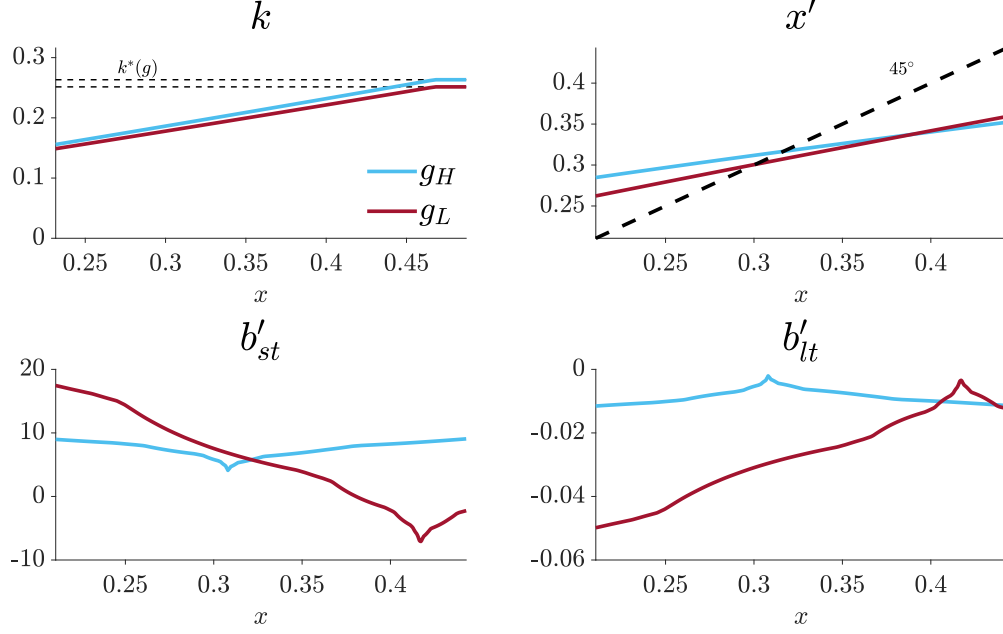


Figure 2: Main Policy Functions of the CEA

is sufficiently high the productivity-maximizing level,  $k^*(g)$ , is reached. Nevertheless, such values of  $x$  are outside the steady state and therefore capital remains distorted in the long-run. Regarding borrowing, when growth is low, the government accumulates a substantial amount of long-term debt. However, it holds short-term assets – especially when *official* buybacks occur. This violates Lemma 2 and explains the reliance on trigger strategies. To obtain short-term debt holdings at the buyback,  $r^{bb}$  should be at least 30 times lower than the calibrated one. Such value is not only way below the limit set by Lemma 2, it also makes little empirical sense. As a result, Markov strategies fail to implement the Planner’s allocation under empirically plausible buyback rates.

I can now compare the bond policy of the CEA with the ones related to the Markov equilibria. Figure 3 depicts the bond policy functions for the MA and the MAND. Starting with the MA, one directly sees that this is a borrowing equilibrium. The government increases its indebtedness in the low growth state as in the CEA. However, it increases both its holdings of short-term and long-term debt. One can even say that the former increases more than the latter consistent with the maturity structure of Argentina. In the high growth state, debt continues to rise in general, while the share of long-term debt increases.

Turning to the MAND, one notices the borrowing limit which takes the form of an horizontal line. This indicates that the government cannot borrow above a certain level. When growth is low, the government issues more short-term and long-term debt as in the MA. However, when growth is high, the *official* buyback program forces the government to maintain



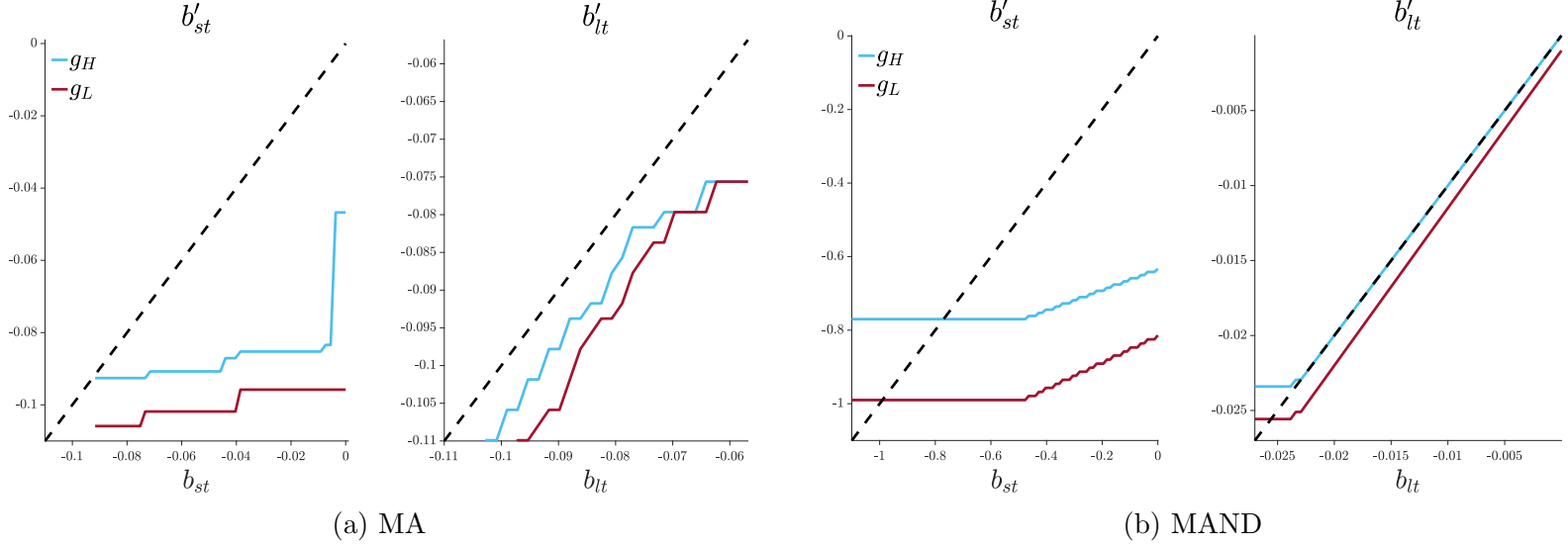


Figure 3: Bond Policies of the Markov Equilibria

its holdings of long-term debt unchanged. As a result, the government adapts its short-term debt position. Note that the level of long-term debt is lower in the MAND than in the MA due to the costly buyback program.

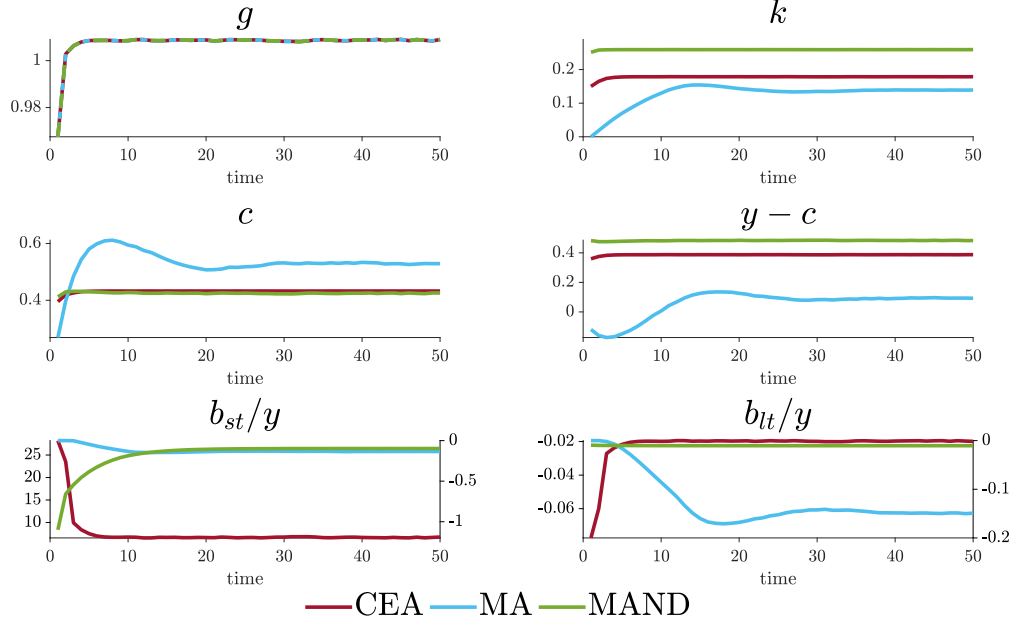
## 6.4 Equilibria comparison

In this subsection, I explore in more details the differences between the Markov equilibria and the CEA. For this purpose, I conduct three main exercises. First, I construct impulse response functions following a stark negative shock in the economy. Second, I look at the dynamic of a specific shock path in both the Markov equilibria and the CEA. Finally, I compute welfare gains with respect to the MA.

Figure 4 depicts the impulse response functions resulting from a stark negative shock on selected key variables. The responses are computed as the mean of 1,000 independent shock histories starting with the lowest shock as well as initial debt holdings and relative Pareto weight drawn from the ergodic set. The blue line represents the MA, the green line the MAND and the red line the CEA. Notice that the relevant axis for the debt figures are on the right-hand sides for the Markov equilibria and the left-hand side for the CEA.<sup>26</sup>

We see that at the outbreak of the shock's realization, capital is distorted in both the MA and the CEA – albeit to a lesser extent in the latter – but not in the MAND. Consumption drops as economies in the MA fall into default. Capital and debt therefore go to zero. The hump-shaped pattern of consumption observed in the MA is due to the debt restructuring

<sup>26</sup>This is because the implementation of the CEA relies on short-term assets.



*Note:* For the debt figures, the relevant axis are on the right-hand sides for the MA and the MAND and the left-hand side for the CEA.

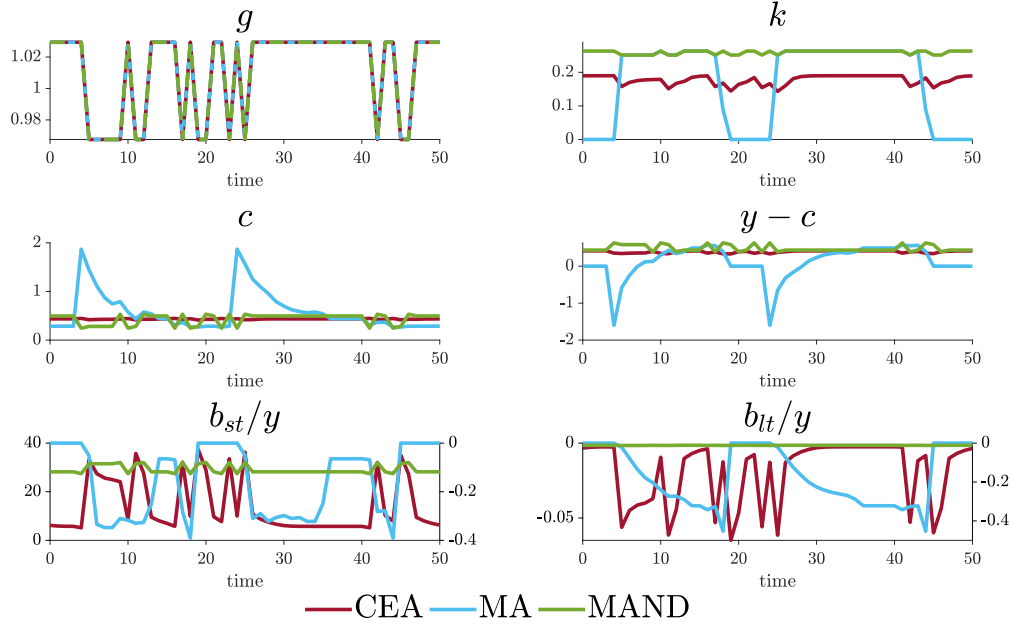
Figure 4: Impulse Response Functions to a Negative  $g$  Shock

and the underlying regain of access to the market. In opposition, defaults do not arise in the CEA and the MAND which can both increase the indebtedness on impact. Maturity shortens at the outbreak of the bad shock's realization in the MA as well as in the MAND and lengthens in the CEA. The Markov equilibria rely mostly on short-term debt, while the CEA use both in opposite directions.

The impulse response functions give an idea of the long-run dynamic of the economy. However, it does not tell how the economy reacts in the short run especially when there is a transition between two values of  $g$ . Thus, I simulate the economy and generate one history of shocks for 400 periods. To avoid that the initial conditions blur the results, the first 350 periods are discarded. Again, the blue line represents the MA, the green line the MAND and the red line the CEA. Moreover, the relevant axis for the debt figures are on the right-hand sides for the Markov equilibria and the left-hand side for the CEA.

Figure 5 depicts the simulation results. One observes that, in the MA, the economy defaults in the transition from  $g_H$  to  $g_L$ . This causes market exclusion and therefore  $k = 0$ . Consumption largely drops and jumps once the government can re-access the markets. The volatility of consumption is therefore very high. In opposition, there are no defaults in the CEA and the MAND. In the transition from  $g_H$  to  $g_L$ , the government adapts the maturity of the debt and increases its indebtedness. Especially, one sees that the level of short-term bonds have similar movements in the MAND and the CEA despite having opposite sign.

The magnitude of the changes is nonetheless different. Consistent with the findings of Buera and Nicolini (2004), the movements in debt holdings are the most pronounced for the CEA and are substantially different than the movements implied by the MA.



*Note:* For the debt figures, the relevant axis are on the right-hand sides for the MA and the MAND and the left-hand side for the CEA.

Figure 5: Simulation of a Typical Path

Having identified the main difference between the MA, the MAND and the CEA, I can now conduct a welfare analysis. Table 4 depicts the welfare gains of the CEA and the MAND in consumption equivalent terms with respect to the MA. Welfare gains are computed through the simulation of 10,000 independent shock histories starting with the lowest shock as well as initial debt holdings and relative Pareto weights drawn from the ergodic set. The details of the welfare computations are presented in Appendix C.

Table 4: Welfare Analysis

Allocation	Welfare gains (percent)	Capital distortion (percent)	$\mathcal{F}$ (percent)
MA	—	41.4	34.7
MAND	7.5	0.0	75.6
CEA	20.1	39.1	100.0

As one can see, the CEA and the MAND imply substantial welfare gains compared to the MA. The gains come mainly from the absence of defaults. Default implies markets exclusion

and therefore  $k = 0$  which is extremely costly for both the lender and the borrower given the Inada conditions on the production function. In that logic, capital distortions are weaker in the CEA and inexistent in the MAND.

Besides the welfare gains, I can compute the distance with respect to the Pareto frontier. For this purpose, I derive a metric measuring the distance between the constrained efficient allocation and any alternative allocation. Consider the value of the lender in any given allocation as a function of the shock and the value of the borrower as  $\ddot{V}^l : G \times \ddot{V}^b \rightarrow \mathbb{R}$ . I then define

$$\mathcal{F}(g) = \frac{\int \ddot{V}^l(g, \ddot{V}^b) d\ddot{V}^b}{\int_{\bar{x}} V^l(g, x) dx}.$$

The metric  $\mathcal{F}$  is bounded between 0 and 1 given Proposition 3. A value of  $\mathcal{F}$  near 1 indicates that an allocation is close to the constrained efficient benchmark, whereas a value close to 0 indicates the opposite.<sup>27</sup> I compute  $\mathcal{F}$  for  $b_{st} \leq 0$  and  $b_{lt} \leq 0$  in the Markov equilibrium without default risk to stay consistent with Lemma 2.

Looking at the metric  $\mathcal{F}$ , the MAND is superior to the MA but not to the CEA. More precisely, the MA is relatively far from the CEA and the MAND can get the economy closer to it. The MAND therefore provides a good approximation of the CEA, whereas the MA performs poorly. The metric  $\mathcal{F}$  is important as it relates to the entire value of the debt contract and not only on the steady state unlike the welfare gains computed above.

## 6.5 Alternative implementation

In this subsection, I present an alternative way of implementing the optimal contract. Most notably, I follow, the approach of Alvarez and Jermann (2000) which relies on state-contingent securities and an endogenous borrowing limit. This limit ensures that the participation constraint is satisfied in equilibrium.

The main difference between the two implementations is that the benchmark case of Section 5 relies on the term structure, while the alternative case relies on changes in security holdings provided that securities are state-contingent.

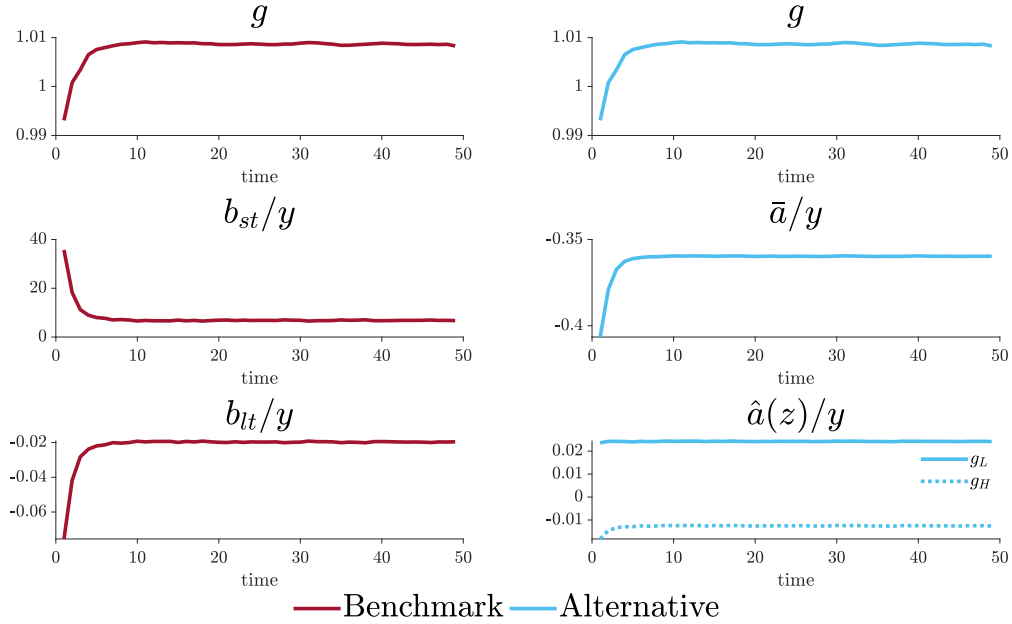
Appendix D presents the details of the alternative implementation. I only highlight here the asset structure of the economy. At the start of a period, the government holds a perpetual security  $a$ . The government can trade  $G$  state contingent securities  $a'(g')$  with a unit price of  $q(g', a'(g')|g)$ . The portfolio  $a'(g')$  can be decomposed into a common bond  $\bar{a}'$

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<sup>27</sup>The metric  $\mathcal{F}$  is based on the same concept as the Gini coefficient which measures the distance between the Lorenz curve and the equity line.

Table 5: Alternative Implementation

	Benchmark	Alternative
$b/y$	54.31	35.97
Spread	-1.50	0.00
$\sigma(b/y)/\sigma(y)$	332.20	0.23
$\sigma(spread)/\sigma(y)$	0.01	0.00
$\rho(b/y, y)$	-0.41	0.87
$\rho(spread, y)$	-0.08	0.00

Figure 6: Impulse Response Functions to a Negative  $g$  Shock

that is independent of the next period state, traded at the implicit bond price  $q(g, a') \equiv \sum_{g'|g} q(g', a'(g')|g)$ , and an insurance portfolio of  $G$  Arrow securities  $\hat{a}'(g')$ . Thus,  $a'(g') = \bar{a}' + \hat{a}(g')$ .

Table 5 presents the main difference between the two implementations. The benchmark case is related to a larger level of indebtedness and a larger volatility of the debt ratio. This comes from the fact that bonds are non-contingent. Thus, large movements in debt holdings are necessary to replicate the state contingency in the contract (Buera and Nicolini, 2004). Besides this, the benchmark implementation displays negative spread owing to *official* buybacks, while the alternative case displays no spread at all. As explained before, the reason behind this is that the alternative implementation does not rely on changes in prices to mimic the state-contingency of the contract given that securities are state-contingent by definition.

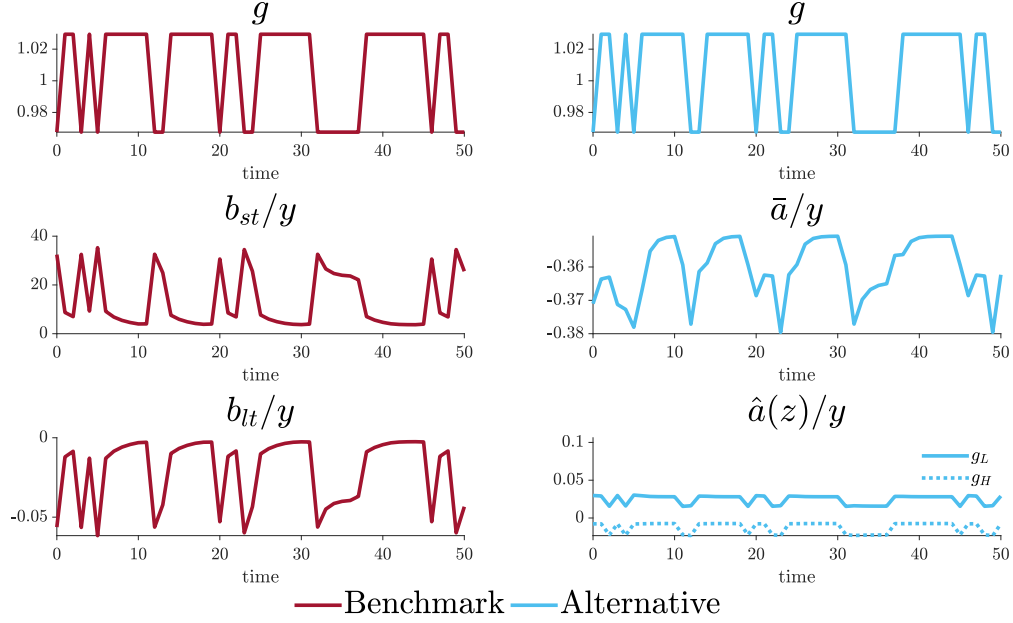


Figure 7: Simulation of a Typical Path

Similar to the previous section, I construct impulse responses to see how the two implementations work. Figure 6 depicts the responses in red for the benchmark implementation and in blue for the alternative one. The Arrow securities do most of the job in the alternative case, while the benchmark implementation needs to adapt both the long-term and the short-term bonds at the same time.

Turning to the simulation in Figure 7, one can see that the level of long-term bond in the benchmark case closely follows the pattern of bonds in the alternative case. The magnitude of change in the former is nonetheless larger than in the latter. In terms of Arrow securities,  $\hat{a}(g_L)$  closely follows the evolution of  $\bar{a}$ , while  $\hat{a}(g_H)$  has the opposite sign. The evolution of  $\hat{a}(g_H)$  is therefore closely mimicking the evolution of  $b_{st}$ . Given that  $\hat{a}(g)$  is state contingent, the alternative implementation needs to change the debt portfolio with lower magnitude.

## 7 Conclusion

This paper derives the constrained efficient allocation emanating from an optimal contract to deduce the optimal sovereign debt management policy. The bottom line is that the reliance on defaults on equilibrium path is inefficient. Instead, changes in maturity and costly debt buyback can implement the constrained efficient allocation. Nevertheless, the implementation often requires highly sophisticated agents capable of building on past history. I show that less sophisticated agents would in fact rely on Markov strategies. Given this, I

derive history-invariant debt management policies inspired by the optimal contract and assess their efficiency. I show that a Markov equilibrium with a no-default constraint and an *official* buyback program provides a better approximation of the constrained efficient allocation than a Markov equilibrium with defaults. The comparison of Argentina and Brazil after the 1990s supports this evidence.

This paper stresses the fact that incomplete markets might not be the reason why a market economy fails to attain constrained efficiency. Rather it can be linked to the incapacity of market participants to build on past history. In further versions, I will develop in greater details the argument that there always exists a Markov equilibria which corresponds to the best (time-invariant) approximation of the constrained efficient allocation. This result is crucial as such approximation is the policy-relevant one.

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# Appendix

## A Price in Markov Equilibrium

The price of one unit of bond of maturity  $j$  for all  $j \in \{st, lt\}$  is given by

$$q_j(g, b'_{st}, b'_{lt}) = \mathbb{E}_{g'|g} \left[ (1 - D(\Omega')) q_j^P(g', b'_{st}, b'_{lt}) + D(\Omega') q_j^D(g', b'_{st}, b'_{lt}) \right], \quad (\text{A.1})$$

where recovery value given by

$$q_j^D(g, b'_{st}, b'_{lt}) = \frac{1}{1+r} \mathbb{E}_{g'|g} \left[ (1 - \lambda) q_j^D(g', b'_{st}, b'_{lt}) + \lambda \frac{W \frac{1+r}{1+r-\mathbb{I}_{j=lt}}}{b'_j} \right],$$

where  $\mathbb{I}_{j=lt}$  is an indicator function taking value one if  $j = lt$  and zero otherwise. In case of repayment, the price depends on the maturity, the repayment growth and the buyback decision.

$$\begin{aligned} q_{st}^P(g, b'_{st}, b'_{lt}) &= \frac{1}{1+r}, \\ q_{lt}^P(g, b'_{st}, b'_{lt}) &= \frac{1}{1+r} \mathbb{E}_{g'|g} \left[ 1 + (1 - M(\Omega')) q_{lt}(g', b''_{st}, b''_{lt}) + M(\Omega') q_{lt}^{bb} \right]. \end{aligned}$$

Given this, a Markov equilibrium can be defined as

**Definition A.3** (Markov Equilibrium). *In this environment, a Markov equilibrium consists of a set of prices,  $\{p(\Omega), q_{st}(g, b'_{st}, b'_{lt}), q_{lt}(g, b'_{st}, b'_{lt})\}$ , a set of policy functions  $\mathcal{G}(\Omega) = \{D(\Omega), M(\Omega), b_{st}(\Omega), b_{lt}(\Omega), \tau(\Omega)\}$  such that, at every possible state  $\Omega$ ,*

1. *Taking  $p$ ,  $q_{st}$  and  $q_{lt}$  as given,  $\mathcal{G}(\Omega)$  solves the government's problem (5)-(7).*
2. *Taking  $p$  as given, the choice of capital by domestic firms is such that*

$$gf_k(k) = p.$$

3. *Taking  $\mathcal{G}(\Omega)$  as given, the price of capital is consistent with*

$$\max_k p(\Omega)(1 - \tau(\Omega))k - k.$$

4. *The price of bonds satisfy (A.1)*

## B Further Characterization

The following lemma derives the inverse Euler Equation which gives the consumption dynamic in the contract.

**Lemma B.1** (Inverse Euler Equation). *Under Assumptions 1 and 3, the inverse Euler equation for a given  $g \in G$  reads*

$$\mathbb{E}_{g'|g} \left[ \frac{1}{u_c(c(g'))(1 + \nu(g'))} \right] = g^{-\sigma} \eta \frac{1}{u_c(c(g))},$$

*Proof.* See Appendix E □

If the participation constraint of the borrower never binds, I obtain that for all  $(g, x)$ ,

$$\frac{1}{u_c(c(g))} \geq \mathbb{E}_{g'|g} \left[ \frac{1}{u_c(c(g'))} \right]$$

with strict inequality when  $\eta g^{-\sigma} < 1$ . In this case, the inverse Euler Equation is a positive supermartingale. Immiseration is a consequence of the theorem stating that supermartingales converge almost surely to  $-\infty$ . Alternatively, when  $\eta g^{-\sigma} = 1$ , consumption remains constant. Under limited commitment of the borrower (i.e.  $\nu(g) \geq 0$ ), one obtains a left bounded positive submartingale. The borrower's participation constraints therefore sets an upper bound on the supermartingale and prevents immiseration.

## C Welfare Analysis

To compute the borrower's welfare, first define the borrower's value for a sequence of consumption  $\{c(g^t)\}$  starting from an initial state at  $t = 0$  as

$$V(\{c(g^t)\}) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{G}_t(g_0) u(c(g^t)) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{G}_t(g_0) \frac{c(g^t)^{1-\sigma}}{1-\sigma},$$

I denote the borrower's consumption allocation in the benchmark model by  $\{c^b(g^t)\}$  and the consumption allocation in the alternative model by  $\{c^a(g^t)\}$ . In addition, I define the consumption-equivalent welfare gain of the alternative model with respect to the benchmark model by  $\chi$  such that

$$V(\{(1 + \chi)c^b(g^t)\}) = V(\{c^a(g^t)\}).$$

Given the functional form of the instantaneous utility one obtains

$$(1 + \chi)^{1-\sigma} \left[ V(c^b(g^t)) \right] = V(\{c^a(g^t)\}).$$

The welfare gain therefore boils down to

$$\chi = \left[ \frac{V(\{c^a(g^t)\})}{V(\{c^b(g^t)\})} \right]^{\frac{1}{1-\sigma}} - 1.$$

## D Alternative Implementation

In what follows, I propose an alternative implementation as the one derived in Section 5. More precisely, I rely on the approach of [Alvarez and Jermann \(2000\)](#) using trade in state-contingent securities and an endogenous borrowing limit.

The structure of the financial market is the following. At the start of a period, the government holds a perpetual security  $a$ . The government can trade  $G$  state contingent securities  $a'(g')$  with a unit price of  $q(g', a'(g')|g)$ . The portfolio  $a'(g')$  can be decomposed into a common bond  $\bar{a}'$  that is independent of the next period state, traded at the implicit bond price  $q(g, a') \equiv \sum_{g'|g} q(g', a'(g')|g)$ , and an insurance portfolio of  $G$  Arrow securities  $\hat{a}'(g')$ . Thus we have that  $a'(g') = \bar{a}' + \hat{a}'(g')$  with

$$\bar{a}' = \frac{\sum_{g'|g} q(g', a'(g')|g) a'(g')}{q(g, a')} \quad \text{and} \quad \sum_{g'|g} q(g', a'(g')|g) \hat{a}'(g') = 0.$$

The last equation represents the market clearing condition of the Arrow securities.

The capital market is the same as in the main text. The lender provides  $k$  at price  $p$  and the government can decide to tax the repayment of capital to the lender at rate  $\tau$ . The government's problem therefore reads

$$W^b(g, a) = \max_{c, \tau, \{a'(g')\}_{g' \in g}} u(c) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} [W^b(g', a'(g'))] \quad (\text{D.1})$$

$$\text{s.t. } c + \sum_{g'|g} q(g', a'(g')|g) (g a'(g') - a) \leq g f(k) - p(1 - \tau)k + a$$

$$\bar{a}' + \hat{a}'(g') \geq \mathcal{A}(g', k'), \quad (\text{D.2})$$

where  $\mathcal{A}(g', k')$  represents the endogenous borrowing limit and is defined such that

$$W(g', \mathcal{A}(g', k')) = V^D(g', k'). \quad (\text{D.3})$$

One can see here the similarity with the borrowing limit defined in Section 4. The lender's problem is static. I nonetheless express it in recursive form.

$$\begin{aligned}
W^l(g, a_l) = & \max_{c_l, k_l, \{a'_l(g')\}_{g' \in g}} c_l + \frac{1}{1+r} g \mathbb{E}_{g'|g} [W^l(g', a'_l(g'))] \\
\text{s.t. } & c_l + \sum_{g'|g} q(g', a'_l(g')|g) (g a'_l(g') - a_l) \leq p(1-\tau)k_l - k_l + a_l.
\end{aligned} \tag{D.4}$$

Given this environment, I can determine a recursive competitive equilibrium in the following terms.

**Definition D.4** (Recursive Competitive Equilibrium (RCE)). *A recursive competitive equilibrium (RCE) is a sequence of prices  $q(g', a'(g')|g)$  and  $p(g, a)$ , value functions,  $W^b(g, a)$  and  $W^l(g, a)$ , an endogenous borrowing limit,  $\mathcal{A}(g', k')$ , as well as policy functions for (i) consumption,  $c(g, a)$  and  $c_l(g, a)$ , (ii) capital,  $k = k(g, a)$  and  $k_l = k_l(g, a)$  as well as (iii) asset holdings  $a'(g') = A(g', g, a)$  and  $a'_l(g') = A_l(g', g, a)$  such that,*

1. *Given the value function for the outside option of the government,  $V^D(g', k')$  as well as asset prices  $q(g', a'(g')|g)$ ,*
  - (a) *the policy functions  $c(g, a)$  and  $A(g', g, a)$ , together with the value function  $W^b(g, a)$ , solve the government problem (D.1) with the endogenous limit,  $\mathcal{A}(g', k')$ .*
  - (b) *the policy functions  $c_l(g, a_l)$ ,  $k_l(g, a)$ , and  $A_l(g', g, a_l)$ , together with the value function  $W^l(g, a_l)$ , solve the lender's problem (D.4) and*
2. *Taking  $p$  as given, the choice of capital by domestic firms is such that*

$$u_c(c)(gf_k(k) - p) = 0.$$

3. *The asset market clears,  $a'(g') + a'_l(g') = 0$  for all  $g' \in G$ .*
4. *The product and capital markets clear,  $c(g, a) + c_l(g, a_l) = gf(k)$  with  $k = k_l$ .*

For the government's problem, taking the first-order conditions with respect to consumption and assets, one obtains

$$\begin{aligned}
u_c(c) &= \mu_{BC}(g, a), \\
q(g', a(g')|g) &= \beta g^{1-\sigma} \pi(g'|g) g^{-\sigma} \frac{u_c(c')}{u_c(c)} \left[ 1 + \sum_{g''|g} q(g'', a''(g'')|g') \right] + \frac{\mu_{EBL}(g', a'(g'))}{u_c(c)},
\end{aligned}$$

where  $\mu_{BC}$  and  $\mu_{EBL}$  are the Lagrange multipliers attached to the budget constraint and the endogenous borrowing limit, respectively. Especially,  $\mu_{EBL}(g', a'(g')) \geq 0$  with  $\mu_{EBL}(g', a'(g')) = 0$  if  $a'(g') > \mathcal{A}(g', k')$ .

Conversely, taking the first-order conditions with respect to consumption, capital and assets of the lender's problem

$$\begin{aligned} 1 &= \mu_{BC}^l(g, a_l), \\ 1 &= p(1 - \tau), \\ q(g', a(g')|g) &= \frac{1}{1+r} \pi(g'|g) (1 + \sum_{g''|g} q(g'', a''(g'')|g')). \end{aligned}$$

Following [Krueger et al. \(2008\)](#), the price is determined by the agent whose constraint is not binding. Therefore the price is determined by

$$q(g', a(g')|g) = \pi(g'|g) (1 + \sum_{g''|g} q(g'', a''(g'')|g')) \max \left\{ \beta g^{-\sigma} \frac{u_c(c(g', a'(g'))}{u_c(c(g, a))}, \frac{1}{1+r} \right\}. \quad (\text{D.5})$$

The following lemma states that the constrained efficient allocation can be implemented as a RCE with state contingent-assets and an endogenous borrowing limit.

**Proposition D.1** (Alternative Implementation). *Given initial conditions  $\{g_0, x_0\}$ , a constrained efficient allocation can be implemented as a competitive equilibrium with state contingent-assets and an endogenous borrowing limit.*

*Proof.* See Appendix [E](#) □

The benchmark implementation presented in Section [5](#) relies on changes in the term premium to mimic the state-contingency in the optimal contract, while this alternative implementation relies on changes in security holdings provided that securities are state-contingent. More importantly, given that securities are state contingent, the assumption that the borrower and the lender keep track of the entire history of play is not anymore necessary. The implementation of the constrained efficient allocation now lies on the assumption of a greater financial sophistication.

## E Proofs

PROOF OF LEMMA [1](#).



The value of permanent autarky is given by

$$v_a(g_t) = \sum_{j=t}^{\infty} \beta^{j-t} \sum_{g^j} \pi(g^j|g_t) \mathcal{G}_j(g_t) u(g_j f(0)),$$

as the lender sets  $k = 0$  in case of default. Permanent autarky is the worst equilibrium outcome as the government could always be better off with  $k = \epsilon$  for small  $\epsilon > 0$  given the Inada conditions on the production function. I show this in Proposition 3.

Permanent autarky is an equilibrium of the market economy. Suppose that the lender believes that  $\tau_t = 1$  as well as that  $D_t = 1$  for all  $t$ . Then, it sets  $k_t = 0$  and  $q_{j,t} = 0$  for all  $j \in \{st, lt\}$ . Given this, the government finds optimal to choose  $\tau_t = 1$   $D_t = 1$  for all  $t$  confirming the lender's beliefs.  $\square$

#### PROOF OF LEMMA 2.

I consider a borrowing Markov equilibrium in which, by Definition 2,  $h_{st}(\Omega) \leq b_{st}$  and  $h_{lt}(\Omega) \leq b_{lt}$  for all  $\Omega$ . Furthermore, consider the following punishment in case of deviation from the *official* buyback policy. The lender can decide not to roll over debt, meaning that  $b'_{st} = 0 > b_{st}$  and  $b'_{lt} \geq b_{lt}$ . This punishment is clearly Markov as it only pertains to the current period, unlike trigger strategies that relies on all future paths of play.

Necessity:

Suppose that  $b_{st} < 0$  and  $r > r^{bb} \geq \frac{(1+r)r}{1+2r}$ . Observe that  $r^{bb} \geq \frac{(1+r)r}{1+2r}$  implies that the *official* buyback such that  $b'_{lt} = b_{lt}$  is at most as costly as the reduction of debt by one unit. To see this,

$$\frac{q_{lt}^{bb} - q_{lt}}{q_{st}} < \frac{\frac{1}{r^{bb}} - \frac{1}{r}}{\frac{1}{1+r}} \leq 1,$$

where the first inequality comes from the fact that  $q_{lt} > \frac{1}{r}$  given that there is no default but *official* buybacks on equilibrium path. The second inequality implies that the *official* buyback premium is lower than the unit price of short term debt. Rearranging leads to

$$r^{bb} \geq \frac{(1+r)r}{1+2r} < r.$$

The question is now the following. Does the borrower prefer to implement the *official* buyback at  $b'_{lt} = b_{lt}$  when  $g = g_H$ , or does it prefer the no-roll-over punishment? Given that I only consider borrowing Markov equilibria without assets, the borrower always wants to hold (weakly) more debt. This together with the condition on the buyback rate ensure that the punishment is always weakly dominated by the *official* buyback as the borrower can still increase its short-term indebtedness while keeping its long-term indebtedness constant.

Sufficiency:

Suppose that the lender can enforce *official* buybacks in a borrowing Markov equilibrium. First, if the borrower holds short-term assets, there is no threat available to the lender as the borrower is in fact the lender of short-term debt. In other words, when  $b'_{st} > 0$ , it is the lender who is auctioning and it cannot exclude the borrower from the auction – as the borrower repaid the debt and has market access. In opposition, when  $b'_{st} < 0$ , the borrower is auctioning – as it seeks to raise resources – and the lender can decide not to participate to this auction. Thus, buybacks are not enforceable in case of short-term asset holdings. Second, if the buyback rate is  $r^{bb} < \frac{(1+r)r}{1+2r}$  and  $b_{st} = -\epsilon$  with  $\epsilon > 0$  arbitrarily close to zero, the borrower might prefer the above punishment as an *official* buyback is more costly than reducing the short-term debt by one unit.

□

PROOF OF PROPOSITION 1.

I prove the proposition by construction. Denote the objects related to the Markov equilibrium with default incentives with “MA” and without default incentives with “MAND”. Given equation (9), for all  $g \in G$ ,

$$V_{MAND}^P(g, b'_{st}, b'_{lt}) \geq V^D(g).$$

Hence, there is no default on equilibrium path. This combined with the state contingent buyback program implies that

$$\begin{aligned} q_{lt}^{MAND}(g, b'_{st}, b'_{lt}) &= q_{lt}^{MAND}(g) \in \left( \frac{1}{r}, \frac{1}{r^{bb}} \right), \\ q_{st}^{MAND}(g, b'_{st}, b'_{lt}) &= q_{st}^{MAND} = \frac{1}{1+r}. \end{aligned}$$

As a result the long-term (short-term) bond price in the Markov equilibrium without default incentives is always strictly (weakly) greater than in the Markov equilibrium with default incentives. Formally for all  $(g, b'_{st}, b'_{lt})$ ,

$$\begin{aligned} q_{lt}^{MAND}(g) &> q_{lt}^{MA}(g, b'_{st}, b'_{lt}), \\ q_{st}^{MAND} &\geq q_{st}^{MA}(g, b'_{st}, b'_{lt}). \end{aligned}$$

First consider the case of only having short-term debt. First, assume (9) does not bind. Given that the short-term bond price in the MAND is weakly greater, the government can always replicate the borrowing of the MA without incurring more cost. The same holds true for the lender. When (9) binds, the borrower in the MAND is constrained. However, the borrower in the MA is facing default and receives the same value. Note that one cannot compare the MAND and the MA for debt portfolio in which (9) would be violated. Hence, the MA and the MAND do not necessarily span each other. Conversely, the lender is strictly better off as there is no default in the MAND meaning that it receives some returns.

Now consider the case of short-term and long-term debt. When  $g = g_L$ , the lender extracts a larger rent than in the MA given that  $r^{bb} < r$ . For the borrower, given that  $b_{lt}^{MA'} \leq b_{lt}$ , the argument made for the short term debt applies. The borrower in the MAND can always replicate the borrowing strategy of the borrower in the MA at lower costs provided that (9) does not bind.

Whenever  $g = g_H$ , the borrower faces better borrowing terms but also need to buyback its debt at the rate  $r^{bb} < r$ . Similar to the second case considered previously, the borrower needs to combine the short-term and the long-term debt to replicate the value in the MA. The idea is to conduct buybacks at a low cost by setting  $b'_{lt} = b_{lt}$  and then adapt the short-term debt. As shown in Lemma 2, this is possible since  $r^{bb} \geq \frac{(1+r)r}{1+2r}$  implies that the *official* buyback such that  $b'_{lt} = b_{lt}$  is at most as costly as the reduction of debt by one unit. The argument made previously for the lender applies here too.  $\square$

## PROOF OF PROPOSITION 2.

I prove the proposition following Bhaskar et al. (2012). I first show that every equilibrium under Assumption 2 is essentially sequentially strict. I then prove that every essentially sequentially strict equilibrium is a Markov (perfect) equilibrium.

I start the proof with some definitions. Given the information structure, I split the histories into two categories: public and private. Public histories are the ones defined in Section 3 – that is  $h_b^t$  and  $h_l^t$ . Private histories of the borrower and the lender at time  $t$  are

the ones tracking the utility shocks – that is  $p_b^t = (p_b^{t-1}, \varrho_{b,t})$  and  $p_l^t = (p_l^{t-1}, \varrho_{l,t})$ , respectively. Finally, I denote the entire history of the play including the privately observed utility shocks by  $\hat{h}^t$ .

In addition, I denote  $\sigma_b$  and  $\sigma_l$  as the strategy profile of the borrower and the lender, respectively. Besides this,  $A_i$  corresponds to the countable set of actions with typical element  $a_i$  for market participant  $i \in \{b, l\}$ . For instance, actions taken by the borrower relate to borrowing, defaults, buybacks and taxation. Moreover,  $W^b(\sigma_b, \sigma_l | h_b^t, p_b^t)$  and  $W^l(\sigma_b, \sigma_l | h_l^t, p_l^t)$  represent respectively the value of the borrower and the lender from the strategy profile  $(\sigma_b, \sigma_l)$  at the relevant histories.

Given that each market participant has some private information regarding their payoff, they need to form beliefs about the unobserved utility shock of the other participants. Denote the belief of agent  $i \in \{b, l\}$  over the entire history  $\hat{h}^t$  as  $\omega_i^{(h_i^t, p_i^t)}$ . I follow [Bhaskar et al. \(2012\)](#) and put the least structure possible on such beliefs. They simply need to be independent of the private payoff shocks and put zero weight to events that history  $\hat{h}^t$  is inconsistent with  $h_i^t$ . With this, I define a Markov equilibrium as

**Definition E.5** (Markov Equilibrium). *A strategy  $\sigma_i$  for  $i \in \{b, l\}$  is Markov if for any two histories  $(h_i^t, p_i^t) \neq (\tilde{h}_i^t, \tilde{p}_i^t)$  ending with the same state  $\Omega$ ,*

$$\sigma_i(h_i^t, p_i^t) = \sigma_i(\tilde{h}_i^t, \tilde{p}_i^t).$$

*A strategy profile  $(\sigma_b, \sigma_l)$  is a Markov equilibrium if  $(\sigma_b, \sigma_l)$  is Markov and for any alternative strategy  $(\tilde{\sigma}_b, \tilde{\sigma}_l)$ ,*

$$W^b(\sigma_b, \sigma_l) \geq W^b(\tilde{\sigma}_b, \tilde{\sigma}_l) \wedge W^l(\sigma_b, \sigma_l) \geq W^l(\tilde{\sigma}_b, \tilde{\sigma}_l).$$

Furthermore, I define a sequential best response as

**Definition E.6** (Sequential Best Response). *A strategy  $\sigma_i$  is a sequential best response to  $(\sigma_{-i}, \omega_i)$ , if for each history  $(h_i^t, p_i^t)$  and each alternative strategy  $\tilde{\sigma}_i$*

$$\int W^i(\sigma_b, \sigma_l | \hat{h}^t) d\omega_i^{(h_i^t)}(\hat{h}^t) \geq \int W^i(\tilde{\sigma}_b, \sigma_l | h_b^t) d\omega_i^{(h_i^t)}(\hat{h}^t).$$

*Strategy  $\sigma_i$  is a sequential best response to  $\sigma_{-i}$  if strategy  $\sigma_i$  is a sequential best response  $(\sigma_{-i}, \omega_i)$  for some  $\omega_i$ .*

Given the information structure, there is no general solution concept which can be used here. That is why, [Bhaskar et al. \(2012\)](#) appeal to the very weak concept of sequential

optimality. Nonetheless, a profile of mutual sequential best response for the borrower and the lender represents a perfect Bayesian equilibrium.

The other concept defined by the aforementioned authors is the current shock strategy which relies at most on the current value of the private shock. Formally

**Definition E.7** (Current Shock Strategy). *A strategy  $\sigma_i$  is a current shock strategy, if for any public history  $(h_i^t, p_i^t)$  and for any two histories,  $p_i^t$  and  $\tilde{p}_i^t$ , both finishing with the same  $\varrho_i$ , then for almost all  $\varrho_i$*

$$\sigma_i(h_i^t, p_i^t) = \sigma_i(h_i^t, \tilde{p}_i^t).$$

The next lemma links Definitions E.6 and E.7. In words, any sequential response relies at most on the current value of the private shock. As a result the history of past private shocks becomes irrelevant.

**Lemma E.2** (Sequential Strictness and Current Shock Strategy). *If  $\sigma_i$  is a sequential best response to  $\sigma_{-i}$ , then  $\sigma_i$  is a current shock strategy.*

*Proof.* Consider a market participant  $i$  with history  $(h_i^t, p_i^t)$ . The expected continuation value from choosing a certain action  $a_i$  under the strategy profile  $\sigma$  is given by

$$W^i(a_i, \sigma_{-i}, \omega_i | h_i^t, p_i^t) = \mathbb{E}_{g'|g} \int \int \max_{\sigma_i} W^i(\sigma_i, \sigma_{-i} | a_i, g', \varrho'_i, \hat{h}^t) d\mu_{P_i}(\varrho'_i) d\omega_i^{(h_i^t)}(\hat{h}^t).$$

Since  $\sigma_{-i}$  and  $\omega_i^{(h_i^t, p_i^t)}$  do not depend on the private history, the value  $W^i(a_i, \sigma_{-i}, \omega_i | h_i^t, p_i^t)$  is also independent of private history. Furthermore, since the density of  $\varrho_i$  is absolutely continuous, the market participant  $i$  can only be indifferent between two actions on a zero measure of the support. For different values of  $\varrho_i$ , the action is unique and independent of the past values of the shock.  $\square$

Given that beliefs on the history of past private shock do not matter, I can suppress the dependence on the beliefs and the private shock realization in the value function. Thus, the expected continuation value from choosing a certain action  $a_i$  under the strategy profile  $\sigma$  is given by

$$W^i(a_i, \sigma_{-i} | h_i^t) = \int \mathbb{E}_{g'|g} \max_{\sigma_i} W^i(\sigma_i, \sigma_{-i} | a_i, g', \varrho'_i, h_i^t) d\mu_{P_i}(\varrho'_i).$$

I then arrive to the first step of the proof. Given that beliefs over private histories are irrelevant for optimality, every perfect Bayesian equilibrium (i.e. a profile of mutual sequential best responses) satisfying Assumption 2 are essentially sequentially strict.

**Lemma E.3** (Sequential Best Response and Perfect Bayesian Equilibrium). *Every perfect Bayesian equilibrium satisfying Assumption 2 is essentially sequentially strict.*

*Proof.* I need to show that for any period, history and for almost all values of the private shock, the optimal action is unique. I consider the case of the borrower first. The borrower's value from action  $a_b$  after the realization of  $\varrho_b$  is given by

$$W^b(a_b, \varrho_b, \sigma_b | h_b^t) = u(a_b, g) + \epsilon \varrho_b^a + \beta g^{1-\sigma} \mathbb{E}_{g'|g} W^i(\sigma_b | a_b, g', h_b^t).$$

Suppose two actions  $a_b$  and  $\tilde{a}_b$ , the equality  $W^b(a_b, \varrho_b, \sigma_b | h_b^t) = W^b(\tilde{a}_b, \varrho_b, \sigma_b | h_b^t)$  implies that

$$\epsilon(\varrho_b^{a_b} - \varrho_b^{\tilde{a}_b}) = u(a_b, g) - u(\tilde{a}_b, g) + \beta g^{1-\sigma} \mathbb{E}_{g'|g} [W^b(\sigma_b | a_b, g', h_b^t) - W^b(\sigma_b | \tilde{a}_b, g', h_b^t)].$$

The set of actions is countable, whereas the set of values of private shocks for which a market participant can be indifferent has measure zero. Hence, for almost all values of  $\varrho_i$ , the set of maximizing actions must be a singleton, and the profile is essentially sequentially strict. The proof naturally extends to the case of the lender and is therefore omitted.  $\square$

Now that we have that all equilibria satisfying Assumption 2 are essentially sequentially strict, I simply need to show that sequentially strict equilibria are Markov equilibria.

**Lemma E.4** (Sequential Strictness and Markov Equilibrium). *Every essentially sequentially strict perfect Bayesian equilibrium is a Markov perfect equilibrium.*

*Proof.* Consider an a  $t$  period history  $h^t$ . As shown previously, the private history matters, so the focus is on public history. Under Assumption 2, the borrower's behavior will not depend on  $h^t$  anymore from  $t + \mathcal{T} + 1$  periods onward given that its memory is bounded to  $\mathcal{T}$  periods back. This means that the lender's value will not depend on  $h^t$  from  $t + \mathcal{T} + 1$  periods. As a result, if the lender strategy is sequentially strict, then  $h^t$  becomes irrelevant from  $t + \mathcal{T} + 1$  periods.

What happens in period  $t + \mathcal{T}$ ? This represents the last period in which strategies could be conditioned on  $h^t$ . However, at that time, the borrower's maximization problem is independent of  $h^t$ . In addition, sequential strictness implies that the maximizing action is a singleton. Applying this argument recursively completes the proof.  $\square$

I have therefore shown that, under the assumption of bounded memory of the borrower, small perturbations in the payoff of the market participants unravel all equilibria except Markov ones.  $\square$

PROOF OF PROPOSITION 3.

From the first-order conditions on consumption,  $c$  is increasing in  $x'$ . Hence, so does the value of the borrower. In opposition, with a greater  $c$ , the value of the lender decreases.

One further shows that the autarkic allocation is not optimal. The proof follows [Aguiar et al. \(2009\)](#). Consider a version of the optimal contract in which the outside option corresponds to the value of permanent autarky is given by

$$v_a(g_t) = \sum_{j=t}^{\infty} \beta^{j-t} \sum_{g^j} \pi(g^j|g_t) \mathcal{G}_j(g_t) u(g_j f(0)),$$

In autarky,  $k = 0$ . Suppose there is an  $\underline{x}$  such that  $u(c(g, \underline{x})) = u(gf(0))$  for all  $g$ . Consider that one increases  $h$  by  $\Delta h$  and  $u(c(g, \underline{x}))$  by  $\theta u_c(gf(0)) \Delta h$  where

$$\theta = \frac{u_c(g_L f(0))}{u_c(g_L f(0)) + \frac{\beta}{1-\beta} \mathbb{E}_{g'|g_L} u_c(g' f(0))} < 1.$$

I defined  $\theta$  such that the borrower's participation constraint holds. To see this, note that the increase of  $h$  increases the borrower's outside option by  $u_c(gf(0)) \Delta h$  as it can benefit from the additional level of capital before going to autarky forever. However, if the borrower does not choose autarky, its value increases by  $\theta(u_c(gf(0)) + \frac{\beta}{1-\beta} \mathbb{E}_{g'|g} u_c(g' f(0))) \Delta h \geq u_c(gf(0)) \Delta h$  by definition of  $\theta$ . Hence the borrower's participation constraint is satisfied. Furthermore, the value of the lender changes by

$$\Delta h \frac{1}{1+r} \left( 1 - \mathbb{E}_{g'|g_L} \left[ \frac{u_c(g' f(0))}{u_c(c(g', \underline{x}))} \right] \theta \right) = \Delta h \frac{1}{1+r} (1 - \theta) > 0.$$

As a result, the autarkic allocation is not optimal. Notice as well that the law of motion of the relative Pareto weight is given by

$$x'(g) = (1 + \nu(g)) \eta g^{-\sigma} x.$$

As one can see, the only source of immiseration for  $x'$  is the borrower's relative impatience. The participation constraint can only increase  $x'$  over time. Hence, any continuation of an efficient allocation is itself efficient. In other words, what I showed above is that there exists a region of *ex post* inefficiencies in the vicinity of  $v_a$  in which the value of both the lender and the borrower can be increased. However, from the law of motion (12), the binding constraint of the borrower only increases the value of the relative Pareto weight. This together with the fact that the initial value of the contract is efficient ensures that the region of inefficiencies is never attained.  $\square$

PROOF OF PROPOSITION 4.

– Part I

The optimal level of capital is given by

$$gf_k(k(g)) - 1 = \nu(g)u_c(gf(k(g)))gf_k(k(g))x.$$

As one can see, as soon as the participation constraint does not bind (i.e.  $\nu(g) = 0$ ), the contract can attain the production-maximizing level of capital  $k^*(g)$  such that  $gf_k(k^*(g)) = 1$ . As soon as this condition is not met,  $k < k^*(g)$ . Thus, define  $x^*(g)$  such that

$$V^b(g, x^*(g)) = V^D(g, k^*(g)).$$

By the above definition, if  $x < x^*(g)$ , capital is distorted in state  $g$ , while if  $x \geq x^*(g)$ , capital is at the production-maximizing level. Moreover as  $V^D(g_L, k^*(g_L)) < V^D(g_H, k^*(g_H))$ ,  $x^*(g_H) > x^*(g_L)$ .

Observe that  $\nu$  is the multiplier attached to the borrower's participation constraint. Hence, when this constraint binds,  $\nu > 0$ , whereas  $\nu = 0$  when it does not. In that logic, the larger is  $\nu$  the more binding is the constraint.

Assume by contradiction that for  $x_1 < x_2$  one has that  $k(g, x_1) \geq k(g, x_2)$  for all  $g \in G$ . Using the first-order condition with respect to capital, one has

$$x = \frac{gf_k(k) - 1}{\nu(g)u_c(gf(k))f_k(k)}.$$

Given that  $x_1 < x_2$ ,

$$\frac{f_k(k(g, x_1)) - 1}{\nu(g)u_c(gf(k(g, x_1)))f_k(k(g, x_1))} < \frac{f_k(k(g, x_2)) - 1}{\nu(g)u_c(gf(k(g, x_2)))f_k(k(g, x_1))}$$

With the assumption that  $k(g, x_1) \geq k(g, x_2)$ , the above inequality is satisfied only if  $\nu(g, x_1) > \nu(g, x_2)$ . This is a contradiction as a lower level of capital should relax the borrower's participation constraint and not the opposite.

The fact that that  $k(g, x) > 0$  for all  $(g, x)$  follows directly from Proposition 3 which shows that the autarkic allocation is not optimal.  $\square$

– Part II



The law of motion of the relative Pareto weight is given by  $x'(g) = (1 + \nu(g))g^{-\sigma}\eta x$ , while the first-order condition on consumption reads  $u_c(c(g)) = \frac{1}{1+\nu(g)}$ .

Given the first-order condition,  $c(g_L, x) \leq c(g_H, x)$  only when  $\nu(g_L) \leq \nu(g_H)$ . Assume by contradiction that  $\nu(g_L) > \nu(g_H)$ . This implies that  $c(g_L, x) > c(g_H, x)$  and  $x'(g_L, x) > x'(g_H, x)$ . Especially, consider the case in which  $\nu(g_L) > \nu(g_H) = 0$ . In this case,

$$\begin{aligned} u(c(g_H)) + \beta g_H^{1-\sigma} V^b(g', x'(g_H, x)) &> V^D(g_H, k), \\ u(c(g_L)) + \beta g_L^{1-\sigma} V^b(g', x'(g_L, x)) &= V^D(g_L, k). \end{aligned}$$

Given that  $g_H > g_L$ ,  $u(g_H f(k(g_H))) > u(g_L f(k(g_L)))$  and  $V^D(g_H, k) > V^D(g_L, k)$ . This implies that

$$u(c(g_H)) + \beta g_H^{1-\sigma} V^b(g', x'(g_H, x)) > u(c(g_L)) + \beta g_L^{1-\sigma} V^b(g', g_L, x'(g_L, x)).$$

which contradicts the fact that  $c(g_L, x) > c(g_H, x)$  and  $x'(g_L, x) > x'(g_H, x)$ . Hence,  $\nu(g_L) \leq \nu(g_H)$  which gives  $c(g_L, x) \leq c(g_H, x)$  and  $x(g_L, x) \leq x(g_H, x)$  as desired.  $\square$

### – Part III

The value of liabilities in the optimal contract for all  $i \in \{L, H\}$  is given by

$$V^l(g, x) \equiv gf(k) - k - c(g, x) + \frac{1}{1+r} g \mathbb{E}_{g'|g} V^l(g', x'(g, x)).$$

Assume by contradiction that for a given  $x$  it holds that  $V^l(g_H, x) \leq V^l(g_L, x)$ . For  $x \geq x^*(g_H)$ , one directly reaches a contradiction as  $c(g_L, x) = c(g_H, x)$  which implies that  $V^l(g_H, x) > V^l(g_L, x)$ . For  $x < x^*(g_H)$ , the participation constraint of the borrower is binding in at least on growth state. That is there is a wedge between the consumption allocations and the borrower gets more in the high growth state. Nonetheless this wedge is only explained by the different incentive to default and does not exhaust the surplus difference between two states for the lender.  $\square$

### PROOF OF PROPOSITION 5.

Two assumptions are here crucial:  $\beta(1+r)g^{-\sigma} \leq 1$  for all  $g \in G$  ensures that the law of motion of the relative Pareto weight eventually crosses the 45° degree line and  $\left(\frac{g_H}{g_L}\right)^{-\sigma} >$

$\beta(1+r)$  ensures that the law of motion of the relative Pareto weight for  $g_L$  crosses the 45° degree line before the one for  $g_H$ . If the former assumption is not met, the relative Pareto weight never ceases to increase. Conversely, if the second assumption is not met, the high growth state is related to a lower relative Pareto weight in steady state than the low growth state. Now, recall the law of motion of the relative Pareto weight

$$x'(g) = (1 + \nu(g))g^{-\sigma}\eta x.$$

The motion of the relative Pareto weight is dictated by the relative impatience,  $\eta g^{-\sigma}$ , and the binding participation constraint,  $\nu$ . I consider two cases. On the one hand, if  $\eta g_L^{-\sigma} < 1$ , the relative Pareto weight increases only if  $\nu(g) > 0$  is sufficiently large to overcome impatience. As we know, when  $x \geq x^*(g)$ ,  $\nu(g, x) = 0$  meaning that impatience eventually dominates the limited commitment issue. On the other hand, if  $\eta g_L^{-\sigma} = 1$  immiseration due to impatience does not exist in the low growth state and the relative Pareto weight remains constant there. In the high growth state, however,  $\eta g_H^{-\sigma} < 1$  and the previous argument applies.

Assumption 1 states that  $\eta g^{-\sigma} \leq 1$  for all  $g$ . However since  $g_H > 1 > g_L$ , having  $\eta g_H^{-\sigma} = 1$  would imply  $\eta g_L^{-\sigma} > 1$  for  $\sigma > 0$ . Hence,  $\eta g_H^{-\sigma} < 1$ , always. As a result,  $x^*(g_H)$  is never reached in the steady state as when the high growth state realizes,  $x'(g_H, x)$  decreases and  $x'(g_L, x) \leq x'(g_H, x)$ .

When  $\eta g_L^{-\sigma} = 1$ , the upper bound of the ergodic set coincides with the lower bound. As show in Proposition 4  $x'(g_L, x) \leq x'(g_H, x)$  meaning that the law of motion of the relative Pareto weight in the low growth state crosses the 45° line before the one of the high growth state. This coupled with the fact that  $x'(g_L, x)$  lies on the 45° when  $\nu(g_L, x) = 0$  leads to  $x^{ub} = x^{lb}$ . Conversely, when  $\eta g_L^{-\sigma} < 1$ , impatience immiserates the relative Pareto in the low growth state implying that  $x^{ub} > x^{lb}$ .

To show the existence of the ergodic set, one shows that the dynamic of the contract satisfies the conditions given by [Stokey et al. \(1989, Theorem 12.12\)](#). Set  $\ddot{x}$  as the midpoint of  $[x^{lb}, x^{ub}]$  and define the transition function  $Q : [x^{lb}, x^{ub}] \times \mathcal{X}([x^{lb}, x^{ub}]) \rightarrow \mathbb{R}$  as

$$Q(x, G) = \sum_{g'|g} \pi(g'|g) \mathbb{I}\{x' \in G\}$$

One wants to show is that  $\ddot{x}$  is a mixing point such that for  $M \geq 1$  and  $\epsilon > 0$  one has that  $Q(x^{lb}, [x, x^{ub}])^M \geq \epsilon$  and  $Q(x^{ub}, [x^{lb}, x])^M \geq \epsilon$ . Starting at  $x^{ub}$ , for a sufficiently long but finite series of  $g_L$ , the relative Pareto weight transit to  $x^{lb}$  (either through impatience or because  $x^{lb} = x^{ub}$ ). Hence for some  $M < \infty$ ,  $Q(x^{ub}, [x^{lb}, \ddot{x}])^M \geq \pi(g_L|g_L)^M > 0$ . Moreover, starting at  $x^{lb}$ , after drawing  $M < \infty$   $g_H$ , the relative Pareto weight transit to  $x^{ub}$  (either through the

binding constraint or because  $x^{lb} = x^{ub}$ ) meaning that  $Q(x^{lb}, [\ddot{x}, x^{ub}])^M \geq \pi(g_H|g_H)^M > 0$ . Setting  $\epsilon = \min\{\pi(g_L)^M, \pi(g_H)^M\}$  makes  $\ddot{x}$  a mixing point and the above theorem applies.  $\square$

### PROOF OF LEMMA 3.

Necessity:

The pricing equation, (2), as well as the capital choice and price conditions, (3) and (4) follow directly from the equilibrium's definition. The budget constraints in the repayment and default states is required by feasibility. The participation constraint, (10), ensures that neither the lender nor the government has an incentive to break the contract and end up in permanent autarky.

Sufficiency:

Let's rely on trigger strategy (Abreu, 1988). That is, each player is punished by the worst outcome of the game (i.e. permanent autarky which is an equilibrium as shown above) if he or she decides to deviate. Since the outcome satisfies (2), (3) and (4), it is optimal. Also as it satisfies the different budget constraints it is feasible. Finally, no deviations from play is profitable given that (10) holds.

$\square$

### PROOF OF PROPOSITION 6.

The proof of this proposition is by construction. Similar to Dovis (2019), I express the policy functions of the implemented contract as a function of the relative Pareto weight,  $x$ , and the growth state,  $g$ . Formally, define

$$\begin{aligned}\bar{\tau}, \bar{p} &: X \rightarrow \mathbb{R}, \\ \bar{D}, \bar{H}, \bar{M} &: G \times X \rightarrow \{0, 1\}, \\ \bar{q}_{st}, \bar{q}_{tl}, \bar{b}_{st}, \bar{b}_{lt} &: G \times X \rightarrow \mathbb{R}.\end{aligned}$$

Notice that the tax policy only depends on  $x$  and not  $g$  as I want to replicate the constrained efficient allocation through the maturity structure of the debt.

Given the timing of actions, the price schedules and bond policies depend on the prospective relative Pareto weights after the growth shock realizes. Those objects can therefore be rewritten as

$$\begin{aligned}\bar{b}_j(g, x) &= \bar{b}_j(x'(g, x)), \\ \bar{q}_j(g, x) &= \bar{q}_j(x'(g, x)) \quad \text{for all } j \in \{st, lt\}.\end{aligned}$$

I first determine the default and *official* buyback policies. Subsequently, I compute the underlying prices. I then define the portfolio of bonds to match the total value of debt  $V^l(g, x)$  implied by the constrained efficient allocation. Finally, I determine the optimal tax rate from the optimality conditions of the lender and the domestic firms.

Given Proposition 3, autarky is never optimal in the contract. Hence, the government never enters into default. That is  $\bar{D}(g, x) = 0$  for all  $(g, x)$ . The government will therefore rely on changes in the maturity structure and *official* buyback as in the Markov equilibrium without default incentives. I assume that *official* buybacks arise only if the economy hits the upper bound of the ergodic set,

$$\bar{M}(g, x) = \begin{cases} 1 & \text{if } g = g_H \text{ and } x = x^{ub} \\ 0 & \text{else} \end{cases}$$

Given the above policies, the short-term bond price equates the risk-free price,

$$\bar{q}_{st}(x) = \frac{1}{1+r},$$

while the long-term bond price,

$$\bar{q}_{lt}(x) = \frac{1}{1+r} \mathbb{E}_{g'|g}[1 + \bar{q}_{lt}(x')].$$

Note further that, the long-term bond price has the following properties.

**Lemma E.5** (Bond Price). *Under Assumption 1, with  $q_{lt}^{bb} = \frac{1}{r^{bb}}$  and  $r^{bb} < r$ , the long-term bond price is the unique fixed point of  $\bar{q}_{lt}$ , is decreasing and is such that*

$$\frac{1}{r^{bb}} > \bar{q}_{lt}(x'(g_H, x)) > \bar{q}_{lt}(x'(g_L, x)) > \frac{1}{r}.$$

*Proof.* See Appendix E □

Having properly determined the different price schedules, I can now determine the bond

holdings and the maturity in order to match the total value of the debt implied by the constrained efficient allocation. Particularly, it must hold that when  $x = x^{ub}$ ,

$$-V^l(g_H, x) = \bar{b}_{st}(x) + \bar{b}_{lt}(x)[1 + q_{lt}^{bb}], \quad (\text{E.1})$$

$$-V^l(g_L, x) = \bar{b}_{st}(x) + \bar{b}_{lt}(x)[1 + \bar{q}_{lt}(x'(g_L, x))]. \quad (\text{E.2})$$

Otherwise, the relationship is given by

$$-V^l(g_H, x) = \bar{b}_{st}(x) + \bar{b}_{lt}(x)[1 + \bar{q}_{lt}(x'(g_H, x))],$$

$$-V^l(g_L, x) = \bar{b}_{st}(x) + \bar{b}_{lt}(x)[1 + \bar{q}_{lt}(x'(g_L, x))].$$

This is a system of 2 equations with 2 unknowns for which Lemma E.5 ensures a unique solution. The maturity structure of the bond portfolio is therefore properly determined.

To complete the proof, I determine the optimal tax rate and the level of intermediate price. From the optimality conditions of the domestic firms and the lender I get

$$gf_k(k) = \frac{1}{1 - \bar{\tau}(x)} = \bar{p}(x). \quad (\text{E.3})$$

Hence, the constrained efficient allocation can be replicated with the above policies for default, *official* buyback, and bond holdings. The optimality conditions of the lender and the domestic firms are satisfied as well as the price schedules.

This concludes the proof as the market allocation satisfies the necessary and sufficient conditions provided in Lemma 3. Especially, I used the budget constraints to determine the optimal bond holdings given the prices computed according to (2). The tax level is set to match the conditions (3) and (4). Finally, the resource constraint and (10) are satisfied as the constrained efficient allocation meet those requirements.  $\square$

#### PROOF OF LEMMA E.5.

Recall that the long-term bond price is given by

$$q_{lt}(g, x) = \frac{1}{1+r} \mathbb{E}_{g'|g} \left[ (1 - D(g', x')) \left\{ 1 + (1 - M(g', x')) q_{lt}(g', x') + M(g', x') q_{lt}^{bb} \right\} + D(g', x') q_{lt}^D(g', x') \right],$$

I consider that  $D(g', x') = 0$  for all  $(g', x')$  and  $M(g', x') = 1$  if  $g' = g_H$  as well as  $x' = x^{ub}$  and  $M(g', x') = 0$  otherwise. From Proposition 5,  $g_H$  and  $x = x^{ub}$  arises with strictly positive

probability for any  $(g, x)$ ,

$$\frac{1}{r^{bb}} > q_{lt}(g, x) > \frac{1}{r}.$$

Define  $Q_{lt}$  as the space of bounded functions  $q_{lt} : [\underline{x}, \bar{x}] \rightarrow [0, \frac{1}{r^{bb}}]$  and  $\mathbb{T} : Q_{lt} \rightarrow Q_{lt}$  as

$$\mathbb{T}q_{lt}(g, x) = \frac{1}{1+r} \sum_{i=1}^N \pi(g_i) [1 + q_{lt}(g', x')].$$

By the Blackwell sufficient conditions  $\mathbb{T}$  is a contraction mapping. As a result, there exists a unique fixed point to  $\mathbb{T}$ ,  $\bar{q}_{lt}$  which is increasing as  $\mathbb{T}$  maps increasing functions into increasing functions. This implies that  $q_{lt}(x'(g_H, x)) \geq q_{lt}(x'(g_L, x))$  as  $x'(g_H, x) > x'(g_L, x)$  for all  $x$  in the above specified domain. Assume now that there exists a  $x$  such that  $q_{lt}(x'(g_H, x)) = q_{lt}(x'(g_L, x))$ . This requires that  $x, x'(g_H, x), x'(g_L, x)$  belongs to a subset  $[x_t, x_{t+1}]$  where  $q_{lt}$  stays constant. Hence, for any  $\ddot{x} \in [x_t, x_{t+1}]$ , it must be that  $x'(g_H, \ddot{x}), x'(g_L, \ddot{x}) \in [x_t, x_{t+1}]$  which is a contradiction as  $x'(g_H, x_{t+1}) > x_{t+1}$  owing to the borrower's relative impatience. Therefore it must be that  $q_{lt}(x'(g_H, x)) > q_{lt}(x'(g_L, x))$ .  $\square$

PROOF OF LEMMA [B.1](#).

The law of motion of the relative Pareto weight is given by

$$x'(g) = (1 + \nu(g))g^{-\sigma}\eta x.$$

and the level of consumption by

$$u_c(c(g)) = \frac{1}{x(1 + \nu(g))}.$$

Isolating  $x$  leads to

$$x = \frac{1}{u_c(c(g))(1 + \nu(g))}. \tag{E.4}$$

Plugging this back into the law of motion gives

$$x'(g) = (1 + \nu(g))g^{-\sigma}\eta \frac{1}{u_c(c(g))(1 + \nu(g))}.$$

Replacing  $x'(g)$  by with the forward equivalent of (E.4) gives

$$\frac{1}{u_c(c(g'))(1 + \nu(g'))} = g^{-\sigma} \eta \frac{1}{u_c(c(g))}.$$

Taking expectations on both sides,

$$\mathbb{E}_{g'|g} \left[ \frac{1}{u_c(c(g'))(1 + \nu(g'))} \right] = g^{-\sigma} \eta \frac{1}{u_c(c(g))},$$

which gives the inverse Euler equation.  $\square$

#### PROOF OF PROPOSITION D.1.

Following Alvarez and Jermann (2000) we prove the proposition by construction. First, define the asset price as

$$q(g', x'|g) = \frac{\pi(g'|g)}{1 + r} \left[ 1 + \sum_{g''|g'} q(g'', x''|g') \right] \max \left\{ g^{-\sigma} \frac{u'(c(g', x'))}{u'(c(g, x))} \eta, 1 \right\}.$$

Second, iterating over the budget constraint of the government and applying the transversality condition gives

$$a(g^t) = \mathbb{E}_t \sum_{j=0}^{\infty} Q(g^{t+j}, x(g^{t+j})|g^t) [c(g^{t+j}, x(g^{t+j})) - Y(g^{t+j}, x(g^{t+j}))], \quad (\text{E.5})$$

where,  $Y(g^t, x(g^t)) = g_t f(k(g^t, x(g^t))) - k(g^t, x(g^t))$  for all  $t$  and  $g^t$ . Similarly, iterating over the budget constraint of the lender leads to

$$\begin{aligned} a_l(g^t) &= \mathbb{E}_t \sum_{j=0}^{\infty} Q(g^{t+j}, x(g^{t+j})|g^t) c_l(g^{t+j}, x(g^{t+j})) \\ &= \mathbb{E}_t \sum_{j=0}^{\infty} Q(g^{t+j}, x(g^{t+j})|g^t) [Y(g^{t+j}, x(g^{t+j})) - c(g^{t+j}, x(g^{t+j}))] \\ &= -a(g^t). \end{aligned} \quad (\text{E.6})$$

The market clearing condition implies that  $a_l(g^t) + a(g^t) = 0$  for all  $t$  and  $g^t$ .

To ensure that the capital level is the same as in the constrained efficient allocation, I

set the capital tax rate and the level of intermediate price according to

$$gf_k(k) = \frac{1}{1 - \tau(a)} = p(a).$$

I now need to establish the correspondence between the initial conditions,  $x_0$ , in the contract and the initial conditions in the recursive competitive equilibrium,  $a_0$ . Given (E.5) and (E.6) evaluated at  $t = 0$ , one can determine  $\bar{a}(g_0, a_0)$  using the budget constraint

$$\begin{aligned} & c(g_0, x_0) + q(g_0, a_1)(\bar{a}' - a_0) + \sum_{g_1|g_0} q(g_1, a_1(g_1)|g_0)\hat{a}'(g_1) + \sum_{g_1|g_0} q(g_1, a_1(g_1)|g_0)a'(g_1) \\ & \leq g_0 f(k) - p(1 - \tau)k + a_0. \end{aligned}$$

and the fact that  $\sum_{g_1|g_0} q(g_1, a_1(g_1)|g_0)\hat{a}'(g_1) = 0$ . Once,  $\bar{a}(g_0, a_0)$  is determined, one can find the holdings of Arrow securities  $\hat{a}'(g', g_0, a_0)$  for all  $g' \in \Theta$ . We can then retrieve the entire portfolio recursively for  $t > 0$ .

Third, define the endogenous borrowing limits such that

$$\mathcal{A}(g, k) = a(g, \tilde{x}(g, k)),$$

where  $\tilde{x}(g, k)$  is the relative Pareto weight when the participation constraint binds at  $(g, k)$ . This definition implies that  $a'(g', g, a) \geq \mathcal{A}(g', k')$ . Hence, the constructed asset holdings satisfy the competitive equilibrium constraints.

Fourth, to ensure optimality of the policy functions by setting

$$\mu_{BC}(g, a) = \frac{1}{x(1 + \nu(g))}$$

Hence, since  $c(g, x)$  satisfies the optimality conditions in the Planner's problem, it is also optimally determined in the competitive equilibrium. For the lenders,  $c_l(g, x)$  is optimal if the asset portfolio is optimally determined. For this observe that

$$\begin{aligned} q(g', a'(g')|g) &= \frac{1}{1+r} \pi(g'|g) g^{-\sigma} \frac{u'(c(g', a'(g')))}{u'(c(g, a))} \eta \left[ 1 + \sum_{g''|g'} q(g'', a''(g'')|g') \right] \\ &> \frac{1}{1+r} \pi(g'|g) \left[ 1 + \sum_{g''|g'} q(g'', a''(g'')|g') \right] \\ &\quad \text{if } a'(g', g, a) = \mathcal{A}(g', k'). \end{aligned}$$

Hence the portfolio is optimally determined. We therefore obtain a one-to-one map between  $x$



and  $a$  for a given  $g$ . More precisely,  $c(g, a) = c(g, x)$ ,  $c_l(g, a) = T(g, x)$  and  $k(g, a) = k(g, x)$ . Thus,  $W^b(g, a) = V^b(g, x)$  and  $W^l(g, a) = V^l(g, x)$ . Furthermore, the endogenous limits binds uniquely and exclusively when the participation constraints of the government binds.  $\square$