

UNIVERSITY COLLEGE LONDON

ESSAYS IN MACROECONOMICS AND
SOVEREIGN DEFAULT

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Declaration of Authorship

'I, Carlo Galli confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed:



Date: 20/01/2020

Abstract

This thesis studies government fiscal, monetary and debt policy, with a particular focus on debt crises and the pricing of default risk.

The first chapter studies the circular relationship between sovereign credit risk, government fiscal and debt policy, and output. I show that, when fiscal policy responds to borrowing conditions in the sovereign debt market, multiple equilibria exist where the expectations of lenders are self-fulfilling. This result is reminiscent of the European debt crisis of 2010-12: while recessionary, fiscal austerity may be the government best response to excessive borrowing costs during a confidence crisis.

The second chapter studies the information sensitivity of government debt denominated in domestic vs. foreign currency: the former is subject to inflation risk and the latter to default. Default only affects sophisticated bond traders, whereas inflation concerns a larger and less informed group. Within a two-period Bayesian trading game, we display conditions under which debt prices are more resilient to bad news. Our results can explain debt prices across countries following the 2008 financial crisis, and also provide a theory of “original sin.”

The third chapter explores the trade-off between strategic inflation and default for a set of large emerging market economies that borrow mostly in their local currency. Using derivatives data, I find a robust, positive correlation between default risk, expected and realised inflation. I use these facts to discipline a quantitative sovereign default model where a government issues debt in domestic currency and lacks commitment to fiscal and monetary policy. I show that simple models of debt dilution via default and inflation have counterfactual implications. I highlight the role of monetary financing in matching the data, allowing inflation to serve a second purpose: in bad times, seignorage is especially useful as a flexible source of funding when other margins are hard to adjust.

Impact Statement

In this thesis, I study the behaviour of default risk and its role in shaping public policy. The relevance of this topic has been highlighted frequently in policy and academic debates, both for emerging market economies and more recently for developed economies.

My work contributes to the academic literature in various ways. In chapter 3, I provide new empirical evidence on the role played by default and inflation spreads when a country borrows in its own currency, and I show how this finding can be used to discipline models of sovereign debt and default. In chapter 2, I show how the pricing of government debt may vary depending on the currency in which it is denominated, and the information available to who is pricing it. This work has been published in a leading economics journal, the *American Economic Review*. In chapter 1, I analyse under what conditions self-fulfilling debt crises similar to those that hit Southern Europe in 2011 may happen.

The contributions of this thesis can also have beneficial use outside of academia. A thorough understanding of what drives the price of government debt, and how this interacts with public policy, can help inform debt policy substantially. My work in chapters 2 and 3 suggests that debt denomination decisions should consider a number of factors, such as the sluggish reaction of inflation to fiscal news or lenders' anticipation of fiscal inflation in times of low output. My work in chapter 1 highlights the mechanism through which panic among investors can significantly hurt a government, and in turn a country. In the continuation of such chapter, which is currently work in progress, I consider what type of policies should be put in place to avoid such debt crises in the first place.

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Introduction

The importance of sovereign debt dynamics and the influence of sovereign bond prices on public policy has come to the forefront of the academic and policy debate during the European debt crisis in the aftermath of the Great Recession. At the same time, questions regarding monetary sovereignty and its interaction with local-currency borrowing has become increasingly important, especially in light of the marked shift to local-currency debt by a number of large emerging market economies. This thesis aims at achieving a better understanding of the costs and benefit of borrowing in a country's own currency, and the way in which government bond spreads interplay with fiscal and monetary policy.

The opening chapter “Self-Fulfilling Debt Crises, Fiscal Policy and Investment,” mainly concerns two important issues: one relates to the possibility of self-fulfilling debt crises in sovereign debt markets, the other to the effectiveness of austerity policies. Pessimistic investors' beliefs on government solvency have often been cited to explain, at least partly, the spike observed in government bond spreads during late 2010, and their subsequent reduction following interventions by the European Central Bank. Austerity policies have sparked a heated debate during the crisis, when fiscal consolidation measures were adopted by southern European countries as a response to the turbulence in sovereign debt markets. Some considered these policies necessary to reduce debt levels and decrease exposure to debt market fluctuations; others argued that their effects were largely contractionary and worsened the debt crisis. The chapter studies in detail the circular relationship between spreads, policy and output, providing a tractable framework to characterise under what conditions there may exist multiple equilibria where the beliefs of sovereign debt market participants are self-fulfilling. In the model, a confidence crisis makes it costlier for the government to obtain external funding, forcing it to increase domestic taxation instead. Higher taxes depress private investment and in turn future output, increasing future default probabilities and ultimately verifying lenders'

pessimistic beliefs, resulting in an equilibrium that is bad for the government. If instead borrowing conditions are favourable, the government can borrow more cheaply and tax less, so investment is high and default probabilities are in turn low. The bad equilibrium illustrates situations where fiscal consolidation is the government best response to excessive borrowing costs, even though it has contractionary effects and is accompanied by low domestic welfare. This result is reminiscent of the European debt crisis of 2010-12: while recessionary, fiscal austerity may be the government best response to excessive borrowing costs during a confidence crisis.

The second chapter “Is Inflation Default? The Role of Information in Debt Crises,” joint work with Marco Bassetto, concerns the sovereign borrowing experience of advanced economies in the aftermath of the financial crisis of 2008, which once again highlighted the important role of the currency in which debt is denominated. Countries which had control over their monetary policy, such as the United States, the United Kingdom, and Japan, were able to borrow at extremely low rates throughout the episode, even though they experienced very high deficit/GDP ratios (the UK) or debt/GDP ratios (Japan). In contrast, peripheral Eurozone countries were either unable to borrow from the market (Portugal, Ireland) or faced volatile interest rates when doing so (Italy, Spain). We dig deeper in the source of frictions that may make the price of a country’s debt less sensitive to adverse news on the government solvency. We study an economy where private agents have dispersed and heterogeneous information about the government’s ability to repay its debt. We contrast two situations: in the first one, the government is forced to outright default when its tax revenues fall short of debt promises, while in the second one a domestic currency is present and the government resorts to the printing press and eventual inflation to cover any shortfalls. To assess the implications of this difference, we analyze a two-period Bayesian trading game. In both economies, government debt is subscribed in the first period by (sophisticated) traders, who take into account the different nature of risk across the two cases (inflation vs. default). In the default economy, the default premium is determined by other traders, who are as sophisticated as the primary market buyers. In the inflation economy, the evolution of prices is driven by the beliefs about fiscal solvency of larger and less sophisticated section of the population, which determine inflation expectations and in turn the price level. We show that in the default economy, primary market debt prices respond more to shocks

because traders anticipate dealing with informed agents in the future. In the inflation economy instead, because it is unlikely that the price level will respond abruptly to news of a fiscal shock, debt is less responsive to news in both periods. In sum, our results confirm that heterogeneity between a small, sophisticated group of bond traders and a large, less informed population that drives the aggregate price level can explain why domestic-currency debt may be less information-sensitive than foreign-currency debt (or debt denominated in a common currency not directly controlled by the domestic central bank).

The third chapter “Inflation, Default Risk and Nominal Debt,” is motivated by the fact that in the last two decades, many emerging market (EM) governments significantly tilted the currency composition of their public debt from foreign to local currency. The inflation and default spreads embedded in government bond interest rates have a critical role in determining the trade-off between the ex-post benefits and the ex-ante costs of these policies, in the presence of time inconsistencies. The chapter studies in detail the relationship between strategic inflation, default and inflation risk for a set of large EM sovereigns. A common argument regarding countries that borrow in their own currency is that they need not default on their debt, because they can always resort to the printing press in case of need. I show that in the data, despite the shift to local-currency debt, default risk for these countries remains non-negligible and displays a robust, positive relationship with realised and expected inflation. I use these facts to discipline the behaviour of default and inflation spreads in a quantitative sovereign default model where a government issues debt in domestic currency and lacks commitment to both fiscal and monetary policy. I find that, to reconcile the model with the data, it is important to account for the role of inflation as a tool to raise fiscal revenues, especially in periods when other margins may be hard to adjust. The model allows to quantitatively evaluate the trade-off between the insurance benefits of nominal debt and the cost of a further source of time inconsistency, when inflation and default risks co-move.

Chapter 1

Self-Fulfilling Debt Crises, Fiscal Policy and Investment

1.1 Introduction

The European debt crisis of 2010-12 raised, in both academic and policy circles, two important issues: one relates to the possibility of self-fulfilling debt crises in sovereign debt markets, the other to the effectiveness of austerity policies. Pessimistic investors' beliefs on government solvency have often been cited to explain, at least partly, the spike observed in government bond spreads during late 2010, and their subsequent reduction following interventions by the European Central Bank. Austerity policies have sparked a heated debate during the crisis, when fiscal consolidation measures were adopted by southern European countries as a response to the turbulence in sovereign debt markets. Some considered these policies necessary to reduce debt levels and decrease exposure to debt market fluctuations; others argued that their effects were largely contractionary and worsened the debt crisis.

These two issues are related by the existence of a negative feedback loop between bond spreads, government fiscal and debt policy, and economic activity. Bond spreads can have a significant impact on policy, because they affect the cost of government borrowing and in turn its decisions regarding the mix between debt and fiscal policy. There is ample descriptive evidence that the turmoil in sovereign debt markets observed during the European debt crisis was a concern for policymakers, and in many occasions the motivation for austerity measures that proved to adversely impact consumption, investment

and output. The dependence of government bond prices on economic activity closes the circle, as default incentives tend to be increasing in debt/GDP ratios, being stronger during recessions and when debt stocks are large.

This chapter studies in detail the circular relationship between spreads, policy and output, providing a tractable framework to characterise under what conditions there may exist multiple equilibria where the beliefs of sovereign debt market participants are self-fulfilling. In the model, a confidence crisis makes it costlier for the government to obtain external funding, forcing it to increase domestic taxation instead. Higher taxes depress private investment and in turn future output, increasing future default probabilities and ultimately verifying lenders' pessimistic beliefs, resulting in an equilibrium that is bad for the government. If instead borrowing conditions are favourable, the government can borrow more cheaply and tax less, so investment is high and default probabilities are in turn low. The bad equilibrium illustrates situations where fiscal consolidation is the government best response to excessive borrowing costs, even though it has contractionary effects and is accompanied by low domestic welfare.

I propose a simple two-period model building on the tradition of [Eaton and Gersovitz \(1981\)](#) and the subsequent quantitative work of [Aguiar and Gopinath \(2006\)](#) and [Arellano \(2008\)](#). I consider a risk-averse, benevolent government that trades defaultable debt with a continuum of foreign risk-neutral investors, and taxes domestic households. Households accumulate capital, produce according to a concave production technology, pay taxes to the government and consume. The government chooses debt, tax and default policy to maximise the utility of domestic households, who suffer a random utility cost in case of default. I assume that the government cannot commit to future actions, and that tax policy and private investment are chosen after the debt auction. This key assumption implies that the government adjusts to external borrowing conditions with debt as well as fiscal policy, and the latter affects the private sector consumption-saving decision. Private investment determines future output and, in turn, future default incentives, which affect debt prices via lenders' expectations. This circular relationship between government bond prices, fiscal policy and private investment creates the possibility of multiple equilibria driven by self-fulfilling expectations on the side of foreign investors.

Following the quantitative literature, I assume that the government moves first in the debt issuance game, choosing debt at maturity (i.e. fixing its future

repayment obligations). Lenders then bid a price, being willing to lend to the government as long as they make zero profits in expectation. For some levels of debt issuance, there exist multiple debt prices that satisfy such zero-profit condition. This coordination problem among lenders is the key mechanism behind the existence of multiple equilibria in the model. It relies on the effect that debt prices have, via government taxation, on household wealth in the first period, which in turn affects investment and government default incentives. I adopt a selection criterion that rules out unstable outcomes, and determines the prices on which creditors coordinate and the terms at which the government can borrow. I then characterise with a general proposition the optimal policy of the government as a function of the debt price schedule it faces and of its initial endowment, and show with a numerical example the existence of multiple equilibria that depend on lenders' self-fulfilling beliefs.

I choose the current specification of the model because it is tractable and allows to present the main mechanism in a transparent way. The results of the chapter however are general, in the sense that the feedback loop linking bond spreads, output and default incentives can also be modelled in other ways. The necessary ingredient is that spreads have real effects that affect future default incentives. As in this chapter, this transmission can be intermediated by policy: multiple equilibria are possible as long as the government undertakes some domestic policy action that (i) responds to current borrowing conditions, and (ii) affects its future repayment incentives, either directly or indirectly through the private sector. Examples of such policy are government reform effort, productive government spending, or taxation: actions that are costly today but increase the likelihood of higher growth tomorrow, or viceversa. Another possibility is that spreads affect real activity directly, for example through the banking sector.¹ While I do not explore this mechanism here, I consider it a force that is complementary to the one analysed in this chapter.

This chapter mainly relates to two strands of the literature on sovereign debt and default. The first concerns equilibrium uniqueness and multiplicity in sovereign default models. As shown by [Auclert and Rognlie \(2016\)](#), the sovereign default framework in the tradition of [Eaton and Gersovitz \(1981\)](#), most common in the quantitative literature, features a unique equilibrium if

¹A large body of work examines the effect of government bond spreads on banks' balance sheets and private credit. See for example [Bocola \(2016\)](#), [Arellano et al. \(2017a\)](#), [Balke \(2017\)](#) and [Bottero et al. \(2014\)](#).

debt is short-term. To analyse the role of beliefs, the literature on multiple equilibria relies on modifications of this framework along several dimensions. Calvo (1988) and subsequent work by Lorenzoni and Werning (2013) and Ayres et al. (2018) assume a different structure for the government debt auction, where the government fixes current auction revenues and future repayment obligations depend on debt prices, taken as given. In this framework, high interest rates imply high future debt, which makes default probabilities high and in turn justifies the high interest rates. Other papers, from the workhorse model of Cole and Kehoe (2000) to more recent work by Aguiar et al. (2016) and Conesa and Kehoe (2017), consider rollover risk by adopting a different timing assumption, whereby the government can issue new debt before deciding whether to default. Aguiar and Amador (2018) and Stangebye (2017) show that multiple equilibria may exist if the Eaton-Gersovitz model is extended to allow for long-term debt. Aguiar et al. (2015), Corsetti and Dedola (2016) and Bassetto and Galli (2019) analyse the interplay between self-fulfilling beliefs and inflation, when debt is denominated in local currency. Bocola and Dovis (2016) evaluate quantitatively the contribution of fundamentals and beliefs in explaining the behaviour of government bond spreads. A feature common to all this literature is that it focuses solely on the interaction between government debt policy and bond spreads, assuming that output is exogenous.²

The second stream of literature relevant for this chapter is that on sovereign default models with dynamic policy and endogenous output.³ Gordon and Guerron-Quintana (2018) and Bai and Zhang (2012) study quantitative models of default risk and capital accumulation that are similar to the framework presented in this chapter. The crucial difference lies in their assumption that domestic policy is contractible, so debt prices do not affect investment but are rather a function of it. Müller et al. (2015) model domestic policy as effort to undertake structural reforms, which is assumed to have a separable cost and thus does not interact with lenders' beliefs in a way that creates the possibility of multiple equilibria. Broner et al. (2014) consider a model with capital and explore the possibility of belief-driven equilibria; in their model multiplicity is driven by a crowding-out effect of government debt on capital, and its interplay

²Cole and Kehoe (2000) do consider a model with capital, but there is no interaction between government fiscal policy and households' investment decisions.

³Arellano and Bai (2016) and Balke and Ravn (2016) also analyse sovereign default and fiscal policy in a model with endogenous output, but assume that both policy and production are static.

with creditor discrimination. Their mechanism is different and complementary to that analysed in this chapter. Closest to my work is [Detragiache \(1996\)](#). She sketches a general framework where policy effort is non-contractible, has non-separable costs and positively affects future repayment probabilities; she observes that multiple equilibria are possible when lenders' coordination failure reduces lending and forces the government to provide less effort. My chapter solidifies this intuition by characterising the equilibrium policy fully, relating it to notions of "fiscal austerity," exploring the implications of decentralising the equilibrium, and considering stable equilibria only.

This chapter also relates to the literature on debt overhang and investment. [Krugman \(1988\)](#) and [Sachs \(1989\)](#) show that, when debt levels are high and taken as given, investment is discouraged because most of the return accrues to creditors. In [Lamont \(1995\)](#), corporate debt overhang can create complementarities in investment that generate multiple equilibria driven by expectations, in a way that is similar to the coordination problem among households that I also study. In more recent work, [Aguiar et al. \(2009\)](#) show that limited commitment on the side of the government leads to under-investment in bad times and when debt is large, as is true for equilibrium policy in this chapter when creditors' expectations severely constrain borrowing.

The remainder of the chapter proceeds as follows: Section 1.2 presents the two-period model; Section 1.3 illustrates the key mechanisms at play with a numerical example and characterises the equilibrium; Section 1.4 discusses some assumptions and alternative model specifications; Section 3.6 concludes. Appendix 1.A presents a simplified, deterministic version of the two-period model that allows to derive closed-form results.

1.2 Two-Period Model

I consider a small open economy with a continuum of measure one of identical households and a government. Time is discrete and there are two periods, $t = 0, 1$.

The government is benevolent and wishes to maximise households' utility. It starts period 0 with a stock of debt due equal to B_0 . It finances debt repayment by borrowing new one-period debt B_1 from international lenders, and collecting lump-sum taxes T_0 . The government lacks a commitment technology, so in period 1 it can choose whether to repay or default on its debt coming due. In

case of repayment, it collects lump-sum taxes T_1 from households. In case of default, it needs not tax, but households are assumed to suffer a random utility cost γ , distributed according to a cumulative distribution function $G(\gamma)$ with support $\Gamma \subseteq (0, +\infty)$.⁴ Following [Lorenzoni and Werning \(2013\)](#) I assume that initial debt B_0 cannot be defaulted upon in period 0.⁵ The budget constraints of the government are given by

$$\begin{aligned} B_0 &= T_0 + q_0 B_1 \\ (1 - \delta_1) B_1 &= T_1 \end{aligned}$$

where δ_1 is a binary variable that takes the value of 1 if the government defaults, and 0 otherwise. Henceforth I will mention debt and tax policy interchangeably since either one pins down the other, conditional on debt price q_0 and initial debt level B_0 . In Section 1.4 I argue that the results of the model are robust to two alternative assumptions: that default entails a proportional output cost, and that the government taxes production (or equivalently consumption) proportionally rather than in a lump-sum way. I choose lump-sum taxation because it isolates the new source of multiplicity in a transparent way.

Households have preferences represented by the utility function

$$u(c_0) + \beta \mathbb{E}_0[u(c_1) - \delta_1 \gamma]$$

over individual consumption levels $\{c_0, c_1\}$, where $u(c_t) := c_t^{1-\eta}/(1-\eta)$ with $\eta > 0$. They produce output using individual capital k_t according to a concave production function $f(k_t) := k_t^\alpha$, and pay lump-sum taxes T_t to the government. Households start with an initial stock of capital equal to k_0 and can only save through capital. For simplicity, I assume that capital fully depreciates over time, and that households produce using a backyard technology, the output of which they consume directly.⁶ The household budget constraints are

⁴The assumption that default has a direct utility cost is made for tractability and follows a large share of the literature.

⁵Alternatively, I consider situations where the government has drawn a high realization of the default cost for period 0 and has thus chosen to repay B_0 .

⁶Assuming instead that production is carried out by a representative firm that rents capital and hires labour (supplied inelastically) from households would deliver the same results, and would not affect the household coordination problem discussed later in Subsection 1.3.1.

given by

$$\begin{aligned}c_0 &= f(k_0) - k_1 - T_0 \\c_1 &= f(k_1) - T_1\end{aligned}$$

where initial capital k_0 is given.

We can now examine the default decision of the government. Let us plug the government budget constraint at $t = 1$ into that of the households, and denote aggregate capital in period t with K_t . The optimal default decision solves

$$\max_{\delta_1} \{(1 - \delta_1)u[f(K_1) - B_1] + \delta_1(u[f(K_1)] - \gamma)\}.$$

It follows that the government defaults on its debt obligations if and only if the utility cost of defaulting is smaller than a threshold equal to the utility differential between default and repayment:⁷

$$\gamma < \hat{\gamma}(K_1, B_1) := u[f(K_1)] - u[f(K_1) - B_1]. \quad (1.1)$$

When it is indifferent, I assume that the government chooses repayment. Importantly, default incentives are decreasing in output and increasing in debt, as is commonly assumed in the sovereign default literature.

I assume that households move *after* the government in period 0. They take as given the quantity of debt issued and its price (and therefore tax policy), and form expectations about default in period 1 accordingly. This timing structure can be interpreted with the fact that private sector behaviour during the period between debt issuance and maturity affects the evolution of GDP and in turn the government default incentives at maturity. A key implication is that foreign lenders who price government debt must anticipate the response of the private sector to the outcome of the debt auction.⁸

We can now examine the household capital investment decision. As households are identical and have the same initial stock of capital, $k_0 = K_0$. Let us replace first-period taxes T_0 with government net lending $B_0 - q_0 B_1$ inside

⁷Under the assumption of log-utility we get the more intuitive condition that the government defaults if debt over GDP is larger than an increasing function of the default cost: $\frac{B_1}{f(K_1)} > 1 - e^{-\gamma}$.

⁸Bai and Zhang (2012) and Gordon and Guerron-Quintana (2018) instead assume that investment is contractible, which is equivalent to assuming households move first in my setting. This implies that capital is an argument of the price function for debt, which eliminates the scope for belief-driven multiple equilibria in the sovereign debt market.

the household budget constraint, and denote initial aggregate wealth with $W_0 := f(K_0) - B_0$. W_0 will be the relevant state variable for both the household and the government problem. Optimal individual investment solves

$$\begin{aligned} \max_{a_1} V(a_1, W_0, q_0, B_1, K_1) := & u[W_0 + q_0 B_1 - a_1] + \beta \int_{\hat{\gamma}(K_1, B_1)} u[f(a_1) - B_1] dG(\gamma) \\ & + \beta \int^{\hat{\gamma}(K_1, B_1)} \{u[f(a_1)] - \gamma\} dG(\gamma) \end{aligned} \quad (1.2)$$

and is thus a function of initial wealth W_0 , government debt policy B_1 , debt price q_0 and aggregate investment K_1 . Solving (1.2) and imposing the symmetric equilibrium condition $a_1 = K_1$ yields the aggregate private sector investment response function

$$K_1^*(W_0, q_0, B_1) := \{K_1 : K_1 \in \arg \max_{a_1} V(a_1, W_0, q_0, B_1, K_1)\}. \quad (1.3)$$

In principle there could be multiple solutions to equation (1.2) due to complementarities in household investment, but in practice this will not be an issue, as explained in Section 1.3.1. Note that this coordination problem is separate, and independent of, the coordination problem among lenders.

Foreign lenders are risk-neutral and perfectly competitive. There is a continuum of them, of measure large enough that their aggregate lending capacity is never constrained. They are thus willing to buy any amount of debt as long as they make zero profits in expectation. The assumption that lenders are atomistic is crucial for the existence of complementarities in the debt issuance game. Lenders' discount factor is given by β^* , which needs not be equal to the households'. For simplicity, I assume that B_1 are discount bonds, which implies that the risk-free price of debt is equal to β^* .

A further assumption regarding the timing of the government debt auction is needed. Following most of the quantitative sovereign default literature, I adopt the timing structure of [Eaton and Gersovitz \(1981\)](#), whereby the government moves before lenders and chooses the quantity of debt it wishes to issue, and then lenders bid and determine the issuance price. It is well-known that, when output is exogenous and debt is short-term, this assumption generally leads to equilibrium uniqueness.⁹ A key point of this chapter is that, if fiscal policy

⁹For a discussion in both finite and infinite horizon settings, see [Lorenzoni and Werning](#)

is non-contractible and has real, dynamic effects on output, then multiple equilibria can arise in the Eaton-Gersovitz timing.¹⁰ The set of zero-profit prices at which lenders are willing to buy debt is given by

$$Q(W_0, B_1) = \{q_0 : q_0 = \beta^* \text{Prob}(\gamma \geq \hat{\gamma}[K_1^*(W_0, q_0, B_1), B_1])\}. \quad (1.4)$$

Repayment probabilities depend on debt as well as investment. Private sector investment depends on debt auction revenues through a wealth effect on households in period 0: in order to repay initial debt B_0 , the government must finance with taxes on households what it does not raise in sovereign debt markets. Because of this, there may exist multiple solutions to equation (1.4) for some (W_0, B_1) pairs. This is the core source of multiple equilibria of the model, and will be examined more in detailed later.

I now define the notion of equilibrium, focusing on symmetric equilibria where all households take the same actions.

Definition 1. *A competitive equilibrium is a collection of government debt and default choices $\{B_1, \delta_1\}$, households' investment choice $\{K_1\}$ and a debt price function $\{Q(W_0, B_1)\}$ such that, given initial wealth W_0 ,*

1. *households choose investment to maximise their expected utility, given government policies and debt prices;*
2. *the debt price function $Q(W_0, B_1)$ satisfies creditors' zero-profit condition for all debt levels $B_1 \in \mathbb{R}$;*
3. *government policies maximise households' expected utility, subject to the households' investment response and the debt price function.*

I restrict the analysis to the set of initial wealth levels (i.e. initial (K_0, B_0) pairs) such that the household budget set allows for positive consumption and investment levels.

Combining conditions (1.1), (1.2) and (1.4) we can focus on the government problem of choosing debt in period 0 to maximise households' utility, subject to its optimal default policy in period 1, to creditors' zero-profit condition and

(2013), Ayres et al. (2018), Aguiar and Amador (2018), Auclert and Rognlie (2016) and Passadore and Xandri (2018).

¹⁰Section 1.4 discusses timing in the context of the existing literature more in detail.

to households' investment response:

$$\begin{aligned}
& \max_{B_1, q_0, K_1} u(W_0 + q_0 B_1 - K_1) \\
& \quad + \beta \left[\int_{\hat{\gamma}(K_1, B_1)} u[f(K_1) - B_1] dG(\gamma) + \int^{\hat{\gamma}(K_1, B_1)} \{u[f(K_1)] - \gamma\} dG(\gamma) \right] \\
& \text{s.t. } q_0 = q(W_0, B_1) \\
& \quad K_1 = k(W_0, q_0, B_1) \\
& \quad W_0 \text{ given}
\end{aligned} \tag{1.5}$$

where $q(W_0, B_1)$ and $k(W_0, q_0, B_1)$ are functions that arise from a selection from the correspondences $Q(W_0, B_1)$ and $K_1^*(W_0, q_0, B_1)$, and that the government takes as given.

1.3 Multiplicity and Equilibrium Policy

This section presents equilibrium policy and highlights the key mechanisms of the model laid out in the previous section. I derive optimality conditions and characterise the general features of equilibrium policy, while presenting a numerical example that shows the existence of multiple equilibria and their properties. In the appendix, I present a simpler version of the model that admits a complete, closed-form characterisation of the equilibrium. This choice is dictated by the fact that a closed-form solution can only be obtained by making a number of simplifying assumptions that eliminate interesting aspects of the model.

The analysis proceeds in three steps. First, I examine the private sector investment response. Second, I show that there may exist multiple zero-profit prices consistent with the same level of debt issuance. I show under what conditions this happens, and I adopt a selection criterion that determines the prices on which lenders coordinate, considering only stable solutions. Third, I analyse the government optimal policy, and show that multiple equilibria exist where policy depends on the debt price schedule faced by the government.

In the parametric example I assume the following: capital share of output $\alpha = 0.4$, risk-aversion parameter $\eta = 1$ (log-utility), households' and lenders' discount factor $\beta = \beta^* = 0.97$, default utility cost log-normally distributed

with mean 0.25, standard deviation 0.25 and support truncated to the interval $\Gamma = [0.1, 4]$.

1.3.1 Private Sector Investment Response

I start by considering households' investment decision conditional on government debt issuance B_1 and debt price q_0 (or, equivalently, tax policy T_0). Households take future default and tax policy as given because they are atomistic, so they do not internalise the effects of their choice on aggregate investment. The individual best response $a_1^*(K_1)$ to aggregate investment K_1 solves the household investment problem in (1.2) and is given by the following first-order condition

$$\begin{aligned} & u'(W_0 + q_0 B_1 - a_1) \\ & = \beta f'(a_1) \left\{ [1 - G(\hat{\gamma}(K_1, B_1))] u'[f(a_1) - B_1] + G(\hat{\gamma}(K_1, B_1)) u'[f(a_1)] \right\}. \end{aligned} \tag{1.6}$$

For a given (W_0, q_0, B_1) triplet, there may in principle exist multiple fixed point solutions $a_1^*(K_1) = K_1$ to equation (1.6), because of complementarities in household investment. In practice, however, various numerical explorations suggest that only in rare cases equation (1.6) does admit multiple solutions, and that this multiplicity has negligible implications for the purpose of characterising the equilibrium. The mechanism is still worth inspecting in detail here, because the forces driving it play a role in the analysis that follows.

Equation (1.6) highlights the role of aggregate capital, and in turn of default probabilities. Future default discourages private investment, because by reneging on its debt obligations the government does not have to tax households in period 1, and this generates a positive wealth effect that reduces households' incentive to invest. Suppose that households expect aggregate investment K_1 to be low, and therefore default to be likely. This means that they do not expect to pay taxes in period 1, which renders their future marginal utility and their saving motive relatively low. The opposite happens if households expect K_1 to be high instead. It follows that, for a given (W_0, q_0, B_1) triplet, complementarities among households may in principle yield multiple solutions to (1.6).¹¹ Complementarities are stronger (i) when period-0 taxes are high

¹¹This logic is analogous to that in the sovereign debt application of [Bassetto \(2005\)](#). There too a future default discourages production, and there exist complementarities in

and wealth is low, since the marginal utility differential between default and repayment states is decreasing in invested capital; and (ii) in the limiting case where the distribution of the utility cost γ has a variance close to zero, so that a marginal change in aggregate capital around the mode of the distribution causes a sharp increase in the marginal benefit of individual capital investment. In Appendix 1.A I show how an alternative assumption about the structure of taxes in period 1 can unambiguously eliminate the issue.

1.3.2 Debt Price Schedules

I now examine creditors' zero-profit condition: for a given level of debt issuance B_1 and initial wealth W_0 , I consider whether there exist multiple zero-profit prices that solve equation (1.4). Earlier, I analysed private sector investment keeping government policy (debt and taxes) *and* debt prices fixed. There, the anticipation of default or repayment had an effect on households' wealth in the *second* period. Now I go backwards in the order of play within the first period, and I consider how a change in the price of debt affects private investment. This approach is consistent with the timing of the government debt auction: lenders bid a price after the government has chosen how much debt to issue, anticipating the effect of debt auction revenues on government tax policy, and in turn on households' wealth, in the *first* period.

The right panel of Figure 1.1 plots private sector aggregate investment $K_1^*(W_0, q_0, B_1)$ as a function of the price of debt q_0 , for three different levels of debt issuance B_1 . The left panel plots the right-hand side of equation (1.4) (that is, repayment probabilities adjusted by lenders' discount factor β^*) as a function of q_0 , for the same three debt levels. Zero-profit prices are represented by markers and correspond to the points where the curves intersect the 45-degree dotted line.

Let us focus on the aggregate investment response first, as determined by condition (1.6) after imposing the equilibrium condition $a_1 = K_1$. As explained in the previous subsection, the marginal benefit of investment is given by the average of marginal utilities in default and repayment states, weighted by the probability of each. Consider for now the curves that correspond to an intermediate level of B_1 , depicted in red. Investment is always increasing in q_0 , because larger debt prices imply more available resources in period 0, reducing

private production decisions that may generate multiple equilibria.

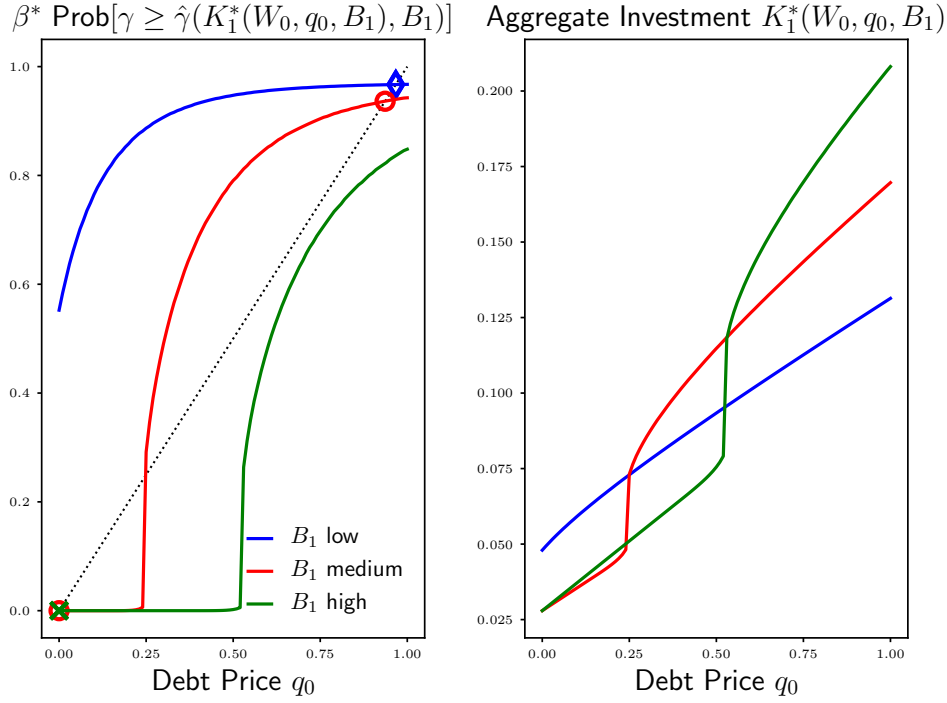


Figure 1.1: Example of zero-profit prices (left-hand side) and capital investment (right-hand side) as a function of q_0 , given W_0 .

the marginal utility of consumption in period 0 and thus the marginal cost of investing extra resources. When q_0 is low, so are revenues from the government debt auction, which force the government to increase period-0 taxes. This negative effect on household wealth in $t = 0$ depresses investment to a level that makes default likely; high default probabilities reinforce this mechanism by also pushing down the motive to invest.¹² In this scenario (represented by values of q_0 roughly below 0.25 in the figure) investment is a constant fraction of households' after-tax wealth, because the log-utility assumption implies income and substitution effects cancel out exactly. As the price of debt increases, so does invested capital, and repayment probabilities eventually move away from zero. This results in a sharp increase in the marginal benefit of saving, because marginal utility is larger under repayment, when households pay taxes in period 1 too. This produces the non-linear increase in investment visible in the right panel of Figure 1.1, which corresponds to the sharp positive jump in repayment probabilities. Larger debt prices are thus associated with a stronger investment motive: lower taxes increase households' wealth in $t = 0$,

¹²The effect of default expectations on investment incentives is discussed in detail in the previous subsection, and is not essential for the multiplicity result.

while higher repayment probabilities reinforce the motive to save by increasing its marginal benefit.

This mechanism does depend on the shape of the default cost distribution and on the curvature of the utility function. The lower is the distribution variance, the less smooth will be the behaviour of private investment to changes in the price of debt, and the wider the range of debt levels for which there exist multiple zero-profit prices.¹³ The role of utility curvature is more complex because it is composed by two counteracting forces. More utility curvature makes taxes in period 1 more painful: on one hand, this means that repayment probabilities are lower when consumption under repayment is close to zero, because default is more attractive; on the other hand, higher curvature implies that the marginal utility differential between repayment and default states is larger. Under this specification of the model, the first effect dominates the second, so more curvature implies a smoother response of K_1^* to q_0 .

When debt belongs to an intermediate region, the joint effect of all these forces determines the existence of multiple zero-profit prices. When instead issued debt is large (small), as indicated by the green (blue) curves in Figure 1.1, there exists only one zero-profit price close to zero (one). The rationale is that, when debt is either low or high, the effect of debt prices on period-0 household wealth is not strong enough to generate the non-linear response of investment just examined.

Figure 1.2 represents an example of the debt price function $Q(W_0, B_1)$ for a given level of initial wealth W_0 , which is the result of repeating the previous analysis for all possible levels of government debt issuance. Ignoring the colouring, we can see that the set of zero-profit prices is given by an inverted-S curve, and the function $Q(W_0, B_1)$ is a correspondence that maps from debt levels B_1 into a set of debt prices in the $[0, \beta^*]$ interval. If the government issues a low (high) amount of debt, it will be certain to get a price close to one (zero) for it, because that is the only price consistent with creditors' zero-profit condition. If instead the government issues an amount of debt inside what I call the "multiplicity region", represented in the figure by all intermediate debt levels inside the $[\underline{B}_1, \overline{B}_1]$ interval, it may get either of the three zero-profit prices consistent with it.

¹³See the model of Appendix 1.A for an example where the role of the default cost distribution can be analysed even more accurately, since the investment response is independent of it.

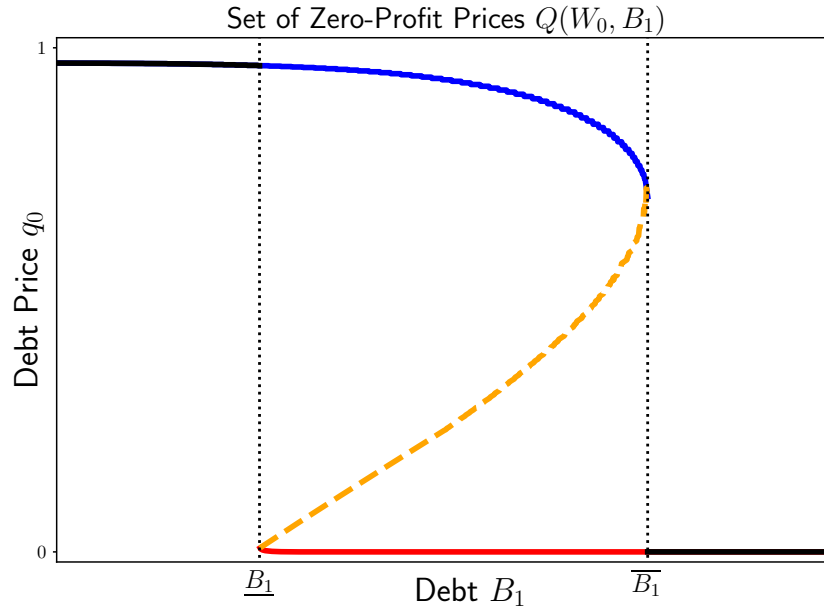


Figure 1.2: Example of debt price function $Q(W_0, B_1)$, for a given initial wealth W_0 .

1.3.3 Timing and Creditors Coordination

From now on, I split the correspondence $Q(W_0, B_1)$ into single-valued schedules. Let us first note that, for all debt levels outside the multiplicity region, $Q(W_0, B_1)$ is single-valued. This will be the “common” part of any schedule, depicted in solid black in Figure 1.2. I define as the “good” schedule $Q_g(W_0, B_1)$ the function composed by the upper envelope of curve in the multiplicity region (in solid blue), together with the common part. This curve will thus feature a discontinuity at \bar{B}_1 , where in the example the price of debt jumps from a price close to 0.7 to one equal to zero. Similarly, I define as the “bad” schedule $Q_b(W_0, B_1)$ the function composed by the lower envelope of the curve in the multiplicity region (in solid red), together with the common part. Lastly, note that the dashed orange part of the curve inside the multiplicity region is unstable, in the sense that it is upward sloping. If the government were restricted to choose a point in that subset of the correspondence, it would always choose the largest possible debt level because that would fetch the highest price. For this reason I ignore such part of the debt price correspondence in the analysis.¹⁴

¹⁴Lorenzoni and Werning (2013) and Ayres et al. (2018) also do not consider equilibria in the unstable part of their debt price schedules, and show the existence of multiple stable equilibria assuming long-term debt or bimodal output distributions. This chapter thus

This criterion to discipline coordination among lenders minimizes the number of discontinuities in each of the price schedules, and offers a clear ranking of schedules from the point of view of the government-borrower. In this example, I choose the two points of discontinuity that coincide with the boundaries of the multiplicity region.¹⁵

Finally, I assume that at the beginning of period 0, the government knows which price schedule it will face when it issues new debt B_1 . The rationale behind this assumption is that, before auctioning off new debt, an issuer can observe conditions in the secondary market and understand *ex ante* at what price it may be able to issue a certain amount of debt. I thus interpret situations in which the government is facing the bad schedule as debt crises, or periods of market turbulence such as the European debt crisis, where sovereign borrowing becomes more difficult and investors are particularly concerned with default risk. In such times the government realises that, if it were to issue a level of debt inside the multiplicity region, it would raise little funds because lenders would coordinate on the bad schedule.

1.3.4 Government Policy and Equilibria

So far, I have shown that the conditions at which the government is borrowing new debt may depend on self-fulfilling beliefs on the side of creditors. The existence of multiple outcomes of the issuance games, i.e. of multiple price schedules, is however a necessary but not sufficient condition for the existence of multiple equilibria. To have the latter, it is also necessary that debt policy indeed depends on which price schedule the government is facing. That is, since the government has the advantage of moving first and choosing the optimal amount of debt to issue, equilibrium tax and debt policies will be a function of creditors' beliefs insofar as the borrowing motive is strong enough to push the government to consider debt levels inside the region that features multiple debt prices.

I now characterize government debt policy and households' investment policy as a function of the initial state W_0 and the debt price schedule $\{Q_i(W_0, B_1)\}_{i=\{g,b\}}$.

proposes an alternative mechanism that also delivers multiple stable equilibria, and does so in the [Eaton and Gersovitz \(1981\)](#) timing.

¹⁵Other pairs of price schedules obtained choosing any two discontinuity points inside the multiplicity region would also satisfy the above-mentioned properties. I pick the two boundaries to make my point more starkly. Other criteria with more than one discontinuity are less compelling, because they would make the price locally increasing in debt issuance.

At any interior point where $Q_i(W_0, B_1)$ is differentiable, the optimality condition for government debt is given by

$$u'(c_0) = \frac{\beta}{Q_i(W_0, B_1) + B_1 \frac{\partial Q_i(W_0, B_1)}{\partial B_1}} u'[f(K_1) - B_1][1 - G(\hat{\gamma}(K_1, B_1))] \quad (1.7)$$

which I obtain after taking the first-order condition of government problem (1.5) with respect to B_1 , and plugging it in equation (1.6). Equation (1.7) shows that the rate of return on debt is the inverse of the marginal revenue from borrowing one additional unit. As is standard in sovereign default models, $B_1 \frac{\partial Q_i(W_0, B_1)}{\partial B_1}$ represents the negative price effect of issuing an additional unit of debt. Combining (1.7) with (1.6) yields

$$\begin{aligned} & f'(K_1)u'[f(K_1)]G(\hat{\gamma}(K_1, B_1)) \\ &= \left(\frac{1}{Q_i(W_0, B_1) + B_1 \frac{\partial Q_i(W_0, B_1)}{\partial B_1}} - f'(K_1) \right) u'[f(K_1) - B_1][1 - G(\hat{\gamma}(K_1, B_1))]. \end{aligned} \quad (1.8)$$

In equilibrium, the difference between the marginal interest paid on debt and the marginal product of capital must be positive, since investment pays off in both repayment and default states while debt does not.

The following proposition further characterises equilibrium policy (the formal proof can be found in the appendix).

Proposition 1 (Risk-free and risky policy).

1. Policy is risk-free and is given by a government borrowing function $B_1^f(W_0)$ and a household constant investment level K_1^f such that

$$f'(K_1^f) = \frac{1}{\beta^*}; \quad B_1^f(W_0) = \frac{f(K_1^f) - \frac{\beta}{\beta^*}(W_0 - K_1^f)}{1 + \beta} \quad (1.9)$$

for all $W_0 \geq W_0^f$, where $W_0^f := K^f + \frac{\beta^*}{\beta} f(K^f) [1 - (1 + \beta)(1 - e^{-\inf(\Gamma)})]$.

2. For all $W_0 < W_0^f$, government and household policy are such that debt is risky and capital investment is below the risk-free level:

$$K_1 < K_1^f; \quad Q_i(W_0, B_1) < \beta^* \quad \forall i \in \{b, g\}.$$

Note that the separation of the state-space in two regions that feature dis-

tinct equilibrium policy is a general result that is independent of the parametrization of the model. It is however difficult to prove formally whether risky policy does involve debt levels in the multiplicity region of the debt price schedules. For this, I consider the following results from the numeric example introduced earlier.

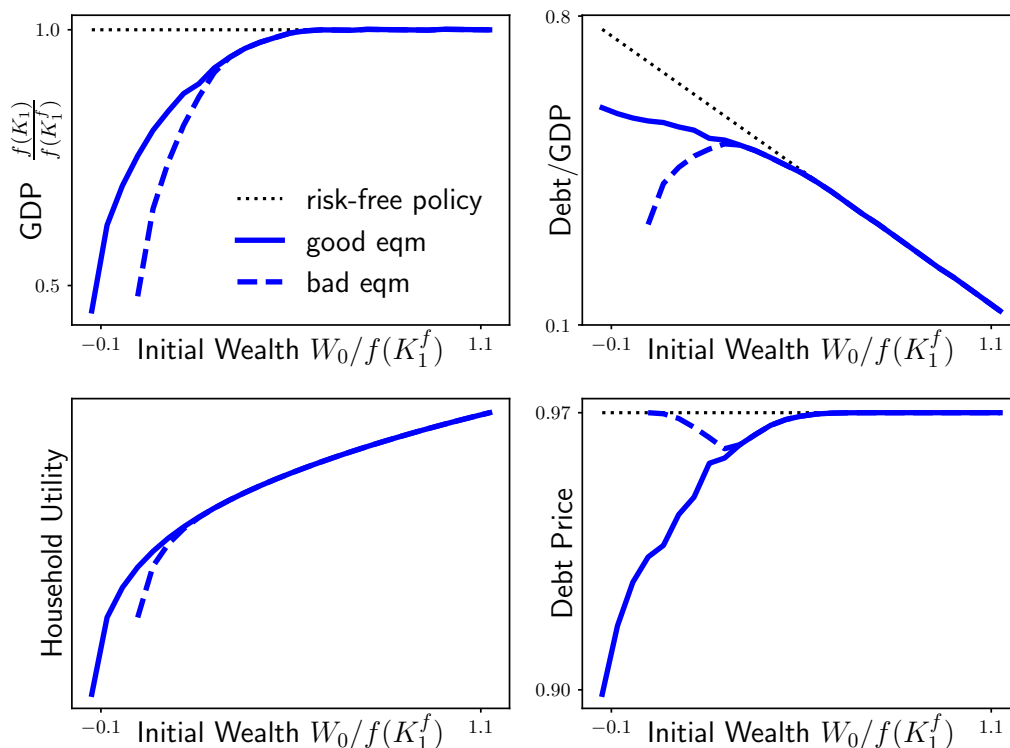


Figure 1.3: Policy functions, household utility and equilibrium debt prices, as a function of initial wealth W_0 scaled by GDP under the risk-free policy $f(K_1^f)$.

Figure 1.3 plots actual GDP $f(K_1)$ (as a ratio to risk-free GDP $f(K_1^f)$), government debt policy (as a ratio to actual GDP), household utility and equilibrium debt prices as a function of initial wealth. Dashed lines denote the bad equilibrium, which I interpret with a debt crisis where lenders' beliefs are pessimistic; solid lines denote the good equilibrium where borrowing conditions are favourable. All curves are truncated at the initial wealth level where the equilibria stop existing because positive consumption is not possible anymore.

When initial wealth is sufficiently large, government and households policy is risk-free:¹⁶ it is unaffected by the problem of lack of commitment, repayment

¹⁶Black dotted lines represent what risk-free policy would look like if it were feasible for any level of initial wealth.

is certain, capital investment is constant at K_1^f and the net interest paid on debt (or earned on savings) is $1/\beta^*$.

For lower levels of wealth, policy is risky: it is constrained by the risk of default, the net interest paid on debt is positive and capital investment is below its risk-free level. The economic intuition behind risky policy is the following: when wealth is low, the desire to front-load consumption is strong enough to make risky debt preferable to risk-free debt, even if that comes at a higher cost due to the presence of a default risk premium; in turn, costlier borrowing lowers the incentive to invest in capital as its opportunity cost rises. When wealth is at an intermediate level, however, the borrowing motive is not strong enough to push debt issuance in the multiplicity region, and policy is unaffected by lenders' beliefs.

When instead initial wealth becomes sufficiently low, it enters a region where equilibrium policy does change depending on debt market conditions. Under the good schedule, the government keeps borrowing relatively large amounts of debt. While the stock of newly issued debt does decrease as wealth becomes lower, the debt/GDP ratio remains high and actually increases, due to lower investment which makes output drop at a faster rate. Under the bad schedule, which I interpret as a confidence crisis, issuing too much debt becomes prohibitively costly (i.e. debt prices would belong to the red part of the price schedule of Figure 1.2) because lenders hold pessimistic beliefs about the behaviour of the private sector. The government effectively becomes debt constrained, and is forced to reduce external borrowing and increase domestic taxation, thereby reducing debt/GDP ratios while depressing private consumption and investment. Because the constraint on borrowing is tighter, positive consumption and investment under the bad equilibrium stop being feasible at larger levels of wealth than under the good equilibrium.

The set of policies under the bad equilibrium can be seen as part of the so-called "fiscal austerity" policy recommendations that were at the centre of the debate during the European debt crisis. The bad equilibrium is thus an example of a situation where government debt markets are in turmoil, pessimistic beliefs are self-fulfilling, and austerity policies that bring down debt/GDP ratios are optimal in the face of prohibitively high borrowing costs, although they are accompanied by lower output growth and especially lower domestic welfare.

The example thus shows that there exist multiple equilibria in the debt

issuance game between foreign lenders and the government. This result is driven by two factors: first, the way in which the government mixes debt and tax policy as a function of borrowing conditions; second, the effect of tax policy on private investment. In bad times, when lenders are pessimistic and fail to coordinate on good debt prices, the government is forced to adjust to adverse borrowing conditions by substituting debt with taxes: these impact households' wealth in the first-period, depressing investment and output.

1.4 Discussion of Assumptions

The current specification of the model was chosen because it is the most transparent way of presenting the mechanisms behind equilibrium multiplicity. However, the result is robust to a number of alternative assumptions that I now illustrate in detail.

First, taxation is assumed to be lump-sum. In period 0 this is obviously an innocuous assumption, while in period 1 it changes the optimality condition for investment. Assuming a proportional tax on production¹⁷ creates an externality that reduces the marginal product of capital in repayment states, working against the wealth effect of taxation in period 1. This dampens the non-linearity of the private sector investment response to the price of debt, and eliminates the potential issue of coordination failure among households highlighted in Subsection 1.3.1. In Appendix 1.A I show that this modification does not affect my results significantly,¹⁸ but proves convenient for closed-form derivations.

Second, default costs are assumed to be direct utility costs. This is a simplification that makes the exposition particularly clean, especially with respect to the analysis of the private sector investment response. An alternative would be to assume that in case of default the economy suffers a production loss equal to a random share of output.¹⁹ This would have a different interpretation, linked to a large area of the literature where defaults are shown to cause production losses due, for example, to disruptions in access to foreign inputs and

¹⁷This would be analogous to assuming taxes on income from capital or labour in a representative firm setting.

¹⁸The crucial driver of multiplicity in the model is the wealth effect that debt prices have in period 0 through taxation, not the wealth effects of default or taxation in period 1.

¹⁹This would be analogous to assuming that the productivity of capital is random, and the cost of default is a fixed share of output.

in the domestic banking sector. However, it would not change the structure of default incentives, that would still be increasing in debt and decreasing in output, nor would it affect the existence and features of equilibrium multiplicity. The non-linearity in the investment response highlighted in Subsection 1.3.2 would be largely unchanged: the difference in the marginal benefit of investment between repayment and default states would come from differences in the marginal product of capital rather than in the marginal utility of second-period consumption. In fact, in the special case of log utility adopted in the example, the first-order condition for investment in equation (1.6) would be identical across the two specifications.

Finally, I make two timing assumptions that are crucial for the results of the model. First, I assume that the structure of the government debt auction follows the Eaton-Gersovitz timing. As [Lorenzoni and Werning \(2013\)](#) carefully point out, this assumption implies that the government implicitly commits to adjust taxes or spending in order to satisfy the budget constraint, in case debt prices were different than expected.²⁰ They argue that it would be more plausible to assume that, in the short term, the margin that adjusts is debt policy rather than fiscal policy. Second, I assume that the private sector moves after the government, because I want to study how private investment responds to fiscal policy. These two assumptions are a reduced form way to represent more complex and realistic environments, where debt is long-term and the state variables affecting the future incentives to default are determined after debt issuance and are not contractible. On one hand, I interpret the length of a period in my chapter as long enough to allow a deterioration in government borrowing conditions to feed through to tax policy and to private investment. On the other hand, the assumption of [Lorenzoni and Werning \(2013\)](#) that the government takes debt prices and current fiscal policy as given would render the model a version of [Calvo \(1988\)](#) with capital, changing the nature of multiplicity but not its existence.

1.5 Conclusion

Default risk is the key determinant of sovereign borrowing costs, which have important implications for the joint dynamics of debt and fiscal policy, espe-

²⁰For a detailed discussion of the implication of different assumptions regarding the timing and structure of the government debt auction, see also [Ayres et al. \(2018\)](#).

cially in countries with weak fundamentals and high stocks of debt and over the medium term. This chapter models in a simple and tractable way the circular relationship between government bond spreads, fiscal and debt policy, and economic activity.

I find that, under certain conditions, the expectations of sovereign debt investors may be self-fulfilling and, in a confidence crisis, induce a government to follow austerity policies that reduce debt levels at the cost of depressed output and consumption. I believe that this can be an interpretation of the dynamics of southern European countries during the European debt crisis of 2010-12, and may be a useful framework for the analysis of scenarios where turbulent conditions in sovereign debt markets condition debt and fiscal policy in meaningful ways.

This chapter studies a specific channel through which sovereign credit risk affects economic activity with a negative feedback loop. The next step in this analysis would be to embed this multiplicity channel in a quantitative model and contrast it with others that have been emphasized in previous work.

Another direction for future work is to study the policy implications of my results. Because multiplicity arises from the fact that lenders are atomistic and may coordinate on bond prices that are bad for the government, promoting lenders' coordination through institutions in the spirit of the London Club would help to solve the problem, without the need to resort to bilateral official lending with attached conditionality.

Appendix 1.A Two-Period Model without Uncertainty

Here I present a two-period model with proportional taxes in $t = 1$. For now I continue to assume that the default cost is random as in the main text; later on I will consider the limiting case where the variance of the default cost distribution goes to zero, in order to draw sharper analytical conclusions. The government budget constraint in $t = 1$ now reads

$$(1 - \delta_1)B_1 = \tau_1 f(K_1) \tag{1.10}$$

where τ_1 is a proportional tax on production that equals $B_1/f(K_1)$ in case of repayment and zero in case of default. The default cutoff of the government

remains identical to (1.1). What changes is the individual investment problem: there is now an externality, given by the proportional tax in repayment states, that reduces the marginal product of capital. The first-order condition for individual capital investment a_1 is given by

$$u'(W_0 + q_0 B_1 - a_1) = \beta f'(a_1) \left\{ [1 - G(\hat{\gamma}(K_1, B_1))](1 - \tau(K_1, B_1))u'[f(a_1)(1 - \tau(K_1, B_1))] + G(\hat{\gamma}(K_1, B_1))u'[f(a_1)] \right\}. \quad (1.11)$$

This illustrates how the proportional tax assumption dampens the sources of household coordination failure highlighted in Subsection 1.3.1: the marginal product of capital under repayment is now smaller than under default, and this largely offsets the marginal utility differential between states. Under the assumption of log-utility, the two differentials cancel out exactly and, after imposing the equilibrium condition $a_1 = K_1$, we get that private sector aggregate investment is a constant fraction of after-tax household wealth in $t = 0$

$$K_1^*(W_0, q_0, B_1) = \frac{\alpha\beta}{1 + \alpha\beta}(W_0 + q_0 B_1). \quad (1.12)$$

This result holds true regardless of the probability of default, making the model more tractable and highlighting the independent role of the default cost distribution in determining repayment probabilities. In fact, plugging equation (1.12) into (1.4) we get that the set of zero-profit prices is given by

$$Q(W_0, B_1) = \left\{ q_0 : q_0 = \beta^* \text{Prob} \left(\gamma \geq \log \left[1 - \frac{B_1}{f \left(\frac{\alpha\beta}{1 + \alpha\beta}(W_0 + q_0 B_1) \right)} \right]^{-1} \right) \right\}. \quad (1.13)$$

As is clear from the right-hand side of the zero-profit condition, the default cutoff is a function of (W_0, q_0, B_1) only and is independent of the structure of $G(\gamma)$. The effect of debt price variations on repayment probabilities is thus all due to the specifics of the distribution. Figure 1.4 plots repayment probabilities and investment responses for different standard deviations of the distribution G , keeping all other parameters equal to those of the numerical example in the main text. The right panel only shows one curve coloured in black, to represent the fact that the investment response is independent of the

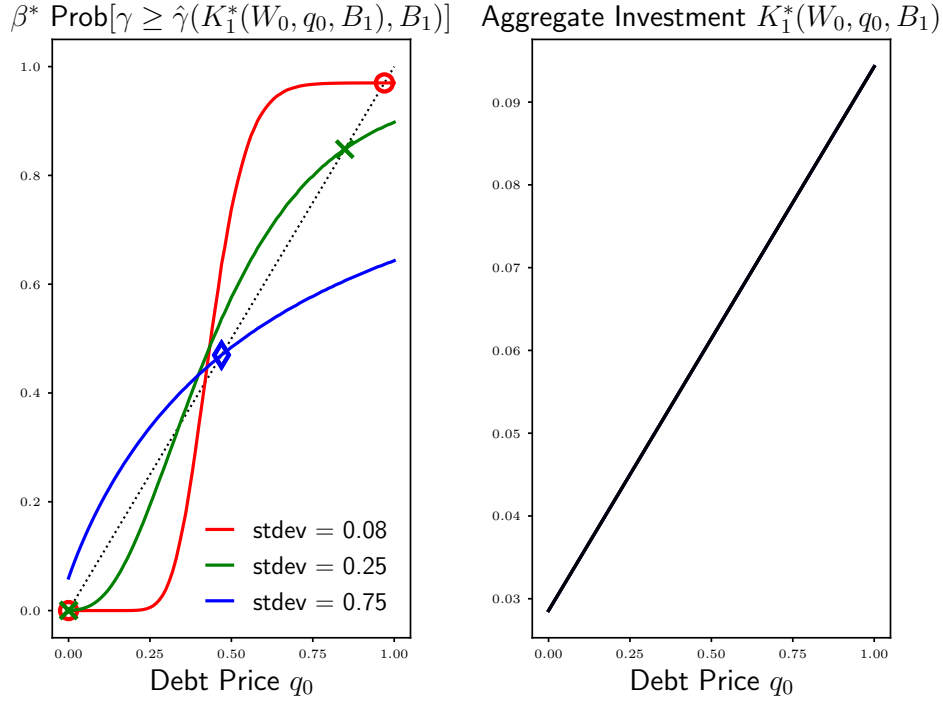


Figure 1.4: Zero-profit prices (left-hand side) and capital investment (right-hand side) as a function of q_0 , given B_1 and W_0 .

default cost variance. What affects the shape of the repayment probability curves in the left panel, and is a key driver of the existence of belief-driven multiple equilibria in this setting, is that the default cost distribution has an interior mode and is not too dispersed, a criterion satisfied by most bell-shaped distributions.

No Uncertainty. I now consider the limiting case where the distribution G is degenerate with all probability mass at a single point $\bar{\gamma} > 0$, which allows to proceed with analytical derivations. Let us denote with

$$\bar{K}_1(B_1) := \left(\frac{B_1}{1 - e^{-\bar{\gamma}}} \right)^{1/\alpha}$$

the threshold for private investment above (below) which the government finds it optimal to repay (default on) its debt B_1 . A sufficient condition for the existence of multiple zero-profit prices is that, for a given (W_0, B_1) pair, the following two conditions on investment are verified simultaneously:

$$K_1^*(W_0, 0, B_1) < \bar{K}_1(B_1) \quad \wedge \quad K_1^*(W_0, \beta^*, B_1) \geq \bar{K}_1(B_1). \quad (1.14)$$

This simply means that, if the government cannot borrow a certain amount of debt because creditors anticipate it will default on it, taxes in period 0 will be high and private investment will indeed be below the repayment threshold; viceversa, if the government can borrow at the risk-free rate because creditors anticipate repayment, taxes will be low and private investment will be above the repayment threshold. It can be proved that, for any non-negative initial wealth level, there always exists a non-empty interval of debt levels such that the conditions of (1.14) are verified. I denote with $\underline{B}_1(W_0) < \overline{B}_1(W_0)$ the lower and upper bounds of such interval.²¹ Note that both borrowing limits are increasing in initial wealth W_0 .

As in the main text, I define the “good” schedule as that under which the government can borrow risk-free up to $\overline{B}_1(W_0)$, and the “bad” schedule as the one that limits risk-free borrowing to $\underline{B}_1(W_0)$.

We can now move on to characterise the government optimal debt policy. The features of equilibrium policy are analogous to those derived in the main text, except that the absence of uncertainty here implies debt is always risk-free. When the borrowing limit is not binding, debt policy is unconstrained and is given by the solution for B_1 to the equation

$$B_1 = \frac{f(K_1^*(W_0, \beta^*, B_1)) - \frac{\beta}{\beta^*}[W_0 - K_1^*(W_0, \beta^*, B_1)]}{1 + \beta}. \quad (1.15)$$

When it is feasible, government and households follow the unconstrained policy of (1.15), which I denote with $B_1^u(W_0)$. The following proposition characterises equilibrium debt policy exactly.

Proposition 2. *Let us denote with $\underline{W}_0 < \overline{W}_0$ the initial wealth levels such that $B_1^u(\overline{W}_0) = \underline{B}_1(\overline{W}_0)$ and $B_1^u(\underline{W}_0) = \overline{B}_1(\underline{W}_0)$.*

1. *Under the bad schedule, equilibrium policy is given by*

$$\begin{cases} B_1^u(W_0) \text{ for } W_0 > \overline{W}_0 \\ \underline{B}_1(W_0) \text{ for } W_0 \leq \overline{W}_0. \end{cases}$$

²¹The first condition of (1.14) is equivalent to $B_1^{1/\alpha} > \frac{\alpha\beta(1-e^{-\gamma})^{1/\alpha}}{1+\alpha\beta}W_0$. The second condition of (1.14) is equivalent to $B_1^{1/\alpha} \leq \frac{\alpha\beta(1-e^{-\gamma})^{1/\alpha}}{1+\alpha\beta}W_0 + \frac{\alpha\beta(1-e^{-\gamma})^{1/\alpha}}{1+\alpha\beta}B_1$.

2. Under the good schedule, equilibrium policy is given by

$$\begin{cases} B_1^u(W_0) \text{ for } W_0 \geq \underline{W}_0 \\ \bar{B}_1(W_0) \text{ for } W_0 < \underline{W}_0. \end{cases}$$

In words, when the government faces the bad schedule it can follow the unconstrained policy for a smaller range of wealth states than under the good schedule, and the risk-free borrowing limit starts binding at a larger level of initial wealth. Additionally, constrained policy under the good schedule is characterised by a looser borrowing limit, that permits a larger level of borrowing, investment and household welfare.

Appendix 1.B Proofs

Proof of Proposition 1. First I prove statement 2, i.e. that when debt policy is risky capital investment is below its risk-free level K_1^f . Let us start by noting that capital can never be above the risk-free level because its marginal return would be inferior to that of risk-free debt, in which case it would be optimal for the government to save using debt rather than capital. Let C_1^R and C_1^D denote second-period consumption under repayment and default respectively, and let us drop the arguments of $\hat{\gamma}(K_1, B_1)$ to save on notation. When policy is risky, first-order condition (1.7) implies that $u'(C_0) > \frac{\beta}{\beta^*} u'(C_1^R)$ since $Q_i(W_0, B_1) < \beta^*$ and $B_1 \frac{\partial Q_i(W_0, B_1)}{\partial B_1} < 0$. Subtracting $u'(C_0)G(\hat{\gamma})$ from both sides of first-order condition (1.6) for investment we get

$$u'(C_0)[1 - G(\hat{\gamma})] = \beta f'(K_1)u'(C_1^R)[1 - G(\hat{\gamma})] + \beta f'(K_1)[u'(C_1^D) - u'(C_0)]G(\hat{\gamma})$$

At the risk-free level of capital, $f'(K_1^f) = 1/\beta^*$ and we obtain

$$[1 - G(\hat{\gamma})] \left[u'(C_0) - \frac{\beta}{\beta^*} u'(C_1^R) \right] = G(\hat{\gamma}) \left[\frac{\beta}{\beta^*} u'(C_1^D) - u'(C_0) \right]. \quad (1.16)$$

From the above derivations and the fact that marginal utility upon default is smaller than marginal utility upon repayment, it must be that $u'(C_0) > \frac{\beta}{\beta^*} u'(C_1^R) > \frac{\beta}{\beta^*} u'(C_1^D)$. This in turn implies that (1.16) cannot hold for $K_1 = K_1^f$, as the RHS of is positive while the LHS is negative.

Second, I prove statement 1, i.e. that the risk-free policy is optimal when

it is feasible. Let K_1^r, B_1^r denote risky policy, and recall that K_1^f, B_1^f denote risk-free policy. Under the risk-free policy, condition (1.7) implies that

$$\frac{\beta}{\beta^*} u'(W_0 + \beta^* B_1^f - K_1^f) = u'[f(K_1^f) - B_1^f]. \quad (1.17)$$

When policy is risky, condition (1.7) implies that

$$\frac{\beta}{\beta^*} u'(W_0 + Q_i(W_0, B_1^r) B_1^r - K_1^r) > u'[f(K_1^r) - B_1^r]. \quad (1.18)$$

By construction, risk-free consumption at $t = 1$ must be larger than risky consumption at $t = 1$ under repayment, which implies

$$u'[f(K_1^f) - B_1^f] < u'[f(K_1^r) - B_1^r]. \quad (1.19)$$

Combining (1.17), (1.18) and (1.19) proves that $u(W_0 + \beta^* B_1^f - K_1^f) > u(W_0 + Q_i(W_0, B_1^r) B_1^r - K_1^r)$. By construction we can also prove that second-period utility under the risk-free policy must be larger than its equivalent under the risky policy, for any realization of γ . ■

Chapter 2

Is Inflation Default? The Role of Information in Debt Crises

2.1 Introduction

The sovereign borrowing experience of advanced economies in the aftermath of the financial crisis of 2008 has once again highlighted the important role of the currency in which debt is denominated. Countries which had control over their monetary policy, such as the United States, the United Kingdom, and Japan, were able to borrow at extremely low rates throughout the episode, even though they experienced very high deficit/GDP ratios (the UK) or debt/GDP ratios (Japan). In contrast, peripheral Eurozone countries were either unable to borrow from the market (Portugal, Ireland) or faced volatile interest rates when doing so (Italy, Spain).¹

In previous crises, such as Latin America in the 1980s and Asia in 1998, currency mismatch was identified as a source of instability, and hence many authors have studied the role of the “original sin” or other causes of financial underdevelopment that led to the mismatch. In the presence of nominal rigidities, having an own currency may allow for a quick devaluation as a means to adjust to domestic shocks, preserving the country’s economy and ability to repay its debt, but only if this debt is denominated in domestic currency.²

¹See e.g. De Grauwe (2012) and Plender (Plender, John. 2011. “Bond vigilantes focus on ability to print money.” *Financial Times*, August 16. <https://www.ft.com/content/fe04b354-c80e-11e0-9501-00144feabdc0>).

²See for example Krugman (Krugman, Paul. 2011, “Wonking Out About the Euro Crisis,” *The Conscience of a Liberal*, August 8, <https://krugman.blogs.nytimes.com/2011/08/08/wonking-out-about-the-euro-crisis-very-wonkish/>; 2011, “The Print-

Compared to those crises, 2008 presents some important differences. First, financial underdevelopment of the debt market was not a cause of the Eurozone countries' difficulties, since they all had an ample and liquid market for government debt denominated in their home currency before joining the Euro. Second, it is not clear that the ability to devalue and thereby spare the economy from a deeper recession was a major factor in explaining the different behavior of interest rates: while it is true that the United Kingdom depreciated the Pound in the wake of the recession, the Yen appreciated substantially against the Euro, exacerbating the slump in Japan.

Our goal is to dig deeper in the source of frictions that may make the price of a country's debt less sensitive to adverse news on the government solvency. A premise of our analysis is that a domestic currency partially insulates a country from default risk, as the government may be able to lean on the central bank to act as a residual claimant on government debt securities. However, the resulting increase in the money supply would be bound to generate inflation, so that default risk would be replaced by inflation risk and we might expect interest rates to spike similarly under the two scenarios. Yet in practice inflation expectations, as well as the behavior of actual inflation, are very sluggish compared to the speed with which default crises, such as Greece's, unfold.

To reconcile these facts, we study an economy where private agents have dispersed and heterogeneous information about the government's ability to repay its debt. We contrast two situations: in the first one, contracts are denominated in an outside currency (the "Euro"), and the government is forced to outright default when its tax revenues fall short of debt promises, while in the second one a domestic currency is present (the "Yen"), and the government resorts to the printing press and eventual inflation to cover any shortfalls. To assess the implications of this difference, we analyze a two-period Bayesian trading game. In both the Euro and the Yen economy, government debt is subscribed in the first period by (sophisticated) bond traders, such as banks or relatively wealthy investors.³ In deciding their actions, these traders take

ing Press Mystery," *The Conscience of a Liberal*, August 17, <https://krugman.blogs.nytimes.com/2011/08/17/the-printing-press-mystery/>). Krugman sketches a theory whereby an asymmetry arises because defaults would lead to larger real haircuts for bondholders than inflation. While it is true that a default is a discrete event and inflation erodes the value of repayments over time, it is not a priori obvious that the cumulative losses would be different in the two scenarios. We consider a benchmark in which losses are the same. Our mechanism would of course remain at work even if inflation were less costly for creditors, as the two channels would complement each other.

³The key distinction for us is not whether these traders are foreign or domestic, but

into account that the different nature of risk across the two cases (inflation vs. default) implies that different actors will be pivotal for future prices. Specifically, in the Euro economy, the default premium in the secondary market is driven by the beliefs of other players entering the bond market, who are likely to be as sophisticated as the original bond traders. In the Yen economy, the evolution of prices is driven by the beliefs about fiscal solvency of a (larger and) less sophisticated section of the population that uses Yen to trade but does not participate in bond markets.⁴ Other than this difference, we impose as much symmetry as possible between the two economies: agents start with identical priors over government solvency, bond traders receive signals with equal precision across the two economies, and the fixed haircut upon default is matched to the loss in value due to inflation. All these assumptions allow us to concentrate on the consequences of heterogeneous information.

We analyze this problem in a dynamic version of a noisy rational expectations equilibrium in the tradition of Grossman (1976) and Hellwig (1980). Admati (1985) first studied learning spillovers in a static environment with multiple assets. The connection between spillovers across assets and over time has been emphasized by Brennan and Cao (1996) in the context of a model that features a one-time private signal. Brennan and Cao (1997) study trade among long-lived and heterogeneously informed agents who learn fundamentals gradually from each other. They use their model to characterize the sign of the flows and their covariance with price movements. They do not focus on the volatility of the price, which in their economy is dominated by the cumulative effect of learning.⁵ Our results are particularly related to Allen, Morris, and Shin (2006) (AMS), who studied an environment in which an asset goes through multiple rounds of trade among overlapping-generations, as is our case. They emphasized the dampening effect of higher-order beliefs on price movements and conversely the greater emphasis that public signals take in that context. Their results represent a polar case of the analysis that we entertain along two dimensions. First, they only consider assets with a linear payoff (as is the case for Brennan and Cao (1997)). As a premise to our ap-

rather that they are a restricted set of the population that is active in financial markets.

⁴We do not model explicitly the frictions that prevent this population from accessing government bond markets. Any fixed cost of access would exclude poorer individuals and is enough to generate our story.

⁵Amador and Weill (2010; 2012) also considered learning from aggregate prices, in the context of stylized macroeconomic models.

plication, we derive results that apply to nonlinear payoffs in general. This is useful to us because we are interested in debt contracts, which are inherently nonlinear. Second, AMS only consider the effect of adding rounds of trade. In our context, this can be viewed as an extreme version of the comparative statics of interest. Specifically, our model with two rounds of trade collapses to a model with a single round if we assume that second-period agents are perfectly informed about fundamentals, so that the price in the second period is equal to the terminal payoff of the asset. The AMS result applies thus to comparing an economy with infinite precision of signals in the second round to one where the precision is finite. We are interested in studying comparative statics about the precision of the information of second-period agents without going to this extreme. This is important because, as shown in our main proposition (Proposition 5), the comparative statics are not necessarily globally monotone.

The structure of our model is closely related to Hellwig, Mukherji, and Tsyvinski (2006) and Albagli, Hellwig, and Tsyvinski (2015) (AHT), where a flexible and particularly tractable specification of noisy information aggregation in market prices is developed. Our work considers a version of their model in which trade occurs repeatedly.

Due to the nature of the payoff that we consider in our application, we are also related to the literature that has used the global-games approach pioneered by Carlsson and van Damme (1993) and Morris and Shin (1998).⁶ Our theorems are related to Iachan and Nenov (2015), whose paper presents a systematic analysis of comparative statics results with respect to the precision of information in static global games; in contrast to their analysis, we are interested in the role of dynamics.⁷

When analyzing the effect of changes in second-period information on the first-period price of an asset, we can distinguish between effects arising from the first and second moment of beliefs of first-period agents about future prices. For linear payoffs, first moments are all that matters and results are simpler. As in AMS, our comparative statics are driven by the failure of prices to

⁶The role of signaling in global games has been studied by Angeletos, Hellwig, and Pavan (2006), and the efficiency of information acquisition has been further analyzed by Angeletos and Pavan (2007; 2009). Dasgupta (2007) and Angeletos, Hellwig and Pavan (2007) studied learning in dynamic global games.

⁷In a static context, the role of differential information has also been studied by Corsetti et al. (2004), who consider a global game with a single large player who may be more or less informed than a continuum of small players.

satisfy the equivalent of a law of iterated expectations. This failure arises both because first-period agents have some private information that is not fully aggregated in the price and possibly because the first-period price itself may not be perfectly observed by second-period traders. Both of these reasons lead traders in the first period to respond less aggressively to their incoming information about fundamentals. This effect is more pronounced, the lower is the quality of information available to agents in the second period. Hence, for linear payoffs we can unambiguously conclude that the price in *both* periods will be less responsive to incoming news, the less well informed agents are in the second period of trade. In the case of nonlinear payoffs, their concavity or convexity interacts with the second moment of beliefs entertained by the agents. When studying the effect of second-period information on first-period prices, a trade-off emerges: better information implies that the second-period price tracks fundamentals more closely, but it also implies that traders in the second period will rely more on their own signals and less on the common information contained in the prior and the first-period price. Whether the second-period price becomes more or less predictable from the perspective of agents in the first period is thus ambiguous. After deriving results for general nonlinear payoffs, we apply them to our case of sovereign debt and default, where clear-cut comparisons are possible.

Our two main propositions compare the responsiveness of the first-period price to incoming news in the Euro economy and the Yen economy, which only differ by the precision of signals observed by agents in the second period. We prove that the price in the Euro economy always responds more to new information in both periods when either of the following is true:

1. The bond traders which participate in the secondary market of Euro bonds have at least as precise information as first-period traders;⁸ or
2. The first-period price is observed in the second period with sufficient noise.

In sum, our results confirm that heterogeneity between a small, sophisticated group of bond traders and a large, less informed population that drives

⁸Note that this proposition does not require comparing the precision of information of second-period vs. first-period agents in the *Yen economy*. In principle, this comparison could be ambiguous, because second-period agents are assumed to be less sophisticated in the Yen economy, but the passage of time might have revealed extra information about government solvency.

the aggregate price level can explain why domestic-currency debt may be less information-sensitive than foreign-currency debt (or debt denominated in a common currency not directly controlled by the domestic central bank). This result can account for why a country which starts from a favorable prior condition may be able to better withstand the arrival of bad news. Conversely, our results also suggest that a country who is perceived as very likely to default may find it easier to borrow in foreign currency in the few instances in which its fundamentals are comparatively more favorable: sophisticated bond traders would find it easier to spot the presence of such conditions, while a pessimistic population may immediately fear (and trigger) hyperinflation. In this way, our work provides an alternative explanation for the “original sin” and connects to the vast literature in international economics that has studied the role of currency mismatch, particularly in the years that follow the 1998 Asian crisis. A review of competing theories of the origins of the mismatch appears in Eichengreen and Hausmann (1999). Examples of theories of crises where foreign-currency debt plays an important role are Aghion, Bacchetta, and Banerjee (2001) and Calvo, Izquierdo, and Talvi (2004). Particularly relevant for our analysis is Bordo and Meissner (2006): they show that currency mismatch and “original sin” are not necessarily harbingers of more frequent crises, provided fundamentals are managed correctly. This is reminiscent of our result, in which it is not necessarily the unconditional probability of eventual default or inflation that increases when debt is denominated in foreign currency: fragility manifests itself instead as a greater volatility of debt prices.

The interplay between secondary markets and sovereign spreads has received attention in other contexts. The participation of foreign vs. domestic investors in secondary markets and the resulting incentives for the government to default have been analyzed by Broner, Martin and Ventura (2010). In Arellano, Bai, and Lizarazo (2017b) movements in secondary-market prices after default cause spillovers among sovereign debtors, as risk-averse creditors pull back from risky lending in the aftermath of losses. Imperfect information in sovereign debt markets plays an important role in Yuan (2005), where losses stemming from bad news in one market may lead liquidity-constrained informed creditors to pull resources invested in other sovereign bonds, leading to less informative prices and contagion across markets. Sandleris (2008) studies an economy where a default reveals adverse information about the state of the economy, with negative consequences for private investment, and Gu

and Stangebye (2018) study variations in risk premia driven by endogenous time-varying information precision. None of the works above studies the role of currency denomination and differential information in determining bond prices. Combining our mechanism with those of several of these other papers is likely to yield interesting interactions worthy of future exploration.

The rest of the chapter is structured as follows. Section 2.2 introduces the basic setup. In Section 2.3 we analyze in detail a general version of the two-stage Bayesian trading game that is the building block of our model. This abstract setup allows for a clear exposition of the forces at play. Section 2.4 deals with our application to sovereign debt. Specifically, Subsection 2.4.1 provides more technical intuition based on the general results of the previous section, while Subsection 2.4.2 presents and discusses our main conclusions emphasizing the macro implications for sovereign debt. In Section 2.5 we show that results are robust to an extension in which the default threshold is endogenous to the price at which government debt is issued, as in Calvo (1988). Conclusions and avenues for future research appear in Section 3.6. Appendix 2.A provides a full description of a stylized macroeconomic model which maps into the Bayesian trading game that we study.

2.2 The Setup

We consider an economy that lasts for three periods, $t = 1, 2, 3$. The economy is populated by two overlapping generations of traders and a government. The government follows a mechanical strategy: it auctions one unit of debt in period 1 and repays it in period 3. We follow here Eaton and Gersovitz (1981) and fix the face value of debt at redemption, which is normalized to one, letting q_1 be the endogenous price at which debt will be issued.⁹ Repayment in period 3 depends on the realization of a fiscal capacity shock θ . Specifically, if $\theta \geq \bar{\theta}$, then the government has enough revenues to repay the debt in full. In contrast, when $\theta < \bar{\theta}$, a default occurs, in which case we assume a fixed haircut and the government only repays $\delta \in (0, 1)$. All agents share a common prior about θ , which is normal with mean μ_0 and variance $1/\alpha_0$.

Each generation of private agents is composed by a unit measure of informed traders and a random mass of noise traders. In their first period of life, informed agents have an endowment that they divide between storage (at a rate

⁹The proceeds of the sale are consumed by the government in period 1.

normalized to zero) and purchases of the asset. In the second period of their life, they liquidate any asset position and consume the proceeds of their investment. The first generation buys bonds from the government in the first period and resells them in the secondary market in the second period; the second generation of traders buys in the secondary market and keeps the asset until maturity in the final period. It follows that in both periods of trade the supply is inelastic, and all the action occurs on the buyers' side. Informed traders are risk neutral and choose their portfolio to maximize expected consumption. Each informed trader i in period t receives a noisy private signal $x_{i,t} = \theta + \xi_{i,t}$, where $\xi_{i,t}$ is distributed according to a normal distribution $N(0, 1/\beta_t)$, and we assume that a law of large numbers across agents applies as in Judd (1985). Based on this signal, informed traders submit price-contingent demand schedules. In submitting their demand, they take into account that the price q_t of the asset in period t is affected by all other traders' demand and is thus an endogenous, public source of information. To preserve tractability, we assume that asset holdings are limited to $\{0, 1\}$.¹⁰ Since our model is dynamic, we must also specify how agents learn from the past: we will assume that second-period traders receive a noisy public signal ρ of the first-period price, with a distribution that we will specify later on. We are interested in the special cases where recall of the past price is either perfect or infinitely noisy, but adopting a general specification will allow us to draw broader results.

Noise traders generate a residual uncontingent demand $\Phi(\epsilon_t/\sqrt{\psi_t})$ for the asset, where Φ is the cumulative standard normal distribution function, $\psi_t > 0$, and ϵ_t is itself distributed according to a standard normal distribution.¹¹ The mass of noise traders is independent of the fundamental and of informed traders' signals. As is standard in this class of models, the presence of noise traders ensures that equilibrium prices do not fully aggregate information, thereby revealing the fundamental.

We will contrast two economies, one in which government debt is denominated in local currency (the "Yen") and one in which it is denominated in

¹⁰Given that we assume risk neutrality, the optimal demand schedule will take the form of a reservation price, below which strategic agents are willing to buy the asset. The lower bound of 0 is equivalent to a short-selling constraint. The upper bound of 1 is equivalent to an indivisibility assumption, which implies that traders cannot hold a non-integer position and do not have enough resources to buy two units. Consistently with the indivisibility assumption, we impose that their holdings must be either 0 or 1, but risk neutrality implies that the analysis is unchanged if traders are instead allowed any position in $[0, 1]$.

¹¹When $\psi_t = 1$, this implies that the residual demand is uniform in $[0, 1]$.

a currency over which the government has no control (the “Euro”). The role of issuing debt in domestic currency is that it avoids explicit default, which is replaced by inflation instead. From the perspective of the dynamic trading game, we treat inflation and default symmetrically, that is, the haircut suffered by holders of government liabilities and the probability of the haircut are the same. Through this channel, bad news about fiscal solvency have the same negative effect on the price of government debt: in one case bad news imply high interest rates because of inflation risk, and in the other because of default risk.

The asymmetry between the inflation and default risk that we emphasize in this chapter concerns differential information by secondary-market participants. The motivation for this asymmetry stems from a different interpretation of who is the relevant participant in the “secondary market” in period two. In the case of the Euro economy, the secondary-market price is dictated by the new generation of bond traders who will take over; short of an immediate fiscal adjustment, which we rule out, there is nothing that the government can do to dampen fluctuations in the price of its debt. In the Yen economy, the ability to print money to intervene in the market for government debt can temporarily substitute for varying demand by bond traders. The extent by which these interventions are stabilizing depends on the beliefs about eventual fiscal solvency of a larger section of the population that uses Yen to trade but does not participate in bond markets; it is likely that they are less well informed about government finances. In Appendix 2.A we provide a micro-founded model which features “workers” who use exclusively cash and “bond traders” who hold the government bonds, and we show formally how this can lead workers to be the pivotal agents in pricing inflation risk in the second period for the Yen economy, while bond traders are pivotal in pricing default risk for the Euro economy. From the perspective of the Bayesian trading game that we have described here, the only difference between the two economies is the precision of the private signal received by agents in the second period (β_2): we will assume that this is lower for the Yen economy than it is for the Euro economy.¹²

¹²In what follows, “traders” in the second period refers to the relevant players that determine the price in either economy, which can be either workers or bond traders depending on the case.

2.3 Strategies, Beliefs, and Equilibrium

The game that we described in the previous section is a dynamic version of the static game analyzed in AHT. It is also related to AMS, who study a dynamic game like ours but only consider linear payoffs and do not analyze the comparative statics which are relevant in our application. To better understand the economic forces at work in the model and compare our results to those previous papers, it is useful to derive the equilibrium for an asset whose payoff is a generic increasing function $\pi(\theta)$. We will then apply this intuition to our specific payoff in the next section.

In each period, the optimal decision by each informed agent takes the form of a demand schedule $d_1(x_{i,1}, q_1)$ or $d_2(x_{i,2}, q_2, \rho)$ that maps from signals into a desired asset position $\{0, 1\}$.

Definition 2. *A Perfect Bayesian Equilibrium consists of bidding strategies $d_1(x_{i,1}, q_1)$ and $d_2(x_{i,2}, q_2, \rho)$ for informed traders in $t = 1$ and $t = 2$ respectively, price functions $q_1(\theta, \epsilon_1)$, $q_2(\theta, \epsilon_2, \rho)$ and posterior beliefs $p_1(x_{i,1}, q_1)$, $p_2(x_{i,2}, q_2, \rho)$ such that*

- (i) *demand schedules d_t are optimal given posterior beliefs p_t ,*
- (ii) *prices q_t clear the market for all $(\theta, \epsilon_t, \rho)$, and*
- (iii) *posterior beliefs p_t satisfy Bayes' Law for all market clearing prices q_t .*

To characterize the equilibrium we work backwards, starting from period 2. The derivation of the second-period equilibrium follows AHT. The expected payoff of buying the risky asset for agent i in period 2 is $\mathbb{E}(\pi(\theta)|x_{i,2}, q_2, \rho) - q_2$. Proposition 5 in the online appendix proves that, whenever q_2 and ρ do not fully reveal the value of $\pi(\theta)$,¹³ posterior beliefs over θ are strictly increasing in $x_{i,2}$ in the sense of first-order stochastic dominance and agents' expected payoffs are a strictly increasing function of $x_{i,2}$. This implies that agents follow monotone strategies of the form

$$d_2(x_{i,2}, q_2, \rho) = \mathbb{1}[x_{i,2} \geq \hat{x}_2(q_2, \rho)], \quad (2.1)$$

¹³Equilibria in which prices reveal more than what is collectively known by the informed traders are ruled out by all the papers in this literature; as an example, a discussion of this point appears in Diamond and Verrecchia (1981), page 227.

where $\mathbb{1}$ is the indicator function and $\hat{x}_2(q_2, \rho)$ is a private signal threshold which is endogenous to the equilibrium.

Integrating strategic players' demand schedules over the signal distribution, the market clearing condition in period 2 is

$$\int d_2(x, q_2, \rho) d\Phi \left[\sqrt{\beta_2}(x - \theta) \right] + \Phi(\epsilon_2/\sqrt{\psi_2}) = 1. \quad (2.2)$$

Using equation (2.1), the aggregate demand of strategic agents is $\text{Prob}[x_{i,2} \geq \hat{x}_2(q_2, \rho)|\theta]$, and the market clearing condition becomes

$$z_2 := \theta + \frac{\epsilon_2}{\sqrt{\beta_2\psi_2}} = \hat{x}_2(q_2, \rho). \quad (2.3)$$

Henceforth we will focus on equilibria where z_2 and q_2 convey the same information, given ρ , and in which ρ does not fully reveal θ .¹⁴ In this case, conditioning beliefs on the endogenous price is equivalent to conditioning them on the exogenous signal z_2 .

An agent whose private signal is at the threshold $\hat{x}_2(q_2, \rho)$ must be indifferent in equilibrium between buying the risky asset or storing its endowment. Combining this with equation (2.3), $q_2(z_2, \rho)$ must satisfy the indifference condition

$$q_2(z_2, \rho) = \mathbb{E}[\pi(\theta)|x_{i,2} = z_2, z_2, \rho]. \quad (2.4)$$

The analysis of equilibrium strategies in $t = 1$ follows that of period two quite closely. Proposition 7 in the online appendix proves that the second-period price is strictly increasing in z_2 , and that this is in turn sufficient to ensure that the beliefs of first-period traders are strictly increasing in their private signal $x_{i,1}$ in the sense of first-order stochastic dominance, as long as the first-period price is not fully revealing. Hence, they too optimally follow monotone strategies described by a threshold signal of the form $d(x_{i,1}, q_1) = \mathbb{1}[x_{i,1} \geq \hat{x}_1(q_1)]$. Repeating the steps that led to (2.3), the market clearing condition in the first period can be rewritten as

$$z_1 := \theta + \frac{\epsilon_1}{\sqrt{\beta_1\psi_1}} = \hat{x}_1(q_1) \quad (2.5)$$

and we have shown that z_1 is an unbiased public signal of θ , with precision

¹⁴Proposition 6 in the online appendix proves that, for debt payoffs and in the absence of recall (i.e. when ρ has infinite variance), a sufficient condition for z_2 and q_2 to convey the same information is that the equilibrium price is a continuous function of θ and ϵ_2 .

$\tau_{q_1} := \beta_1 \psi_1$. As in period two, we focus on equilibria where q_1 and z_1 convey the same information.¹⁵

We assume that the price signal ρ observed by second-period agents is given by

$$\rho = z_1 + \sigma_\eta \eta_1, \quad (2.6)$$

with $\sigma_\eta \geq 0$ and $\eta_1 \sim N(0, 1)$.¹⁶ ρ is therefore an unbiased public signal of θ , with conditional variance $1/\tau_\rho := \text{Var}(\rho|\theta) = 1/\tau_{q_1} + \sigma_\eta^2$. τ_ρ represents the precision of the information on θ contained in ρ for $t = 2$ agents.

The equilibrium price in the first period is therefore given by

$$q_1(z_1) = \mathbb{E}[q_2(z_2, \rho) | x_{i,1} = z_1, z_1]. \quad (2.7)$$

2.3.1 Equilibrium in the Second Period

From (2.3) and (2.6) we can derive the beliefs about θ of a strategic trader in period two:

$$\theta | x_{i,2}, z_2, \rho \sim N \left(\frac{\alpha_0 \mu_0 + \beta_2 x_{i,2} + \tau_{q_2} z_2 + \tau_\rho \rho}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho}, \frac{1}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho} \right), \quad (2.8)$$

where $\tau_{q_2} := \beta_2 \psi_2$ represents the precision of information revealed by the market price in the second period. For the marginal trader, for whom $x_{i,2} = z_2$, we thus get

$$\theta | x_{i,2} = z_2, z_2, \rho \sim N \left(\frac{\alpha_0 \mu_0 + (\beta_2 + \tau_{q_2}) z_2 + \tau_\rho \rho}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho}, \frac{1}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho} \right). \quad (2.9)$$

Using the beliefs of the marginal agent in equation (2.4), the equilibrium price is given by

$$q_2(z_2, \rho) = \int \pi(\theta) d\Phi \left(\frac{\theta - (1 - w_\rho - w_{z_2}) \mu_0 - w_{z_2} z_2 - w_\rho \rho}{\sigma_2} \right) \quad (2.10)$$

¹⁵For debt payoffs and in the case of no recall, Proposition 6 applies to period 1 as well, so that continuity of q_1 as a function of θ and ϵ_1 is sufficient.

¹⁶The parametric expression of the noise is assumed for tractability. Of course, in our main cases $\sigma_\eta = 0$ or $\sigma_\eta = \infty$, in which case the specific distribution of η is irrelevant. It is worth noting that, since the price is in equilibrium a nonlinear function of z_1 , the signal structure implies that the noise in the observation of the price is higher in regions of the fundamentals in which the price itself is more volatile. This is a plausible assumption.

where $w_\rho := \frac{\tau_\rho}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho}$ and $w_{z_2} := \frac{\beta_2 + \tau_{q_2}}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho}$ are the Bayesian weights given by the second-period marginal trader to ρ and z_2 respectively, and $\sigma_2 := (\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho)^{-1/2}$ is the standard deviation of her conditional beliefs. As is clear from equation (2.10), q_2 exists and is unique for all $z_2 \in \mathbb{R}$.

As the precision of the private information received by second-period traders increases (β_2 increases), the information revealed by the second-period price becomes more precise as well (τ_{q_2} increases). Both of these forces imply that the beliefs of the marginal trader become more concentrated, and more responsive to z_2 . However, in what follows an important role will also be played by the predictability of the second-period price q_2 , based on period-1 information. When q_2 responds more to z_2 , it is affected more by the fundamental θ , but also by the noise ϵ_2 , over which period-1 agents have no information.

2.3.2 Equilibrium in the First Period

Having derived q_2 explicitly, we can now do the same for the equilibrium price in $t = 1$. First-period traders' posterior beliefs about θ are given by

$$\theta | x_{i,1}, z_1 \sim N \left(\frac{\alpha_0 \mu_0 + \beta_1 x_{i,1} + \tau_{q_1} z_1}{\alpha_0 + \beta_1 + \tau_{q_1}}, \frac{1}{\alpha_0 + \beta_1 + \tau_{q_1}} \right). \quad (2.11)$$

First-period traders are not affected by θ directly, but rather they use these beliefs to forecast q_2 , which in turn is a function of z_2 and ρ . The marginal trader's posterior beliefs on z_2 and ρ are given by

$$\begin{aligned} z_2 | (x_{i,1} = z_1, z_1) &\sim N \left((1 - w_1) \mu_0 + w_1 z_1, \sigma_{2|1}^2 := \frac{1}{\alpha_0 + \beta_1 + \tau_{q_1}} + \frac{1}{\tau_{q_2}} \right) \\ \rho | (x_{i,1} = z_1, z_1) &\sim N (z_1, \sigma_\eta^2) \end{aligned} \quad (2.12)$$

where $\sigma_{2|1}^2$ is the variance of *new* second-period information z_2 conditional on first-period information (x_1, z_1 and prior), and $w_1 := \frac{\beta_1 + \tau_{q_1}}{\alpha_0 + \beta_1 + \tau_{q_1}}$ is the Bayesian weight given to z_1 by the marginal trader in the first period. Imposing market clearing and the indifference condition of the marginal trader, the

online appendix shows that the first-period price is given by

$$q_1(z_1) = \int \pi(\theta) \frac{1}{\sqrt{w_{z_2}^2 \sigma_{2|1}^2 + w_\rho^2 \sigma_\eta^2 + \sigma_2^2}} \cdot \phi \left(\frac{\theta - \mu_0(1 - w_\rho - w_{z_2} w_1) - z_1(w_\rho + w_{z_2} w_1)}{\sqrt{w_{z_2}^2 \sigma_{2|1}^2 + w_\rho^2 \sigma_\eta^2 + \sigma_2^2}} \right) d\theta, \quad (2.13)$$

where ϕ is the density function of a standard normal distribution. Equation (2.13) expresses the period-1 price as an expectation with respect to θ , according to a distorted measure that accounts for the fact that period-1 agents care about forecasting q_2 and not θ directly. Both this distorted measure and the true beliefs about θ conditional on the information of the marginal trader (given by equation (2.11)) are normal; let their means and variances be $(\tilde{\mu}_1, \tilde{\sigma}_1^2)$ and (μ_1, σ_1^2) respectively. We can derive intuition about the key drivers of our results by comparing these moments, which, after some algebra, can be rewritten as

$$\mu_1 = \mu_0 + (z_1 - \mu_0) \frac{\beta_1 + \tau_{q_1}}{\alpha_0 + \beta_1 + \tau_{q_1}} \quad (2.14)$$

$$\tilde{\mu}_1 = \mu_0 + (z_1 - \mu_0) \frac{\beta_1 + \tau_{q_1}}{\alpha_0 + \beta_1 + \tau_{q_1}} \left[1 - \left(1 - \frac{\tau_\rho}{\beta_1 + \tau_{q_1}} \right) \frac{\alpha_0}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho} \right] \quad (2.15)$$

and

$$\sigma_1^2 = \frac{1}{\alpha_0 + \beta_1 + \tau_{q_1}} \quad (2.16)$$

$$\begin{aligned} \tilde{\sigma}_1^2 = \sigma_1^2 & \left\{ 1 + \frac{1}{\alpha_0 + \beta_2 + \tau_\rho + \tau_{q_2}} \right. \\ & \cdot \left[\tau_\rho \left(1 - \frac{\tau_\rho}{\tau_{q_1}} \right) \frac{\alpha_0 + \beta_1 + \tau_{q_1}}{\alpha_0 + \beta_2 + \tau_{q_2} + \tau_\rho} + (\beta_1 + \tau_{q_1} - \tau_\rho) \right. \\ & \left. \left. + (\beta_2 + \tau_{q_2}) \left(\frac{1 + \frac{\alpha_0 + \beta_1 + \tau_{q_1}}{\tau_{q_2}}}{1 + \frac{\alpha_0 + \tau_\rho}{\beta_2 + \tau_{q_2}}} - 1 \right) \right] \right\}. \end{aligned} \quad (2.17)$$

For our purposes, an important observation is that $\tilde{\mu}_1$ is an affine function of z_1 , the information contained in the first-period price, which we will henceforth call the “market signal.” When z_1 is less than the prior mean μ_0 (either because

of a bad realization of the fundamentals θ or a bad realization of the noise-trader shock ϵ_1), we get $\tilde{\mu}_1 > \mu_1$, with the reverse occurring when $z_1 > \mu_0$. In contrast, the difference between σ_1^2 and $\tilde{\sigma}_1^2$ is entirely driven by the moments of the signal distributions and is independent of the realization of any shock.

We are interested in studying how the first-period price is affected by the quality of information in the second period. When π is differentiable, we can integrate (2.13) by parts and we obtain

$$\begin{aligned} \frac{\partial q_1}{\partial \beta_2} = & \left[\int \pi'(\theta) \frac{1}{\tilde{\sigma}_1} \phi\left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1}\right) d\theta \right] \frac{\partial \tilde{\mu}_1}{\partial \beta_2} \\ & + \left[\int \left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1}\right) \pi'(\theta) \frac{1}{\tilde{\sigma}_1} \phi\left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1}\right) d\theta \right] \frac{\partial \tilde{\sigma}_1}{\partial \beta_2}. \end{aligned} \quad (2.18)$$

AMS study linear payoffs. In this case, π' is constant and the second term is zero: only distortions in the mean have an effect. Comparing equations (2.14) and (2.15), we notice that the difference is driven by two wedges:

- When $\tau_\rho < \beta_1 + \tau_{q_1}$, the information of the marginal trader in the first period is not fully passed on to the marginal trader in the second-period. As a consequence, the second-period price direct response to z_1 is dampened, which in turn spills over to the incentives for the first-period agents to incorporate the incoming news.
- The extent by which dampening occurs depends on the quality of information in the second period. In the limiting case in which $\beta_2 + \tau_{q_2} \rightarrow \infty$, the second-period price tracks θ perfectly anyway and the loss of period-1 information arising from $\tau_\rho < \beta_1 + \tau_{q_1}$ is irrelevant. In contrast, the less precise the information is in the second period, the more the information loss contributes to a muted response of q_2 to fundamentals with a corresponding effect in period 1.

Turning to the implications for the first-period price, we then obtain the following proposition:

Proposition 3. *If $\pi(\theta)$ is affine in θ , the price q_1 is unaffected by the second-period information if and only if $\tau_\rho = \beta_1 + \tau_{q_1}$. When $\tau_\rho < \beta_1 + \tau_{q_1}$, there exists a cutoff \bar{z} such that the price is increasing in β_2 for $z_1 > \bar{z}$ and decreasing for $z_1 < \bar{z}$.*

Proof. If $\pi(\theta) = \bar{\pi} + \pi_\theta\theta$, we get that $\partial q_1/\partial\beta_2 = \pi_\theta\partial\tilde{\mu}_1/\partial\beta_2$, so the result follows immediately from equation (2.15). Note that, by the definition of ρ in equation (2.6), $\tau_\rho \leq \tau_{q_1}$, so the proposition covers all the possibilities. ■

Remark 1. *Within our setup, $\beta_1 = 0$ implies also that $\tau_{q_1} = 0$, so $\tau_\rho = \beta_1 + \tau_{q_1}$ only happens in the degenerate case when period-1 agents rely uniquely on prior information. Nonetheless, the proposition would apply to more general environments where an exogenous public signal is present and τ_{q_1} may be strictly positive even if no agent has any private information in the first period.*

Proposition 3 proves a single-crossing property of the price q_1 : conditional on good [bad] news (high z_1), the *first-period* price is increasing [decreasing] in the precision of the signal of *second-period* agents.¹⁷ In what follows, we will informally discuss this single-crossing property as meaning that the price is more (or less) responsive to incoming news.¹⁸

When π' is not constant, distortions in the variance also have an effect on the price. In a static context, this effect has been analyzed by AHT. When π is twice differentiable, we can rewrite the second integral in equation (2.18) as

$$\int \left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) \pi'(\theta) \frac{1}{\tilde{\sigma}_1} \phi \left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) d\theta = \int \pi''(\theta) \phi \left(\frac{\theta - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) d\theta. \quad (2.19)$$

Equation (2.19) highlights the role of concavity or convexity of the asset payoff function. For example, in the case of a convex payoff, any force that increases $\tilde{\sigma}_1$ would increase the first-period price.

In a dynamic context, the factors that drive $\tilde{\sigma}_1$ are richer than the simpler static case, as they reflect a two-way interaction between the information in the first and second period. We can highlight four main factors.

- All the distortions rely on the fact that the second-period price does not perfectly track the fundamentals. The term $\alpha_0 + \beta_2 + \tau_\rho + \tau_{q_2}$ in the first row of (2.17) represents the information available to the marginal trader in the second period: the more precise this information is, the

¹⁷This single-crossing only applies outside of the degenerate case in which $\tau_\rho = \beta_1 + \tau_{q_1}$.

¹⁸An even stronger notion of responsiveness requires the derivative of the price with respect to z_1 to be increasing in β_2 at any given point. In the case of linear payoffs, this is also true. However, we focus our attention to the single-crossing property because it is the one relevant in our application to sovereign debt. In that case, the price function flattens out away from the default threshold, since debt either becomes risk free or is defaulted upon for sure. Additional precision makes it more likely that debt falls into these regions, in which the price is locally not as responsive, while the single-crossing property still applies.

smaller the wedge between σ_1^2 and $\tilde{\sigma}_1^2$, since in the limit we converge to a situation in which $q_2 = \pi(\theta)$ and dynamic trading is irrelevant.

- When second-period agents observe the first-period price imperfectly, the noise in their observation acts as a second disturbance in the determination of q_2 . From the perspective of first-period traders, this extra noise increases the variance of their payoff. This effect is captured by the first term in the second row of the wedge in equation (2.17). It vanishes when the first-period price is observed without noise ($\tau_\rho = \tau_{q_1}$) or when it is not observed (equivalent to $\tau_\rho = 0$), in which case second-period agents do not react to ρ (and hence to this new source of noise).
- Even when q_1 is perfectly observed by traders in the second period, a wedge arises from the fact that they do not share the same private information as that of the marginal trader in the first period. This effect, represented by the second term in the second row of the wedge in equation (2.17), is similar to what we already discussed in the case of the first moment.
- Finally, the term in the last row combines the role of information frictions in the two periods and also reflects the fact that increased precision in the second period makes q_2 less predictable in the first period. The ratio inside the square bracket is bigger than one both because second-period agents have less information about the first period ($\beta_1 + \tau_{q_1} \geq \tau_\rho$) and because they have their own private information, which makes them more responsive to the market signal z_2 ($\beta_2 + \tau_{q_2} \geq \tau_{q_2}$).

The total effect of β_2 on $\tilde{\sigma}_1$ is ambiguous. The first and second economic force described above lower $\tilde{\sigma}_1$ when β_2 increases, while the last one goes in the opposite direction.¹⁹ With some algebra, it can be shown that either $\tilde{\sigma}_1$ is monotonically decreasing in β_2 or it has one interior maximum.²⁰

For a fully general payoff, the total effect of nonlinearities is thus a complicated combination of the way in which concavity and convexity move within the state space and of the non-monotonic behavior of the variance. To establish more definite results, we return to our specific payoff of interest.

¹⁹The third force is independent of β_2 .

²⁰An interior maximum arises if $\alpha_0 > \max\{0, \tau_\rho[2\psi_2(1 - \tau_\rho/\tau_{q_1}) - 1]\}$, see the online appendix for details.

2.4 The Role of Differential Information for Sovereign Debt

In our application, the payoff function is given by

$$\pi(\theta) = \begin{cases} \delta & \text{if } \theta < \bar{\theta} \\ 1 & \text{if } \theta \geq \bar{\theta}. \end{cases} \quad (2.20)$$

For this payoff, equation (2.13) simplifies to

$$q_1(z_1) = \delta + (1 - \delta)\Phi \left[\frac{\mu_0 - \bar{\theta}}{\tilde{\sigma}_1} + K(z_1 - \mu_0) \right], \quad (2.21)$$

with

$$K := \frac{w_\rho + w_{z_2} w_1}{\tilde{\sigma}_1}. \quad (2.22)$$

Figure 2.1 illustrates this price as a function of the realization of the shock z_1 for two different values of K : the higher K is, the more sensitive the price is. More precisely, a higher K leads to a lower price when first-period agents receive negative news about government solvency (z_1 low), while the converse is true for high values of z_1 .

The coefficient K illustrates some of the trade-offs that we have discussed in the general case. When second-period agents receive better information, they rely more on their signals and less on the information conveyed by the first-period price, that is, w_ρ decreases, while w_{z_2} increases. From the perspective of the first-period price, the second-period price tracks fundamentals better, but may track the period-1 information z_1 less closely. The presence of $\tilde{\sigma}_1$ at the denominator reflects the further effects from the nonlinearity in the payoff.

2.4.1 Mean and Variance Effects in the Case of Debt

As in the case of a generic increasing payoff, the effect of β_2 on q_1 can be decomposed into one component primarily driven by the monotonicity of the payoff (the first term of the sum in equation (2.18)) and a second component related to convexity/concavity (the second term). Since the debt payoff in equation (2.20) is not differentiable, equation (2.18) does not apply directly.

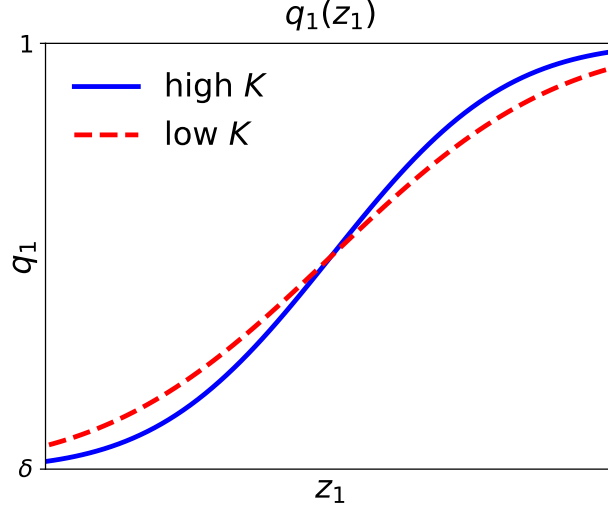


Figure 2.1: Illustration of $q_1(z_1)$. A higher K corresponds to a first-period price that is more sensitive to the realization of the market signal z_1 .

However, after some algebra we obtain the following similar expression:

$$\frac{\partial q_1}{\partial \beta_2} = (1 - \delta) \frac{1}{\tilde{\sigma}_1} \phi \left(\frac{\bar{\theta} - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) \frac{\partial \tilde{\mu}_1}{\partial \beta_2} + (1 - \delta) \left(\frac{\bar{\theta} - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) \frac{1}{\tilde{\sigma}_1} \phi \left(\frac{\bar{\theta} - \tilde{\mu}_1}{\tilde{\sigma}_1} \right) \frac{\partial \tilde{\sigma}_1}{\partial \beta_2} \quad (2.23)$$

Intuitively, the connection between (2.18) and (2.23) stems from the fact that the debt payoff concentrates all the slope in a single point, being “convex” just to the left and “concave” just to the right.²¹

Consider first the effect of β_2 on q_1 arising from monotonicity, which is captured by changes in $\tilde{\mu}_1$. This effect has the same sign as $z_1 - \mu_0$: in the case of bad news ($z_1 < \mu_0$), the price is decreasing in β_2 , with the reverse occurring when $z_1 > \mu_0$. As second-period agents become better informed, any bad (good) news will be better detected in the second period and drive q_2 further down (up), so first-period agents are also led to react more aggressively and trigger bigger price movements in q_1 as well.

The role of convexity is more complex. For the step function that represents the debt payoff, the convexity element dominates at low values of z_1 , while concavity dominates for high values. For low values of z_1 , equation (2.15) shows that $\tilde{\mu}_1$ is below the default threshold $\bar{\theta}$; equation (2.23) then shows

²¹A more formal statement to this end can be made by considering a family of approximating payoffs: $\pi^a(\theta; \lambda) = \delta + (1 - \delta)\Phi\left(\frac{\theta - \bar{\theta}}{\lambda}\right)$. This family is indeed convex for $\theta < \bar{\theta}$ and concave otherwise. As $\lambda \rightarrow 0$, all the change is concentrated in a neighborhood of $\bar{\theta}$ and (2.18) converges to (2.23).

that increases in the distorted variance $\tilde{\sigma}_1$ raise the price. The reverse occurs when z_1 is high and $\tilde{\mu}_1 > \bar{\theta}$. The effect of β_2 on $\tilde{\sigma}_1$ itself is ambiguous and reflects the race between how closely q_2 tracks fundamentals vs. how closely it tracks the first-period information z_1 .

To establish our comparative-statics results, what is important is that, in the case of debt, both the effects on the mean and the variance are driven by the jump in the payoff at the threshold. This gives the two terms in equation (2.23) a common structure that collapses all of these effects in the coefficient K defined in equation (2.22) above and thus permits clear-cut comparisons.

2.4.2 Main Results

From equation (2.21) we derive our main results, which provide conditions under which a government that faces a bad shock realization compared to its prior would benefit from a decrease in second-period agents' information precision. In terms of our "Euro" vs. "Yen" interpretation, these conditions ensure that bond prices are more resilient to bad shocks when second-period agents are unsophisticated households (the Yen economy) than in the Euro economy, where the relevant agents in the second period are well-informed bond traders.

Proposition 4. *When the first-period price is observed with sufficient noise by second-period traders, the responsiveness of the price is strictly increasing in the precision of second-period information, even in the first period. Formally, there exists a cutoff level $\hat{\tau}_\rho \in (0, \beta_1\psi_1]$ such that, when $\tau_\rho \leq \hat{\tau}_\rho$, K is strictly increasing in β_2 .²²*

Proof. See Appendix 2.B. ■

When the first-period price is observed with sufficient noise, the proposition provides a global result justifying our motivating observation, that bond prices will react more to incoming news in the Euro economy than they will in the Yen economy.

In terms of the comparative statics of equation (2.23), Proposition 4 ensures that the mean effect always dominates the variance component.

²²The two extreme cases of $\tau_\rho = 0$ and $\tau_\rho = \beta_1\psi_1$ correspond to the cases in which the first-period price is either unobserved or perfectly observed by second-period agents, respectively.

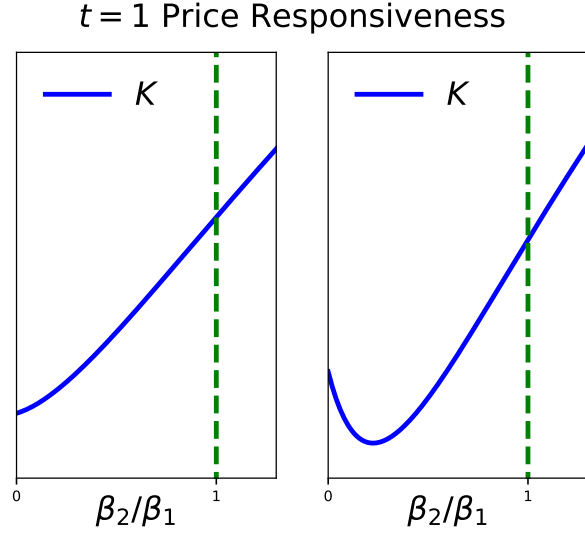


Figure 2.2: Coefficient K as a function of β_2/β_1 , for $\tau_\rho \leq \hat{\tau}_\rho$ (left) and $\tau_\rho > \hat{\tau}_\rho$ (right).

Depending on the values of all other parameters, Proposition 4 may apply even when the first-period price is perfectly recalled in the second period. However, when this is not the case, we can still prove the following result:

Proposition 5. *Assume that $\psi_2 \geq \psi_1$ and $\beta_2^A \geq \beta_1$. Let $\beta_2^B < \beta_2^A$. Holding all other parameters fixed, K evaluated at β_2^A is greater than at β_2^B .*

Proof. See Appendix 2.B. ■

Proposition 5 compares two values of the signal precision, β_2^A and β_2^B . According to our interpretation, greater values of β_2 and ψ_2 arise when debt is denominated in a currency over which the country has no control. In this case (represented by β_2^A), inflation is not an option, debt is subject to the risk of outright default, and second-period agents correspond to a new cohort of well-informed bond traders. When the marginal agent is a bond trader in both periods, it is natural to assume that the information received (through their private signal and the market signal) by players in the second period is at least as good as that of the first period, which is reflected in the assumption that $\beta_2^A \geq \beta_1$ and $\psi_2 \geq \psi_1$.²³ In the second case (represented by β_2^B), a country issues debt denominated in local currency which allows recourse to inflation rather than outright default. Here, second-period agents are workers setting

²³In addition, second-period agents also learn from the first-period price; this proposition applies regardless of the quality of this extra piece of information.

their prices in the local currency. We do not take a stance on the quality of the workers' information relative to *first*-period traders: on the one hand, we assume that they are less sophisticated, but on the other hand the passage of time might have revealed more news about government finances. We only need to compare the quality of the workers' information to that of *second*-period traders: here, less sophistication by the workers means that their precision β_2^B is strictly smaller than the traders' β_2^A . Under these assumptions, Proposition 5 shows that our main result holds: in Figure 2.1, the dashed line represents the price of debt when it is denominated in the domestic currency (the Yen economy), and the solid line is the price when it is issued in a foreign currency (the Euro economy).²⁴

Proposition 5 shows that the price of debt is more resilient to bad shocks when issued in domestic currency. We view this result as particularly relevant for countries that start from a favorable prior: for them, there is limited upside from further confirming the creditors' belief that there is ample fiscal space, while there is substantial downside risk should they find out that fiscal constraints are tighter than they appeared. This is a good description of Eurozone countries in 2008, as well as other major developed economies, all of which paid very low interest rates before the onset of the crisis.

Our result also highlights a potentially opposite conclusion for a country that starts from an adverse prior. For such a country, issuing domestically-denominated debt may immediately lead workers to expect high inflation, and this pessimism will spill over to the traders who underwrite the debt, through the channels that we emphasize. When realized fiscal space is indeed limited, as will happen often if the prior is correct, there is not much that can be done to sustain the price of debt. However, in the event that fundamentals are more favorable, well-informed traders will be better placed to detect the situation, and debt will correspondingly fetch a higher price when issued in foreign currency. We view this as more relevant for countries such as those of Latin America and this may be another explanation for their past inclination to issue dollar-denominated debt.²⁵

²⁴In the main text, we focus on the comparative statics with respect to β_2 . In the online appendix, we show that K is globally strictly increasing in ψ_2 as well, so that the analogous of Proposition 2 applies to that parameter independently of the degree of price recall. The comparative statics with respect to ψ_2 are simpler than those with respect to β_2 , because ψ_2 only affects the precision of the market signal and does not interact with the private information accruing to individual investors.

²⁵This reason is complementary to the time-inconsistency forces emphasized by

2.5 Endogenous Default Threshold

In the previous sections we assumed that the terminal payoff is independent of the price at which the security is issued in the first period. In particular, in the case of government debt, this means that the default cutoff is exogenous. We now consider an extension in which the debt default threshold is given by a function $\bar{\theta}(q_1)$. As an example, this happens if the debt auction follows the same structure as in Calvo (1988): the government requires a given revenue from the auction, which we normalize to unity, while its repayment obligations in the final period depend on the interest rate and are given by $1/q_1$. Since higher interest rates (lower q_1) imply a higher promised repayment, in general the default threshold $\bar{\theta}(q_1)$ will be a decreasing function.

For simplicity, we focus here on the case in which there is perfect recall of the first-period price: $\tau_\rho = \beta_1 \psi_1$. In this case, the construction of an equilibrium is very similar to what we did in Section 2.3. All the steps that lead to equation (2.21) remain the same, where $\bar{\theta}$ is replaced by $\bar{\theta}(q_1)$. As of period 2, $\bar{\theta}(q_1)$ is a given, so that existence and uniqueness given q_1 are established as before. The main difference arises in equation (2.21), where now the endogenous threshold implies that $q_1(z_1)$ is only implicitly characterized by a solution to the following equation:

$$q_1 = \delta + (1 - \delta)\Phi \left[\frac{\mu_0 - \bar{\theta}(q_1)}{\tilde{\sigma}_1} + K(z_1 - \mu_0) \right], \quad (2.24)$$

where $\tilde{\sigma}_1$ and K are given by the same expressions as in the case of an exogenous threshold, as defined in equations (2.17) and (2.22).

In Section 2.4, we could establish results about the sensitivity of the price to z_1 by simply studying the properties of the coefficient K . Now, the analysis is complicated by the fact that q_1 appears on the right-hand side through its effect on the default threshold, and we can no longer prove that the price functions drawn for two different values of β_2 cross only once, as in Figure 2.1. In fact, the introduction of an endogenous default threshold creates a new source of complementarity and could even generate multiple equilibria if information is sufficiently precise (Hellwig, Mukherji and Tsyvinski (2006), Angeletos and Werning (2006)). However, even if single-crossing fails, or even if multiple

Calvo (1989), Bohn (1990), Aguiar et al. (2013), Engel and Park (2019), and Ottonello and Perez (2019a).

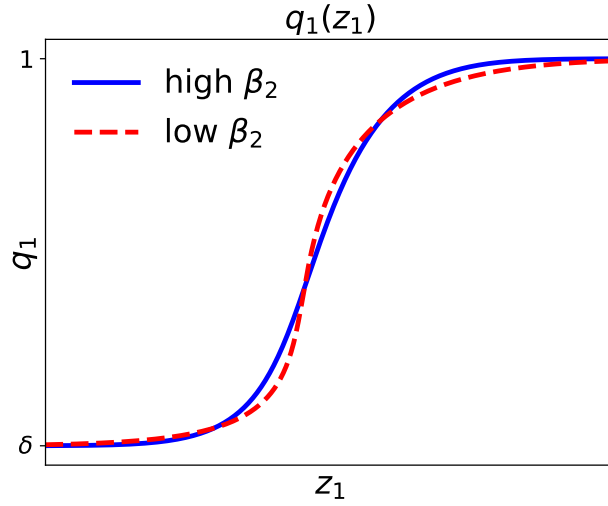


Figure 2.3: $q_1(z_1)$ for a case in which multiple crossings occur with an endogenous default threshold.

equilibria arise, we can still prove that none of these complications affect the behavior following tail events, where multiplicity does not arise and comparative statics remain the same as what we established in Section 2.4. Formally:

Proposition 6. *Assume that $\psi_2 \geq \psi_1$ and $\beta_2^A \geq \beta_1$. Let $\beta_2^B < \beta_2^A$. Then there exist two cutoff levels $\hat{z}_1^L \leq \hat{z}_1^H \in \mathbb{R}$ such that when $z_1 < \hat{z}_1^L$, q_1 evaluated at β_2^A is smaller than at β_2^B , whereas the reverse occurs for $z_1 > \hat{z}_1^H$, holding all other parameters fixed.*

Proof. See Appendix 2.B. ■

Figure 2.3 illustrates a case with multiple crossings.²⁶ The intuition behind Proposition 6 is that, for z_1 large in absolute value, the dominant force determining how the price moves with β_2 remains K , for which we already proved theorems in the previous section.

²⁶The price functions in the figure are obtained under the following parametrization: $\bar{\theta}(q_1) := 1/q_1, \alpha = 15, \beta_1 = 10, \beta_2^{\text{high}} = 10, \beta_2^{\text{low}} = 0.001, \psi_1 = \psi_2 = 0.1, \tau_\rho = \beta_1 \psi_1, \mu = 1.22, \delta = 0.654$. The extreme difference between β_2^{high} and β_2^{low} reflects the fact that, while conceptually possible, parameter values where multiple crossings occur are not as common, and it is especially difficult to find values where the multiple crossings can be seen easily in a graph.

2.6 Conclusion

Inflation risk and default risk affect the real value of maturing government debt in a similar way. However, the general price level is driven by the interaction among a much larger fraction of the population than the restricted group of people who actively participate in the government debt market. To the extent that information about government finances is unevenly distributed within the population, we have shown that this asymmetry has important implications for the resilience of debt prices in the face of adverse shocks.

In this chapter, we emphasized one reason why inflation reacts sluggishly to fundamentals. Our results would also apply in different contexts where other frictions force a slower adjustment in the prices of goods relative to asset prices, such as sticky-price models.

Our analysis opens a new dimension for the study of optimal debt management, in addition to the traditional channels of fiscal hedging and time consistency. The next step in this direction is to further develop a full theory of the optimal denomination of debt. Such a theory would take into account the insurance aspect that we have studied here, together with the effects of different structures of debt on the ex ante expected borrowing costs.²⁷

Finally, the information sensitivity of assets play a major role in the work of Gorton and Ordoñez (2014). While combining their forces and ours in a self-contained model is beyond the scope of our project, their theory and our work are complementary in accounting for sudden sovereign crises: as debt becomes more information-sensitive through the channels that we emphasize, Gorton and Ordoñez' forces would lead first-period agents to invest in even greater information acquisition, leading to further volatility and possibly market freezes.

Appendix 2.A Microfoundations

In this section we introduce a stylized macroeconomic model that underpins our assumption from the main text that the inflation expectations of a (larger

²⁷As emphasized in AHT, in the context of the model that we adopt, the relationship between the expected price of a security and its fundamental expected value ex ante is driven by the concavity or convexity of the payoff as a function of the underlying fundamental. In our case, the payoff of the first-period traders takes the shape of a normal cumulative distribution function, with both a convex and a concave piece that play against each other, so that we cannot establish a definite ranking.

and) unsophisticated group of agents drive the secondary-market price of debt for the Yen economy, while the default expectations of sophisticated bond traders determine the secondary-market price in the Euro economy. Other than this distinction, the model is such that the two economies are the same; the model maps exactly into the setup of our main text, where the only difference between the two economies is the precision of information of the agents that are pivotal in the second period.

We consider an economy that lasts for three periods. There is a single consumption good in each period. We consider two alternative scenarios: in the first one, the unit of account is exogenously fixed (the “Euro”) and the price of the consumption good is normalized to 1. In the second case, the value of a unit of account (the “Yen”) is endogenous.

The economy is populated by multiple generations of four types of agents: strategic workers, noise workers, strategic bond traders, and noise bond traders. In addition, a government is also present.

Workers are born in period 2 and die in period 3.²⁸ Strategic workers are endowed with one unit of the consumption good in period 2 and wish to consume in period 3; they are risk neutral and have access to a storage technology which has a yield normalized to zero. Negative storage is not allowed. Noise workers demand one unit of consumption in period 2, and can produce exclusively in period 3. To consume, they trade with strategic workers using nominal contracts, denominated in Euros or Yen, depending on the regime.²⁹ The relative mass of noise vs. strategic workers is $\Phi(\epsilon_2^w/\sqrt{\psi_2^w})$, where Φ is the normal cumulative distribution function and ϵ_2^w is i.i.d. with a standard normal distribution. Neither strategic workers nor noise workers have access to the bond market. Their asset position is limited to storage, trade credit with each other, and cash, which they may acquire from the bond traders.³⁰

Under the Euro scenario, workers do not interact with bond traders, and their interaction with the government is limited to paying a lump-sum tax which is a negligible fraction of their endowment.

²⁸We could add workers that live in periods 1 and 2, but these would not interact with bond traders, and so their presence would not have any effect on our results.

²⁹We do not model the reason why workers coordinate on nominal contracts. Euro contracts are equivalent to real contracts in our setup. Yen-denominated contracts favor strategic workers, as they can reap information rents at the expense of noise workers.

³⁰The assumption that workers cannot buy government bonds could be justified by indivisibility constraints as in Wallace (2000).

Bond traders live for two periods, and there will be overlapping generations of them. Their mass is negligible compared to workers; hence, when the two groups trade, the price is set by the workers. Bond traders are endowed with goods in the first period of their life,³¹ which they want to consume in the second period. Strategic traders can store their endowment at a return normalized to 0. Alternatively, they can sell some of their endowment in exchange for a government bond, which in period 1 can be purchased from the primary market and in period 2 from the secondary market, soon to be described. To preserve tractability, we assume that holdings of government debt are limited to $\{0, 1\}$. Noise traders do not get a choice; they absorb a fraction $\Phi(\epsilon_t^b/\sqrt{\psi_t^b})$ of the government bonds supplied to the market, where ϵ_t^b is i.i.d. with a standard normal distribution.

We next describe the government. We normalize its positions in per capita terms with respect to one cohort of strategic bond traders. In the first period, the government issues nominal bonds, backed by taxes that will be collected in period 3. Revenues from bond issuance are spent in a public good which does not affect the marginal utility of private consumption. When government bonds are denominated in Euros, they mature only in period 3, when the government has access to tax revenues. When instead the Yen is present, bonds are repaid in cash in period 2, and period-3 revenues are used to repurchase cash, as in Cochrane (2005).³² This arrangement corresponds to one of the important observations from which we started: that inflation is sluggish in advanced countries and workers often do not realize immediately that the government is resorting to the printing press to cover its fiscal needs.³³ In period 1, the government auctions one unit of bonds with a promised repayment $\hat{s}(q_1)$ in period 3, where q_1 is the inverse of the (gross) nominal interest rate. Two examples of the function \hat{s} are the following:

- $\hat{s}(q_1) \equiv \hat{s} \equiv 1$, corresponding to the Eaton-Gersovitz (1981) timing, in

³¹We assume that their endowment is always sufficient to buy one unit of government bonds.

³²The interpretation of this assumption is that the government can always smooth over any rollover risk by temporarily leaning on the central bank to purchase bonds. In the case of Japan, a more literal interpretation is actually true, since the Bank of Japan has monetized about half of the government net debt, that is, 80 percent of GDP.

³³We view this assumption as particularly appropriate for a government who has in the past established a reputation for stability. There are examples in history where this assumption would be violated. Sargent (1986) discusses cases in which inflation responded quickly to fiscal news, and other, more recent cases in which doubts about the fiscal stance led to sluggish adjustments.

which the government offers bonds making a fixed unit future repayment in period 3, and q_1 represents the first-period discount; this is the case that we consider in most of the chapter, up to Section 2.5.

- $\hat{s}(q_1) \equiv 1/q_1$, corresponding to the Calvo (1988) timing, in which the government offers bonds to raise a fixed amount of revenues (one) in period 1 and $1/q_1 - 1$ represents promised interest payments in period 3.

The ability of the government to raise revenues without a default in period 3 is limited by a single random variable θ . If $\theta \geq \hat{s}(q_1)$, revenues from current and future taxes are sufficient to repay the debt in full (under the Euro interpretation) or to maintain the price of goods pegged at parity with the Yen (when the government has its own currency). When instead $\theta < \hat{s}(q_1)$, tax revenues are insufficient to avoid explicit default or inflation. In this case, we assume that the government imposes an exogenous haircut and only repays $\delta\hat{s}(q_1)$ units of the consumption good in period 3. When debt is denominated in Euros, this is implemented directly as a haircut upon default. When instead debt is denominated in Yen, the revenues $\delta\hat{s}(q_1)$ are available to repurchase Yen, implying that the price level at which Yen are withdrawn becomes $1/\delta$.

The prior about θ and the signals observed by the agents are described in Section 2.2. The key distinction is about the information of workers vs. bond traders in the second period: we assume that workers get a private signal with precision β_2^w , while bond traders get a signal with precision $\beta_2^b > \beta_2^w$.

2.A.1 Trading in the Euro Economy

The pattern of trade for the Euro economy is described in Figure 2.4, where flows of goods are represented by solid arrows and flows of bonds by dashed arrows. In the Euro economy, there is no uncertainty about the value of nominal contracts, which is fixed at 1. At these prices, strategic workers (“SW”) are indifferent between storing their endowment or lending it at a rate zero to the noise workers (“NW”). Hence, they will absorb all of the demand $\Phi(\epsilon_2^w/\sqrt{\psi_2^w}) \in (0, 1)$ with no effect on their lending rate and no interaction with the bond market.

Next, we consider bond trading in the secondary market (period 2). Bond supply is fixed at one: both strategic and noise traders who purchased the bond in period 1 (“Traders₁”) must sell it to consume.

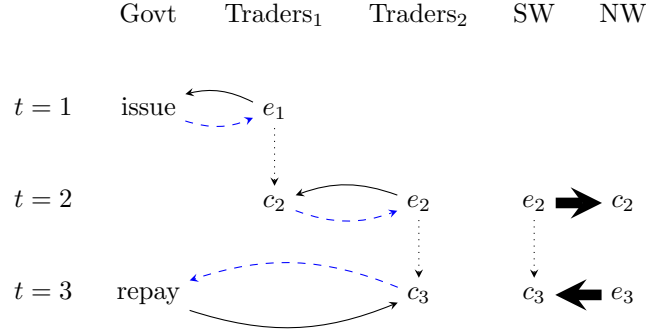


Figure 2.4: Markets and trading in the Euro scenario. Goods (solid); Bonds (dashed); Storage (dotted). e_t and c_t are endowment and consumption in period t , SW and NW stand for strategic and noise workers respectively.

Strategic bond traders born in period 2 (“Traders₂”) must choose whether to store their entire endowment or purchase a government bond in the secondary market.³⁴ Defining $q_2 := 1/(1 + R_2)$, where R_2 is the nominal interest rate (yield to maturity) in the secondary market, the expected net profit from buying the bond is

$$\hat{s}(q_1) [\delta + (1 - \delta)\text{Prob}(\theta \geq \hat{s}(q_1)|\mathcal{I}_{i,2}^b) - q_2], \quad (2.25)$$

where $\mathcal{I}_{i,t}^b$ is the information available to bond trader i in period t . We denote by D_t^b the demand for bonds by strategic bond traders in period t ; this demand depends on the price q_t , but also on the details of available information, in particular the degree of price recall τ_ρ . Second-period strategic bond traders must absorb a fraction $1 - \Phi(\epsilon_2^b/\sqrt{\psi_2^b})$ of bonds in equilibrium, with the balance purchased by noise traders. Market clearing will then require

$$D_2^b = 1 - \Phi\left(\epsilon_2^b/\sqrt{\psi_2^b}\right). \quad (2.26)$$

Going back to period 1, strategic bond traders born at that time must choose whether to store their entire endowment or purchase a government bond in the primary market. The expected profit from buying a bond is

$$\hat{s}(q_1) \{ \mathbb{E}[q_2|\mathcal{I}_{i,1}^b] - q_1 \}.$$

³⁴They could also lend to noise workers at the same rate as storage; since their mass is negligible compared to workers, this would not affect the market-clearing condition for trade credit between periods 2 and 3.

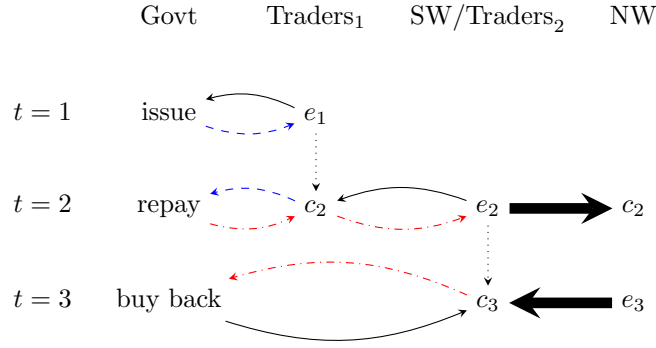


Figure 2.5: Markets in the Yen scenario. Goods (solid); Bonds (dashed); Cash (dot-dashed); Storage (dotted). e_t and c_t are endowment and consumption in period t , SW and NW stand for strategic and noise workers respectively.

Market clearing in the first period requires

$$D_1^b = 1 - \Phi \left(\epsilon_1^b / \sqrt{\psi_1^b} \right). \quad (2.27)$$

2.A.2 Trading in the Yen Economy

Figure 2.5 represents trading in the Yen economy. As in Figure 2.4, solid arrows represent flows of goods and dashed arrows represent flows of bonds; in addition, dot-dashed arrows represent the flows of cash. In this case, there is no uncertainty about the nominal repayment from government bonds, which happens in cash in period 2. However, the terminal value of cash in period 3 depends on tax revenues. Strategic workers must decide whether to store their endowment until period 3 or to sell their goods in period 2 for cash or trade credit, at a price P_2 . Noise workers will demand goods in period 2 in exchange for trade credit, in a fixed amount $\Phi(\epsilon_2^w / \sqrt{\psi_2^w}) \in (0, 1)$. Traders born in period 1 will also use their cash to buy goods in period 2; by assumption, their demand is negligible compared to that of the workers (the thick arrows between SW/Traders₂ and NW in Figure 2.5 are designed to remind the reader of this).

The payoff for a strategic worker of selling a unit of goods right away relative to storing it is

$$\mathbb{E} \left(\frac{1}{P_3} | \mathcal{I}_{i,2}^w \right) - \frac{1}{P_2}, \quad (2.28)$$

where $\mathcal{I}_{i,2}^w$ is the information available to the worker and P_3 is the nominal price level in period 3, which is either 1 or $1/\delta$, depending on whether $\theta \geq \hat{s}(q_1)$.

Hence, equation (2.28) becomes

$$\delta + (1 - \delta)\text{Prob}(\theta \geq \hat{s}(q_1) | \mathcal{I}_{i,2}^w) - \frac{1}{P_2}. \quad (2.29)$$

Letting D_2^w be the fraction of strategic workers selling the goods in period 2 (demanding cash or trade credit), market clearing in period 2 requires

$$D_2^w = \Phi(\epsilon_2^w / \sqrt{\psi_2^w}) = 1 - \Phi(-\epsilon_2^w / \sqrt{\psi_2^w}). \quad (2.30)$$

Since there is no secondary market for government bonds in period 2, noise traders are not active.³⁵ Strategic traders face the same choice as the workers: either store their endowment or sell it for cash or trade credit. Since their mass is negligible relative to that of the workers, their choice has no effect on market clearing and prices.

Going back to period 1, the problem of strategic bond traders in period 1 is similar to the Euro economy, except that their payoff is now a fixed amount of Yen with uncertain value rather than an uncertain amount of Euros. The expected profit from buying a bond is

$$\hat{s}(q_1) \left\{ \mathbb{E}\left[\frac{1}{P_2} | \mathcal{I}_{i,1}^b\right] - q_1 \right\},$$

and market clearing is still given by (2.27).

2.A.3 Comparing the Two Economies

The construction of an equilibrium in the two economies is very similar. The only difference between the two concerns the identity of the marginal agent in period 2. In the Euro scenario, this is a bond trader active in the secondary market, while in the case of Yen-denominated debt it is a worker selling her goods in exchange for nominal payments. This is seen comparing equations (2.25) and (2.26) for the Euro economy with equations (2.29) and (2.30) of the Yen economy.

The parameters of interest are thus the relative information that workers and second-period traders have about the government's ability to raise taxes in the final period. Our key assumption is that bond traders are more informed

³⁵Recall that we assumed that the demand from noise traders is a fraction of the supply of bonds.

Table 2.1: Comparison of the payoffs of strategic agents in period 2.

	Euro	Yen
Identity of marginal buyer	bond trader	worker
Goods given up at $t = 2$	$\hat{s}(q_1)q_2$	1
Goods received at $t = 3$:		
- w/o default/inflation	$\hat{s}(q_1)$	$P_2/P_3 = P_2$
- with default/inflation	$\delta\hat{s}(q_1)$	$P_2/P_3 = \delta P_2$
Return:		
- w/o default/inflation	$1/q_2$	P_2
- with default/inflation	δ/q_2	δP_2

than workers, that is, they have a more precise signal ($\beta_2^b > \beta_2^w$) and face less market noise ($\psi_2^b > \psi_2^w$).

Table 2.1 highlights the symmetry between the two scenarios, which we exploit to collapse the two cases into a single problem. Accordingly, we drop the superscripts referring to workers and traders, we define $q_2 := 1/P_2$ in the case of the Yen, and we refer to “demand” by second-period strategic agents as their real demand for risky assets, which is their *supply* of goods: in the case of the Euro, traders acquire government bonds in the secondary market, whereas in the case of the Yen workers acquire cash or trade credit.

We thus proceed by analyzing a single problem. Defining $\bar{\theta}(q_1) := \hat{s}(q_1)$, this is precisely the economy of Section 2.2 when $\hat{s}(q_1)$ is constant and normalized to 1, and that of Section 2.5 for the extension in which the default threshold depends on the first-period price of debt and q_1 is the inverse of the gross interest rate at issuance. Our analysis proceeds from here by studying comparative statics with respect to β_2 .³⁶

³⁶We exploit the symmetry of the normal distribution in equation (2.30) and renormalize $\epsilon_2^w = -\epsilon_2^w$ in the case of the Yen economy.

Appendix 2.B Proofs

Proof of Proposition 4. First, with some algebra it is possible to show that the sign of $\partial K/\partial\beta_2$ is equal to the sign of the following expression³⁷

$$\begin{aligned} & \beta_2\psi_1(1+\psi_2)[\beta_1(1+\psi_1+2\psi_2)+2\psi_2(\beta_1\psi_1-\tau_\rho)] \\ & + (1+\psi_1)\tau_\rho[\beta_1\psi_1(2\psi_2-1)-2\psi_1\tau_\rho] + \alpha\psi_1[2\beta_1(1+\psi_1)\psi_2 - (1+2\psi_2)\tau_\rho] \end{aligned}$$

which is linear in β_2 with a positive slope coefficient. Let $\hat{\beta}_2$ be the unique value of β_2 for which the above expression is zero.

Second, note that $\hat{\beta}_2$ is a quadratic function of τ_ρ , with a positive coefficient on the quadratic term and a unique positive root which we denote with $\tilde{\tau}_\rho$. It follows that $\hat{\beta}_2 \leq 0$ if and only if $\tau_\rho \leq \tilde{\tau}_\rho$. This condition is always verified when $\beta_1 \leq \frac{\alpha(2\psi_2-\psi_1)}{\psi_1(1+\psi_1)}$, because in this case $\tilde{\tau}_\rho$ is greater than its upper bound $\beta_1\psi_1$; when instead $\beta_1 > \frac{\alpha(2\psi_2-\psi_1)}{\psi_1(1+\psi_1)}$, we have that $\tilde{\tau}_\rho \in (0, \beta_1\psi_1)$. Together with the definition of $\hat{\tau}_\rho := \min\{\tilde{\tau}_\rho, \beta_1\psi_1\}$, this proves the proposition. ■

Proof of Proposition 5. To prove the proposition it is sufficient to prove that $K(\beta_2 = \beta_1) > K(\beta_2 \rightarrow 0)$. This implies that, even when $\tau_\rho \in (\hat{\tau}_\rho, \beta_1\psi_1]$ and K has a positive interior minimum in β_2 (defined by $\hat{\beta}_2$ in the previous proof), such minimum is smaller than β_1 and that K is locally increasing at $\beta_2 = \beta_1$. Please refer to the online appendix for explicit algebra derivations. ■

Proof of Proposition 6. Define $q_1^A(z_1)$ and $q_1^B(z_1)$ to be the equilibrium prices in the first period when information precision in the second period is β_2^A and β_2^B respectively. Similarly, define K^A and K^B to be the values of K from equation (2.22) for the two precision values. Examine the argument of the cumulative distribution function on the right-hand side of (2.24). The second term is linear in z_1 with coefficient K , while the first term is a bounded function of z_1 since $\bar{\theta}(q_1) \in (\bar{\theta}(1), \bar{\theta}(\delta))$. It follows that, if (and only if) $K^A > K^B$, then there exists \hat{z}_1^L such that $q_1^A(z_1) < q_1^B(z_1)$ for all $z_1 < \hat{z}_1^L$. The same argument applies for the upper threshold \hat{z}_1^H . The comparison of K^A and K^B was derived in Proposition 5. ■

³⁷Further details are provided in the online appendix.

Chapter 3

Inflation, Default Risk and Nominal Debt

3.1 Introduction

In the last two decades, many emerging market (EM) governments significantly tilted the currency composition of their public debt from foreign to local currency.¹ Borrowing in local currency makes inflation an additional instrument for public debt management, on top of repayment through fiscal surpluses and outright default. This raises the questions of what is the interplay between the temptations to default on sovereign debt or to inflate it away, and how these incentives shape macroeconomic policies in EM. The inflation and default spreads embedded in government bond interest rates have a critical role in determining the trade-off between the ex-post benefits and the ex-ante costs of these policies, in the presence of time inconsistencies. A key empirical regularity in the sovereign default literature is the counter-cyclicality of default spreads, which constrains borrowing in situations where the government needs it the most. Whether inflation spreads display the same or the opposite feature has crucial implications for the ability of the issuer to use debt policy as a way to smooth shocks over time.

This chapter studies in detail the relationship between strategic inflation, default and inflation risk for a set of large EM sovereigns. A common argument regarding countries that borrow in their own currency is that they need not default on their debt, because they can always resort to the printing press in

¹See [Du and Schreger \(2016b\)](#) and [Ottonello and Perez \(2019b\)](#).

case of need. I show that in the data, despite the shift to local-currency debt, default risk for these countries remains non-negligible and displays a robust, positive relationship with realised and expected inflation. I use these facts to discipline the behaviour of default and inflation spreads in a quantitative sovereign default model where a government issues debt in domestic currency and lacks commitment to both fiscal and monetary policy. I find that, to reconcile the model with the data, it is important to account for the role of inflation as a tool to raise fiscal revenues, especially in periods when other margins may be hard to adjust. The model allows to quantitatively evaluate the trade-off between the insurance benefits of nominal debt and the cost of a further source of time inconsistency, when inflation and default risks co-move.

In Section 3.2, I document a number of stylised facts on the relationship between default risk, inflation risk, realised inflation and exchange rate depreciation for a set of ten large EM countries. I exploit the availability of over-the-counter derivatives that price default and currency risks separately: I use Credit Default Swaps (CDSs) as an indicator of default risk, and fixed-for-fixed Cross-Currency Swaps (XCSs) as an indicator of the expected depreciation of a currency against the US dollar, which I use as a proxy for expected inflation. Using different assets has the advantage of avoiding an econometric decomposition of local-currency sovereign spreads into default and currency premia, and addresses liquidity problems in government debt markets as the derivatives I analyse are standardised and liquid.

I highlight three novel facts that emerge from the data. First, I look at long-run averages across countries: I find that countries with high default risk display high inflation levels, both realised and in expectation. Second, I show that, within each country, inflation and default risk are positively correlated at quarterly frequencies. This relationship is robust to controlling for global risk factors that may drive investors' risk premia. Third, I find that default risk also co-moves, within each country, with realised inflation and exchange rate depreciation.

Based on this evidence, I develop a quantitative sovereign default model with nominal debt to study the joint behaviour of default risk, expected and realised inflation. The model is a version of [Arellano \(2008\)](#) where external debt is denominated in domestic currency and the government lacks commitment to both fiscal and monetary policy. I follow the literature in assuming that inflation is a continuous instrument with convex costs, while default is a

binary choice that entails a fixed output cost and temporary exclusion from debt markets.

First, I test the simplest version of the model, where inflation only serves the purpose of diluting the real value of debt, an assumption common to both sovereign default and monetary models. A priori, it is not obvious whether inflation and default risks co-move positively. After a bad shock, the temptation to inflate and reduce the debt burden is stronger, as long as default does not occur, but at the same time the government gets closer to a default, after which debt is reduced via a haircut and inflation incentives are weaker. I evaluate these mechanisms quantitatively, and find that the model predicts a negative correlation between inflation and default risks, since inflation and default are substitute instruments. Moreover, the model generates low levels of inflation upon default. These results are at odds with my empirical findings, and with the fact that sovereign defaults are generally followed by periods of abnormally high inflation.²

Second, I highlight the role that monetary financing (or seignorage) has in reconciling the model with the data, by allowing inflation to serve a second purpose. I augment the model with endogenous government spending and money in the utility function: the latter creates a role for money and allows to model inflation costs explicitly, the former generates a motive for the government to use seignorage as a tax instrument to transfer resources from the private to the public sector.

In the model, inflation therefore serves a dual purpose: it is both a tax on foreign lenders, as it dilutes the real value of external debt when it is unanticipated, and a tax on domestic money holdings, which is especially useful when other margins may be hard to adjust, such as during the periods of autarky following a default. The relative importance of these two functions, as well as the way in which they are embedded into expectations and sovereign bond spreads, are crucial for the ability of this framework to generate the comovement between inflation and default risk that I observe in the data. This in turn hinges on two fundamental properties of the model: the correlation between inflation and the cycle, and the behaviour of inflation upon default. Inflation cyclicality is driven on one hand by the cyclical properties of external debt, and on the other hand by the strength of the incentive to use the inflation tax to smooth public spending over the cycle. The behaviour of inflation

²See [Na et al. \(2018\)](#), [Reinhart and Rogoff \(2009, 2011\)](#) and references therein.

upon default depends, as in the benchmark model described previously, on the relative importance of the debt dilution and the tax motives. Default happens in bad times, where the need to smooth spending via the inflation tax is high; at the same time, a default wipes off a substantial fraction of debt, which reduces the incentives to further dilute it with inflation.

I quantitatively evaluate the importance of these forces with a numerical example, and I find that, when public good demand is sufficiently inelastic, the tax motive is strong, reduces the repayment-default inflation differential, and allows the model to match the co-movement of inflation and default risks that I observe in the data. Although an exact calibration of the model is still in progress at the moment, I provide an analytical decomposition of the mechanism that drives the asset price co-movement, and highlight in detail the conditions under which its behaviour mirrors the data.

The sovereign default literature has mostly studied the implications of default risk in real models. I complement this analysis by studying the way in which default premia interact with inflation premia, when the government cannot commit to monetary policy. I use my empirical findings to discipline this relationship within a framework where there exists a single policymaker.³ The model allows to quantitatively evaluate the trade-off between the benefits of nominal debt, via the use of inflation as a way to obtain state-contingent real returns, and the cost of a further source of time inconsistency when inflation and default risks co-move. My findings suggest that the expectation of inflation as a source of fiscal revenues, both during repayment and in default periods, has important implications for the conduct of monetary policy. This is a natural starting point to think about the institutional relationship between the fiscal and the monetary authority and its credibility, and to discipline time-consistent models of fiscal-monetary interactions.

Relation to the Literature. This chapter relates to several strands of the literature on sovereign default, monetary and exchange rate policy.

A literature that dates back to the seminal work of [Calvo \(1988\)](#) analyses time-consistent monetary and fiscal policy with sovereign default, considering the role of inflation and exchange rate devaluation as an implicit way to default on local-currency debt, and their interplay with explicit default. A number of recent papers have addressed this issue by embedding a monetary side into

³Or where the objective function of the fiscal and monetary authority coincide.

real sovereign default models in the tradition of [Eaton and Gersovitz \(1981\)](#), [Arellano \(2008\)](#), [Aguiar and Gopinath \(2006\)](#) and subsequent work. [Nuño and Thomas \(2015\)](#) and [Aguiar et al. \(2014\)](#) consider a planning problem and study the trade-off between the ex-post benefits and the ex-ante costs of discretionary inflation as a way to dilute the real value of debt. Closest to my work are [Roettger \(2019\)](#) and [Sunder-Plassmann \(2018\)](#), who exclude lump-sum taxation and consider the distortions created by monetary policy in an optimal policy framework. I contribute to the literature in a number of ways. First, I show that the simple planner version of this framework is not well-suited to the study of EM economies, because it does not match the asset price facts observed in the data. Second, I model the monetary side of the economy in a more flexible way, to allow for realistic money demand elasticities. Third, I analyse in detail the asset pricing implications of the model and their real effects, isolating the mechanisms that are key to reconcile the model with the data.

There are other papers that consider the relationship between inflation and default when debt is nominal, but take quite different approaches. [Araujo et al. \(2013\)](#), [Aguiar et al. \(2013, 2014\)](#), [Corsetti and Dedola \(2016\)](#) and [Bassetto and Galli \(2019\)](#) examine the role of inflation as partial default within the context of self-fulfilling runs on government debt. By contrast, I abstract from belief-driven crises and follow most of the quantitative literature in focusing on defaults driven by fundamentals. [Engel and Park \(2018\)](#), [Ottonello and Perez \(2019b\)](#) and [Du et al. \(2016\)](#) study the currency composition of debt when the government lacks commitment to repay and to inflate, in order to rationalise the recent surge in local-currency borrowing. I abstract from this margin for reasons of tractability, and focus on countries that have self-selected into issuing most of their debt in local currency.

A recent body of work studies optimal default and monetary policy in economies with nominal rigidities. [Na et al. \(2018\)](#) show how downward wage rigidities can rationalise the joint occurrence of defaults and large exchange rate devaluations: during a default, optimal exchange rate policy calls for a reduction in the real value of wages that stimulates employment. [Bianchi et al. \(2019\)](#) and [Bianchi and Mondragon \(2018\)](#) consider a similar framework to respectively study optimal fiscal policy and self-fulfilling debt runs. [Arellano et al. \(2019\)](#) embed an external default model within a New Keynesian open economy framework with commitment on the monetary side, and study the

co-movement of default spreads with realised inflation and short-term nominal rates. In these papers, inflation either creates deadweight losses (in the case of price rigidities) or reduces involuntary unemployment (in the case of wage rigidities), while it does not provide debt relief since debt is assumed to be denominated in foreign currency. By contrast, I study a framework where inflation has the different functions of debt dilution and source of revenues for the fiscal authority.

Finally, the treatment of inflation as a source of fiscal revenues in this chapter is also related to the literature on currency and balance-of-payment crisis, dating back to the seminal contribution of [Krugman \(1979\)](#) and the large body of subsequent work. With respect to this class of models, I consider default, and I model endogenously the reason behind the use of seignorage revenues to fund fiscal deficits.

The chapter proceeds as follows: Section 3.2 presents a number of stylised facts about the relationship between default risk, currency risk, and realised inflation; Section 3.3 presents the model environment; Section 3.4 illustrates the main mechanisms of the model; Section 3.5 analyses the quantitative performance of the model; Section 3.6 concludes.

3.2 Empirical Observations

This section documents a number of facts about the relationship between default risk, currency risk, realised inflation and exchange rate depreciation. Data are quarterly series. Most of the data is for the period 2004q1-2018q4, although some data series for some countries start later. The countries I consider are: Brazil, Colombia, Indonesia, Mexico, Malaysia, Poland, Russia, Thailand, Turkey, South Africa. These countries are chosen on the basis of data availability, but they also share two important features: first, they all have freely floating or managed floating exchange rates, according to the categorisation of [Ilzetzi et al. \(2019\)](#); second, a large share of their debt is denominated in local currency, as illustrated by Figure 3.1 which plots the average share of local-currency total public debt over the period 2004-2018.

The data sources are the following. All data on derivatives prices, government bond interest rates, inflation and exchange rates is taken from Bloomberg. Inflation is defined as the annual change in the national consumer price index. Output and debt data are taken from the World Bank, the IMF, and where

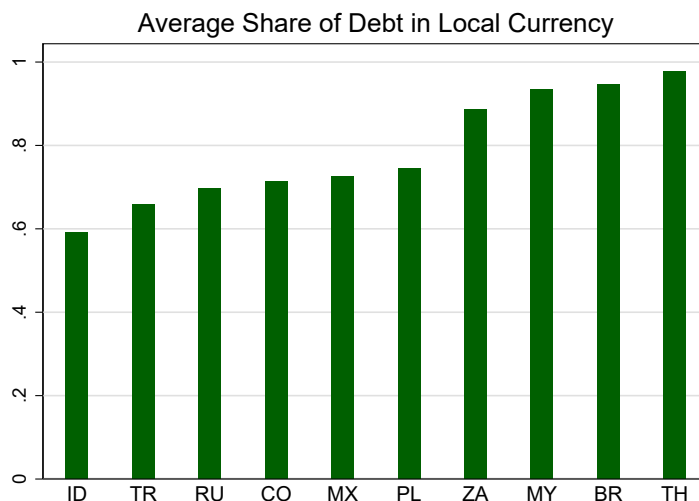


Figure 3.1: Average share of local-currency total public debt by country over the period 2004-2018. Country labels: Brazil (BR), Colombia (CO), Indonesia (ID), Mexico (MX), Malaysia (MY), Poland (PO), Russia (RU), Thailand (TH), Turkey (TR), South Africa (ZA).

necessary from national statistical offices.

To measure default risk, I use credit default swaps. These are OTC derivatives that quote the premium (commonly called spread) that investors can pay in order to fully insure themselves against a credit event on a country's government debt. Credit events include a set of circumstances that are normally associated with default and debt restructuring, such as postponements or cancellation of interest or principal payments. A number of features make these derivatives a particularly compelling measure of default risk: first, they are denominated in US dollars, which means that the payoff of the instrument is insulated from the value of the issuer's currency and its expected correlation with a default episode; second, they are based on bonds issued under international law, which shields them from country-specific idiosyncracies and capital control legislation;⁴ third, they are standardised instruments, which gives them a constant maturity and makes them more liquid than foreign currency government debt; fourth, for those countries where sufficiently good data is available, I show in the appendix that CDSs are highly correlated with foreign currency bond spreads. Lastly, because mark-to-market positions in

⁴The downside of this feature is that, in the case of a selective default only on domestic-law debt, these CDSs would not get triggered. However, default on international debt is widely believed to have a higher, if at all different, likelihood than default on domestic debt, so I consider the default risk embedded in these assets a lower bound.

over-the-counter derivatives are collateralised on a daily basis, counterparty risk is not a concern for any of the derivatives data used in this chapter. For the purpose of this analysis, I use CDS spreads for the five year maturity, which is the most liquid. To help interpret the data, I back out risk-neutral implied default probabilities assuming a constant default hazard rate function.⁵

To measure currency risk, I use the price of fixed-for-fixed cross-currency swaps (XCSs henceforth). For reasons of liquidity and consistency with the measure of default risk, I look at five year maturities. The XCS rate is essentially the long-term equivalent of the interest rate differential implied by exchange rate forwards. Assuming risk neutrality, I use this implied rate as a measure of the expected depreciation of a country's currency against the US dollar. Since these instruments are not directly quoted in financial markets, I follow [Du and Schreger \(2016a\)](#) and construct them by combining fixed-for-floating cross-currency swaps and local currency interest rate swaps. I use XCSs rather than exchange rate forwards because the latter are only generally liquid up to 12 month maturities, while the former are liquid up to 10 year maturities.

I now uncover a number of stylised facts regarding the relationship between default risk, currency risk and inflation. First, I document the long-run property of these variables, across countries. Second, I document their short-run properties, over time and within each country.

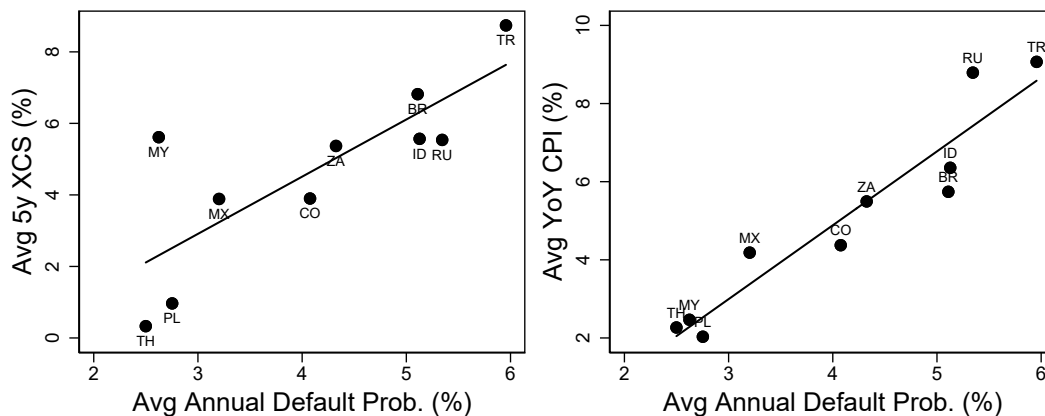


Figure 3.2: Long-term averages for the period 2004q1-2018q4. The left panel plots average default probabilities against average XCS rates. The right panel plots average default probabilities against year-on-year consumer price inflation.

⁵Explicit derivations are provided in the appendix.

Long-Run Facts. Figure 3.2 highlights two cross-country relationships: long-run default risk is positively correlated with long-run currency risk, as proxied by XCS rates (left panel), as well as with long-run realised CPI inflation (right panel). This implies that countries with historically high default probabilities tend to have historically high inflation and exchange rate depreciation, both realised and in expectation.

This finding is robust to the time interval considered, as long as it is of sufficient length: Figure 3.7 in the appendix shows the same picture for the period 2010q1-2018q4.

Short-Run Facts. The first short-run fact concerns the relationship between default and currency risk. Figure 3.3 shows, for each country, the quarterly correlation of CDSs and XCSs. Except for Malaysia, these correlations all suggesting that default and currency risks co-move not only at long-run frequencies, but also in the short-run, within each country. As the data on these asset prices is available at virtually any frequency, it is also possible to show that the positive correlations are there also at shorter time frequencies.

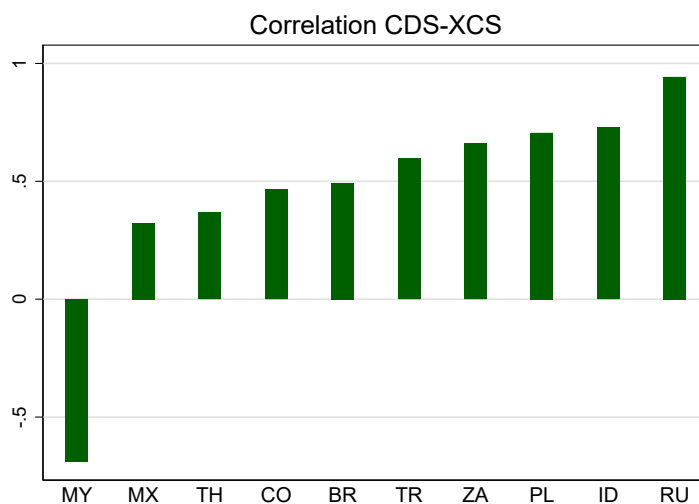


Figure 3.3: Short-run correlation of five year CDSs with five year XCSs, ordered by country. Quarterly data for the period 2004q1-2018q4.

An obvious concern that could arise regarding this fact, is that this short-run co-movement is driven by global risk factors that affect the discount factor of foreign investors trading both assets, rather than by country-specific variables. I check that this is not the case by running a panel regression of five year CDS-implied default probabilities against five year XCS rates, controlling for

both country and time fixed effects. Controlling for time fixed effects should account for any common, time-varying component affecting the relationship between our measures of default and currency risk. The resulting linear coefficient on XCS rates is equal to 0.437, with a standard deviation of 0.096.⁶ This lets us conclude that the relationship between default and currency risk still stands even after controlling for a global factor, and that a one percentage point increase in expected exchange rate depreciation is linked, on average, with an increase in the probability of default just below half a percentage point.

The second short-run fact concerns the relationship between default risk and nominal variables. Figure 3.4 shows, for each country, the quarterly correlation between one year absolute changes in CDSs, one year percentage changes in the nominal exchange rate (left panel), and CPI inflation (right panel). The figure highlights that not only default risk is associated with currency *risk*, as highlighted in the previous paragraphs, but also with the rate of change of the nominal exchange rate and the price level.

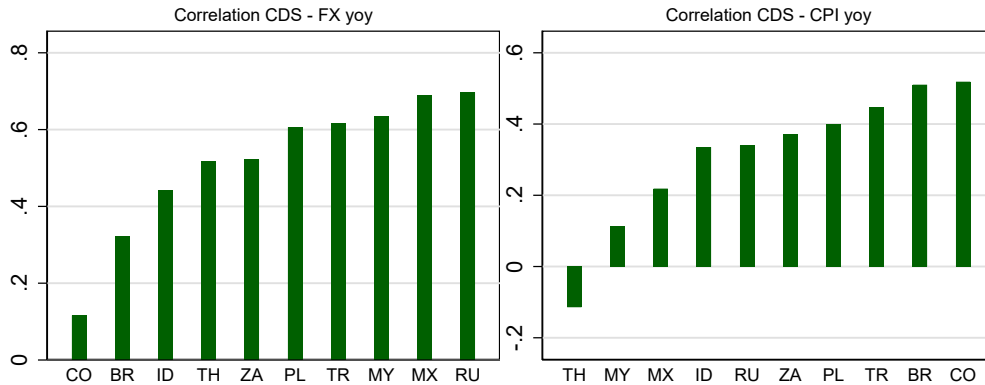


Figure 3.4: Short run correlations of one year absolute changes in CDSs (of five year maturity) with one year percentage changes in the nominal exchange rate (left panel), and CPI inflation (right panel). Quarterly data for the period 2004q1-2018q4, ordered by country.

These facts call for a joint analysis of the behaviour of inherently fiscal, such as default risk, and monetary issues, such as expected and realised inflation and exchange rate depreciation, as data for this sample of emerging market economies suggests these variables exhibit a significant co-movement both in the short and long run.

⁶Standard errors are clustered at the country level.

3.3 Model

I now consider a infinite-horizon, quantitative sovereign default model with money in the utility function, endogenous government spending, and where the government engages in strategic default and inflation. As will be explained more in detail later on, I will consider two versions of this framework, one in which the government can use lump-sum taxation (the “benchmark” model), and another one in which it cannot (the “restricted” model).

The environment I study is given by a small open economy that is populated by a benevolent government, a continuum of measure one of atomistic households, and where the government can trade bonds with a continuum of foreign, risk-neutral lenders. I now present in detail the problem of each of these players.

3.3.1 Households

Households get utility from consumption of the private good c_t , from the ratio M_t/P_t of nominal money balances M_t to the aggregate price level P_t , and from public good consumption g_t . Their preferences are given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t U^h(c_t, M_t/P_t, g_t)$$

where the period- t utility function displays strong separability and is given by

$$U(c_t, m_t, g_t) = \frac{c_t^{1-\gamma}}{1-\gamma} + \alpha_m \frac{m_t^{1-\eta}}{1-\eta} + \alpha_g \frac{g_t^{1-\zeta}}{1-\zeta}. \quad (3.1)$$

In each period, households take prices and government policy as given, and choose consumption c_t , money holdings M_{t+1} , and domestic bond holdings B_{t+1}^d . Domestic bonds are risk-free, pay the gross risk-free rate R_f , and are only traded among households. Household income is given by an exogenous stochastic endowment y_t that follows the AR(1) process

$$\log(y_t) = \rho_y \log(y_{t-1}) + \epsilon_t, \quad \epsilon_t \sim N(0, \sigma_\epsilon^2), \quad (3.2)$$

a fraction τ_t of which is paid in taxes to the government. The household budget

constraint is given by

$$c_t + \frac{M_{t+1}}{P_t} + \frac{1}{R_t} \frac{B_{t+1}^d}{P_t} = \frac{M_t}{P_t} + \frac{B_t^d}{P_t} + y_t(1 - \tau_t). \quad (3.3)$$

In their decision problem, households take government monetary, debt and spending policy as given. Combining the first-order conditions for consumption, money and bond holdings yields two standard Euler equations for money and domestic bonds

$$\frac{U_{c,t}^h}{P_t} = \beta \mathbb{E}_t \left[\frac{U_{c,t+1}^h + U_{m,t+1}^h}{P_{t+1}} \right] \quad (3.4)$$

$$\frac{1}{R_t} \frac{U_{c,t}^h}{P_t} = \beta \mathbb{E}_t \left[\frac{U_{c,t+1}^h}{P_{t+1}} \right] \quad (3.5)$$

where $U_{x,t}^h$ denotes marginal utility with respect to variable x in period t . Equation (3.4) is the households' money demand equation, and will have a crucial role in determining the equilibrium price level as a function of the government money supply.

Combining the two Euler equations we can express the domestic risk-free rate as a function of the expected future marginal rate of substitution between consumption and real money balances

$$R_t - 1 = \mathbb{E}_t \left[\frac{U_{m,t+1}^h}{U_{c,t+1}^h} \right]. \quad (3.6)$$

Under the current preferences specification there is no satiation point for real money balances, and therefore the Friedman rule only holds in the limiting case where $U_{m,t+1}^h \rightarrow +\infty$.

3.3.2 Government Problem

I study the problem of a single policymaker that encompasses both the fiscal and the monetary authority; in other words, government policy here can be thought of as the union of fiscal and monetary policy when the respective authorities act in a coordinated way and share the same objective.

It can borrow externally using debt instruments that are short-term, non-contingent, defaultable and denominated in local-currency. The government is benevolent and maximises the utility of households. Its objective function

is given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c_t, m_t, g_t)$$

where the period- t utility function is given by

$$\frac{c_t^{1-\gamma}}{1-\gamma} + (\alpha_m + \alpha_\nu) \frac{m_t^{1-\eta}}{1-\eta} + \alpha_g \frac{g_t^{1-\zeta}}{1-\zeta}, \quad (3.7)$$

where c, m, g are the aggregate values of private good consumption, real money balances and public good consumption respectively.

There are two differences between equation (3.7) and the objective function of households in equation (3.1): first, I assume the government has a discount factor that is different from that of households; second, I assume that the government gets additional utility from the aggregate level of real money balances, which is an externality that agents do not take into account in their individual decision-making process, as they are atomistic and there is a continuum of them. The first assumption is needed in order for the model to be able to target both average government debt service and the domestic risk-free rate. The former depends crucially on the degree of impatience of the government, and the latter depends the rate of time preference of households. While it is not common to target domestic risk-free rates in sovereign default models, it is important to do so here: as is shown in Appendix 3.B.2, the semi-elasticity of household money demand to the interest rate depends crucially on the level of such rate, which I discipline by targeting its empirical equivalent. The second assumption adds an additional cost of surprise inflation to the problem of the government. This represents an additional channel that corrects the government lack of commitment to inflation, and allows to drive a wedge between the domestic risk-free rate and the average debt-money ratio. These objects are otherwise identical in the benchmark model, as I show in detail in Section 3.4.

Timing. At the beginning of each period, the government can be either in good credit standing or in default, depending on its default history.

When it is in good standing, it first chooses whether to default or repay its debt due B_t . If it repays, it then chooses spending g_t , the money supply M_{t+1} , the tax rate τ_t and new debt B_{t+1} , which is issued to foreign lenders at a price of q_t . If the government decides not to repay, it switches to a default standing. When it is in default, the government is temporarily excluded from

international debt markets, and the domestic economy incurs an output loss that reduces output to $y^d(y_t) \leq y_t$.

I assume that default is partial and the length of the exclusion period is random: in all periods that follow a decision to default, with probability θ the government gets a chance to re-enter debt markets at the condition of repaying a fraction $(1 - h)$ of its outstanding nominal debt obligation. If it accepts, it repays the debt and re-enters debt markets; if it declines, it keeps its default standing, and its outstanding debt remains equal to a fraction $(1 - h)$ of the amount due prior to the re-entry offer. This assumption has two implications: first, upon default debt effectively becomes long-term; second, the government has always the chance to remain in default for a period long enough that its debt obligations become arbitrarily small as it receives a sufficient number of haircuts. The latter implication is important to ensure that eventually the government always re-enters credit market: it could otherwise be possible that, depending on the size of the defaulted debt stock and on the level of inflation upon default, the government never finds it optimal to re-enter credit markets.

During default periods, the government still chooses spending, the money supply and the tax rate.

The government budget constraint during periods of repayment is given by

$$\tau_t y_t + q_t \frac{B_{t+1}}{P_t} + \frac{M_{t+1}}{P_t} = \frac{M_t}{P_t} + \frac{B_t}{P_t} + g_t \quad (3.8)$$

where all variables have been introduced in the previous paragraphs. The budget constraint of the government during periods of default is instead given by

$$\tau_t y^d(y_t) + \frac{M_{t+1}}{P_t} = \frac{M_t}{P_t} + g_t. \quad (3.9)$$

3.3.3 Lenders

Foreign lenders are risk-neutral, perfectly competitive, and have an opportunity cost of capital equal to the international gross risk-free rate R^* , which I assume constant for simplicity. They are indifferent with respect to the amount of government bonds they buy, as long as they make zero profits in expectation. The zero-profit price of a unit of government debt is given by

$$q_t = \frac{1}{R^*} \mathbb{E}_t \left[\frac{1 - \delta_{t+1}}{1 + \pi_{R,t+1}} + \frac{\delta_{t+1} q_{D,t+1}}{1 + \pi_{D,t+1}} \right]$$

where δ_t is a default indicator that takes the value of 1 if the government chooses to default at t and zero otherwise, $\pi_{R,t+1}, \pi_{D,t+1}$ denote the net inflation rate $P_{t+1}/P_t - 1$ conditional on repayment and default respectively, $q_{D,t+1}$ denotes the price of debt upon a default in period $t + 1$.

The value of debt upon default in some period t is in turn given by

$$q_{D,t} = \frac{1}{R^*} \mathbb{E}_t \left[(1 - \theta) \frac{q_{D,t+1}^n}{1 + \pi_{D,t+1}^n} + \theta \delta_{t+1} \frac{(1 - h) q_{D,t+1}^o}{1 + \pi_{D,t+1}^o} + \theta (1 - \delta_{t+1}) \frac{1 - h}{1 + \pi_{R,t+1}} \right].$$

The first term inside square brackets denotes the case, which I denote with superscript n , where the government does not receive an offer to re-enter credit markets. The second term denotes the case, which I denote with superscript o , where the government receives an offer to re-enter markets but decides to reject it, so it remains in default and its debt receives a haircut h . The third term denotes the case where an offer to re-enter is received and accepted.

From the debt price of new debt, it is easy to derive the model counterparts of the default and inflation risks I analysed in the empirical section. Expected default is given by

$$DP_t := \mathbb{E}_t \delta_{t+1}, \quad (3.10)$$

while expected inflation (or exchange rate depreciation, which are identical in the model) are given by

$$XCS_t := \mathbb{E}_t [\delta_{t+1} \pi_{D,t+1} + (1 - \delta_{t+1}) \pi_{R,t+1}]. \quad (3.11)$$

3.3.4 Equilibrium

I consider the time-consistent Markov-perfect equilibrium where the government internalises the effect of its policies on household allocations, current and future equilibrium prices, and future government policies.⁷

I drop time subscripts and move to a recursive formulation where x and x' respectively indicate the current and future value of variable x .

The only exogenous state variable in the model is given by the output shock y . The aggregate endogenous state variables are the stocks of government debt B and money M . A well known fact in the time consistent policy literature is that, in this class of models, the ratio of government debt to the money stock

⁷In time-consistent Markov-perfect equilibria, the government takes as given the policies of its future self.

is a sufficient statistic for the government endogenous state.

Accordingly, I normalise all *nominal* variables by the aggregate stock of money M , and denote the normalised version of nominal variable X with $\tilde{X} := X/M$.⁸ The current aggregate state is then given by the pair (\tilde{B}, y) .

In a Markov equilibrium, government policies only depend on the value of the current aggregate state variables. As households are atomistic, they take as given current and future private and government policies.

To describe the equilibrium, it is necessary to consider *current* government policy actions as well as its future policy functions.

Current government policy is the set of default, spending, money growth and future debt-to-money choices $s := (\delta, g, \mu, \tilde{B}')$. Government policy functions are given by a mapping from the aggregate state to policy choices $\mathcal{H} : (\tilde{B}, y) \rightarrow s$.

Households move after the government, and their actions depend on the aggregate state as well as on government current and future policies. Let $\mathcal{S} := (\tilde{B}, y, s)$ summarise the aggregate state and current government policy, i.e. the variables that are relevant for the current equilibrium in the private sector. Analogously, $\mathcal{S}' := (\tilde{B}', y', s' = \mathcal{H}(\tilde{B}', y'))$ will summarise the future aggregate state and future government policy.

Definition 3 (Private Sector Equilibrium). *Given aggregate state and current government policies \mathcal{S} , and future government policies \mathcal{H} , a symmetric private sector equilibrium (PSE) consists of*

- *Households' policies for consumption $c(\mathcal{S})$, money demand $\tilde{M}'^d(\mathcal{S})$ and domestic bond holdings $\tilde{B}'^d(\mathcal{S})$,*
- *The risk-free interest rate on domestic bonds $R(\mathcal{S})$ and the inverse of the price level $m(\mathcal{S})$,⁹*

such that:

1. *Households' policies are optimal, i.e. satisfy their budget constraint (3.3) and the Euler equations for money (3.4) and domestic bonds (3.5);*

⁸ It is worth noting that, under this normalisation, the gross inflation rate will now be given by $1 + \pi' = m(1 + \mu)/m'$, where μ is the net growth rate of money and $m := M/P$ is the real stock of money.

⁹Aggregate real money balances m are effectively the inverse of the price level, normalised by the aggregate stock of money. Mathematically, $m = 1/\tilde{P} = M/P$.

2. *The markets for money balances and domestic bonds clear.*

Money market clearing simply requires that $\tilde{M}'^d = 1$. Domestic bonds are in zero net supply, so market clearing requires that domestic bond holdings are zero at all times.

Combining its conditions, we can summarise the PSE with the household budget constraint

$$c(\mathcal{S}) + (1 + \mu)m(\mathcal{S}) = m(\mathcal{S}) + y(1 - \tau) \quad (3.12)$$

and the money demand equation

$$(1 + \mu)m(\mathcal{S}) = \frac{\beta_h}{U_c(\mathcal{S})} \mathbb{E}[(U'_c(\mathcal{S}') + U'_m(\mathcal{S}'))m'(\mathcal{S}')]. \quad (3.13)$$

Government Problem. I now characterise the recursive problem of the government. The government is benevolent, and chooses debt, monetary and spending policy to maximise households' utility, internalising the effect of its policies on the private sector equilibrium and on the price of debt. At this point it is worth recalling that, while the government does maximise households' static utility, it has a discount factor that is different from that of the households.

Let us first specify the bond price functions conditional on repayment and default, which are two endogenous objects that the government takes into account when formulating its debt issuance decision.

The debt price for newly issued debt must satisfy the zero-profit condition for lenders given by

$$q(\mathcal{S}) = \frac{1}{1 + r_f} \mathbb{E}_{y'|y} \left[\frac{1 - \mathcal{H}_\delta(\mathcal{S}')}{1 + \pi'_R(\mathcal{S}, \mathcal{S}')} + \frac{\mathcal{H}_\delta(\mathcal{S}')q_D(\mathcal{S}')}{1 + \pi'_D(\mathcal{S}, \mathcal{S}')} \right] \quad (3.14)$$

where \mathcal{H}_δ denotes the future government default policy, and $1 + \pi'_i(\mathcal{S}, \mathcal{S}') = m(\mathcal{S})(1 + \mu)/m'(\mathcal{S}')$ where $i = R$ in repayment and $i = D$ in default. The price of debt depends on the current state (through y , because of the persistence of output), current government policy (which determines the current price level and future default incentives), future states (which also determine future default incentives) and future policy (which affect the default decision as well as the price level and in turn future inflation).

Analogously, the price of defaulted debt is given by

$$q_D(\mathcal{S}) = \frac{1}{R^*} \mathbb{E} \left\{ (1 - \theta) \frac{q_D(\mathcal{S}'_n)}{1 + \pi'_D(\mathcal{S}, \mathcal{S}'_n)} + \theta(1 - h) \left[\frac{\mathcal{H}_\delta(\mathcal{S}'_o) q_D(\mathcal{S}'_o)}{1 + \pi'_D(\mathcal{S}, \mathcal{S}'_o)} + \frac{1 - \mathcal{H}_\delta(\mathcal{S}'_o)}{1 + \pi'_R(\mathcal{S}, \mathcal{S}'_o)} \right] \right\} \quad (3.15)$$

where the $\{o, n\}$ subscripts respectively denote the case where the government receives or not a haircut on debt together with the offer to re-enter credit markets.

Let $V^R(\tilde{B}, y), V^D(\tilde{B}, y)$ denote respectively the value of repayment and default for the government. The value of the option to default is given by

$$V(\tilde{B}, y) = \max_{\delta} \left\{ (1 - \delta) V^R(\tilde{B}, y) + \delta V^D(\tilde{B}, y) \right\}.$$

During periods of repayment, the value of the government is given by

$$V^R(\tilde{B}, y) = \max_{g, \mu, \tilde{B}'} U(c(\mathcal{S}), m(\mathcal{S}), g) + \beta \mathbb{E}_{y'|y} V(\tilde{B}', y')$$

subject to the PSE conditions with $\mathcal{S} = (\tilde{B}, y, \delta = 0, g, \mu, \tilde{B}')$ and the small open economy resource constraint¹⁰

$$y + q(\mathcal{S}) \tilde{B}' (1 + \mu) m(\mathcal{S}) = c(\mathcal{S}) + g + \tilde{B}' m(\mathcal{S}). \quad (3.16)$$

The value of default is given by

$$V^D(\tilde{B}, y) = \max_{g, \mu} U(c(\mathcal{S}), m(\mathcal{S}), g) + \beta \mathbb{E}_{y'|y} \left[\theta V \left(\frac{\tilde{B}(1 - h)}{1 + \mu}, y' \right) + (1 - \theta) V^D \left(\frac{\tilde{B}}{1 + \mu}, y' \right) \right]$$

subject to the PSE conditions with $\mathcal{S} = (\tilde{B}, y, \delta = 1, g, \mu, \tilde{B}' = \tilde{B}/(1 + \mu))$ and the autarky resource constraint upon default

$$y^d(y) = c(\mathcal{S}) + g.$$

¹⁰The non-normalised equivalent of the resource constraint is given by the (perhaps more familiar)

$$y + q \frac{B'}{P} = \frac{B}{P} + c + g.$$

I can now define the recursive equilibrium of the economy.

Definition 4 (Markov-Perfect Equilibrium). *A recursive equilibrium consists of*

- *government value functions $V(\tilde{B}, y), V^R(\tilde{B}, y), V^D(\tilde{B}, y)$,*
- *associated current government policies for default $\delta(\tilde{B}, y)$, spending $g(\tilde{B}, y)$, money growth $\mu(\tilde{B}, y)$ and borrowing $\tilde{B}'(\tilde{B}, y)$*
- *a PSE denoted by \mathcal{P}*

such that:

1. *Value and policy functions solve the government problem, given the aggregate state $\{\tilde{B}, y\}$, the debt price functions (3.14)-(3.15) and the PSE \mathcal{P} .*
2. *\mathcal{P} is the PSE associated with government value and policy functions.*
3. *Current policy and value functions are consistent with future policy and value functions.¹¹*

3.4 Model Analysis

In this section I characterise optimal policy for the government. As explained earlier, the government chooses borrowing and spending internalising the effect of these policies on household consumption and real money balances, via the price level, both in the current and in future periods.

3.4.1 Benchmark Model

Here I characterise optimality within the benchmark model where the government is assumed to be free to set the tax rate on households' endowment in every period. When evaluating the quantitative performance of this model, I will also assume that the curvature of the utility from public good consumption is equal to that of private good consumption. These two assumptions are made in order to make the model behave in a way that resembles existing papers in the literature on sovereign default and strategic inflation, such as [Aguiar et](#)

¹¹That is, $\delta = \mathcal{H}_\delta$ and likewise for g, μ, \tilde{B}' .

al. (2014) and Nuño and Thomas (2015). I thus use this framework to assess how well the existing literature performs with respect to the facts uncovered in the previous empirical section.

When the government can set the tax rate, it has lump-sum taxation available. Lump-sum taxes are a source of domestic revenues that is preferable to money issuance, as the latter creates inflation which hurts private money holdings. In this case, the only purpose of issuing money domestically then becomes that of affecting the price level and in turn the real value of the government external debt obligations. It is of course true that creating inflation through the money supply will affect transfer resources from the private to the public sector, but the government will simply use lump-sum taxes or transfers to offset such effect, which allows the domestic economy to be at its first best.

Intra-temporal optimality, repayment. The static first-order conditions of the government problem with respect to private good consumption, public good consumption and real money balances can be summarised as

$$U_c = U_g \quad (3.17)$$

$$U_m = \tilde{B}U_c. \quad (3.18)$$

The first condition shows that, with lump-sum taxes, there is never a wedge between the marginal utility of the public and private good consumption. The second condition highlights the incentives to use inflation as a way to implicitly default on government external debt. The cost of generating surprise inflation is represented by the left-hand side, and is given by the presence of money in the utility function. The benefit of surprise inflation is given by a reduction in the real value of external debt repayment, which the government values at the marginal utility of consumption.

Comparing equations (3.18) and (3.6) highlights the rationale behind the introduction of α_ν in the government objective function: without a wedge between the cost of inflation for households and the government, the risk-free interest rate would equate at all times the debt-money ratio, which would not allow to obtain a realistic value for the semi-elasticity of money demand to the interest rate.¹²

¹²See Section 3.3.2 for a discussion of this issue.

Inter-temporal optimality, repayment. The inter-temporal optimality condition for the debt-to-money ratio is given by

$$q_{\tilde{B}'} \tilde{B}' + q = \beta \mathbb{E} \frac{U'_c}{U_c} \frac{m'}{m(1+\mu)}, \quad (3.19)$$

where $q_{\tilde{B}'}$ is the partial derivative of the price of government debt with respect to \tilde{B}' , and $\frac{m'}{m(1+\mu)}$ is the inverse of the gross inflation rate (cfr. footnote 8). Equation (3.19) is a Euler equation for defaultable debt that is standard in sovereign default models.

Optimality, Default. The first-order conditions of the government problem with respect to public good consumption, private good consumption, real money balances and the growth rate of the stock of money are given by

$$U_c = U_g \quad (3.20)$$

$$-m_{(\mu)} U_m = \frac{\partial \beta \mathbb{E} \left[(1-\theta) V^D \left(y', \frac{\tilde{B}}{1+\mu} \right) + \theta V \left(y', \frac{\tilde{B}(1-h)}{1+\mu} \right) \right]}{\partial \mu}. \quad (3.21)$$

As in the case of repayment, the condition (3.20) shows that the marginal utilities of private and public good consumption are equated at all times, when lump-sum taxation is available. During default periods, the government is in autarky and the resource constraint is only a function of real variables, so there is no direct relationship between the real and the monetary sides of the economy.

Condition (3.21) highlights the effects of changes in the growth rate of the money supply. First, an increase in money growth is given by a reduction in the future debt-money ratio, which will be valued by the government upon re-entry into international debt markets. This is represented by the term on the right-hand side. Second, money supply affects the price level, hence current real money balances, through the household money demand equation. This is represented by the term on the left-hand side.

The reason why households' money demand enters in the default problem but not the repayment one, is that in repayment, the government effectively has two instruments to affect \tilde{B}' : debt issuance and money issuance. In default, the former is not available, so the money demand equation in (3.13) determines a one-to-one relationship between money supply and the value of money.

Discussion The static and dynamic optimality conditions highlight the similarities between the benchmark model and a part of the literature: first, the government is effectively facing a planner problem domestically; second, it uses external, defaultable debt to smooth household consumption over time; third, it sets inflation in order to reduce the real value of debt, at a cost which in this model is given by households money in the utility.¹³ All these are common features of a number of sovereign default models that analyse the role of inflation as a substitute of default. As I show below, this class of models has troubles in matching the empirical facts I uncover in Section 3.2.

3.4.2 Restricted Model

In the restricted model, I assume that the tax rate is exogenous. This is an extreme assumption that greatly simplifies the analysis; however, what is important is that taxation cannot respond quickly to output shocks. My results would therefore still carry through in any setting where there exists some adjustment friction that constrains the speed at which taxes can respond to shocks.

When lump-sum taxes are not available, the need to finance a desired level of public good provision introduces an additional motive for the government to use inflation: the government can recur to seignorage as a way to raise domestically an amount of funds larger or smaller than the flow it receives exogenously from taxes. In this setting inflation thus acquires a second function, on top of its role as a way to make the real value of external debt state-contingent ex-post. The main result of this chapter derives from the fact that, once this additional function of inflation is taken into account, the co-movement between default risk, inflation risk and realised inflation goes back to being positive, and consistent with my empirical findings.

In this context, the Private Sector Equilibrium becomes a constraint to the government problem. As I show in Appendix 3.B.3, the repayment problem boils down to the choice of consumption of the private good and the new debt-money ratio, while the default problem reduces to the only choice of the growth rate of money. All other government policies and equilibrium prices can be then backed out from the Private Sector Equilibrium conditions or the lenders' break-even conditions.

¹³In [Nuño and Thomas \(2015\)](#) and [Aguiar et al. \(2014\)](#), the cost of inflation is given by a quadratic utility cost for the government.

Intra-temporal optimality, repayment. Combining the first-order conditions for consumption of the private and public good, we get

$$U_c - U_g = \frac{\partial m}{\partial c}(U_g \tilde{B} - U_m).$$

The left- and right-hand side respectively represent the marginal benefit and cost of re-allocating a unit of resources from public spending to private consumption. The term $\frac{\partial m}{\partial c}$ on the right-hand side represents the effect of an increase in private consumption on money demand, which reduces the price level (and increases real money balances); that in turn has an effect which depends on the marginal utility from real money balances (i.e. the cost of surprise inflation) and the effect of inflation on the government budget constraint, evaluated at the marginal utility of spending.

Thus changes to the price level and in turn to inflation (i) allow to transfer resources between the government and the private sector, (ii) reduce the debt burden by diluting the real value of external debt, and (iii) reduce the real value of money balances, thus hurting household through the utility they derive from them.

In the reduced model, when the exogenous stream of taxes is too low,¹⁴ public good consumption is below its first best level ($U_g > U_c$) and at the same time the cost of generating further revenues through seignorage is too large ($U_m > U_g \tilde{B}$). The opposite is true when the exogenous stream of taxes is too high. In the benchmark model, lump-sum taxation does not distort any margin and there is no wedge between U_g and U_c . At the same time, the only purpose of surprise inflation is to default implicitly on debt, and the value of such action depends on the marginal utility of public and private consumption, so also the wedge between U_m and $U_g \tilde{B}$ is equal to zero at all times.

Inter-temporal optimality, repayment. The inter-temporal optimality condition for the debt-to-money ratio is given by

$$\hat{q}_{\tilde{B}'} \tilde{B}' + q + \frac{\partial \log \mathcal{M}}{\partial \tilde{B}'} \left(\frac{U_m}{U_g} - \tilde{B} \right) = \beta \mathbb{E} \frac{U'_g}{U_g} \frac{m'}{(1 + \mu)m}, \quad (3.22)$$

¹⁴Compared to the optimal tax rate implied by the planner allocation in the benchmark model.

where $\hat{q}_{\tilde{B}'}$ is the partial derivative of the expectation term of q with respect to \tilde{B}' ,¹⁵ and \mathcal{M} represents household demand for real money balances and is defined as the right-hand side of equation (3.6).

Looking at condition (3.22), the terms $\hat{q}_{\tilde{B}'}\tilde{B}' + q$ on the left-hand, as well as the whole right-hand side, are identical to the Euler equation (3.19) of the benchmark model. The last term on the right-hand side represents the impact, via the money demand equation, of the future debt-money ratio on real money balances, which in turn have a net effect which is analogous to that described in the previous paragraph. The incentives of the government to borrow will thus be intrinsically dependent on the elasticity of money demand to \tilde{B}' .

Optimality, Default. In periods of repayment, the government can work on two margins: the consumption-saving decision of the households, and the resource constraint with the rest of the world. During default periods instead, only the former margin is available, so I focus on the choice of the money growth rate. Again, Appendix 3.B.3 illustrates the simplified problem and explains how to back out the other equilibrium variables from the choice of μ .

The first-order condition for μ is given by

$$\frac{\partial \beta \mathbb{E} \left[(1 - \theta) V^D \left(y', \frac{\tilde{B}}{1 + \mu} \right) + \theta V \left(y', \frac{\tilde{B}(1 - h)}{1 + \mu} \right) \right]}{\partial \mu} - c_{(\mu)}(U_g - U_c) = -m_{(\mu)} U_m. \quad (3.23)$$

Equation (3.23) displays the effects of an increase in the growth rate of money. First, it reduces the future debt-money ratio that determines the government incentive to re-enter in credit markets once it has a chance to do so. This is represented by the first term on the left-hand side. Second, it reduces real money balances through the money demand equation, which is represented by the term at the right-hand side. Third, it reduces households' wealth and in turn their consumption, by increasing the amount of resources the government is collecting from the private sector through seignorage. This channel is represented by the second term on the left-hand side, and is only present in the full model where τ is fixed. In the model with lump-sum taxes, the marginal utilities of private and public consumption are equalised, and the resources taken away from households with seignorage are rebated to them via lump-sum taxation.

¹⁵That is, not deriving $(1 + \mu)m$ with respect to \tilde{B}' . $\hat{q}_{\tilde{B}'}$ here is thus identical to $q_{\tilde{B}'}$ in the benchmark model.

3.5 Quantitative Evaluation

Although an exact calibration of the model is currently work in progress, I here display a numerical example aimed at displaying the key properties of each of the two models. First, I describe the parametrisation. Second, I analyse the model mechanics, and in particular how well each model does in matching the empirical results of Section 3.2.

Parametrisation. A period is a quarter. Table 3.1 show the parameters that are chosen externally. Unless otherwise specified, I use data for the period 2004q1-2018q4 and average are computes over this period. Household and government preferences are as specified in Sections 3.3.1 and 3.3.2. The curvature γ of the utility from private consumption is set equal to 2, a standard value in the quantitative sovereign default literature. The curvature η of the utility from real money balances is set to 3 and is chosen to match the elasticity of money demand¹⁶ as reported in the empirical studies of [Benati et al. \(2019\)](#) and [Ball \(2001\)](#). The curvature ζ of the public good utility is an important parameter in the model, as it determines the relative volatilities of private and public consumption, and in turn the incentive for the government to use inflation to collect fiscal revenues. The value I choose for this parameter are different in the two models, so I postpone its discussion to where I discuss the quantitative performance separately.

The process for output is given by

$$\log(y_t) = \rho_y \log(y_{t-1}) + \epsilon_t, \quad \epsilon_t$$

where ϵ_t is normally distributed with mean zero and variance σ_ϵ^2 . I estimate the output process parameters on de-trended quarterly real GDP data for each country.¹⁷ I then take the median estimate for the autoregressive coefficient and the innovation standard deviation, which are 0.9293 and 0.0115 respectively. The costs of default are assumed to be non-linear and are modelled, following several works in the literature, as

$$y^d(y) = y - \max\{0, d_0 y + d_1 y^2\}.$$

¹⁶Appendix 3.B.2 explains the derivation in detail.

¹⁷GDP data for each country is seasonally adjusted and de-trended using a linear filter. Although longer time series are available for most countries, I restrict the period length to 2004q1-2018q4 in order to match the asset price data.

The international risk-free rate is set to 0.00598, which is equal to the average annualised nominal rate on 5-year US Treasuries. The probability of re-entry is taken from [Arellano \(2008\)](#) and is set to 0.282, which implies an average exclusion from credit markets of about 3.5 quarters. This is admittedly a short period of time, but is chosen among the available estimates to give the benchmark model the best possible chance to generate high inflation upon default. The default recovery rate is taken from [Cruces and Trebesch \(2013\)](#) and is set to 0.63.¹⁸

Table 3.1: Parameters selected directly.

Variable	Symbol	Value	Source
Risk-aversion coefficient	γ	2	Conventional value
International risk-free rate	r_f	0.00598	US Treasury rate
Log-output autocorrelation coeff.	ρ	0.9293	estimated
Log-output innovation st.dev.	σ_ϵ	0.0115	estimated
Re-entry probability	θ	0.282	Arellano (2008)
Debt recovery rate upon default	$1 - h$	0.63	Cruces and Trebesch (2013)
Money in utility curvature	η	3	Prior literature

Solution Method. I solve the model numerically on Julia using value function iteration. I follow [Gordon \(2019\)](#), [Dvorkin et al. \(2018\)](#) and [Arellano et al. \(2019\)](#) and use taste shocks to render the probability distribution of some of the government future policy choices non-degenerate. This substantially improves the convergence properties of the model, which otherwise struggles to converge due to the presence of money, which is effectively a very long-term asset. Appendix 3.B.4 explains how this approach is implemented in detail.

3.5.1 Benchmark Model

I now present the quantitative performance of the benchmark model. I set $\zeta = \gamma$ in order to nest the standard model of the quantitative sovereign default literature where there is no distinction between private and public consumption. The remaining parameters are chosen to match a number of targets, as illustrated by Table 3.2 in the following way. The discount factor β to match the average debt service ($\tilde{B}m$ in the model), the household discount factor β_h

¹⁸It is worth noting that this differs from the convention in the CDS industry, which is to assume lower recovery rates: 40 percent for senior unsecured credit in advanced economies, and 25 percent for emerging markets.

to match the average domestic risk-free rate ($R-1$ in the model), the money in the utility constant α_m to match the long-term average of the monetary base (m in the model), the government additional money in the utility constant to match average CPI inflation ($\tilde{P}'(1+\mu)/\tilde{P}$ in the model), the public good utility constant α_g to match the average private to public good consumption ratio (c/g in the model). Finally, the default cost parameters d_0 and d_1 are chosen to match the mean and standard deviation of 5 year CDS-implied annual default probabilities. These risk-neutral probabilities are backed out from CDS par spreads assuming a constant hazard rate of default. The detailed derivation can be found in Appendix 3.B.1.¹⁹

Variable		Value	Target	Data	Model
Govt discount factor	β	0.83	Debt service/GDP	0.058	0.088
Household discount factor	β_h	0.99	Risk-free rate	0.073	0.064
MIU constant	α_m	2.7e-5	Monetary base/GDP	0.098	0.112
MIU constant (govt)	α_ν	1.5e-3	CPI Inflation	0.049	0.038
Public good utility constant	α_g	0.07	c/g ratio	3.67	3.66
Default cost parameter	d_0	-0.3	Default prob. (mean)	0.045	0.029
Default cost parameter	d_1	0.325	Default prob. (st. dev.)	0.020	0.052

Table 3.2: Parameters selected to match targets.

Non-Targeted Moments. Table 3.3 shows the performance of the model with respect to a number of non-targeted moments of interest. The first line displays the correlation between CDS-implied default probabilities, DP_t , and expected inflation implied in the price of government debt, XCS_t , which is the model equivalent of the cross-currency swap rates analysed in the empirical section of the chapter.²⁰ Clearly, the benchmark model delivers a correlation between these two asset prices of opposite sign with respect to what we observe

¹⁹Real default models typically target risk-neutral default spreads rather than probabilities. Using this model's notation, the price of a hypothetical foreign-currency (i.e. real) bond would be

$$q(y, b') = \frac{1}{1+r_f} \mathbb{E}[1 - \delta' + \delta'(1-h)].$$

Defining the default spread as $s := \frac{1}{q} - (1+r_f)$, the one-to-one relationship between default probabilities and spreads is given by

$$\mathbb{E}(\delta) = \frac{1}{(1+r_f)} \frac{s}{h}.$$

²⁰ DP_t and XCS_t are explicitly defined in equations (3.10) and (3.11) respectively.

in the data. The reason for this is that, in this model, inflation expectations are pro-cyclical (as highlighted in the second row of the table), while default spreads are counter-cyclical (as highlighted in the third row). Finally, there is essentially no relationship between realised inflation and default spreads, which is also at odds with the empirical evidence. The next paragraph provides an intuitive explanation of these moments.

Moment	Model	Data
$\rho(DP_t, XCS_t)$	-0.25	0.46
$\rho(y_t, XCS_t)$	0.43	0.02
$\rho(y_t, DP_t)$	-0.55	-0.2
$\rho(DP_t, \pi_t)$	0.02	0.31

Table 3.3: Non-targeted moments, benchmark model.

Equilibrium Policy and Asset Prices Figure 3.5 illustrates the behaviour of three important equilibrium variables. The left panel plots the policy function for new real debt issuance, as a function of output (on the horizontal axis) and of three levels of initial real debt (I pick the average level of debt and two other values that are one standard above/below the mean). The picture clearly shows that the model displays a common feature of sovereign default models: debt is strongly procyclical, which means that the government on average experiences capital inflows in good times (when output is high), and outflows in bad times (when output is low). This is consistent with empirical findings on the cyclicity of the trade balance in emerging market economies.

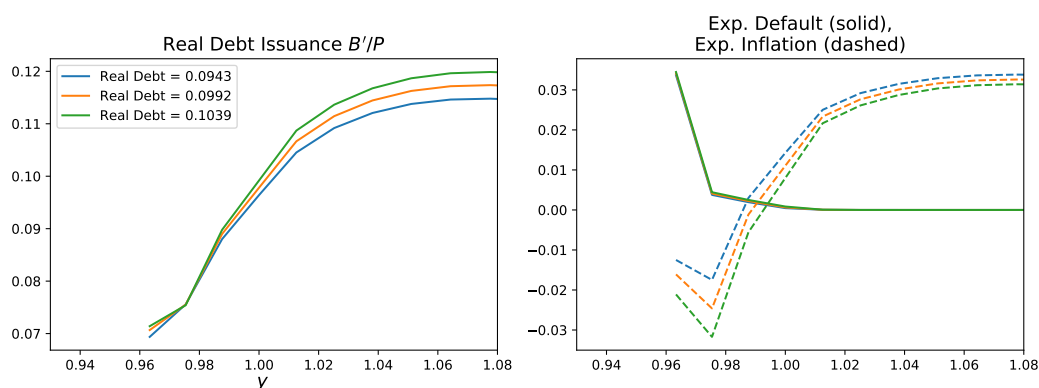


Figure 3.5: Equilibrium Debt Policy and Expected Default/Inflation.

A direct implication of this is that inflation incentives are also pro-cyclical.

The reason for this is that, in this model, inflation only serves the purpose of manipulating the real value of debt. Clearly then the incentive to do so will be stronger, the larger is the stock of debt to be repaid. As explained previously, larger debt stocks are more likely during periods of high output. There is however a possible counteracting force: the incentive to inflate will also be higher in periods of low output, because that is when a lower debt burden is most valued by the government.

This is a force that is quantitatively weaker than that derived from the size of the debt stock. The right panel of Figure 3.5 plots the expected default (solid lines) and expected inflation (dashed lines) associated with equilibrium debt policy. The picture shows that, as is common in default models, default spreads are counter-cyclical. This is driven by the strong incentive of the government to borrow in bad times, and by the fact that output persistence makes the debt price schedule for debt less favourable as a future default is more likely. Inflation expectations are instead pro-cyclical, since the behaviour of debt is the prevalent force driving inflation incentives.

In sum, the quantitative performance of the benchmark model allows us to conclude that, when the only purpose of inflation is to serve as an implicit default instrument, the very features at the core of sovereign default models are those that imply the model is at odds with the data along a number of important real and financial dimensions. The following section highlights how a small modification to the model allows to reconcile the model with the empirical evidence.

3.5.2 Reduced Model

I now consider the quantitative implication of the reduced model, where I assume that the tax rate at which the government collects taxes from the private sector is exogenous and constant.

The parametrization of this model is as follows. First, I set the curvature of public good utility $\zeta = 5$, to strengthen incentive of the government to use inflation as a source of revenues to finance spending. It is important to note that this parametric assumption alone would not change the qualitative properties of the benchmark model analysed in the previous subsection. As in the benchmark model, the remaining parameters are chosen to match a number of targets, as illustrated by Table 3.4. It is worth discussing the role of the tax

rate τ : the difference between tax revenues τy and the desired level of public good consumption g determines the desired amount of deficit, which must be financed with either new debt or inflation. It can of course happen that the government aims to run a surplus, in which case debt policy and seignorage will be used to transfer resources to households. I thus aim to discipline the model by calibrating τ to the coefficient of variation of seignorage (i.e. the ratio between the standard deviation and the mean).

Variable		Value	Target	Data	Model
Govt discount factor	β	0.65	Debt service/GDP	0.058	0.041
Household discount factor	β_h	0.997	Risk-free rate	0.073	0.067
MIU constant	α_m	2e-5	Monetary base/GDP	0.098	0.103
MIU constant (govt)	α_ν	8e-4	CPI Inflation	0.049	0.057
Public good utility constant	α_g	8e-4	c/g ratio	3.67	3.64
Default cost parameter	d_0	-0.07	Default prob. (mean)	0.045	0.033
Default cost parameter	d_1	0.0975	Default prob. (st. dev.)	0.020	0.027
Tax rate	τ	0.215	CV(Seignorage)		10

Table 3.4: Parameters selected to match targets.

Non-Targeted Moments. Table 3.5 displays the model performance with respect to the same non-targeted moments against which we evaluated the benchmark model in the previous section. The table clearly shows that the model succeeds in matching a number of important features of the data: default and inflation risks co-move (first line), default spreads remain counter-cyclical (third line), and default risk is positively correlated with realised CPI inflation (fourth line). The main driver of this substantial change in the model performance is highlighted in the second line: realised and expected inflation have now become strongly counter-cyclical. This is consistent with the empirical evidence of realised inflation cyclicity in emerging market economies.

Moment	Model	Data
$\rho(DP_t, XCS_t)$	0.43	0.46
$\rho(y_t, XCS_t)$	-0.73	0.02
$\rho(y_t, DP_t)$	-0.53	-0.2
$\rho(DP_t, \pi_t)$	0.34	0.31

Table 3.5: Non-targeted moments, reduced model.

Equilibrium Policy and Asset Prices Figure 3.6 plots equilibrium debt policy in the left panel, money supply policy in the middle panel, and equilibrium expected default (solid lines) and inflation (dashed lines) in the right panel. The three coloured lines indicate three different initial levels of real debt (equal to, above and below the simulated mean by one standard deviation). As the graph shows, debt policy is moderately pro-cyclical, especially for low values of output. As in the benchmark model, the reason for this is that the government would like to borrow more in bad times, but it does not because it is costlier to do: output is persistent, a future default is more likely, and therefore lenders charge higher interest rates on government debt. This implies that, when output is low, the government needs to use seignorage as an alternative source of revenues to fund levels of public spending above its exogenous tax revenues. The strength of this motive is stronger, the higher the curvature of the utility from public good consumption, and the higher the deficit the government would like to run. In the current calibration, this “tax” motive behind money supply, seignorage and inflation becomes stronger than the “default” motive of inflation which was the only force present in the benchmark model. The relationship between inflation and the cycle thus dominates that between inflation and debt, making realised and expected inflation rise in bad times (as highlighted by the right panel), as default spreads do.

Another aspect worth noting is that money growth, and in turn inflation, is significantly higher of repayment than in times of default, which suggests that the debt dilution motive is still the dominant force in determining contrasts between default and repayment periods.

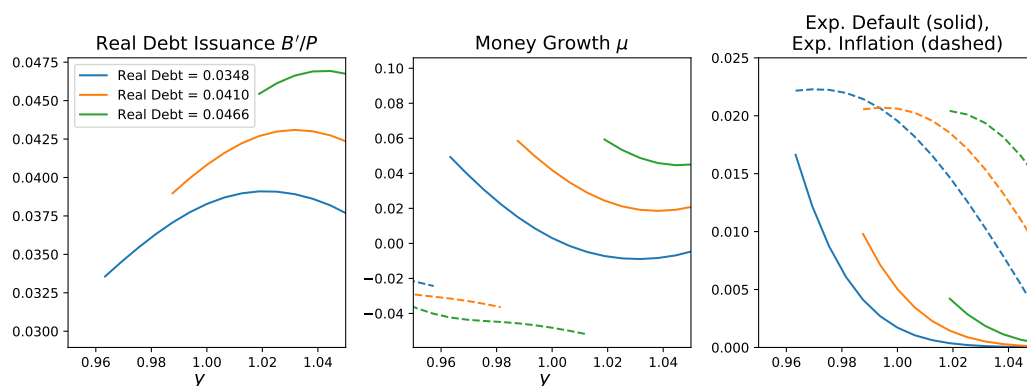


Figure 3.6: Equilibrium Debt Policies and Asset Prices.

Analytical Decomposition of Asset Prices. I now analyse the behaviour of asset prices more in depth, proposing an analytical framework to assess the relative importance of the forces highlighted in the previous paragraph. Let default risk DP_t and inflation risk XCS_t be given by (3.10) and (3.11) respectively.

The key factor in determining the co-movement of these risks is given by the relationship between inflation expectations XCS and the cycle. The reason is that a key feature of the model is given by the fact that default spreads are counter-cyclical, as can be seen in the figure.²¹ If inflation spreads are also, at least moderately, counter-cyclical, then the model has a chance of matching the data. It is therefore instructive to explore what are the drivers behind the cyclicity of inflation spreads, looking at how they change with output shocks.

We can decompose the derivative of inflation spreads with respect to output (assuming a continuous output distribution as well as differentiability in the debt and inflation policy functions)

$$\frac{\partial XCS(y, \tilde{B}')}{\partial y} = \frac{\partial}{\partial y} \int [\delta(\tilde{B}', y')\pi_D(\tilde{B}', y') + (1 - \delta(\tilde{B}', y'))\pi_R(\tilde{B}', y')]f(y', y)dy'$$

in the following components

$$\begin{aligned} &= \frac{\partial \tilde{B}'}{\partial y} \int \frac{\delta' \partial \pi'_D + (1 - \delta') \partial \pi'_R}{\partial \tilde{B}'} dF(y'|y) \\ &+ \int^{\hat{y}} \pi'_D \frac{\partial f(y'|y)}{\partial y} dy' + \int_{\hat{y}}^y \pi'_R \frac{\partial f(y'|y)}{\partial y} dy' + \int_y \pi'_R \frac{\partial f(y'|y)}{\partial y} dy' \\ &- \frac{\partial \tilde{B}'}{\partial y} \frac{\partial \hat{y}}{\partial \tilde{B}'} [\pi'_R(\tilde{B}', \hat{y}) - \pi'_D(\tilde{B}', \hat{y})]f(\hat{y}|y). \end{aligned}$$

Let us consider this decomposition in light of a *drop* in output, which as said previously tends to correspond to a rise in default spreads.

- The first component, represented in the first row, shows the effect on expected inflation through debt: since debt is pro-cyclical in the model, a drop in output corresponds to a lower future debt-to-money ratio, which brings about less expected inflation, since inflation is increasing in \tilde{B} . This effect make XCS pro-cyclical.

²¹This is consistent with the data, and a fundamental feature of quantitative sovereign default models.

- The second component, represented in the second row, shows the effect on expected inflation through a shift in the distribution of y' due to the persistence of the output process: a drop in output implies lower expected output. This has an ambiguous effect: in the repayment region, this shifts probability mass to states where inflation is higher, since realised inflation is counter-cyclical; on the other hand, this channel also shifts mass to the default region, where inflation will be lower. The net effect depends on the slope of π_R as a function of output, and on the size of the $\pi_R - \pi_D$ differential.
- The third component, represented in the third row, isolates the effect on expected inflation through a change in the default cutoff \hat{y} : a drop in output implies a drop in debt issuance, which means the cutoff decreases, i.e. the default region is smaller. This increases expected inflation, because of the sign of the $\pi_R - \pi_D$ differential. This effect makes XCS counter-cyclical, but is likely to be small as it depends on the output distribution density at \hat{y} .

As explained previously, the calibrated version of the model shows that the second component is the key driver of the counter-cyclicity of expected inflation.

3.6 Conclusion

In this chapter, I have studied in detail the relationship between strategic inflation, default and inflation risk. In the data, default risk for a set of EM sovereigns is sizeable and positively related to realised and expected inflation. A simple model of default and debt dilution via inflation has a hard time in matching these facts, because inflation and default are essentially substitutes. To reconcile the model with the data, it is important that inflation also serves a second purpose: that of generating fiscal revenues, which is especially useful in bad times and during periods of autarky.

The model I develop allows to quantitatively evaluate the trade-off between the insurance benefits and the time-inconsistency costs of issuing debt in domestic currency, showing that the way in which default and inflation risks move is crucial in this regard. In light of this, the chapter offers a natural

starting point to study the interplay between fiscal-monetary interactions and the welfare benefits of local-currency debt.

Appendix 3.A Empirical Appendix

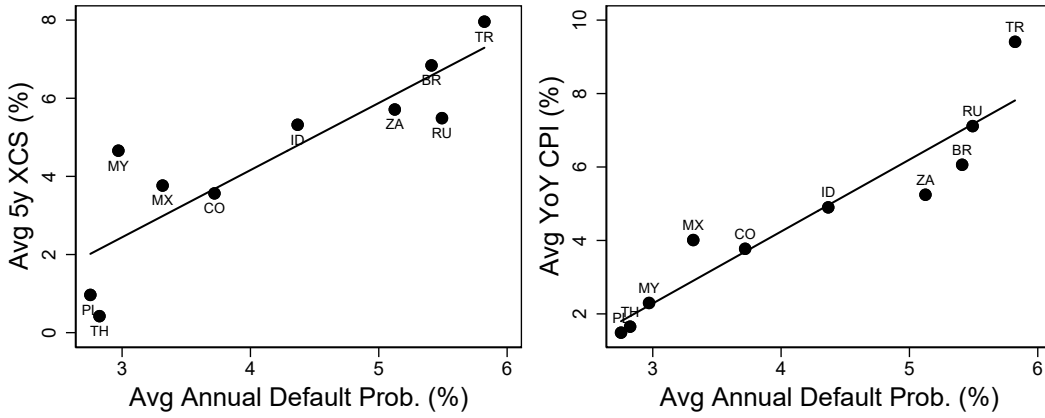


Figure 3.7: Long-term averages for the period 2010q1-2018q4. The left panel plots average default probabilities against average XCS rates. The right panel plots average default probabilities against realised CPI inflation.

Appendix 3.B Theory Appendix

3.B.1 CDS-Implied Default Probabilities

To extract default probabilities from CDS spreads, I follow the finance and asset pricing literature and model default as the first jump of a (potentially inhomogeneous) Poisson process, with $\lambda(t)$ denoting the default intensity, or hazard rate function. $\lambda(t)$ thus represents the probability that default happens at time t , conditional on not having happened before. In turn, the survival probability is given by

$$S(t) = P e^{-\int_0^t \lambda(u) du} \quad (3.24)$$

which becomes $S(t) = e^{-\lambda t}$ if the hazard rate is assumed constant.

A CDS contract is composed of two legs, the premium leg and the protection leg. The premium leg consists of periodic payments of a premium expressed in percentage terms of the notional, also called par spread, until maturity or the default event, whichever comes first. The protection leg consists of a one-off repayment of the notional, if default occurs before maturity, or nothing otherwise.

I now write down the pricing formulas for both legs. In doing so, I adopt the following simplifying assumptions: interest rates, default intensity and recov-

ery rate are independent, and the premium leg pays the spread continuously until default (otherwise we would need to consider premium arrears to be paid upon default). Let U_{par} represent the par spread, $DF(t)$ the risk-free discount factor used to discount a period- t cash-flow back to time 0, T_1 the time of default (i.e. the first jump of the Poisson process), and $S(t)$ the survival probability up to t .

The PV of the premium leg is given by the present value of all premium payments, discounted by the risk-free rate and the survival probability:

$$PV_{prem} = \mathbb{E} \left\{ \int_0^T DF(t) U_{par} \mathbb{1}[T_1 > t] \right\} = U_{par} \int_0^T DF(t) S(t) dt. \quad (3.25)$$

The PV of the protection leg is given by the present value of the random payment of the notional loss given default, denoted LGD , at default time T_1 , if such time is before expiry T , and zero otherwise:

$$PV_{prot} = \mathbb{E} \{ DF(T_1) \times LGD \times \mathbb{1}[T_1 \leq T] \} = LGD \int_0^T DF(t) S(t) \lambda(t) dt. \quad (3.26)$$

It follows that the par spread is given by

$$U_{par} = \frac{LGD \int_0^T DF(t) S(t) \lambda(t) dt}{\int_0^T DF(t) S(t) dt}. \quad (3.27)$$

Assuming that the hazard rate is constant ($\lambda(t) = \lambda$) simplifies the expression to

$$\lambda = \frac{U_{par}}{LGD}. \quad (3.28)$$

The probability of default in $(0, t)$ is thus given by

$$\text{DefProb}_t = 1 - S(t) = 1 - e^{-\lambda t} = 1 - e^{-\frac{U_{par}}{LGD} t}. \quad (3.29)$$

3.B.2 Money Demand Elasticities

Under the parametric assumptions of the model, the money demand equation (3.4) is given by

$$R_t - 1 = \mathbb{E} \frac{\alpha_m (M_{t+1}/P_{t+1})^{-\eta}}{C_{t+1}^{-\sigma}}.$$

Linearising this equation around the stochastic steady state we get

$$\mathbb{E} \log(M_{t+1}/P_{t+1}) = \frac{const}{\eta} + \frac{\gamma}{\eta} \mathbb{E} \log c_{t+1} - \frac{1}{i\eta} i_t \quad (3.30)$$

where i is the steady state interest rate and $const$ is a constant. It follows that the semi-elasticity of future real money balances to the interest rate is given by $(i\eta)^{-1}$, which under my calibration targets is equal to a value of -5.21 : for a 100 basis points increase in i_t , future real money balances are on average 5.21% lower. The elasticity of future real money balances to the interest rate is instead given simply by $1/\eta$, which is equal to $1/3$ at the chosen level of the curvature of money in the utility.

3.B.3 Policy Implementation

For a given aggregate state (\tilde{B}, y) , consider an arbitrary choice of private consumption c and future debt-money ratio \tilde{B}' . The right-hand side of the money demand equation (3.13) is thus pinned down, as \mathcal{S}' is given by the choice of \tilde{B}' and future equilibrium policies. This in turn pins down the left-hand side of the household budget constraint (3.12), determining real money balances m . The value of μ can then be backed out from (3.13), while the value of g can be obtained through the resource constraint (3.16).

3.B.4 Numerical Solution Method

The government recursive problem after the addition of taste shocks is as follows. All of the shocks introduced below $(\epsilon_R, \epsilon_D, \epsilon_{\tilde{B}'}, \epsilon_\mu)$ are assumed to be identically and independently distributed according to a Gumbel distribution with a mean of $-\bar{\mu}$, where $\bar{\mu}$ is the Euler-Mascheroni constant, and a standard deviation of one.

The value of the option to default is

$$V(\tilde{B}, y) = \max_{\delta \in \{0,1\}} \left\{ (1 - \delta)[V^R(\tilde{B}, y) + \rho_\delta \epsilon_R] + \delta[V^D(\tilde{B}, y) + \rho_\delta \epsilon_D] \right\}.$$

The value function of the government upon repayment is

$$V^R(\tilde{B}, y, \{\epsilon_{\tilde{B}'}\}) = \max_{\tilde{B}'} \left\{ W^R(\tilde{B}, y; \tilde{B}') + \rho_{\tilde{B}'} \epsilon_{\tilde{B}'} \right\}$$

where

$$W^R(\tilde{B}, y; \tilde{B}') = U(c(\tilde{B}'), m(\tilde{B}'), g(\tilde{B}')) + \beta \mathbb{E}_{y'|y} V(\tilde{B}', y').$$

Each \tilde{B}' choice is thus associated with an element of the taste shock vector $\{\epsilon_{\tilde{B}'}\}$. The value function of the government upon default is

$$V^D(\tilde{B}, y, \{\epsilon_\mu\}) = \max_\mu \left\{ W^D(\tilde{B}, y; \mu) + \rho_\mu \epsilon_\mu \right\}$$

where

$$\begin{aligned} W^D(\tilde{B}, y; \mu) &= U(c(\mu), m(\mu), g(\mu)) \\ &+ \beta \mathbb{E} \left[\theta V \left(\frac{\tilde{B}(1-h)}{1+\mu}, y' \right) + (1-\theta) V^D \left(\frac{\tilde{B}}{1+\mu}, y' \right) \right]. \end{aligned}$$

Each μ choice is thus associated with an element of the taste shock vector $\{\epsilon_\mu\}$.

The above assumptions imply that for each choice $x = \tilde{B}', \mu, \delta = 1, \delta = 0$, the probability of observing such choice is given by

$$\mathbb{P}(x|\tilde{B}, y) = \frac{\exp [W^i(\tilde{B}, y, x)/\rho_x]}{\sum_x \exp [W^i(\tilde{B}, y, x)/\rho_x]}.$$

Furthermore, the expected value of each of the three value functions described above can be written as

$$V^i(\tilde{B}, y) = \rho_x \log \left\{ \sum_x \exp [W^i(\tilde{B}, y, x)/\rho_x] \right\}.$$

In the calibration of the model, I choose the smallest values of $\rho_{\tilde{B}'}, \rho_\mu, \rho_R, \rho_D$ such that the model converges. The magnitude of each of these parameters can be illustrated as follows. Consider some choice x'' that yields a 0.05% drop in utility when compared to the optimal choice (in the absence of taste shocks), that is $\log \frac{W^i(\tilde{B}, y; x'')}{\max_x W^i(\tilde{B}, y; x)} = -0.05\%$. I now compute the probability of making choice x'' , i.e. to make a “suboptimal” choice that delivers a lower utility than what would be the optimal choice in the absence of taste shocks.

- I set $\rho_{\tilde{B}'} = 1e - 3$. The probability of a suboptimal (as defined above) choice is

$$\mathbb{P}[\tilde{B}''_{(-.05\%V^R)}|\tilde{B}, y] = 1e - 12.$$

- I set $\rho_\mu = 5e - 3$. The probability of a suboptimal (as defined above) choice is

$$\mathbb{P}[\mu_{(-.05\%V^D)}|\tilde{B}, y] = .001.$$

- I set $\rho_{R,D} = 5e - 3$. The probability of a suboptimal (as defined above) choice is

$$\mathbb{P}[\delta_{(-.05\%V^R)}|\tilde{B}, y] = .057.$$

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Statement of Conjoint Work

Note on the joint work in Carlo Galli's thesis "Essays in Macroeconomics and Sovereign Default".

Chapter 1, "Self-Fulfilling Debt Crises, Fiscal Policy and Investment", is single-authored by Carlo Galli.

Chapter 2, "Is Inflation Default? The Role of Information in Debt Crises", is co-authored work between Carlo Galli and Marco Bassetto and each author contributed equally.

Chapter 3, "Default Risk, Inflation and Nominal Debt", is single-authored by Carlo Galli.