Financial Dollarization and Central Bank Crediblity.*

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Abstract

Why do firms and banks hold foreign currency denominated liabilities? In this paper, we argue that foreign currency debt, by altering the effect of a devaluation on output, has a disciplining effect when the Central Bank's objectives differ from the social optimum. However, under imperfect information, bad priors about the Central Bank induce excess dollarization of liabilities, which in turn limits the ability of the Central Bank to conduct an optimal monetary policy. In addition the economy may become stuck in a "dollarization trap" in which dollarized liabilities limit the ability of agents to learn the true type of the monetary authority. The model has clear-cut policy implications regarding the taxation of foreign currency liabilities as a way to encourage perfect information and avoid dollarization traps. Moreover, it reinforces the existing argument for Central Bank independence. Finally, we believe this model to be consistent with a growing empirical literature on the determinants of foreign currency liabilities and their relationships to Central Bank credibility.

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1 Introduction

Much has been written recently on the impact of foreign currency denominated debt in emerging market economies. A series of papers have argued that liability dollarization played an important role in recent "crisis" episodes in East Asia (and more recently in Argentina) and as such is an important source of financial fragility. Another line of research has discussed how governments should respond to dollar-debt, in particular how dollar-debt alters the trade-offs between fixed and flexible exchange rates. The debate on dollar-debt has been particularly vigorous in Latin America, where a substantial fraction of total debt is denominated in dollars in many countries as described in figure (1).

In this paper we argue that, by altering the effect of a devaluation on output, dollar-debt can play a role in disciplining an overly expansive monetary authority. This restraint does not come for free. In the short run dollar debt increases the likelihood of financial distress and limits the capacity of the Central Bank to conduct stabilizing monetary policy. In the long run, the presence of dollar-debt may limit the ability of the monetary authority to gain credibility, as it is difficult for agents to determine how the Central Bank would behave in the absence of dollarized liabilities.

In our model, when information is complete, interest rates adjust to incorporate the disciplining effects of dollar-debt, leading to an optimal currency composition choice by firms. When the Central Bank exhibits a devaluation bias, lenders are willing to make dollar loans cheaper. Agents then take on larger amounts of dollar-debt making a devaluation more costly, thus mitigating such a bias. In this framework, portfolio compositions optimally trade-off the cost of an excessive devaluation with the likelihood of such an event.

The level of dollar-debt may no longer be optimal when agents are uncertain about the true parameters of the economy. If the Central Bank lacks credibility, then dollarization may exceed its full-information level. The immediate effect of this lack of credibility is that agents tie the hands of the Central Bank excessively, restricting its ability to conduct monetary policy. In the long-run, the effects of imperfect information can be exacerbated, as excess dollarization has additional dynamic effects. By taking on dollar-debt, agents also limit the Bank's capacity to reveal its type. By doing so, the economy can be stuck in an a long run equilibrium with suboptimal (too high) levels of dollar-debt and imperfect learning. A useful analogy to the dynamic problem is that of a parole board deciding whether to release a convict. Leaving the convict in prison will make it extremely costly for the good prisoner to differentiate himself from the evil bastard. Priors about the convict will remain unchanged, as any good behavior in prison is attributed to the restrictions placed on the convict's freedom. Similarly, a seemingly responsible monetary policy can be interpreted as the outcome of large amounts of dollar-debt rather than an absence of a devaluation bias, making dollarization a persistent phenomenon.

The key result of this paper is that giving agents the option to mute the Central Bank has perverse effects when the latter lacks credibility. We then raise the question of dollar-debt taxation and capital account liberalization. In particular, we argue that, by temporarily restricting agents' ability to take on dollar-debt, governments can give the opportunity to the Central Bank to gain credibility at a lower cost.

We believe this model to be consistent with stylized facts surrounding dollarization of liabilities in emerging economies. The first of these is the overall lack of success of empirical papers in determining causes of dollarization, or the "mystery of original sin" as it is referred to by Hausmann

and Panizza (2002). If the optimal currency composition of debt is (at least in part) determined by agents priors regarding the monetary authority, it is not surprising that current macroeconomic variables fail to capture much of the cross-country variation in liability dollarization. The second fact is the positive and significant correlation between inflationary history, financial development and dollarization: dollarization seems to be high in economies in which monetary authorities lack credibility. To illustrate this correlation, Figure (2) plots the measure of "original sin" of Hausmann and Panizza against average inflation in the previous two decades.

Our model combines two strands of the dollar-liability literature: (i) that which explores the effects of exchange rate policy on the optimal choice of debt composition by private agents and (ii) that which explores the effects of dollarized debt on the response of an economy to aggregate shocks and therefore on exchange rate policy. In particular we assume that debt composition affects the optimal exchange rate policy and that simultaneously expectations about exchange rate policy have a bearing on the optimal currency composition of debt by agents. This paper is also related to the literature on optimal monetary policy and the debate on fixed versus floating exchange rates[1]. The contribution of this paper to the dollar-debt literature is two-fold. On the one hand we discuss the role of dollar-debt issued by private agents as a disciplining device for the monetary authority. On the other hand, we discuss the implications of dollar-debt on Central Bank credibility in an imperfect information setting.

The paper proceeds as follows. In section 2 we provide a brief overview of existing empirical and theoretical literature on liability dollarization and by doing so, motivate some of the assumptions made elsewhere in the paper. Section 3 sets up our basic model and solves it under full information. The following section, section 4, introduces signalling issues and makes the main point of the paper: agents can be stuck in persistent states where they have imperfect knowledge about the parameters of the economy. Section 5 discusses possible policy implications, while section 6 concludes.

2 Causes and Effects of Dollar-Debt... What Do We Know?

At center stage in the discussion of dollar-debt is the mismatch that foreign currency debt generates between the currency denomination of assets and liabilities. Following a devaluation, an agent with a currency mismatch will see the "peso" value of his debt expand by more than that of his assets or income. The key assumption in this literature, is that the resulting drop in the net worth has real costs: a balance-sheet effect. Consequently, the expansionary effect which a depreciation is typically assumed to have, may be attenuated or even reversed by the effects of a devaluation on firms that are highly leveraged in dollar-debt.

A first strand of the literature has developed models to explore the macroeconomic implications of currency mismatches. In the work of both Krugman (1999a, 1999b) and Aghion, Bachetta, and Banerjee (2001), the balance-sheet effect is assumed to be large enough to dominate the expansionary Mundell-Fleming effects. This strongly *negative* relationship between investment and depreciation can give rise to multiple equilibria, and hence the potential for an expectation-driven exchange rate crisis. The potentially destabilizing effects of a devaluation in the presence of dollar-debt are also discussed in Céspedes, Chang and Velasco (2001) - although the authors emphasize that dollar-debt does not necessarily lead to "macroeconomic damnation".

[1] See Rogoff (1995) for an overview of the literature.

Although it is clear that many economies in East Asia had substantial levels of dollar-debt both in the banking sector and on firms' balance sheets, empirical evidence on how large the resulting balance-sheet effects may have been is far from conclusive[2]. On the one hand, Claessens and Djankov (2000) argue that inflated domestic debt and interest payments may have led to wide scale insolvency and liquidity problems in East Asian firms. On the other hand, Bleakley and Cowan (2002) provide evidence that the balance-sheet effect, although present in firms in Latin America, is dominated by the competitiveness gains from a devaluation.

Independently from where the empirical and theoretical debate on the effects of dollar-debt may stand, there is evidence that monetary authorities do factor debt composition variables into their exchange rate policies. Although they do not test it empirically, Calvo and Reinhart (2002) argue that pervasive liability dollarization may be one cause of the "fear of floating". Panizza, Hausmann and Stein (2001) investigate this proposition, and find a relationship between a country's exchange rate policy and its ability to borrow internationally in its own currency – which they argue is an indicator of a country's ability to avoid currency mismatches. More specifically, they find that countries that can borrow abroad in their own currencies hold lower levels of reserves and allow larger fluctuations in the exchange rate relative to reserves and interest rates. Along these same lines, Levy-Yeyati, Sturzenegger and Reggio (2003), using a *de facto* and *de jure* exchange regime classification, find that foreign currency-denominated liabilities (measured relative to money stocks) are positively correlated with the probability of pegging the exchange rate against a major currency.

A second strand of the literature on dollar-debt looks at firm and country level determinants of dollar liabilities. The key question here being, if dollar-debt exposes firms to substantial exchange rate risk, why do they take it on in the first place? Most of the explanations that have been put forward in the literature rely a failure in uncovered interest rate parity, which leads to a lower *ex ante* dollar rate. One set of models argues that dollarized debt entitles the creditor to larger payments in those states of the world in which default is likely, lowering the required interest payments on dollar-debt[3]. Another set of models emphasizes how interest rates adjust to incorporate disciplining effects of dollar-debt on firm behavior. In Jeanne (2000a and 2000b), for example, dollar-debt reduces information asymmetry and moral hazard. Lenders then incorporate these effects into the rates they charge on peso and dollar debt loans. Finally, in Calvo (1999) and (2001) the failure of uncovered interest parity can be attributed to the interaction of information asymmetries, regulatory restrictions in the banking sector and to the costs of forming devaluation expectations[4].

The extent to which agents take advantage of the cheaper foreign–currency credit is then determined by impact of a currency mismatch on the volatility of their net-worth and the costs of this increased volatility[5]. In this context a pegged exchange rate regime is a form of insurance against exchange rate fluctuations. In the words of Mishkin (1996): "*daily fluctuations in the exchange rate in the flexible regime have the advantage of making clear...that there is a substantial risk involved in*

[2] See Eichengreen and Hausmann (1999), World Bank (2001) for data on dollarization in East Asia

[3] For Schneider and Tornell (2001) these transfers takes place within the banking sector, where bailouts to dollar indebted banks acompany devaluations. Chamon (2001), on the other hand, argues that defaults are often correlated with depreciations, so that holders of dollar debt recieve a larger share of the liquidated assets.

[4] Regulatory constraints on currency mismatch encourage foreign banks to lend in the their own currency so that they charge a premium on peso rates. Similar regulatory constraints force domestic banks to match dollar deposits with dollar loans. Because of information advantages, these banks have incentives to place this debt domestically leading to a lower equilibrium rate on dollar loans.

[5] That risk averse firms choose debt composition to hedge exchange rate shocks (i.e. to "match") is discussed for the banking sector by Ize and Levy-Yeyati (1998) and Arteta (2002), and for firms by Conesa-Labastida (1997), Calvo (2001), Martinez and Werner (2001) and Cowan (2002).

issuing liabilities denominated in foreign currencies". Along these lines, an additional reason, often cited for dollarized debt, is the lack of an adequate long-term domestic currency debt market - the original sin view of Eichengreen and Hausmann (1999). According to this view, firms are willing to take on exchange rate risk to avoid the interest rate risk inherent in short-term peso liabilities.

Empirically there is no evidence on the alleged failures of uncovered interest rate parity and some evidence that higher exchange rate volatility reduces currency mismatch. Using cross-country data for the banking sector, Arteta (2002) finds evidence that more volatile exchange rate regimes reduce the share of foreign currency denominated loans and deposits. Additional evidence is provided by Martinez and Werner (2001) using a sample of Mexican firms. They find that matching is higher and average dollarization lower after the "tequila" crisis, a period of flexible exchange rates[6]. Probably because of lack of data, there is scarce empirical work on other possible cross-country determinants of dollar-debt. One exception to this is the recent work by Eichengreen, Hausmann and Panizza (2002). The title of their paper ("The Mystery of Original Sin: The Case of the Missing Apple") sums up their main conclusion, namely countries with very similar macroeconomic situations have vastly different levels of dollarization. Amongst the few variables that are positively correlated with "domestic original sin" (foreign currency debt in total domestic borrowing) are the level, variance and maximum past value of inflation, and financial development - all proxies for monetary policy credibility.

3 A Static Complete Information Framework

Consider an economy with a continuum of identical agents and one good used for both production and consumption. Agents invest one unit in a project with stochastic returns. As entrepreneurs have no resources, they borrow from lenders. We assume that supply of such goods is infinite. The country is endowed with a Central Bank, which controls exchange rates. We denote by s the change in the exchange rate e (the price of dollars in terms of pesos) between $T = 0$ and $T = 1$. The timing of the economy is as follows:

- at time $T = 0$, contracts are signed between lenders and entrepreneurs. The space of contracts is restricted to the set of debt contracts linear in s. Such financial contract can thus be considered as linear combinations of peso-debt contracts and dollar-debt contracts. We normalize the exchange rate so that $e = 1$ at $T = 0$.
- at time $T = 1$, a demand shock $\tilde{x}$ is realized, the Central Bank observes the contracts signed at time $T = 0$ and sets its exchange rate policy s. $\tilde{x}$ is assumed to be distributed over R^+ with distribution function $F(.)$ with mean m. For technical reasons, we assume that $F(.)$ is integrable.
- at time $T = 2$, output Y is realized. Payments are made to lenders, consumption takes place and agents die.

[6] Cowan (2002) obtains similar results in a sample of five countries from Latin America and the Carribean. In addition, the correlations obtained by Hausmann, Panizza and Stein (2001) and Levy-Yeyati, Sturzenegger and Reggio (2003) also suggest that dollarization is higher in pegged exchange regimes.

3.1 Technology and Preferences

Characterizing the output function Y is crucial to our paper. We take the view that exchange rates have real effects on output. On the one hand, by raising the exchange rate, the Central Bank is able to have a positive effect on aggregate demand - a Mundell-Fleming effect. On the other hand, following Lahiri and Végh (2001) and Jeanne (2002), we assume that changes in the exchange rate also have adverse effects on output - a distortionary effect. Thus, the exchange rate has a non-monotonic impact on output, depending on which of the Mundell-Fleming or distortionary effects dominates.

An additional feature of Y is specific to our model. Following Jeanne (2003) we assume that there is a level of dollar-debt $D_m \geq 0$ that minimizes the effects of exchange rate fluctuations on firm balance sheets. The gap between the level of dollar debt held by entrepreneurs and this "matching" level $|D - D_m|$ increases the cost of a devaluation.

In order to account for the effects previously described, we will specify the output function as follows:

$$Y(x|s, D) = x + \theta s - L(s, |D - D_m|), \tag{1}$$

where $x + \theta s$ is aggregate demand, and the θs term captures the Mundell-Fleming effect. The function $s \to L(s, D)$ satisfies the Inada conditions. Furthermore, for any $s, D \geq 0$, $L(.)$ is continuously differentiable with respect to (s, D) and

$$L_{sD}(.) > 0. \tag{2}$$

Hence, the loss function $L(.)$ incorporates the distortionary effect of exchange rate changes at each level of dollarization D, as well as the balance-sheet effect through condition (2)[7]. For simplicity in the rest of the discussion we assume that $D_m = 0$, in the understanding that it is really deviations from an optimal level of dollarization that have costly real effects on output. Finally, we assume that the cost related to the balance-sheet effect is convex, so that for any $s, D \geq 0$,

$$L_{DD}(.) > 0. \tag{3}$$

Agents are risk-neutral, maximizing time $T = 2$ expected output, as they do not consume at date $T = 0$, nor do they have access to any savings instrument. Lenders are risk-neutral and value $T = 0$ and $T = 2$ consumption equally. Furthermore, in this economy, the Central Bank sets exchange rate policy in order to maximize an exogenous objective function. The crucial assumption is that there is a mismatch between the Central Bank's objective function and the welfare of the representative entrepreneur. Indeed, we assume that the Central Bank values inflation more than what is socially optimal, so that the Central Bank gross utility function (i.e. before debt repayments) is given for any $x \in R$ by

$$W_{CB}(x, s, D) = Y(x|s, D) + \phi(s)$$

where the term $\phi(s)$ captures additional Central Bank utility gain from inflation. We assume that $\phi(.)$ is increasing and concave and $\phi(0) = 0$. Although the text refers to the term $\phi(s)$ as seniorage, it could equally well be a result of Central Bank time inconsistency. The mismatch is captured by the fact that entrepreneurs gross welfare is given by

$$W(s, D) = E_x Y(x|s, D).$$

[7] A costly-verification model augmented with a Mundell-Flemming effect would generate such a loss function (see Chamon 2002, or Jeanne 2003).

3.2 Optimal Portfolio Choice

Assuming that a central planner decides dollarization and devaluation levels, the choice of peso-debt d, dollar-debt D and devaluation level s is given by:

$$\max_{s,d,D} E_x Y\left(x|s,D\right)$$

subject to lenders' break-even condition:

$$E_x\left\{\min\left[d+(1+s)D; Y\left(x|s,D\right)\right]\right\}=1,$$

which can also be written, after an integration by parts,

$$d+(1+s)D=1+\int_0^{d+(1+s)D} F\left(Y|s,D\right)dY,$$

where $F\left(.|s,D\right)$ is the cumulative distribution of output Y, contingent on the vector $\left(s,D\right)$, and the feasibility condition:

$$D\geq 0.$$

The first-order conditions then imply that the optimal level of dollar-debt is $D^{FB}=0$ and the optimal exchange rate policy s^{FB} satisfies the first-order conditions, i.e.

$$\theta=L_s\left(s^{FB},0\right). \tag{4}$$

Regularity conditions imply that s^{FB} is well-defined. The social planner sets exchange rate policy in order to optimally tradeoff the Mundell-Flemming and distortionary effects. Note that, by adopting a linear demand function, we voluntarily ignored the countercyclical characteristics of monetary policy, making the choice of s^{FB} independent of the realization of $\tilde{x}$. Finally, under the regularity assumptions, the lenders' break-even condition determines the first-best level of peso-debt

$$d^{FB}=1+\int_0^{d^{FB}} F\left(Y|s^{FB},0\right)dY.$$

3.3 Equilibrium Analysis

We first consider the unconstrained exchange rate policy and portfolio decisions. The equilibrium outcome is determined by lenders' interest rate choices for peso and dollar debt, agents' portfolio decisions and market-clearing conditions. In order our initial intuition to hold, it is critical that there is some coordination among lenders. Thus we assume:

Assumption A0: There is perfect coordination among lenders.

Although assumption A0 seems strong, partial coordination is enough for our results to hold. When taken together with perfect competition on the credit market, A0 is equivalent to assuming a single lender (a large bank) that breaks even in equilibrium because it faces the threat of entry from other financial institutions and has a fixed cost. In a decentralized equilibrium under assumption A0, lenders end up being price setters. To clarify the analysis we will details the timing of events at $T=0$, the contracting stage:

1. Lenders offer interest rate menus to borrowers $\{r(\alpha), R(\beta)\}$ where α and β are the amounts borrowed in pesos and dollars respectively.

2. Borrowers make their portfolio choices $\{\alpha, \beta\}$ accordingly.

3.3.1 The Central Bank's Reaction Function

The Central Bank observes financial contracts signed at time $T = 0$. Such contracts consist of a portfolio composition $\{\alpha, \beta\}$ with corresponding interest rates $\{r, R\}$. From now on, we define $T = 1$ level of peso liabilities as $d \equiv \alpha r$ and similarly for dollar liabilities: $D \equiv \beta R$. As lenders always break-even in equilibrium, the second-best exchange rate policy is given by the Central Bank's $T = 1$ first-order conditions, i.e.

$$\theta + \phi'(s) = L_s(s, D). \tag{5}$$

The regularity conditions assumed previously imply that for any non-negative level of dollar-debt, the exchange rate response is well-defined, continuous and differentiable with respect to D. We henceforth denote the exchange rate response to a level D of dollarization s_D, while d_D is the corresponding level of peso-debt. Indeed, the implicit function theorem, our technology assumptions and the balance-sheet effect imply that, for any $D \geq 0$,

$$\left(\frac{ds_D}{dD}\right)_D = -\frac{L_{sD}(s_D, D)}{L_{ss}(s_D, D) - \phi''(s_D)} < 0, \tag{6}$$

making s_D a decreasing function of dollar-debt.

In this world, the Central Bank values a devaluation more than entrepreneurs do, which induces a depreciation bias in exchange rate policy. In particular, for $D = 0$, the Central Bank's first-order condition implies that the second-best is characterized by excess devaluation, which leads to higher interest payments. To see this, consider the break even condition for s_0,

$$d_0 = 1 + \int_0^{d_0} F(Y|s_0, 0)\, dY.$$

The optimality condition for the first-best exchange rate policy implies that for any $Y \in R^+$,

$$F\left(Y|s^{FB}, 0\right) < F(Y|s_0, 0),$$

implying a premium on peso-debt:

$$d_0 > d^{FB}.$$

The first-best exchange rate policy translates into a distribution of output that first-order stochastically dominates the distribution generated by a second-best exchange rate policy. Thus the premium on peso-debt is lower in the former case as default is less frequent and repayment in case of default is higher.

3.3.2 Agents' Portfolio Choices

We restrict the set of contracts to menus such that r and R are continuously differentiable functions of the amounts borrowed, α and β respectively. Furthermore, we restrict menus so that repayments

are increasing functions of amounts borrowed: $\forall \alpha, \beta \geq 0$,

$$\begin{aligned} r(\alpha) + \alpha r'(\alpha) \geq 0, \\ R(\beta) + \beta R'(\beta) \geq 0. \end{aligned} \tag{7}$$

As dollar and peso loans are perfect substitutes as far as production and consumption are concerned, we have that in equilibrium $\alpha+\beta = 1$. Agents therefore face a menu $\{r(\alpha), R(1-\alpha)\}_{\alpha\in[0,1]}$ and choose the currency denomination of their debt payments to minimize expected payments in $T = 2$

$$\min_{\alpha} r(\alpha)\alpha + R(1-\alpha)(1-\alpha)$$

Then, indexing equilibrium outcomes by SB, we have for an interior solution:

$$r\left(\alpha^{SB}\right) + \alpha^{SB} r'\left(\alpha^{SB}\right) = (1 + s_{D^{SB}})\left[R\left(1-\alpha^{SB}\right) + \left(1-\alpha^{SB}\right) R'\left(1-\alpha^{SB}\right)\right]. \tag{8}$$

The optimal portfolio choice equalizes the marginal cost of an extra peso borrowed with the cost of an extra dollar borrowed. Under conditions assumed in (7), agents' optimal portfolio choices $\left\{\alpha^{SB}, 1-\alpha^{SB}\right\}$ are uniquely defined, so that either $\alpha^{SB} = 0$, or $\alpha^{SB} = 1$ or (8) holds.

3.3.3 Lenders' Interest Rate Decision

Given the borrowers' reaction function (8), the choice of interest rates menus $\{r(.), R(.)\}$ pins down the choice of debt portfolios $\{d, D\}$, where for any menus $\{r(.), D(.)\}$, $d = \alpha^{SB} r\left(\alpha^{SB}\right)$ and $D = \left(1-\alpha^{SB}\right) R\left(1-\alpha^{SB}\right)$. Equilibrium interest rate choices then maximize expected repayments to lenders, or equivalently, expected output:

$$\left(d^{SB}, D^{SB}\right) = \arg\max_{d,D} E_x Y(x|s_D, D) = \arg\max_{d,D} \{m + \theta s_D - L(s_D, D)\} \tag{9}$$

subject to

$$D \geq 0 \tag{10}$$

$$d + (1+s_D) D = 1 + \int_0^{d+(1+s_D)D} F(Y|s_D, D)\, dY \tag{11}$$

and the Central Bank's reaction function s_D:

$$\theta + \phi'(s_D) = L_s(s_D, D). \tag{12}$$

Under assumption A0, lenders indeed internalize the Central Bank's reaction function. Given that (12) defines a continuously differentiable exchange rate response from the Central Bank, agents' first-order conditions for an interior solution can now be written:

$$\left(\frac{ds_D}{dD}\right)_{D^{SB}} \left[\theta - L_s\left(s_{D^{SB}}, D^{SB}\right)\right] = L_D\left(s_{D^{SB}}, D^{SB}\right) \tag{13}$$

Furthermore, the break-even condition (11) binds and thus determines the level of peso-debt according to

$$d^{SB} + (1+s_{D^{SB}}) D^{SB} = 1 + \int_0^{d^{SB}+\left(1+s_{D^{SB}}\right)D^{SB}} F\left(Y|s_{D^{SB}}, D^{SB}\right) dY. \tag{14}$$

The trade-off captured in (13) weighs the marginal benefits of increasing dollar liabilities against the corresponding losses. These benefits arise from reductions in the devaluation-related distortion, as measured by the left-hand side of (13) . An increase in dollar-denominated debt puts a downward pressure on exchange rate policy, which is then reflected in productivity gains. This effect is illustrated in figure (3). The first panel of the figure corresponds to (12), and shows the marginal costs and benefits for the central bank of a devaluation at two levels of dollar-debt: 0 and D^{SB}. The lower panel shows the expected output that follows from the Central Bank's best response for each level of dollarization. As can be seen in the figure agents trade off the direct costs of dollar-debt (the downward shift in the E_xY curve due to $L_D > 0$) against the benefits of a less expansionary exchange rate policy.

While equilibrium portfolios of liabilities $\left(d^{SB}, D^{SB}\right)$ are uniquely determined, a multitude of financial contracts can achieve such outcome. Thus, we make a further assumption on equilibrium conditions, the "no arbitrage" condition: any equilibrium menus of interest rates must satisfy

$$r\left(\alpha^{SB}\right) = \left(1 + s_{D^{SB}}\right) R\left(1 - \alpha^{SB}\right). \tag{15}$$

Under condition (15) , when interest rates on a peso is equal to devaluation-adjusted interest rates on a dollar, equilibrium portfolio choices and interest rates are thus uniquely determined. Note that off-equilibrium interest rates are not necessarily unique. The following proposition summarizes the results obtained so far:

Proposition 1 *The optimization program (9) under constraints (10) and (11) has a unique solution* $\left(d^{SB}, D^{SB}\right)$ *such that the first-order necessary and sufficient condition*

$$\left(\frac{ds_D}{dD}\right)_{D^{SB}} \left[\theta - L_s\left(s_{D^{SB}}, D^{SB}\right)\right] = L_D\left(s_{D^{SB}}, D^{SB}\right),$$

in which for any x, D,

$$\left(\frac{ds_D}{dD}\right)_D = -\frac{L_{sD}\left(s_D, D\right)}{L_{ss}\left(s_D, D\right) - \phi''\left(s_D\right)},$$

and the break even condition

$$d^{SB} + \left(1 + s_{D^{SB}}\right) D^{SB} = 1 + \int_0^{d^{SB} + \left(1 + s_{D^{SB}}\right) D^{SB}} F\left(Y | s_{D^{SB}}, D^{SB}\right) dY$$

holds.
Furthermore, interest rates and portfolio decisions are defined by

$$\begin{aligned} r\left(\alpha^{SB}\right) &= \frac{d^{SB}}{\alpha^{SB}}, \\ R\left(1 - \alpha^{SB}\right) &= \frac{D^{SB}}{1 - \alpha^{SB}}, \end{aligned}$$

such that if the "no-arbitrage" condition (15) *holds then the first-order condition for borrowers determines a unique portfolio choice* α^{SB}*:*

$$\alpha^{SB} r'\left(\alpha^{SB}\right) = \left(1 + s_{D^{SB}}\right)\left(1 - \alpha^{SB}\right) R'\left(1 - \alpha^{SB}\right).$$

Proof. *We just need to prove that the solution is indeed interior. Under the Inada conditions assumed previously, we observe that for* $D = 0$

$$\left(\frac{ds_D}{dD}\right)_0 \left[\theta - L_s\left(s_0, 0\right)\right] > L_D\left(s_0, 0\right)$$

which implies that program (9) *has an interior solution.* ■

3.4 Some comments

In this model, dollar liabilities have a disciplining effect on the government. Lenders price interest rates on peso and dollar-debt in such a way that agents take on dollar-debt, which then obliges the government not to devaluate excessively. To see this, let's consider the break-even condition (14)

$$d^{SB} + (1 + s_{D^{SB}}) D^{SB} = 1 + \int_0^{d^{SB}+(1+s_{D^{SB}})D^{SB}} F\left(Y|s_{D^{SB}}, D^{SB}\right) dY.$$

and let's compute the effect of an increase in dollar-denominated liabilities on the denomination of peso-debt . After noting that $F(Y|s, D)$ is continuously differentiable in (s, D) uniformly with respect to $Y \geq 0$, we apply the implicit function theorem to (14) ,

$$\left(\frac{d}{dD} d^{SB}\right)_{D^{SB}} = -(1 + s_{D^{SB}}) \tag{16}$$

$$-\frac{\left(\frac{ds_D}{dD}\right)_{D^{SB}} D^{SB} \times F\left(d^{SB} + (1 + s_{D^{SB}}) D^{SB}\right)}{1 - F\left(d^{SB} + (1 + s_{D^{SB}}) D^{SB}|s_{D^{SB}}, D^{SB}\right)} \tag{17}$$

$$-\frac{\int_0^{d^{SB}+(1+s_{D^{SB}})D^{SB}} \left[\frac{dF}{dD}\left(Y|s_{D^{SB}}, D^{SB}\right)\right] dY}{1 - F\left(d^{SB} + (1 + s_{D^{SB}}) D^{SB}|s_{D^{SB}}, D^{SB}\right)} \tag{18}$$

Increasing the level of dollar-denominated debt payments affects peso payments through:

- *An accounting effect* (right-hand side of (16)): from an accounting perspective dollar-denominated liabilities are substitutes for peso-debt; taking one extra unit of dollar-debt allows firms to reduce their peso payments by $1 + s_{D^{SB}}$.
- *A disciplining effect or risk-premium effect* (captured in (17) and (18)): an increase in dollar-denominated liabilities, by inducing a relatively more pro-output exchange rate policy decreases the risk-premium as it lowers the probability of default (term in (17)) and at the same time increases repayments in states of nature where default occurred (term in (18)).

The idea that dollarization has a disciplining effect on Central Banks when there is incentive mismatch is not new (see, for example Borenzstein et al (1996), Chang and Velasco (2001), Gale and Vives (2002), or Tirole (2002)). Similar arguments have been made to support the introduction of government debt indexed to the exchange rate or inflation. In most cases, however cost and benefit analyses of dollarization consider dollarization as a policy variable.

The focus so far of the paper has been instead to investigate how markets, by setting interest rates on peso and dollar-debt, provide incentives to investors to choose their portfolio composition in order to mitigate the effects of a misalignment of incentives between Central Banks and agents. In order for this effect to hold, we assume that coordination is taking place between lenders, so that the disciplining effect is internalized. Indeed, lenders incorporate the fact that an additional dollar liability has a disciplining effect on the Central Bank – thus decreasing the probability of default – so that they are willing to make dollar loans cheaper relatively to peso loans[8]. Is this a

[8] In Tirole (2002), as interest rates for dollar debt are fixed at international rates, the decentralized equilibrium does not internalized the disciplining effect, potentially yielding under-dollarization of liabilities. Not allowing interest

valid assumption? Table (1) shows one measure of bank concentration for a sample of emerging market economies from three regions: Latin America, East Asia and Eastern Europe. In all regions the three largest banks concentrate over 50% of total bank assets, suggesting that coordination amongst domestic lenders is indeed feasible.

In this complete information setting, portfolio choices are optimal. Expected output is maximized, or equivalently, the probability of low realizations of output, or crises, is minimized. In the following sections, we will investigate mechanisms that provide a rationale for a suboptimal portfolio composition leading to excess dollarization. In particular we discuss the implications of imperfect knowledge about the parameters of the model - specifically the preferences and effectiveness of the Central Bank.

It is important to emphasize that in this model, debt denominated in dollars is strictly equivalent to debt denominated in pesos contingent on the exchange rate. Indeed, pesos and dollars are perfect substitutes as far as current consumption is concerned. Moreover, under purchasing power parity, dollar debt is an inflation-indexed peso-debt.

4 A Signaling Model of Central Bank Credibility

Consider now that some characteristics of the economy are unknown to agents, and that they therefore learn about the parameters of the economy. To be more specific, assume that agents have imperfect knowledge about m, the mean of the distribution of $\tilde{x}$; the Central Bank's effectiveness at smoothing macroeconomic shocks θ; and the devaluation bias $\phi(.)$. Hence, the parameters $(m, \theta, \phi) \in M \times \Theta \times \Phi$ are unknown, while we assume that other functional forms, such as the distributions and the function $L(.)$, are perfectly known to agents[9]. To simplify the analysis, we will assume that the Central Bank can have only two types

- a "good" type, $\phi^g(.)$, where $\phi^g(.) = 0$.
- a "bad" type $\phi^b(.)$, where $\phi^b(.)$ is increasing and concave.

Thus, the set of possible Central Bank's types is reduced to $\Phi = \left\{\phi^g, \phi^b\right\}$. Although our analysis will hold irrespective of what type is the true type, for the policy relevance of our argument, we will assume that the Central Bank does not exhibit a devaluation bias and hence is of type $\{m^g, \theta^g, \phi^g(.)\}$. The plausibility that the true type could be type b is the starting point of our discussion on Central Bank's credibility.

Moving away from the static framework, we now consider dynasties of entrepreneurs. Each dynasty, in generation $t \geq 0$, is endowed with some priors $\mu_t(m, \theta, \phi)$ about the values of the parameters of the economy. For any $t \geq 0$, dynasty-$(t+1)$ agents' priors are equal to dynasty-t agents' posteriors. The transmission of information is then as follows. For any $t \geq 0$, given

rates on peso and dollar to adjust in order to reflect the relative forces involved lead most models to end up with polar cases, as in Chamon and Hausmann (2002): either the economy fully dollarizes ($D = \infty$) and the Central Bank fixes, i.e. $s = 0$, or the economy borrows essentially in domestic currency ($D = 0$) and the Central Bank floats, i.e. $s = s_0$

[9] Priors $\mu_t(.)$ are probability measures over $M \times \Theta \times \Phi$. Equivalently we could have assumed, without altering our results, that agents where uncertain about the the function L.

their priors $\mu_t(m, \theta, \phi)$, agents choose a contract (d_t, D_t), the Central Bank sets an exchange rate depreciation s_t and the output is realized according to the stochastic process defined by (1). While they do not observe the realization of $\tilde{x}$, agents observe the exchange rate and realized output and update their beliefs accordingly. They then bequeath their beliefs to the next generation. As in the static version of the model the exchange rate is normalized to one for $T = 0$ of each generation. We assume that there is no savings technology, so that all output in a given generation is consumed. However, there is some intergenerational altruism so that the Central Bank as well as agents maximize a discounted flow of payoffs, with discount factor δ. We assume that δ is the same for agents and the Central Bank and that this property is common knowledge.

At this stage it is useful to provide a brief description of the main results we obtain in this section. The first of these is trivial: given that agents choose the level of dollar-debt based on their priors regarding Central Bank preferences, imperfect information will always lead to inefficiently high levels of dollarized debt. The key issue then becomes how these priors evolve over time. Assuming that Central Banks can affect learning by signaling their types leads us to our second result. The learning process can be characterized by two possible outcomes: a pooling and a separating equilibrium.

- In the pooling equilibrium each generation updates their beliefs based on the observed values of the exchange rate and output. Learning is imperfect, however, as agents only have two equations ((1) and (5)) to identify three parameters. They observe output but do not know how much is due to the macroeconomic component, x, and how much is due to the monetary component, θs; similarly, while they observe the exchange rate level s, agents do not know whether the Central Bank has a high ability to increase productivity (hig value of θ) or it has a large seignorage motive (steep $\phi(.)$). The result is that economies can be stuck in persistent states of high dollar-debt when agents wrongly attribute the observed outcomes to a Central Bank of type-b.
- In the separating equilibrium the full information outcome ($D = 0$) ensues in every period after separation.

Which equilibria is selected will depend on the costs to the Central Bank of playing a signaling strategy. Our third main result is that this cost depends on the initial level of dollarization, itself driven by agents' priors about the Central Bank. If the initial level of dollar-debt is too high the Central Bank will decide to induce coordination on the pooling equilibrium. The intuition behind this result is straight-forward: dollarization narrows the wedge between the optimal policies of "good" and "bad" central banks, making it harder for a good Central Bank to distinguish itself. In the final subsection we relate this result to borrowers behavior. If initial priors are "bad" enough then dollar-debt will be high leading the Central Bank to select the pooling equilibrium. On the other extreme, "good" priors will lead to the signaling equilibrium and efficient levels of dollar debt. An interesting outcome occurs in the intermediate region. If priors are good enough, then agents may have incentives to take on less dollar-debt than a static game suggests if this leads the Central Bank to a choose the separating equilibrium.

The rest of this section proceeds as follows. We start by characterizing the pooling equilibria and the updating process. In the following subsection we characterize the separating equilibria. We finish by analyzing the optimal strategies of the Central Bank and individual agents.

4.1 Signaling Game: definition

In this section, we analyze the ability of the Central Bank to signal to the markets its willingness to conduct a "good" exchange rate policy. We start by defining the signalling game that Central Banks and agents are playing. In this standard overlapping generation model, for each generation $T \geq 0$, the Central Bank of type (m, θ, ϕ) has expected payoffs

$$W_{\phi}(T) = \sum_{t \geq T} \delta^{t-T} \left[(m + \theta s_t) + \phi(s_t) - L(s_t, D_t) \right],$$

while agents maximize payoffs

$$W(T) = E_{\mu_T} \sum_{t \geq T} \delta^{t-T} \left[E_{\mu_t}(m + \theta s_t) - L(s_t, D_t) \right].$$

While agents choose a sequence of financial contracts $(d_t, D_t)_{t \geq 0}$, Central Banks choose a sequence of exchange rate regimes $(s_t)_{t \geq 0}$. The question is now to investigate whether the "good" Central Bank can signal her type to markets.

While a complete analysis of the signaling game is not the purpose of this section, we analyze conditions of existence of a separating equilibrium, and characterize the pooling equilibria in a dynamic learning game. Thus, we restrict attention to stationary strategies, adopting a Markov perfect equilibrium concept.

4.2 Pooling Equilibria: Characterization

When the only possible equilibria are pooling equilibria, agents have imperfect knowledge about the parameters of the economy. This section characterizes the behavior of agents' beliefs along an infinite sequence of pooling equilibria. The issue of whether such sequence exists will be discussed some paragraphs below. As a common feature of these models is to exhibit many pooling equilibria, we restrict attention to the best sequence of pooling equilibria, so that off-equilibrium beliefs are somewhat "reasonable".

4.2.1 Equilibrium Characterization and the Transmission of Information

Building on the results of section 3, the sequence (d_t, D_t) of financial contracts verifies: $\forall t \geq 0$,

$$(d_t, D_t) \in \arg\max_{d,D} E_{\mu_t} \left\{ E_x \left[Y(x|s, D) \,|m, \theta, \phi \right] \right\} \tag{19}$$

subject to:

- the Central Bank's reaction function: $\forall (m, \theta, \phi) \in Supp(\mu_t)$,

$$\theta + \phi'(s) = L_s(s, D). \tag{20}$$

- and lenders' break-even condition:

$$d + (1+s) D = 1 + E_{\mu_t} \int_0^{d+(1+s)D} F(Y|m, \theta, s, D) \, dY. \tag{21}$$

Existence and uniqueness of such contracts is given by regularity properties considered previously. Note that under the assumed regularity conditions, $d(.)$, and $D(.)$ are continuous functions.

Some additional points on the notation: instead of considering the random variable $\tilde{x}$, we will focus on $\tilde{Y} \equiv \tilde{x} + \theta s - L(s, D)$. $F(.|m, \theta, s, D)$ will refer to the distribution function of $\tilde{Y}$, were (m, θ, ϕ) the true parameters and (s, D) is given by the Central Bank's reaction function (20), while D is agents' choice of dollarization. Finally, $dG(.|m, \theta, \phi)$ denotes the conditional distribution function of the pair (Y, s).

We now turn to the learning process per se. Agents update their information rationally, so that Bayes' rule induces the following transition process: $\forall (m, \theta, \phi) \in Supp(\mu_t)$

$$\mu_{t+1}(m, \theta, \phi | R, s) = \mu_t(m, \theta, \phi) \frac{dG(R, s|m, \theta, \phi)}{\sum\limits_{(m', \theta', \phi') \in M \times \Theta \times \Phi} dG(R, s|m', \theta', \phi') \mu_t(m', \theta', \phi')} \tag{22}$$

While the transition process is well-defined, the evolution of beliefs is ambiguous. When agents observe a high realization of output, they can either update their beliefs so that higher values of m are more likely, or so that the Central Bank has a larger impact on output (i.e. θ is large). Similarly, a given devaluation can be attributed either to an effective Central Bank (high θ) or a large objective mismatch ($\phi'(.) = \phi^{b'}(.) > 0$). As such priors condition the choice of dollarization, one can now guess what is likely to happen: starting with priors that the Central Bank has no positive impact on the output function, agents will take on large amounts of dollar debt, taking exchange rate policy off the hands of "supposedly ineffective" Central Bankers. Any high realization of output is then attributed to large exogenous demand shocks. Similarly, starting with priors that the Central Bank has a strong preference for devaluation ($\phi'(.) = \phi^{b'}(.) > 0$) agents will take on dollar debt to avoid excessive devaluation. Low realizations of s are seen as the response to the dollar debt and not a confirmation of low devaluation preferences.

4.2.2 Limit Beliefs and Actions

We can then characterize the set of limit beliefs and actions along an infinite sequence of pooling equilibria. The first result is that the process defined by (22) converges with probability one to some limit beliefs that we denote $\mu_\infty(m, \theta, \phi)$. The property is standard to Bayesian learning. As expected posteriors are equal to the priors (any bias would be incorporated into the prior), the learning process has the martingale property, and thus converges with probability 1. Then, equations (20) and (21) imply by continuity that dollarization levels and exchange rate policy variables also converge with probability 1 to some values D_∞, $d_\infty$and s_∞.

Lemma 2 *For any initial distribution of beliefs $\mu_0(.)$, the process $(\mu_t)_{t\geq 0}$ defined by (22) converges almost surely to some limit beliefs $\mu_\infty(.)$. The processes $(D_t)_{t\geq 0}$, $(d_t)_{t\geq 0}$, and $(s_t)_{t\geq 0}$ converge almost surely to some limit actions $D_\infty = D(\mu_\infty)$, $d_\infty = d(\mu_\infty)$, and $s_\infty = s(\mu_\infty)$ respectively.*

Proof. *In the text.* ■

It is worth investigating whether the argument made in the previous paragraph indeed holds. In cases where initial priors are such that $(m^g, \theta^g, \phi^g) \in Supp(\mu_0)$, a necessary characteristics of limit beliefs is given in the following proposition:

Proposition 3 *For any initial distribution of beliefs $\mu_0(.)$ such that $(m^g, \theta^g, \phi^g) \in Supp(\mu_0)$, along an infinite sequence of pooling equilibria, limit beliefs $\mu_\infty(.)$ and actions D_∞, d_∞ and s_∞ are characterized by:*

- $(m^g, \theta^g, \phi^g) \in Supp(\mu_\infty)$
- *If* $\left(m^b, \theta^b, \phi^b\right) \in Supp(\mu_\infty)$, *then*

$$\theta^b + \phi^{b\prime}(s_\infty) = \theta^g, \tag{23}$$

and

$$m^b + \theta^b s_\infty = m^g + \theta^g s_\infty. \tag{24}$$

Proof. *The proof uses a standard argument in the Bayesian learning literature (see e.g. Smith and Sorensen, 2000). First, consider the process generated by Bayes' rule* (22) : *stationary beliefs imply that any $(m, \theta, \phi(.))$ and $\left(m', \theta', \phi'(.)\right)$ in $Supp(\mu_\infty)$ must verify for any feasible $(Y, s) \in R^2$, $dG(Y, s|m, \theta, \phi(.)) = dG\left(Y, s|m', \theta', \phi'(.)\right)$, which implies that $dF(Y|m, \theta, \phi(.)) = dF\left(Y|m', \theta', \phi'(.)\right)$. As these two distributions differ only with respect to their means,* (24) *must hold. Moreover, x and s are related by the central bank's reaction function* (20), *thus stationarity holds only if* (23) *holds. Sufficiency can easily be checked. The second part of the argument is to notice that the likelihood ratio $\lambda_t(m, \theta, \phi(.)) \equiv \mu_t(m, \theta, \phi(.)) / \mu_t(m^g, \theta^g, \phi^g(.))$ has the martingale property. Thus it converges with probability 1, which implies that $\mu_\infty(m^g, \theta^g, \phi^g(.)) > 0$.* ■

The lack of identification is precisely why learning does not occur. Agents potentially face imperfect learning as they only have two equations ((23) and (24)) to identify the three parameters $\left(m, \theta, \phi'(s)\right)$.

4.2.3 Comments

Along a sequence of pooling equilibria, agents can be stuck in persistent states where they have imperfect knowledge about the parameters of the economy. If agents believe that the Central Bank objectives differ from social welfare (i.e. $\phi(.) > 0$), they will take on a large amount of dollar-denominated debt. In turn the Central Bank reacts in such a way that it does not contradict agents' beliefs. Then, observing realized output, agents can potentially attribute all the difference to the exogenous demand shock $\widetilde{x}$. High output can be interpreted as a high value of m while keeping priors about ϕ constant. On the other hand, agents can attribute low output not to a bad productivity shock but to bad behavior from the Central Bank (steep $\phi(.) > 0$). In the long-run, experience is entirely consistent with expectation and no additional learning takes place. Countries can therefore be locked in "dollarization traps", putting themselves in situations where low output is more likely to occur and attributing crises to bad governance of monetary policy, while at the same time tying the hands of potentially potent (and beaning) policy makers.

4.3 Separating Equilibria: Characterization

As we only focus on Markov perfect equilibria, we will analyze the conditions for existence of separating equilibria at time $t = 0$. As agents observe the Central Bank's exchange rate policy and the realization of output, we can state the first result:

Lemma 4 *Along any equilibrium path, $\forall t > 0$, the following holds:*

$$\Theta \cap Supp\left(\mu_t\right) \subset \left\{\theta^b, \theta^g\right\}, \tag{25}$$

$$M \cap Supp\left(\mu_\infty\right) \subset \left\{m^b, m^g\right\}, \tag{26}$$

where

$$\theta^b + \phi'\left(s_t\right) = \theta^g, \tag{27}$$

$$m^b + \theta^b s_\infty = m^g + \theta^g s_\infty. \tag{28}$$

Proof. *As agents observe the exchange rate adopted by the Central Bank, such choice must be consistent with* (20), *so that* (27) *must hold. Note that $\phi^g = 0$. Furthermore, in the long run, the mean of $F\left(.|s_\infty, D_\infty\right)$ is perfectly known to agents so that* (28) *must hold.* ■

If complete separation is achieved at any point in time, then separation is sustained in all subsequent periods, and corresponding subgames are characterized by full-information outcomes. Indeed if separation occurs, then agents know perfectly the type of the Central Bank they are facing; optimal portfolio composition ensues. The second preliminary result can thus be stated as follows:

Lemma 5 *Consider an equilibrium sequence of exchange rate regimes $\left(s_t\right)_{t\geq 0}$.*
If there exists $T \geq 0$, such that

$$\sum_{m\in M}\left[\mu_{T+1}\left(m, \theta^g, \phi^g | s_T\right)\right] = 1,$$

then, for any $t \geq T+1$,

$$D_t = 0, \text{ and } s_t = s_0^g,$$

where s_D^g is the exchange rate response of a Central Bank of type g.
If there exists $T \geq 0$, such that

$$\sum_{m\in M}\left[\mu_{T+1}\left(m, \theta^b, \phi^b | s_T\right)\right] = 1,$$

then, for any $t \geq T+1$,

$$D_t = D^b, \text{ and } s_t = s_D^b,$$

where s_D^b is the exchange rate response for a Central Bank of type b.

Proof. *In the text.* ■

As we restrict attention to stationary strategies, we can consider, without loss of generality, the game played at time $T = 0$. We will henceforth restrict ourselves to initial priors which verify (25) to (28). Denoting by D_0, the initial level of dollarization adopted by agents, and $\left(\sigma_D^g, \sigma_D^b\right)$ the exchange rate regimes adopted in period $t = 0$ by Central Banks of each of the types (g, b) respectively. Note that under condition (3), Central Banks' preferences satisfy the *single-crossing property*. The short-term cost of limiting monetary expansion is larger for a Central Bank of type b than it is for a Central Bank of type g. Separating equilibria are then characterized by the following conditions:

- Optimality for type-b Central Banks: $\forall D_0 \geq 0$,

$$\sigma^b_{D_0} = s^b_{D_0}$$

- Central Bank's reaction function (equation (23)):

$$s^b_{D_0} = s^g_{D_0}$$

- Incentive-compatibility constraint for type-b Central Banks:

$$\begin{aligned} & \left[\theta^b s^b_{D_0} - L\left(s^b_{D_0}, D_0\right) + \phi\left(s^b_{D_0}\right)\right] - \left[\theta^b \sigma^g_{D_0} - L\left(\sigma^g_{D_0}, D_0\right) + \phi\left(\sigma^g_{D_0}\right)\right] \\ \geq \quad & \delta\left\{\left[\theta^b s^b_0 - L\left(s^b_0, 0\right) + \phi\left(s^b_0\right)\right] - \left[\theta^b s^b_D - L\left(s^b_D, D\right) + \phi\left(s^b_D\right)\right]\right\} \end{aligned} \tag{29}$$

Separation requires a depressed exchange rate, so that a Central Bank of type b is not willing to mimic a Central Bank of type g. The single-crossing property ensures that the incentive-compatibility constraint for type g Central Banks holds. As we did for the analysis of pooling equilibria, and to simplify further discussions, we will assume that off-equilibrium beliefs are reasonable, selecting as unique separating equilibrium, the outcome such that (29) holds with equality: a Central Bank of type g will choose an exchange rate regime which is the least costly, given that (29) must hold.

4.4 Equilibrium Concept and Equilibrium Outcome

4.4.1 Equilibrium Refinement

Imposing strategies to be stationary implies that the equilibrium is Markov Perfect. However, we have seen in the previous paragraphs, that for any initial level of debt D_0, pooling and separating equilibria could coexist, while voluntarily ignoring semi-separating equilibria. We further adopted a domination-based refinement of beliefs, which consisted of assuming that off-equilibrium beliefs were reasonable, as they do not assign positive probability to a player taking a strictly dominated action. Thus, in the pooling equilibrium, no action that is not short-term optimal was ruled out; similarly, in separating equilibria, any action that made (29) hold strictly was considered as unreasonable.

However, refinements such as the Cho-Kreps intuitive criterion (see Cho and Kreps, 1987) consistently select as unique equilibrium outcome the best separating equilibrium as described in the previous paragraph. We will thus depart from this refinement and adopt a Pareto-dominance-based equilibrium concept: *agents coordinate on the Pareto-dominating equilibrium.* We believe that such refinement is relevant for the situation we are modeling: a Central Bank of type g might not want to play an expensive signaling strategy if the costs compared to a pooling equilibrium situation are large.

4.4.2 Equilibrium Outcome

Under such equilibrium selection assumption, the initial level of dollarization D_0 determines the "cost" of separation. When the cost is too high, the Central Bank may decide to induce coordination on the pooling equilibrium. The next proposition formalizes the result:

Proposition 6 *There exists a threshold $\hat{D}$ such that for any level D_0 of initial dollar-debt level, we have the following:*

- *If $D_0 > \hat{D}$, then the unique equilibrium exhibits pooling strategies at time $t = 0$.*
- *If $D_0 < \hat{D}$, then the unique equilibrium is a separating equilibrium.*

Proof. *Denoting by $V_p(m, \theta, \phi)$ and $V_s(m, \theta, \phi)$ the continuation values for Central Banks of type (m, θ, ϕ), we first remark that such values do not depend on D_0. Indeed, the Markov perfection restriction implies that these continuation values depend only on posterior beliefs. We can now compare payoffs to the Central Banks in the separating and pooling cases. Under the pooling situation, the two types of Central Banks receive*

$$E_{\mu_0}\left\{(1-\delta)\left[m + \theta s_{D_0} - L\left(s_{D_0}, D_0\right) + \phi\left(s_{D_0}\right)\right] + \delta V_p\left(m, \theta, \phi\right)\right\},$$

while the separating situation yields

$$E_{\mu_0}\left\{(1-\delta)\left[m + \theta \sigma_{D_0} - L\left(\sigma_{D_0}, D_0\right) + \phi\left(\sigma_{D_0}\right)\right] + \delta V_s\left(m, \theta, \phi\right)\right\}.$$

Thus a separating equilibrium forms if and only if

$$\begin{aligned} & (1-\delta) E_{\mu_0}\left\{m^g + \theta^g\left(s^g_{D_0} - \sigma^g_{D_0}\right) - \left[L\left(s^g_{D_0}, D_0\right) - L\left(\sigma^g_{D_0}, D_0\right)\right]\right\} \\ \leq \; & \delta E_{\mu_0}\left\{\left[V_s\left(m^g, \theta^g, \phi^g\right) + V_s\left(m^b, \theta^b, \phi^b\right)\right] - \left[V_p\left(m^g, \theta^g, \phi^g\right) + V_p\left(m^b, \theta^b, \phi^b\right)\right]\right\}. \end{aligned} \tag{30}$$

In other words, the short-term losses due to costly signaling outweigh the long-term gains of an unconstrained optimal portfolio composition. Considering that (29) *binds, we can rewrite* (30) *as*

$$\left(\theta^g - \theta^b\right)\left(s^g_{D_0} - \sigma^g_{D_0}\right) + \phi\left(s^g_{D_0}\right) - \phi\left(\sigma^g_{D_0}\right) \leq \Delta, \tag{31}$$

where Δ is given by the parameters of the model and is independent of D_0. Applying the implicit function theorem to (29)*, we can conclude after observing that* (2) *holds, that the difference $\left(s^g_{D_0} - \sigma^g_{D_0}\right)$ is continuously increasing in D_0 and*

$$\lim_{D_0 \to \infty}\left(s^g_{D_0} - \sigma^g_{D_0}\right) = +\infty.$$

There exists $\hat{D} \in R$, such that (31) *holds if and only if $D_0 \leq \hat{D}$. For large enough values of δ, we have $\hat{D} > 0$.* ■

The intuition of the result can be found in the proof, yet some comments can be helpful. The whole objective of dollarization is to narrow the wedge created by the inflationary bias of a Central Bank of type b. Thus, as dollarization levels increase, the second-best solution for Central Banks g and b get closer and closer. Thus, in order to discriminate the two types, it is necessary for the type-g Central Bank to inflict itself a large cost, in order to deter mimicking from a type-b Central Bank (condition (29)). Thus, as dollarization increase, the cost of getting a separating equilibrium increases, eventually making the separating payoff worse than the pooling case, so that (30) holds.

We now turn to borrowers' behavior. Depending on their priors, agents may or may not be willing to lower their level of dollarization at time $T = 0$ in order to obtain a separating equilibrium.

The willingness to experiment depends on the perceived costs and benefits at the beginning of the period. For any beliefs $\mu_t(.)$, we then denote, by abuse of notation, $\mu_t \equiv \Sigma_{m\in M}\left[\mu_t\left(m,\theta,\phi|\theta^b,\phi^b\right)\right]$, the prior that the Central Bank is of type b. We conclude the paragraph with the following important result:

Proposition 7 *There exists a threshold $\hat{\mu}$, such that an equilibrium with separating strategies at time $t=0$ exists if and only if $\mu_0 \leq \hat{\mu}$.*

Proof. *Agents trade-off the expected loss of having a low level of dollar-debt level with the expected gains from better information as a separating equilibrium can be achieved. Consider the initial level of dollar debt $\hat{D}$. Payoffs to borrowers in the separating case are given by*

$$\begin{aligned}&\mu_0\left\{(1-\delta)\left[E_{\mu_0}m^b+\theta^b s^b_{\hat{D}}-L\left(s^b_{\hat{D}},\hat{D}\right)\right]+\delta\left[E_{\mu_0}m^b+\theta^b s^b_{D^b}-L\left(s^b_{D^b},D^b\right)\right]\right\}\\&+(1-\mu_0)\left\{(1-\delta)\left[E_{\mu_0}m^g+\theta^g\sigma^g_{\hat{D}}-L\left(\sigma^g_{\hat{D}},\hat{D}\right)\right]+\delta\left[E_{\mu_0}m^g+\theta^g s^g_0\right]\right\},\end{aligned} \tag{32}$$

while, sticking to a pooling equilibrium strategy, agents would get

$$\max_{D_0} E_{\mu_0}\left\{(1-\delta)\left[m+\theta s^g_{D_0}-L\left(s^g_{D_0},D_0\right)\right]+\delta\left[V_p(m,\theta,\phi)\right]\right\} \tag{33}$$

Rearranging the two equations (32) *and* (33)*, a separating strategy brings short-term losses equal to*

$$(1-\delta)\left[\begin{array}{c}\max_{D_0}\left[E_{\mu_0}m+\theta s^g_{D_0}-L\left(s^g_{D_0},D_0\right)\right]\\-\left\{\mu_0\left[E_{\mu_0}m^b+\theta^b s^b_{\hat{D}}-L\left(s^b_{\hat{D}},\hat{D}\right)\right]+(1-\mu_0)\left[E_{\mu_0}m^g+\theta^g\sigma^g_{\hat{D}}-L\left(\sigma^g_{\hat{D}},\hat{D}\right)\right]\right\}\end{array}\right] \tag{34}$$

while long-term gains are given by

$$\delta\left[\begin{array}{c}\mu_0\left[E_{\mu_0}m^b+\theta^b s^b_{D^b}-L\left(s^b_{D^b},D^b\right)\right]+(1-\mu_0)\left[E_{\mu_0}m^g+\theta^g s^g_0\right]\\-E_{\mu_0}\left[V_p(m,\theta,\phi)\right]\end{array}\right] \tag{35}$$

Applying Jensen's inequality to (34) *and* (35)*, we see that short-term losses are an increasing (and concave) function of μ_0, while long-term gains are a decreasing (and convex) function of μ_0. Thus, there exists $\hat{\mu}\in[0,1]$, such that for any initial beliefs μ_0,*

$$D_0 > \hat{D} \Leftrightarrow \mu_0 > \hat{\mu}.$$

■

These results can well be summarized in figure (4). The horizontal line graphs μ_0, agents' priors that the Central Bank is of type b. A high value of μ_0 thus indicates a low credibility. The vertical axis plots the corresponding initial levels of dollar-denominated liabilities. The dotted line is the linearized one-period optimal level of dollar-debt, while the plain line is the dynamic optimal level. Although the true type is $\phi^g(.)$, yet agents set off with "bad" priors about the Central Bank, not only don't they wish to experiment and give authorities a chance to prove their good behavior, but they take on high levels of dollar-debt, which makes separating equilibria not sustainable (right). With "better" priors about the parameters of the economy, agents are willing to experiment, taking on smaller dollar denominated loans than their priors would have suggested in a static game (center). Finally, when dollarization levels are low anyway, experimentation does not involve any additional cost in terms of short-term suboptimal portfolio composition (left).

4.4.3 Equilibrium Dynamics

In the previous paragraphs, we characterized pooling and separating equilibria. We have seen that once separation occurs at a given period, then there is separation ever after, and dollar-debt holdings are unconstrained-optimal. Given that the true type of the Central Bank is $\phi^g(.) = 0$ the question is to know whether and under what conditions imperfect learning can arise. Obviously, if agents start with single-valued priors, no learning takes place and they keep these priors for ever. Similarly, if agents put a zero-probability on the true parameters (m^g, θ^g, ϕ^g) then, imperfect learning will trivially persist. Finally, it is possible that an economy which starts with priors $\mu_0(.)$ such that $(m^g, \theta^g, \phi^g) \in Supp(\mu_0)$ will remain for ever with such beliefs. The next proposition formulates the result:

Proposition 8 *Let's consider some stationary beliefs $\mu_\infty(.)$, along with an infinite sequence of pooling equilibria, such that $(m^g, \theta^g, \phi^g) \in Supp(\mu_\infty)$ and $\mu_\infty(.)$ verifies (23) and (24). For any initial distribution of beliefs $\mu_0(.)$, such that $Supp(\mu_0) = Supp(\mu_\infty)$, the following propositions hold:*

- *If $\mu_0(m^g, \theta^g, \phi^g) \leq \mu_\infty(m^g, \theta^g, \phi^g)$, then $\mu_t(.)$ converges to some stationary beliefs characterized by imperfect learning with probability 1.*
- *If $\mu_0(m^g, \theta^g, \phi^g) > \mu_\infty(m^g, \theta^g, \phi^g)$, then $\mu_t(.)$ converges to some stationary beliefs characterized by imperfect learning with positive probability.*

Proof. *This proposition is a result proved in McLennan (1984), and replicated in Piketty (1995).* ■

We thus showed that economies that are very similar in many respects, can have very different equilibrium trajectories. In any neighborhood of $\hat{\mu}$, identical countries that differ only by initial priors can experience drastically different behavior from investors. Under some conditions of the parameters of the economy, namely $\hat{\mu} > \mu_\infty$, identical countries with identical priors have a positive probability to be on two different long-run trajectories.

5 Policy Implications

Throughout this paper we have discussed cases in which imperfect learning can lead to sub-optimal levels of dollarized liabilities. Our argument therefore reinforces the commonly accepted wisdom that Central Bank's independence is a central element in a sound monetary policy. However, we have clear-cut predictions as to the taxation of dollar-debt. As discussed in section 4 dollar-debt makes separating equilibria costly. A tax on dollar-debt will "encourage" agents to lower their dollar-debt holdings giving the authorities a chance to prove their good behavior. We are aware that many of these issues have been discussed extensively in the literature of monetary policy. Our contribution is to emphasize that dollarization of liabilities provides an additional justification for providing markets with the means to identify the relevant parameters in the economy.

5.1 Central Bank's Independence and Transparency

Even though the case for Central Bank's independence and transparency is not new, our paper reinforces the argument by emphasizing the need to convey credible information to markets. Not only does Central Bank's independence mitigate the political economy issue at the heart of the problem (the function $\phi(.)$) but a verifiable mandate allows the market to take decisions under perfect information, at least along the dimension of interest in this paper. In a recent article regarding the situation in Argentina, Caballero and Dornbusch (2002) emphasized this need for credibility to overcome existing devaluation priors:

> Specifically, a board of experienced foreign central bankers should take control of Argentina's monetary policy. This would have many of the virtues of a currency board without the costs of having to adopt a monetary policy tailored to somebody else's needs. The new pesos should not be printed on Argentine soil.

Our paper makes the case that if Central Bank independence is a first-best solution, transparency is crucial to achieve the second-best.

5.2 Taxation of Dollar Liabilities

This section is devoted to the determination of the tax policy on dollar debt that induces a separating equilibrium to form at time t. We are interested in looking at the tax policy that a Central Bank without devaluation bias (i.e. $\phi(.) = 0$, the "good" Central Bank as we have been referring to so far) should adopt when she faces priors $\mu_t(.)$ about her type.

The timing of the game is the following:

- The government observes agents priors $\mu_t(.)$ and sets a tax on dollar-debt τ_t.
- Agents make their portfolio decisions
- The Central Bank sets an exchange rate policy
- Output is realized, beliefs are updated and bequeathed.

We assume that tax revenues are redistributed to agents in the form of a lump-sum transfer at the end of the period. We also make the critical assumption that a tax level τ_t does not convey information about the type of the Central Bank that agents may face. Thus, a fiscal incentive choice τ_t is no signaling device. In addition, taxation adds an additional distortionary cost $\gamma(\tau_t)$, increasing and convex. Such cost is borne by entrepreneurs. A simple backward induction argument will guide our subsequent discussion.

5.2.1 A separating tax incentive

In this paragraph, we characterize the fiscal incentive that the government should design in order to allow the "good" Central Bank to build credibility in the subsequent period. The government

thus internalizes the behavior of each of the agents in the economy: given agents' priors $\mu_t(.)$ and the tax scheme τ_t, debt contracts are determined by

$$(d_t, D_t) \in \arg\max_{d,D} E_{\mu_t}\left\{E_x\left[Y\left(x|s,D\right)|m,\theta,\phi\right]\right\} - \tau_t D \tag{36}$$

subject to:

- A type-b Central Bank reaction function:

$$s = s_D$$

  where $\forall D \geq 0$, s_D is defined by

$$\theta^b + \phi'\left(s_D\right) = L_s\left(s_D, D\right)$$

- A type-g Central Bank reaction function defined by (29):

$$s = \sigma_D^G$$

- and lenders' break-even condition[10]:

$$E_{\mu_t}\left[d + (1+s)D\right] = 1 + E_{\mu_t}\int_0^{d+(1+s)D} F\left(Y|m,\theta,s,D\right)dY.$$

The first-order condition gives a dollarization choice D_t satisfying:

$$E_{\mu_t}\left[\left(\frac{ds}{dD}\right)_{D_t}\left[\theta - L_s\left(s,D_t\right)\right] - L_D\left(s,D_t\right)\right] = \tau_t. \tag{37}$$

The optimal tax policy is then defined as the level of taxation τ_t that induces separation at lowest cost. Thus (36) implicitly assumed that separation occurs after t. Type-g Central Bank sets a tax level in order to maximize

$$\max_{\tau} E_x\left[Y\left(x|s,D\right)\right] - \gamma\left(\tau\right) \tag{38}$$

subject to agents' reaction function (37)

$$E_{\mu_t}\left[\left(\frac{ds}{dD}\right)_{D_t}\left[\theta - L_s\left(s,D_t\right)\right] - L_D\left(s,D_t\right)\right] = \tau_t, \tag{39}$$

the separation condition:

$$D_t \leq \hat{D}, \tag{40}$$

and the now standard Central Bank's reaction function (12) and the lender break-even condition (11).

[10] The break-even condition is unchanged as we assume that tax revenues are redistributed through lump-sum transfers, so that they increase pledgeable income by the same amount.

Additional regularity assumptions on the functions involved in the model allow us to apply the local inversion theorem to (37) in order to get for any $D_t \leq \hat{D}$,

$$\left(\frac{dD_t}{d\tau}\right)_{\tau_t} = E_{\mu_t}\left[\theta\left(\frac{d^2 s}{dD^2}\right)_{D_t} - \left(\frac{d^2 L(s,D)}{dD^2}\right)_{D_t}\right]^{-1} < 0.$$

An increase in the level of taxation decreases the initial level of dollar-debt that agents are willing to take. Such preliminary analysis finally yields the first-order conditions for an interior choice of a tax level τ_t:

$$\left(\frac{dD_t}{d\tau}\right)_{\tau_t}\left[\left(\frac{d\sigma_D^g}{dD}\right)_{D_t}\left[\theta^g - L_s\left(\sigma_{D_t}^g, D_t\right)\right] - L_D\left(\sigma_{D_t}^g, D_t\right)\right] = \gamma'(\tau_t). \tag{41}$$

The government trades off the distortionary costs of taxation (right-hand side of (41)) with the experimentation costs when dollarization levels are high (left-hand side of (41)). Indeed, an increase in the tax rate creates an incremental distortion, but by decreasing the initial level of dollarization, makes a separating strategy less costly in terms of foregone short-term productivity.

5.2.2 A pooling tax incentive

If priors about the Central Bank's type are bad enough, the equilibrium distortionary cost of taxation $\gamma(\tau_t)$ might not be worth paying. Yet, although time t outcome does not imply separation of Central Bank's types, tax incentives are beneficial as they reduce the distortionary cost of excessive dollar-denominated liabilities. Similarly to the previous paragraph, the government chooses a level of taxation τ_t in order to solve the program:

$$\max_{\tau} E_x\left[Y(x|s,D)\right] - \gamma(\tau)$$

subject to agents' reaction function

$$\left[\left(\frac{ds_D}{dD}\right)_{D_t}\left[E_{\mu_t}(\theta) - L_s(s_D, D_t)\right] - L_D(s_D, D_t)\right] = \tau_t, \tag{42}$$

and the Central Bank's reaction function (12) and the lender break-even condition (11). Note that in the pooling case, agents expect the Central Bank to adopt an exchange rate policy s_D, defined regardless of its type by (12). An identical procedure implies that levels of dollar-denominated liabilities decrease when τ_t increases, according to

$$\left(\frac{dD_t}{d\tau}\right)_{\tau_t} = \left[E_{\mu_t}(\theta)\left(\frac{d^2 s_D}{dD^2}\right)_{D_t} - \left(\frac{d^2 L(s_D, D)}{dD^2}\right)_{D_t}\right]^{-1} < 0$$

so that the type-g government now faces the trade-off:

$$\left(\frac{dD_t}{d\tau}\right)_{\tau_t}\left[\left(\frac{ds_D^g}{dD}\right)_{D_t}\left[\theta^g - L_s\left(s_{D_t}^g, D_t\right)\right] - L_D\left(s_{D_t}^g, D_t\right)\right] = \gamma'(\tau_t). \tag{43}$$

In this case, the government trades off the distortionary costs of taxation (right-hand side of (43)) and the distortionary costs of excess dollarization levels (left-hand side of (43)). A marginal increase in the tax rate will create a marginal distortion, but at the same time will reduce dollarization levels, relaxing the pressure on exchange rate policy.

5.2.3 Towards an optimal tax policy

Conditions (41) and (43) define the optimal one-period tax rate in the events of separation or pooling respectively. Whether the government wants to achieve separation in the first place or delay such intervention then depends on the equilibrium path of beliefs and the discount rate δ. In the current version of the draft, we will not formally characterize the optimal tax scheme. Yet, we want to provide some intuition regarding the tensions involved. A costly (separating) intervention will always be worth undertaking when agents are patient enough. This being said, the right timing of the intervention will crucially depend on the pre-intervention learning path. However, in cases where agents are eventually learning, the implementation of a separating tax policy trades off the distortionary losses of taxation and the the learning speed. Thus if agents are learning quickly enough, it might be optimal not to appeal to separating taxes and restrict attention to mitigating short-term distortions stemming from excess dollarization. The reverse holds when agents are learning slowly the true parameters of the economy or they are not learning at all and converge towards a dollarization trap.

6 Concluding Remarks

In this paper, we argued that dollarized liabilities, by creating a disciplining effect on the Central Bank, can help correct a devaluation bias. However, when information is imperfect, the economy can be stuck in a dollarization trap: a benevolent Central Bank that lacks credibility may face high levels of dollarization, making a stabilization monetary policy hard to implement and, at the same time, making it costly to build credibility. We analyzed the optimal tax schemes that governments should design to mitigate the short-term distortions due to excess levels of dollarized liabilities and to allow long-term learning, thus avoiding dollarization traps.

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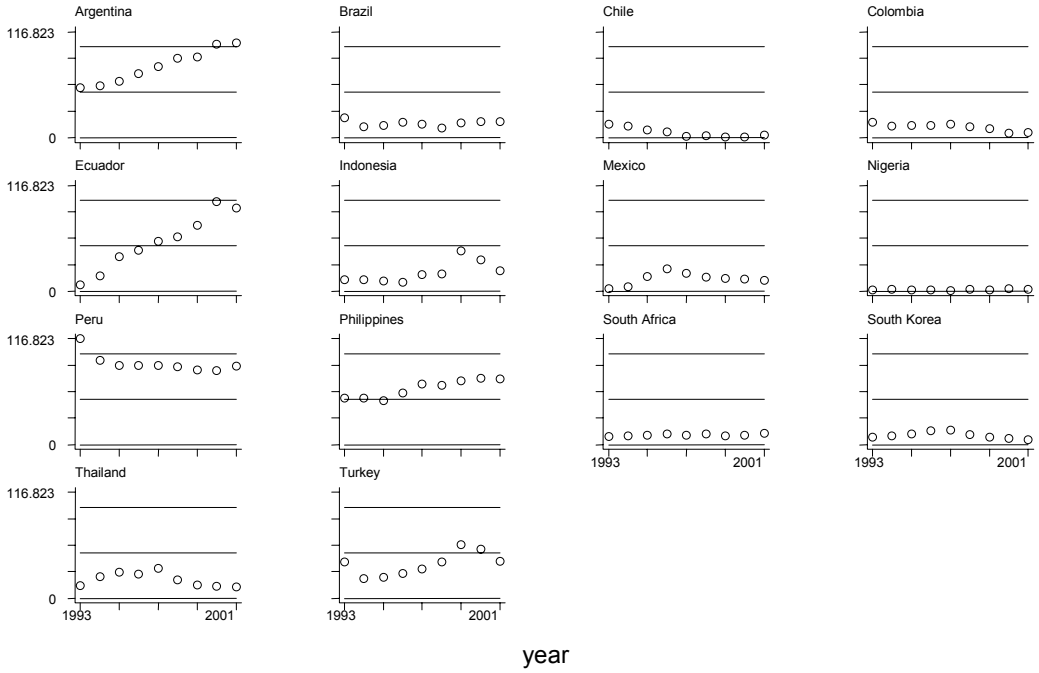
Table 1. Bank Concentration

Three largest banks Assets/Total Assets

	Region		
year	Latin America	East Asia	Eastern Europe
1990	*0.70*	*0.63*	*0.80*
1991	*0.74*	*0.59*	*0.84*
1992	*0.67*	*0.55*	*0.74*
1993	*0.56*	*0.59*	*0.67*
1994	*0.51*	*0.46*	*0.61*
1995	*0.47*	*0.46*	*0.59*
1996	*0.48*	*0.45*	*0.56*
1997	*0.55*	*0.51*	*0.67*
1990-1997	*0.57*	*0.53*	*0.67*

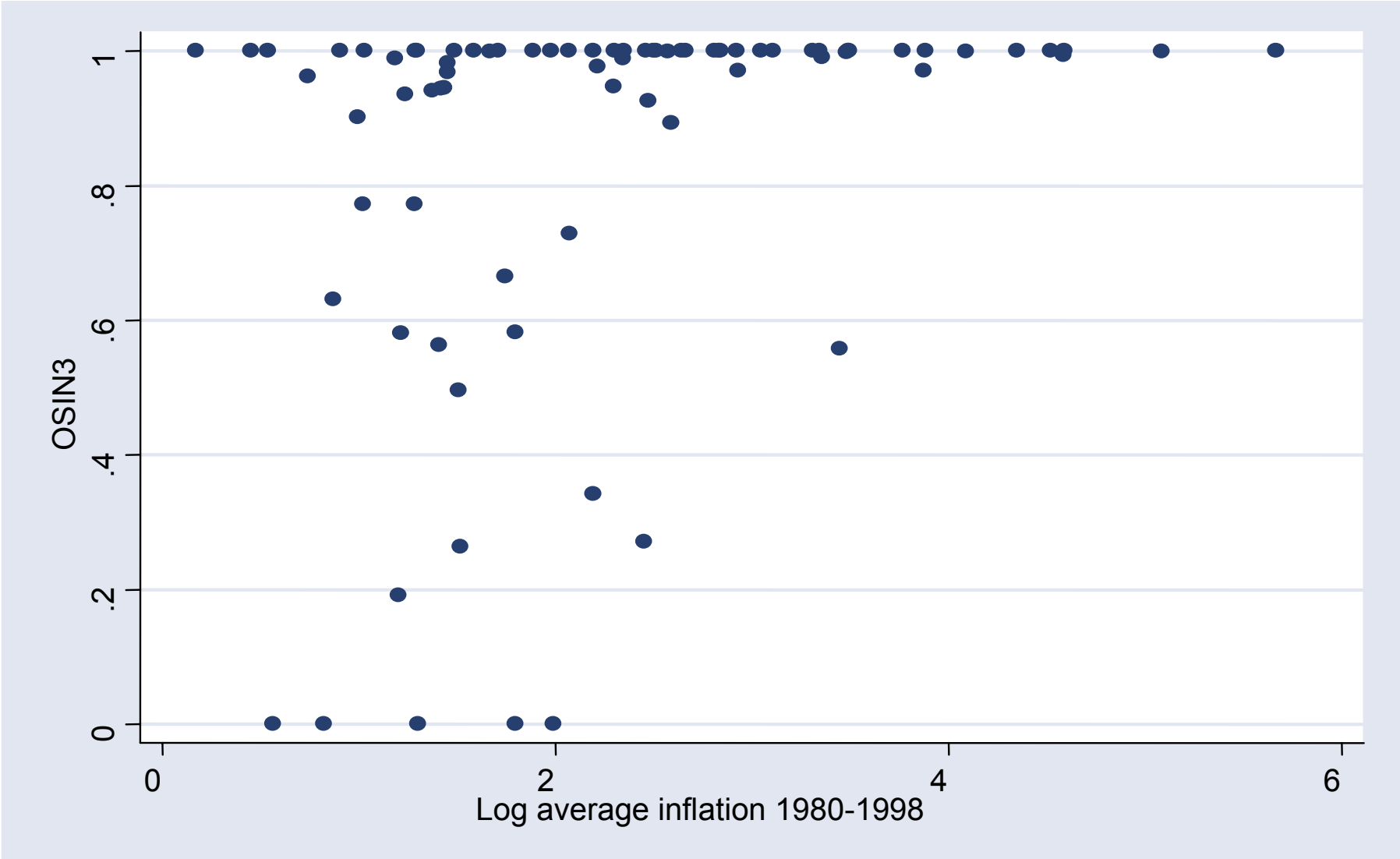
Source: Beck, et. al. (1999) "A New Database on Financial Development and Structure", Working Paper 2146, World Bank.

Figure 1: Dollar-Denominated Liabilities to Total Credit



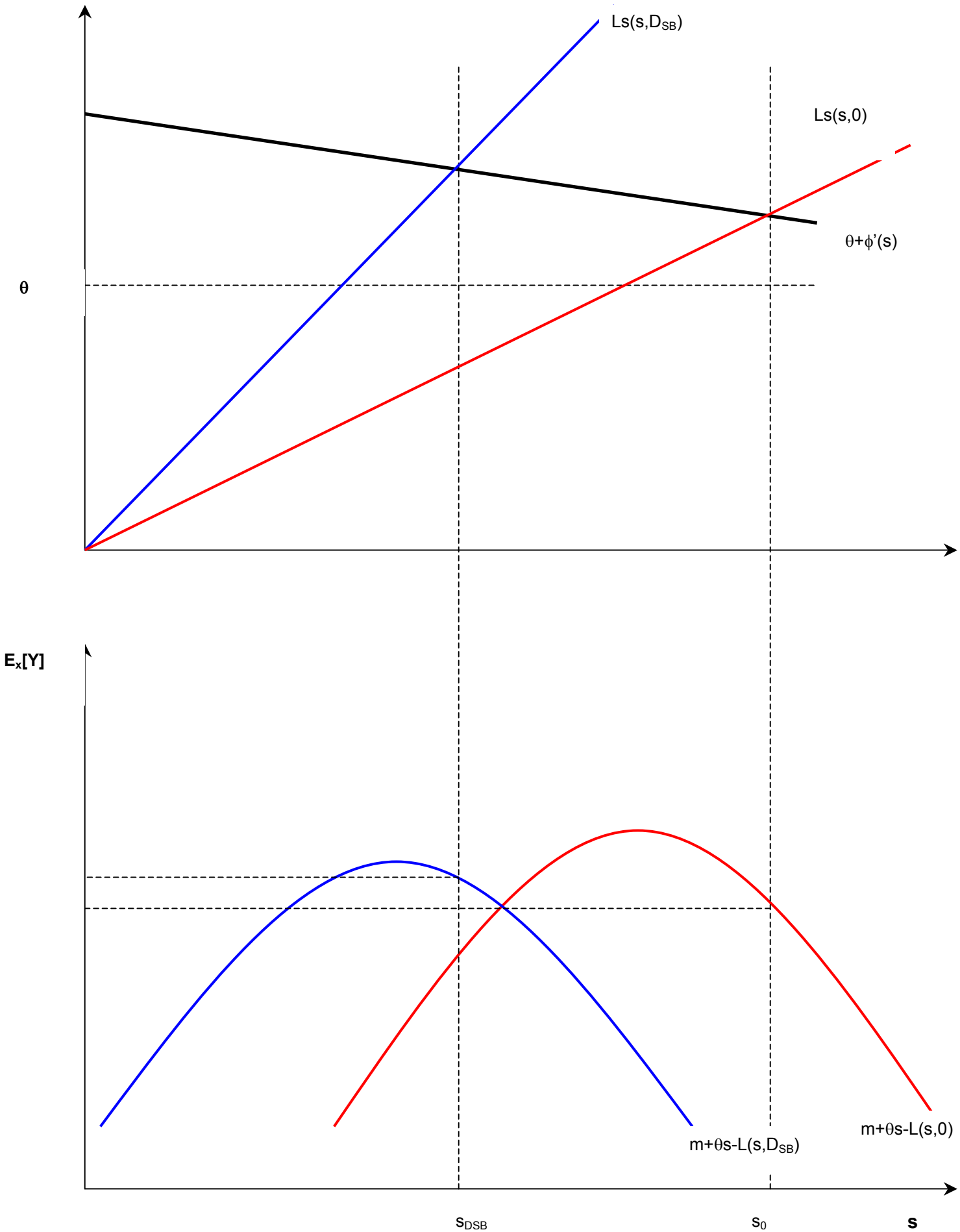
Source:
This variable if from Calvo and Izquierdo (2003) and is calculated as the ratio of dollar-denominated liabilities to total credit, where we proxy the former as the sum of dollar deposits and foreign liabilities. The data regarding dollar deposits is hard to come by with, particularly for countries with low levels of liability dollarization. Therefore, the authors assume this variable equal to zero for those countries whose Central Bank does not publish this information. Apart from this measure, all series are from the IFS (IMF).

Figure 2: Inflation and Original Sin



Source: Hausmann and Panizza (2002)

Figure 3. The Full Information Optimum



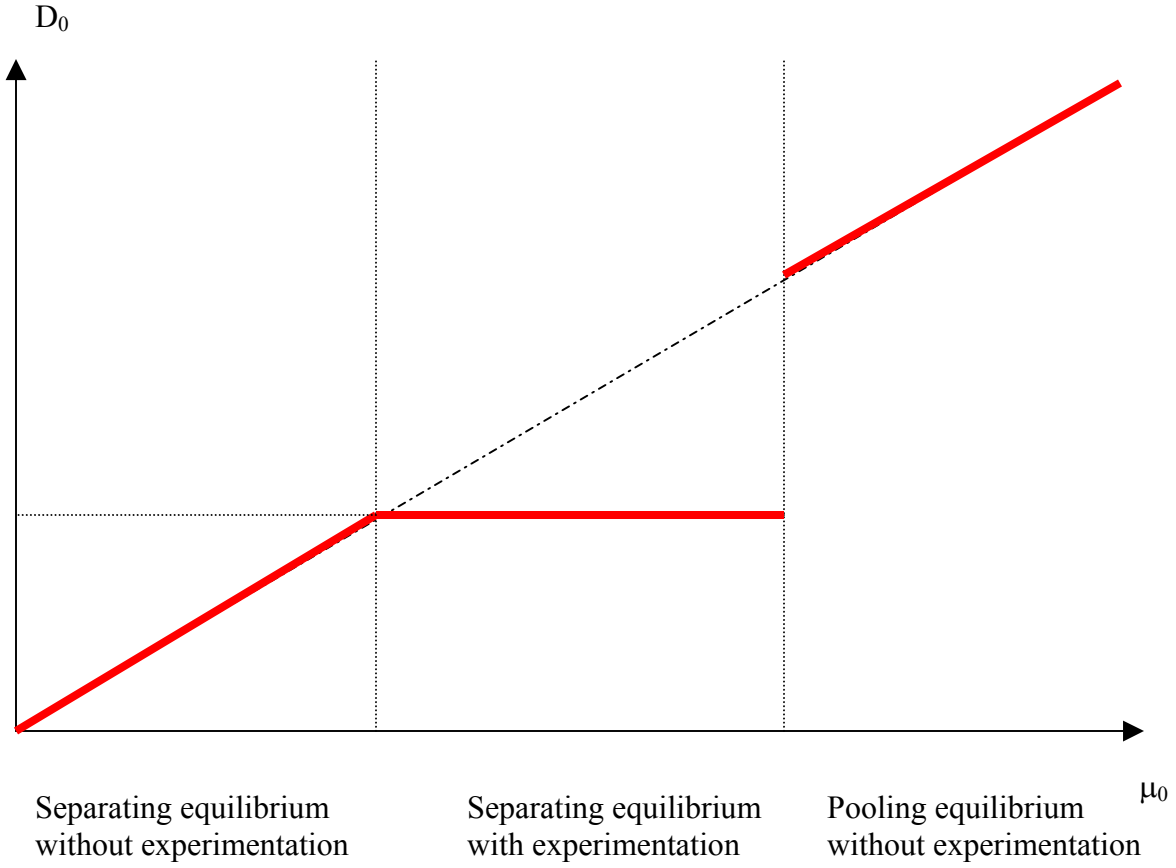


Figure 4. Initial Priors and Equilibrium Outcomes