A Model of the International Monetary System

Emmanuel Farhi*　　Matteo Maggiori†

March 2017

Abstract

We propose a simple model of the international monetary system. We study the world supply and demand for reserve assets denominated in different currencies under a variety of scenarios: a Hegemon vs. a multipolar world; abundant vs. scarce reserve assets; a gold exchange standard vs. a floating rate system. We rationalize the Triffin dilemma, which posits the fundamental instability of the system, as well as the common prediction regarding the natural and beneficial emergence of a multipolar world, the Nurkse warning that a multipolar world is more unstable than a Hegemon world, and the Keynesian argument that a scarcity of reserve assets under a gold standard or at the zero lower bound is recessionary. Our analysis is both positive and normative.

JEL Codes: D42, E12, E42, E44, F3, F55, G15, G28.
Keywords: Reserve currencies, Triffin Dilemma, Great Depression, Gold-Exchange Standard, ZLB, Nurkse Instability, Confidence Crises, Safe Assets, Exorbitant Privilege.

*Harvard University, Department of Economics, NBER and CEPR. Email: farhi@fas.harvard.edu.
†Harvard University, Department of Economics, NBER and CEPR. Email: maggiori@fas.harvard.edu.

We thank Pol Antras, Julien Bengui, Guillermo Calvo, Dick Cooper, Ana Fostel, Jeffry Frieden, Mark Gertler, Gita Gopinath, Pierre-Olivier Gourinchas, Veronica Guerrieri, Guido Lorenzoni, Arnaud Mehl, Brent Neiman, Jaromir Nosal, Maurice Obstfeld, Jonathan Ostry, Helene Rey, Kenneth Rogoff, Jesse Schreger, Andrei Shleifer, Jeremy Stein, and seminar participants at the NBER (IFM, MEFM, EFMB), University of California Berkeley, University of Chicago Booth, Yale University, Boston College, Boston University, Stanford (GSB, Econ Dept.), MIT Sloan, LSE, LBS, Oxford University, Imperial College, PSE Conference of Sovereign Risk, Harvard University, CREI-Pompeu Fabra, Brown University, Yale Cowles Conference on General Equilibrium Theory, Einaudi Institute, Toulouse School of Economics, University of Virginia, University of Lausanne, IEES, IMF, ECB, BIS, Boston Fed, ECB-Fed biennial joint conference, Minnesota workshop in macroeconomic theory, Wharton conference on liquidity, Bank of Italy, Boston Fed, Bank of Canada annual conference, Hydra conference, SED, Econometric Society, Chicago Booth junior conference in international macro-finance, CSEF-IGIER Symposium on Economics and Institutions. We thank Michael Reher for excellent research assistance. Maggiori gratefully acknowledges the financial support of the NSF (1424690), and Weatherhead Center for International Affairs at Harvard University.

1 Introduction

Throughout history, the International Monetary System (IMS) has gone through radical transformations that have shaped global economic outcomes. It has been the constant focus of world powers, has fostered innumerable international policy initiatives, and has captured the imagination of some of the best economic minds. Yet it remains an elusive topic with little or no intellectual organizing framework. A manifestation of this fuzziness is that, even among economists, there is no consensus regarding the defining features of the IMS.

We consider the IMS as the collection of three key attributes: (i) the supply of and demand for reserve assets; (ii) the exchange rate regime; and (iii) international monetary institutions. A major contribution of our paper is to show how the modern theoretical apparata developed to analyze sovereign debt crises, oligopolistic competition, and Keynesian macroeconomics, can be combined to build a theoretical equilibrium framework of the IMS.[1] Our framework provides a collection of new insights. It also allows us to match the historical evidence, to make sense of the leading historical debates, and to demonstrate their current relevance.

The key ingredients of the model are as follows. World demand for reserve assets arises from the presence of international investors in the Rest of the World (RoW) with mean-variance preferences. Risky assets are in elastic supply, but safe (reserve) assets are supplied by either one (monopoly Hegemon world) or a few (oligopoly multipolar world) risk-neutral reserve countries under Cournot competition. Reserve countries issue reserve assets that are denominated in their respective currencies and have limited commitment. Ex-post, in bad states of the world, they face a trade-off between on the one hand devaluing their currencies and inflating away the debt to limit real repayments, and on the other hand incurring the resulting "default cost"; ex-ante, they issue debt before interest rates are determined. This allows for the possibility of self-fulfilling confidence crises à la Calvo (1988).

The model is both flexible and modular. It allows us to incorporate a number of important additional features: nominal rigidities under either a gold-exchange standard or a system of floating exchange rates, liquidity preferences and network effects, fiscal capacity, currency of pricing, endogenous reputation, and private issuance. The model is solvable with pencil and paper and delivers closed-form solutions.

We begin our analysis with the case of a monopoly Hegemon issuer. The IMS consists of three successive zones that correspond to increasing levels of issuance: a Safety zone, an Instability zone, and a Collapse zone. In the Safety zone, the Hegemon never devalues its currency, irrespective of investor expectations. In the Instability zone, the Hegemon only devalues its currency when it is confronted with unfavorable investor expectations. Finally, in the Collapse zone, the Hegemon always devalues its cur-

[1] A non-exhaustive list of the relevant sovereign default literature, following Eaton and Gersovitz (1981), includes contributions to the study of self-fulfilling debt crises (Calvo (1988), Cole and Kehoe (2000), Aguiar et al. (2016)), and of contagion (Lizarazo (2009), Arellano and Bai (2013), Azzimonti, De Francisco and Quadrini (2014), Azzimonti and Quadrini (2016)). While we show that tools from the sovereign default literature are useful to understand some features of the IMS, our focus and model are different from this literature. We focus on the issuance of safe assets, while the sovereign debt literature focuses on risky debt; we provide results on social welfare under monopolistic issuance and analyze the effects of oligopolistic competition on the issuance of safe assets.

rency, once again irrespective of investor expectations.

In this setting, the Hegemon obtains monopoly rents in the form of a positive endogenous safety premium on reserve assets. The trade-off between maximizing monopoly rents and minimizing risk confronts the Hegemon with a stark choice: restrict its issuance or expand it at the cost of risking a confidence crisis. We show that this dilemma is exacerbated in situations in which the global demand for reserves outstrips the safe debt capacity of the Hegemon.

In addition to its positive predictions, the model also lends itself to a normative analysis. Contrary to the intuition that the monopoly distortion present in our model should lead to under-issuance, we show that the Hegemon may either under- or over-issue from a social welfare perspective. We trace this surprising result to the fact that the Hegemon's decisions involve not only the traditional quantity dimension, but also an additional risk dimension: by issuing more and taking the risk of a confidence crisis, the Hegemon fails to internalize the risk of destroying the infra-marginal surplus of the rest of the world. This infra-marginal surplus is higher, and hence over-issuance is more likely to obtain, the more convex the demand curve for reserve assets. We draw an analogy with the classic monopoly theory of quality developed by Spence (1975) in a context in which quality is related to quantity via an endogenous equilibrium mapping.

These results rationalize the famous Triffin dilemma (Triffin (1961)). In 1959, Triffin exposed the fundamental instability of the Bretton Woods system and predicted its collapse; he foresaw that the U.S., confronted with a growing foreign demand for reserve assets from the rest of the world, would eventually stretch itself so much as to become vulnerable to a confidence crisis that would force a devaluation of the Dollar. Indeed, time proved Triffin right. Faced with a full-blown run on the Dollar, the Nixon administration first devalued the Dollar against gold in 1971 (the "Nixon shock") and ultimately abandoned convertibility and let the Dollar float in 1973.

Despres, Kindleberger and Salant (1966) dismissed Triffin's concerns about the stability of the U.S. international position by providing a "minority view", according to which the U.S. acted as a "world banker" providing financial intermediation services to the rest of the world: the U.S. external balance sheet was therefore naturally composed of safe liquid liabilities and risky illiquid assets. They considered this form of intermediation to be natural and stable.

Our model offers a bridge between the Triffin and minority views: while our model shares the latter's "world banker" view of the Hegemon, it emphasizes that banking is a fragile activity that is subject to self-fulfilling runs during episodes of investor panic. Importantly, the runs in our model pose a much greater challenge than runs on private banks à la Diamond and Dybvig (1983), as there is no natural Lender of Last Resort (LoLR) with a sufficient fiscal capacity to support a Hegemon of the size of the U.S.

Our theoretical foundations allow us to be much more precise than this earlier informal literature was. The model identifies the relevant indicator of the underlying fragility as the gross external debt position of the Hegemon, and not its net position, as sometimes hinted at by Triffin. It allows us to clarify how the problem is in part external, as originally emphasized by Triffin, and also in part fiscal as recently conjectured by Farhi, Gourinchas and Rey (2011) and Obstfeld (2011). It also enables us to make predictions regarding the factors that are likely to accentuate the dilemma, and to identify possible remedies.

We show that the deeper logic that underlies the Triffin dilemma extends well beyond this particular historical episode. Indeed, it can be used to understand how the expansion of Britain's reserves ultimately led to a confidence crisis on Sterling — partly due to France's attempts to liquidate its sterling reserves — which resulted in the devaluation of Sterling in 1931 and forced the U.K. off the gold-exchange standard. Similarly, the U.S., the other meaningful issuer of reserve assets at the time, faced a confidence shock following Britain's devaluation, and ultimately also had to devalue in 1933 (see Figure 1 Panel (c)). Figure 1 Panel (a) illustrates the creation, expansion, and demise of the gold-exchange standard of the 1920s: monetary reserve assets expanded as a percentage of total reserves from 28% in 1924 to 42% in 1928, but then shrank to 8% by 1932.

Our model shows that the core of the Triffin logic transcends the particulars of exchange rate regimes. It does not rely on the gold-exchange standard, and it is relevant to the current system of floating exchange rates, because reserve assets embed the implicit promise that the corresponding reserve currencies will not be devalued in times of crisis. The model cautions that the high demand for reserves in the post-Asian-crisis global-imbalances era may activate the Triffin margin. Indeed, Gourinchas and Rey (2007*a*,*b*) have documented that the U.S. activities as a world banker are today performed on a much grander scale than when originally debated in the 1960s.[2] In other words, the "bank" has gotten bigger and so have the fragility concerns emphasized by our model. The U.S. external debt, which currently stands at 158% of GDP and of which 85% is denominated in dollars, heightens the possibility of a Triffin-like event. A number of economists have warned against a possible sudden loss of confidence in the Dollar: perhaps most prominently, Obstfeld and Rogoff (2001, 2007) have argued that the likely future reversal of the U.S. current account would lead to a 30% depreciation of the Dollar.

Our model uncovers an important interaction between the Triffin logic and the exchange rate regime. To understand this interaction, we introduce nominal rigidities, gold, and study a gold-exchange standard. We model gold as a reserve asset and the gold-exchange standard as a monetary policy regime that maintains a constant nominal price of gold in all currencies. The gold parity completely determines the stance of monetary policy (the interest rate), thus leaving no room for domestic macroeconomic stabilization: a lower price of gold is associated with tight-money (a higher interest rate). Fluctuations in the demand/supply of reserve assets affect the "natural" interest rate (the real interest rate consistent with full employment). Since the nominal interest rate cannot adjust, this results in fluctuations in output. Recessions occur when reserve assets are "scarce", i.e. when there is excess demand for reserve assets at full employment and at prevailing world interest rates.

The structure of the IMS can therefore catalyze the sort of recessionary forces emphasized by Keynes (1923). Keynes argued not only that the world should not return to a gold standard, in order to free up monetary policy for domestic stabilization, but also that, if the world were to return to a gold standard,

[2] A recent theoretical literature has predominantly focused on the asymmetric risk sharing between the U.S. and RoW (Bernanke (2005), Gourinchas and Rey (2007*a*), Caballero, Farhi and Gourinchas (2008), Caballero and Krishnamurthy (2009), Mendoza, Quadrini and Rıos-Rull (2009), Gourinchas, Govillot and Rey (2011), Maggiori (2012)).

it should not do so at pre-WWI parities because the ensuing tight money policy would be recessionary. These arguments were not successful in the short run, and by the time of the Genoa conference in 1922 the world was largely back on a tight gold standard. The conference, however, recognized the reserve-scarcity argument and attempted to solve it by expanding the role of monetary assets as reserves in addition to gold (see Figure 1 Panel (a)), thereby giving rise to a gold-exchange standard.

We show that the Triffin dilemma is particularly acute under a gold-exchange standard. Indeed in such a regime, the Hegemon faces a perfectly elastic demand curve which increases its incentives to issue. However, the Hegemon's issuance capacity might not be sufficient to prevent a world recession. A confidence shock has particularly severe repercussions in this setting since, by wiping out the effective stock of reserves, it causes an even more severe recession. Furthermore, for any given level of issuance, confidence crises are more likely since the Hegemon now faces an extra ex-post incentive to devalue in order to stimulate its economy. Such domestic output stabilization considerations played an important role in the U.K.'s decision to devalue Sterling in 1931, and the U.S.'s decision to devalue the Dollar in 1933 and again in 1971-73.

Under a floating exchange rate regime, away from the Zero Lower Bound (ZLB), world central banks can adjust interest rates and stabilize output. At the ZLB, interest rates are fixed and the economics of the IMS mimic those of the gold-exchange standard. Hence, our model draws a profound parallel between the events and debates of the 1920s and 1960s and those of our time.[3] It also links two frequently-opposed views: the Keynesian view that emphasizes the expansionary effect of debt issuance, and the financial stability view that stresses the associated real economic risks. In our model, at the ZLB, the Hegemon faces increased incentives to issue and take the risk of a crisis (as in the financial stability view), its issuance stimulates output as long as no crisis occurs (as in the Keynesian view), but the crisis, if it occurs, is amplified by Keynesian mechanisms.

Until this point, we have focused on an IMS that is dominated by a Hegemon with a monopoly over the issuance of reserve assets. Of course, this is a simplification. Historically, the IMS under the gold-exchange standard of the 1920s was multipolar with the U.K. and the U.S. as a de facto duopoly: Figure 1 Panel (b) shows that 52% and 47% of the world reserves were held in pounds and dollars, respectively, in 1928. While the current IMS is dominated by the U.S., it also features other, competing, issuers. Indeed, Figure 1 Panel (d) shows that the Euro and the Yen already play a reserve-currency role. There is speculation that the future of the IMS might involve other reserve currencies, such as the Chinese Renminbi.

We explore the equilibrium consequences of the presence of multiple reserve asset issuers for both the total quantity of reserve assets and for the stability of the IMS. More precisely, we analyze a multipolar world with oligopolistic issuers of reserve assets that compete à la Cournot. Under full commitment, competition increases the total supply of reserves, reduces the safety premium, and is therefore beneficial.

[3] Our results in Section 5 when we consider sticky prices at the ZLB are related to Caballero and Farhi (2014), Caballero, Farhi and Gourinchas (2016), Eggertsson and Mehrotra (2014), Eggertsson et al. (2016), who also investigate the potential recessionary effect of the scarcity of (reserve) assets, but do not take into account the oligopolistic nature of reserve issuance and the limited commitment of the issuers with the associated potential for crises.

Furthermore, the largest benefits accrue with the first few entrants. This paints a bright picture of a multipolar world, as extolled by Eichengreen (2011) among others.

Our analysis suggests that limited commitment may significantly alter this picture and render the benefits of competition U-shaped: a lot of competition is good, but a little competition may be of limited benefit or even detrimental. With a large number of issuers, total issuance is high but individual issuance is low and each issuer operates in its Safety zone, so that the equilibrium coincides with that under full commitment. A darker picture may emerge with only a few issuers if, as hypothesized by Nurkse (1944), the presence of several reserve assets worsens coordination problems and leads to instability as investors substitute away from one reserve asset and towards another. This warning is important given that, in practice, most multipolar scenarios only involve a limited number of reserve issuers.

Nurkse famously pointed to the instability of the IMS during the interregnum between Sterling and the Dollar. The 1920s were dominated by fluctuations in the share of reserves denominated in these two currencies (Eichengreen and Flandreau (2009)); it was precisely these frequent switches of RoW reserve holdings between the two currencies that led Nurkse to his skeptical diagnosis.

In our model, this possibility arises because limited commitment gives a central role to coordination among investors. For example, we show that when moving from a monopoly Hegemon to a duopoly, worsening coordination problems might not only lead to a less stable IMS but also to a fall in the total supply of reserve assets. This aspect of our work is complementary to He et al. (2015), who study the selection of reserve assets among two possible candidates using global games.

We also show that our framework can be generalized to capture a number of key additional aspects of the IMS. This highlights the versatility of our framework, and the fruitfulness of our approach. In the interest of space, we only briefly alert the interested reader to these extensions, in which we study: a micro-foundation of the cost of devaluations as the expected net present value of future monopoly rents accruing to a particular reserve issuer, highlighting another limit to the benefits of competition through the erosion of "franchise value"; private issuance of reserve assets; liquidity and network effects; fiscal capacity; currency of goods pricing; endogenous entry leading to a natural monopoly; the endogenous emergence of a Hegemon and its characteristics; and LoLR and risk-sharing arrangements to reduce the world demand for reserves.

2 The Hegemon Model

In this section, we introduce a baseline model that captures the core forces of the IMS. We consider the defining characteristics of reserve assets to be their safety and liquidity, and think of the world financial system as being characterized by a scarcity of such reserve assets, which can only be issued by a few countries. We trace the scarcity of reserve assets to commitment problems, which prevent most countries from issuing in significant amounts. In this section, we consider the limit case with only a single issuer (the Hegemon) of reserve assets. We later consider a multipolar model with several issuers in Section 6.

2.1 Model Setup

There are two periods ($t=0,1$) and two classes of agents: the Hegemon country and RoW, where the latter is composed of a competitive fringe of international investors. There is a single good. The Hegemon and RoW endowments of this good at $t=0$ are respectively w and w^*, where stars indicate RoW variables.

There are two assets: a risky real asset that is in perfectly elastic supply, and a nominal bond that is issued exclusively by the Hegemon and is denominated in its currency. There are two states of the world at $t=1$, indexed by H and L. The L state, which we refer to for mnemonics as a disaster, occurs with probability $\lambda \in (0,1)$. The risky asset's exogenous real return between time $t=0$ and $t=1$ is $R^r_H > 1$ in state H and $R^r_L < 1$ in state L. We define the short-hand notation $\sigma^2 = Var(R^r)$ and $\bar{R}^r = \mathbb{E}[R^r]$.[4]

The RoW representative agent does not consume at $t=0$ and has mean-variance preferences over consumption at time $t=1$ with risk aversion $\gamma > 0$ given by

$$U^*(C_1^*) = \mathbb{E}[C_1^*] - \gamma\, Var[C_1^*].$$

The Hegemon representative agent is risk neutral over consumption in both periods

$$U(C_0, C_1) = C_0 + \delta \mathbb{E}[C_1],$$

with a rate of time preference given by $\delta = 1/\bar{R}^r$ ensuring indifference with respect to the timing of consumption.

Devaluations. At time $t=1$, after uncertainty is resolved, the Hegemon chooses its nominal exchange rate. We denote the proportional change in the exchange rate by e, with the convention that a decrease in the exchange rate ($e<1$) corresponds to a devaluation. The real ex-post return of Hegemon bonds is Re, where $R = \tilde{R}/\Pi^*$ is the ratio of the nominal yield $\tilde{R}$ in the Hegemon currency determined at $t=0$, and the inflation rate Π^* in RoW, which we assume to be deterministic. For most of the paper, the reader is encouraged to think of $\Pi^* = 1$ (a simplification without loss of generality except for ZLB considerations).

In this baseline setup, we assume that deviations from some "commonly agreed-upon" path (i.e. a state-contingent plan) of the exchange rate generate a utility loss for the Hegemon (at $t=1$). We focus on the incentives of the Hegemon to devalue in bad rather than in good times by only allowing the Hegemon to devalue its currency in a disaster. This is a stylized way of capturing the notion that the temptation to devalue is higher after a bad shock. This would happen if the Hegemon were also risk averse with a decreasing marginal utility of consumption, but to a lesser extent than RoW.

For simplicity, we assume that the Hegemon can only choose two values of $e = \{e_H, e_L\}$,with $e_H = 1$ and $e_L < 1$. We assume throughout the paper that $e_L = R^r_L / R^r_H$. This assumption simplifies the analysis

[4] We take RoW to be composed of many countries and, within each country, many types of reserve buyers (central banks, private banks, investment managers, etc.). We therefore assume that RoW is competitive and takes world prices of assets as given. The reader can think of R^r as the return on a risky bond that is not a reserve asset. For simplicity, we introduce a single risky asset in the model, but one could also think more generally of many gradations of riskiness. We assume that RoW cannot short the Hegemon bond, i.e. it cannot issue the bond. This clarifies the nature of the monopoly of the Hegemon, but it is not a binding constraint since RoW is a purchaser of the bond in equilibrium.

at little cost to the economics by making the Hegemon debt, when it is risky, a perfect substitute for the risky asset.[5,6]

If the Hegemon chooses to devalue in a disaster, it pays a fixed utility cost $\tau(1-e_L) > 0$. The normalization by $1-e_L$ is introduced only for notational convenience and is innocuous since e_L is a fixed constant. This cost is exogenous in the present one-period setup and can be interpreted equally as a direct cost or as a reputation cost; indeed we formally show in Section 7 that it can be rationalized in a dynamic setting as the probabilistic loss of future monopoly rents (cheaper financing) that the Hegemon suffers after a devaluation of its currency in a stochastic-punishment equilibrium with grim trigger strategies.

The devaluation acts as a partial default. Indeed, in the baseline model of this section it is isomorphic to a partial default. In Section 5, in which we introduce nominal rigidities, this isomorphism breaks down since devaluations lead to changes in relative prices either between goods or between goods and gold, whereas partial defaults do not. We choose to model devaluations and not defaults because, historically, lower repayments by reserve issuers have always been achieved via devaluations and not via outright defaults (e.g. the U.K. in 1931, and the U.S. in 1933 and 1971-73).

Confidence crises. The timing of decisions follows the self-fulfilling crisis model of Calvo (1988). The timeline is summarized in Figure 2; here we describe the decisions starting from the last one and proceeding backwards. At $t=1$, after observing the realization of the disaster, the Hegemon sets its exchange rate by taking as given the interest rate on debt R and the amount of outstanding debt b to be repaid to RoW. At $t=0^+$, a sunspot is realized; the interest rate R on the quantity of debt b being sold by the Hegemon is determined, and RoW forms its portfolio. The sunspot ω takes realization s (for safe) with probability α, and r (for risky) with the complement probability. At time $t=0^-$, the Hegemon determines how much debt b to issue and its investment in the risky asset.

The crucial element in this Calvo timing is that the real value of nominal debt to be sold b is set before the interest rate to be paid on it R is determined, and cannot be adjusted depending on the interest rate. This timing generates the possibility of multiple equilibria, depending on RoW investors' expectations regarding the future exchange rate e in the event of a disaster. Indeed, as we shall see below, it gives rise to three zones for b: a Safety zone, an Instability zone, and a Collapse zone. In the Safety zone, $e=1$ independently of the realization of the sunspot, so that the Hegemon debt is safe. Conversely, in the Collapse zone, $e=e_L$ independently of the sunspot, so that the Hegemon debt is risky. In the Instability zone, $e=1$ and the Hegemon debt is therefore safe if the sunspot realization is s, and $e=e_L$ and the Hegemon debt is therefore risky if the sunspot realization is r.

Our decision to focus on strategic risk rather than fundamental risk is motivated by the historical evidence. The different incarnations of the IMS (e.g. the gold-exchange standard of the 1920s, and the Bretton Woods system of the 1950s-1960s) tend to be stable for considerable periods of time and

[5] In general, the elasticity of the demand for risky Hegemon debt is an increasing function of the covariance between the exchange rate and the return on the risky asset. Monopoly power and monopoly rents are a decreasing function of this covariance.

[6] As an extension, one can consider a different configuration with $e_H > 1$ and $e_L < 1$, which allows for the possibility of the reserve asset being a hedge (a negative "beta" asset) instead of a risk-less asset. We consider the risk-less configuration in this paper, as it provides most of the economics while making the model as simple as possible.

then collapse very abruptly in crises that resemble confidence crises both in the data and in the writings of contemporaries and economic historians. In modern economic theory, one prominent way to model confidence crises is via self-fulfilling mechanisms of the sort we adopt here. This is not to say that fundamental risk plays no role, and indeed many of our results would go through with fundamental shocks.

It is useful to define short-hand notation for expectation operators.

Definition 1 *We define $\mathbb{E}^+[x_1]$ to denote the expectation taken at time $t = 0^+$ of random variable x_1 the realization of which will occur at $t = 1$. We further define $\mathbb{E}^s[x_1]$ to be the expectation taken at $t = 0^+$ conditional on the safe realization of the sunspot, and $\mathbb{E}^r[x_1]$ to be the expectation taken at $t = 0^+$ conditional on the risky realization of the sunspot. We define $\mathbb{E}^-[x_1]$ to be the expectation taken at $t = 0^-$ before the sunspot realization.*

RoW demand function for debt. The RoW portfolio optimization problem at $t = 0^+$ is given by

$$\max_{b, C_1^*} \quad \mathbb{E}^+[C_1^*] - \gamma \, Var^+(C_1^*),$$

$$s.t. \quad w^* = x^* + b \quad x^* \geq 0 \quad b \geq 0,$$

$$x^* R^r + bRe = C_1^*,$$

where $x^* \geq 0$ and $b \geq 0$ denote investment in the world risky asset and in Hegemon debt respectively.

If the Hegemon debt is expected to be safe, then the optimality condition for the portfolio of RoW leads to a linear demand curve for Hegemon debt

$$R^s(b) = \bar{R}^r - 2\gamma(w^* - b)\sigma^2. \tag{1}$$

Interest rates increase with the amount of debt, and decrease with the risk aversion of RoW (γ), the background riskiness of the economy (σ^2), and the savings/endowment of RoW (w^*).[7]

If, instead, the Hegemon debt is expected to be risky, then it is a perfect substitute for the risky asset. No arbitrage then requires that $R = R_H^r$, so that $\mathbb{E}^r[Re] = \bar{R}^r$ and the demand for the Hegemon debt is infinitely elastic.[8]

The Hegemon issuance problem. Issuance by the Hegemon at $t = 0^-$ is the solution of the following problem

$$\max_{x, b, C_0, C_1(\omega)} \quad \mathbb{E}^-[C_0 + \delta(C_1(\omega) - \tau(1 - e(b, \omega)))],$$

[7]The demand for safe assets as a macroeconomic force has also been analyzed in different contexts by: Dang, Gorton and Holmstrom (2015), Gorton and Ordonez (2014), Moreira and Savov (2014), Gorton and Penacchi (1990), Gorton and Ordonez (2013), Hart and Zingales (2014), Greenwood, Hanson and Stein (2015), Gennaioli, Shleifer and Vishny (2012).

[8]Proposition A.1 in the appendix provides more details on the exclusion of the possibility of backward bending demand for risky debt. We impose the parameter restriction $\bar{R}^r - 2\gamma w^* \sigma^2 > 0$ to guarantee that the demand function never violates free disposal. The restriction ensures that yields on risk-free debt are always greater than -100%: i.e. prices of debt must be strictly positive. Violation of this condition would result in cases of arbitrage: debt could have negative prices despite having strictly positive payoffs.

$$s.t.\;\; w - C_0 = x - b,$$

$$xR^r - bR(b,\omega)\, e(b,\omega) = C_1(\omega),$$

$$b \geq 0 \quad x \geq 0,$$

where $x \geq 0$ is investment in the risky asset, $R(b,\omega)$ is the function that maps the amount of debt being issued at $t = 0^-$ and the sunspot realization into the equilibrium interest rate, and $e(b,\omega)$ is the function that maps the outstanding debt and the sunspot realization into the equilibrium exchange rate at $t = 1$.

This problem can be rewritten in the following intuitive form

$$\max_{b\geq 0} \quad b\left(\bar{R}^r - \mathbb{E}^-[R(b,\omega)e(b,\omega)]\right) - \mathbb{E}^-[\tau(1-e(b,\omega))]. \tag{2}$$

The Hegemon takes into account the effects of its issuance on the interest rate on its debt as well as on its future incentives to devalue at $t = 1$ in case of a disaster depending on the realization of the sunspot at $t = 0^+$. Note that the Hegemon is indifferent between investing in the risky asset, to be consumed at time $t = 1$, and consuming the proceeds of the debt sale b at time $t = 0$. The term $b\bar{R}^r$ in equation (2) captures these benefits.[9]

2.2 Full-Commitment Equilibrium

To build intuition and a reference point for future outcomes, we first solve the baseline model under full commitment. That is, we assume that the Hegemon can commit to the future exchange rate when deciding how much debt to issue at time $t = 0^-$ or, equivalently, that $\tau \to \infty$, so that there is an infinite penalty for devaluing. In this case, the Hegemon never devalues ($e(b,\omega) = 1$) and its debt is always safe ($R(b,\omega) = R^s(b)$).

The maximization problem for the Hegemon then becomes

$$\max_{b\geq 0} \quad V^{FC}(b) = b(\bar{R}^r - R^s(b)), \tag{3}$$

which states that utility maximization is the same as maximizing the expected wealth transfer that the Hegemon receives from RoW. The wealth transfer is the product of two terms: the amount of debt issued, b, and the safety premium on that debt, $\bar{R}^r - R^s(b)$.

The Hegemon trades off a larger debt issuance against a lower safety premium, leading to the optimality condition

$$\bar{R}^r - R^s(b) - b\, R'^s(b) = 0. \tag{4}$$

This optimality condition is a type of Lerner formula; the monopolist issues debt at a mark-up over

[9]For example, our model is consistent with but does not require the Hegemon to issue debt and concurrently hold a large portfolio of risky assets against it. The model is equally consistent with a setup where the Hegemon borrows to finance immediate spending.

marginal cost that depends on the elasticity of the demand function

$$\frac{\bar{R}^r - R^s(b)}{R^s(b)} = \frac{bR'^s(b)}{R^s(b)}.$$

From the demand function for safe debt in equation (1), the slope of the demand curve is: $R'^s(b) = 2\gamma\sigma^2$. Substituting this into Equation (4), we get

$$b = \frac{1}{2\gamma}\frac{\bar{R}^r - R^s(b)}{\sigma^2} \geq 0. \tag{5}$$

Equilibrium issuance depends positively on the Sharpe ratio of the risky asset, and negatively on the coefficient of risk aversion. It can be obtained in closed form by solving equation (5), yielding

$$b^{FC} = \frac{1}{2}w^*.$$

Equilibrium debt issuance under full commitment only depends on foreign wealth, because the parameters γ and σ increase the level and decrease the elasticity of the demand curve with offsetting effects on equilibrium issuance. Plugging back into equation (5), we obtain the interest rate $R^s(b)$ on reserve assets

$$R^s(b^{FC}) = \bar{R}^r - \gamma\sigma^2 w^*.$$

The safety premium on reserve assets is $\gamma\sigma^2 w^*$, which is increasing in RoW risk aversion (γ), the riskiness of the risky asset (σ), and the wealth of RoW (w^*).

From the Hegemon budget constraints, we have: $C_0 + \delta\mathbb{E}[C_1] = w + \delta b^{FC}(\bar{R}^r - R^s(b^{FC}))$. On average, the Hegemon consumes more than the average proceeds that would result from entirely investing its wealth in the risky asset. This extra positive (on average) transfer from RoW is the monopoly rent given by

$$b^{FC}(\bar{R}^r - R^s(b^{FC})) = \frac{1}{2}\gamma\sigma^2 w^{*2}. \tag{6}$$

For reasons that will later become clear, we term these monopoly rents the "exorbitant privilege". Like the safety premium, the exorbitant privilege is increasing in risk aversion (γ), the pool of savings (w^*) of RoW, and the background risk (σ). We collect all results under commitment in the proposition below.[10]

Proposition 1 ***(Full-Commitment Equilibrium).*** *Under full commitment, the Hegemon chooses to issue risk-free debt and commits not to devalue in a disaster. The equilibrium interest rate, issuance, and exorbitant privilege (monopoly rent) are given by*

$$R^s(b^{FC}) = \bar{R}^r - \gamma\sigma^2 w^*, \quad b^{FC} = \frac{1}{2}w^*, \quad \textit{and} \quad b^{FC}(\bar{R}^r - R^s(b^{FC})) = \frac{1}{2}\gamma\sigma^2 w^{*2}.$$

It is illuminating to contrast the Hegemon monopoly equilibrium with that of perfect competition,

[10] Proposition A.2 in the Online Appendix provides mild conditions under which equilibrium prices are arbitrage free.

which obtains when the Hegemon, instead of taking into account the increase in the interest resulting from an increase in its issuance, takes the interest rate as given.

Lemma 1 ***(Perfect-Competition Equilibrium).*** *Under perfect competition and full commitment, the equilibrium is characterized by*

$$R^s(b) = \bar{R}^r, \quad \textit{and} \quad b = w^*.$$

RoW is fully insured and there is no safety premium.

Proof. Optimal portfolio choice given risk neutrality of the Hegemon implies that expected returns on all assets have to be equalized, hence $\bar{R}^r - R^s(b) = 0$. Imposing zero excess returns in the demand function of RoW for safe debt (equation (1)) pins down equilibrium debt supply $b = w^*$. ■

In the 1960s, French Finance Minister and future President Valery Giscard d'Estaing famously accused the U.S. of enjoying an exorbitant privilege due to its reserve status and its ensuing ability to finance itself at cheaper rates than RoW. In our model, this expected transfer of wealth to the Hegemon is a compensation for risk — a feature shared with Gourinchas and Rey (2007*a*), Caballero, Farhi and Gourinchas (2008), Mendoza, Quadrini and Rıos-Rull (2009), Gourinchas, Govillot and Rey (2011), Maggiori (2012) — but, crucially, the Hegemon is able to influence the terms of the compensation via its supply of reserves. There is a sense in our model in which the privilege is truly exorbitant, since it is a pure monopoly rent.

The size of the exorbitant privilege depends both on the size of the safety premium and on the amount of reserves (b). It is therefore important to discuss different interpretations of what this stock of assets corresponds to in reality. In all cases, b is not to be interpreted as the total stock of reserve assets being issued, but as the part of the stock that is held by foreigners, i.e. an external liability of the Hegemon. A narrow interpretation would include only the fraction of the Hegemon short-term government debt that is held by RoW, while a broad interpretation would include any safe asset — including those issued by the private sector — that are denominated in the reserve currency and held by RoW. Under the latter broader interpretation, which we favor, the data counterpart to b is the gross safe external liabilities of the Hegemon country denominated in the reserve currency. We refer the reader to Section 7 for a formal extension of the model to account for private issuance.

3 Limited Commitment and the Triffin Dilemma

We now turn to limited commitment. We first analyze the equilibria that occur for a given quantity of debt b, and then study the optimal issuance of b from the perspective of the Hegemon.

If a disaster has occurred at $t = 1$, the Hegemon decides whether to devalue its currency by solving

$$\max_{C_1, e \in \{1, e_L\}} \quad C_1 - \tau(1 - e),$$

$$s.t. \quad sR^r_L - b\, R\, e = C_1.$$

The Hegemon chooses to devalue if and only if $bR(1-e_L) > \tau(1-e_L)$. Intuitively, the Hegemon devalues and chooses $e_L < 1$ instead of $e_H = 1$ if the gains from lower real debt repayment to RoW investors are greater than the associated penalty $\tau(1-e_L)$. The condition for a devaluation can be simplified into the following threshold rule:

$$b\,R > \tau. \tag{7}$$

If $bR > \tau$, then the Hegemon chooses to devalue in bad times at $t=1$. At time $t=0^+$, RoW agents anticipate that the Hegemon will devalue and therefore treat Hegemon debt as a perfect substitute for the risky asset; they require $R = R^r_H$ and are then willing to absorb any quantity of debt. This outcome is possible for all $b > \underline{b}$, where $\underline{b} = \tau/R^r_H$.

If $bR \leq \tau$, then the Hegemon does not devalue in bad times at $t=1$ and its debt is therefore safe. The interest rate is then $R = R^s(b)$. This outcome is possible for all $b < \bar{b}$,[11] where

$$\bar{b} = \frac{-\bar{R}^r + 2w^*\gamma\sigma^2 + \sqrt{(\bar{R}^r - 2w^*\gamma\sigma^2)^2 + 8\gamma\sigma^2\tau}}{4\gamma\sigma^2}. \tag{8}$$

Both outcomes are possible if $b \in [\underline{b}, \bar{b}]$. We collect these results in the lemma below. They fully describe the equilibrium functions $e(b,\omega)$ and $R(b,\omega)$.

Lemma 2 ***(The Three Zones of the IMS).*** *For a given level of issuance b at $t=0^-$, the structure of continuation equilibria for $t=0^+$ onwards is as follows:*

1. *If $b \in [0, \underline{b}]$ (Safety zone) there is a unique equilibrium, the safe equilibrium, under which the Hegemon does not devalue in the disaster state at $t=1$. The interest rate on its debt is given by $R^s(b) = \bar{R}^r - 2\gamma(w^* - b)\sigma^2$ and is increasing in b, and there is a safety premium $\bar{R}^r - R^s(b) = 2\gamma(w^* - b)\sigma^2 > 0$.*

2. *If $b \in (\underline{b}, \bar{b}]$ (Instability zone) there are two equilibria: the safe equilibrium described above; and the collapse equilibrium under which the Hegemon devalues in the disaster state at $t=1$, the interest rate on its debt is $R = R^r_H$, and there is no safety premium.*

3. *If $b \in (\bar{b}, w^*]$ (Collapse zone) there is a unique equilibrium, the collapse equilibrium described above.*

As is well understood, monetary and fiscal decisions interact in a profound way. In our model, monetary and fiscal decisions are made by a single decision maker navigating two conflicting objectives ex post: maintaining the value of the currency and easing the fiscal burden by inflating away the debt. Depending on which objective prevails, one can think of the economy as operating either in a regime of "monetary" or "fiscal" dominance. Historical examples of abrupt shifts from monetary to fiscal dominance abound. They

[11] $\bar{b}$ is the only positive root of the quadratic equation that corresponds to the inequality $b(\bar{R}^r - 2\gamma(w^* - b)\sigma^2) \leq \tau$. In this paper, we focus on the interesting case $\bar{b} \leq w^*$, which requires the parameter restriction $\tau \leq \bar{R}^r w^*$ so that commitment is sufficiently limited that the Hegemon cannot provide RoW with full insurance. Imposing this condition results in the following ordering: $\underline{b} \leq \bar{b} \leq w^*$. The first inequality holds because $R^s(b) < \bar{R}^r \quad \forall b \in [0, \bar{b}]$, conditional on the debt being safe. Therefore, $\bar{b}\bar{R}^r > \tau$.

are the subject of an important literature in monetary economics, starting with the celebrated unpleasant monetarist arithmetic result of Sargent and Wallace (1981) and more closely related to the mechanism in our model with the literature on the fiscal theory of the price level starting with Leeper (1991), Sims (1994) and Woodford (1994). Such shifts arise endogenously in our model as the equilibrium outcomes of a fully-specified policy game, the ex-post and ex-ante stages of which are summarized above in Lemma 2 and below in Proposition 2.

3.0.1 Hegemon Optimal Issuance of Debt

Multiple equilibria are possible at $t = 0^+$ when issuance is in the Instability zone. Our focus is on strategic issuance rather than on equilibrium selection, and so we adopt the simplest possible selection device in the form of a sunspot: we select the safe equilibrium if the realization of the sunspot is s, and the collapse equilibrium otherwise. Accordingly, we define a function $\alpha(b) \in [0,1]$ to denote the $t = 0^-$ probability that the continuation equilibrium for $t = 0^+$ onward is the collapse equilibrium

$$\alpha(b) = \begin{cases} \alpha(b) = 0, & \text{for} \quad b \in [0, \underline{b}], \\ \alpha(b) = \alpha, & \text{for} \quad b \in (\underline{b}, \bar{b}], \\ \alpha(b) = 1, & \text{for} \quad b \in (\bar{b}, w^*]. \end{cases}$$

This constant-probability formulation has the advantage of simplicity and is a benchmark in the literature (see Cole and Kehoe (2000), as well as the literature that follows).[12]

By analogy with the full-commitment problem in equation (3), the Hegemon maximization problem is

$$\max_{b \geq 0} \quad V(b) = (1 - \alpha(b))V^{FC}(b) - \alpha(b)\lambda\tau(1 - e_L), \tag{9}$$

where we remind the reader that $V^{FC}(b) = b(\bar{R}^r - R^s(b))$ is the value function under full commitment and λ the probability of a low return on the risky asset (the L state). This formulation shows that maximizing utility is equivalent to maximizing the expected wealth transfer from RoW, net of the expected cost of a possible devaluation. The value function in equation (9) is discontinuous at $\underline{b}$ (if $\alpha \in (0,1)$) and $\bar{b}$, and is otherwise twice continuously differentiable. Note that $V^{FC}(b) \geq V(b)$ with equality only for $b \in [0, \underline{b}]$. This value function is illustrated in Figure 3, with the value function under full commitment plotted as a dotted line for comparison. We characterize optimal issuance in the proposition below, and then describe it intuitively using Figure 3.

[12] One could consider many alternative functions $\alpha(b)$ — continuous or discontinuous, monotonically increasing or not. One alternative would be to consider a function $\alpha(b)$ that jumps in the interior of the Instability zone, in order to capture the notion of "neglected risk" (Gennaioli, Shleifer and Vishny (2012, 2013)), a sudden change in the perception of risk. The economics of our main results is robust to more general choices of $\alpha(b)$ and, in particular, to an increasing smooth function of the probability of the bad sunspot. One could also consider refinements, such as for example along the lines of the global games literature. This would lead to an indicator function for $\alpha(b)$ with an endogenous cutoff in the Instability zone. To capture the crucial risk component at the heart of the Triffin argument in such a setup, one could add a publicly observable shock to the cost of default τ realized after the issuance decision but before issuance actually takes place.

Proposition 2 ***(Limited-Commitment Equilibrium and the Triffin Dilemma).*** *Under limited commitment, equilibrium issuance by the Hegemon can be described as follows:*

1. *If $b^{FC} \in (0, \underline{b}]$, then the Hegemon issues b^{FC} in the Safety zone.*
2. *If $b^{FC} \in (\underline{b}, \bar{b}]$, then the Hegemon issues $\underline{b}$ in the Safety zone or b^{FC} in the Instability zone, whichever generates higher net monopoly rents.*
3. *If $b^{FC} \in (\bar{b}, w^*]$, then the Hegemon either issues $\underline{b}$ in the Safety zone or $\bar{b}$ in the Instability zone, whichever generates higher net monopoly rents.*

In all equilibria, the Hegemon enjoys an exorbitant privilege in the form of positive net expected monopoly rents.

Figure 3 illustrates some of the possible equilibrium outcomes from the above proposition. Panel A corresponds to case 1, in which the Hegemon finds it optimal to issue in the interior of the Safety zone.

More interesting for us are cases 2 and 3, in which the Hegemon faces a meaningful trade-off — or "dilemma" — between issuing less debt and remaining in the Safety zone ($\underline{b}$) or issuing more debt and entering the Instability zone (either b^{FC} or $\bar{b}$). For example, Panel B illustrates case 2 for a parametrization that leads the Hegemon to prefer issuing more debt, at the risk of a confidence crisis.[13] This trade-off is our model's rationalization of the Triffin dilemma, which Kenen (1963) summarizes as:

> Triffin has dramatized the long-run problem as an ugly dilemma: If the present monetary system is to generate sufficient reserve assets to lubricate payments adjustment, the reserve currency countries must willingly run payments deficits enduring a deterioration of their net reserve positions that could erode foreign confidence in the reserve currencies. If, contrarily, the reserve currency countries are to maintain their net reserve positions, there must someday be a shortage of reserve assets and this will cause serious frictions in the process of payments adjustment.[14]

Whether a Triffin dilemma arises in our model (cases 2 and 3) or not (case 1) depends upon the level of RoW demand for reserve assets (w^*), compared to the safe debt capacity of the Hegemon (τ). More precisely, it depends upon whether $b^{FC} = 1/2w^* > \tau/R^r_H = \underline{b}$. In cases 2 and 3 ($b^{FC} > \underline{b}$), there exists

[13] In our model, interest rates do not signal the possibility of a collapse until it occurs; that is, for a given level of issuance, safe interest rates are independent of the probability of collapse $\alpha(b)$. However, the Hegemon fully considers the probability of an increase in interest rates in case of a collapse, and reduces its issuance as this probability increases. Furthermore, if we allowed for longer (than 1 period) debt maturities, the yields on these longer maturities would increase with the probability of collapse.

[14] In our model, the motive for reserve accumulation is risk aversion and/or a desire for liquidity by RoW (as later introduced in Section 4 and Appendix A.2.5); this provides a more general illustration of the demand for reserves than the original balance-of-payments/defense-of-exchange-rates reasons highlighted by Triffin (1961). This more general motive for reserve accumulation is consistent with the dramatic accumulation of reserves during the post-Asian-crisis global-imbalances period under floating exchange rates, and with the resurgence of a Triffin-style dilemma in this environment. Kenen (1960) is an early attempt to assess the logic of the Triffin dilemma, with related contributions by Kenen and Yudin (1965), Hagemann (1969), Aliber (1964, 1967), Fleming (1966), Cooper (1975, 1987).

a threshold $\alpha_m^* \in (0,1)$ such that the Hegemon issues at the boundary of the Safety zone $\underline{b}$ if and only if $\alpha > \alpha_m^*$, and otherwise issues either b^{FC} (case 2) or $\bar{b}$ (case 3).[15] All else equal, an increase in RoW demand for safe assets ($\uparrow w^*$) or a decrease in the safe debt capacity ($\downarrow \tau$) activates the Triffin margin; the Hegemon then faces a choice between a safe option with a low level of debt at the boundary of the Safety zone and a risky option with a high level of debt $\left(\min\left\{b^{FC},\bar{b}\right\}\right)$ in the Instability zone.

The reader is reminded of the discussion in Section 2.2 that b is to be interpreted as the gross external safe liabilities of the Hegemon that are denominated in the Hegemon's currency irrespective of whether the issuance is from the government or the private sector (see Section 7 for a formal treatment). For example, in 2015 U.S. government and agencies debt accounted for \$6.2trn out of \$10.5trn of total debt securities held by foreign residents with the rest being accounted for by private issuance (source: Treasury International Capital System). By contrast, England before 1914 had low government debt to GDP ratios and a large fraction of safe external debt was issued by the British banking system.

Our model makes specific predictions regarding the fragility of the Hegemon, which are lacking in Triffin's writings: it ties its vulnerability to a confidence crisis to the Hegemon gross external-debt position, and not to the net position as hinted at times by Triffin. The origin is partly external, as originally emphasized by Triffin, and partly fiscal as recently emphasized by Farhi, Gourinchas and Rey (2011) and Obstfeld (2011). Indeed, in practice, safe external debt of the Hegemon is composed of both public and private securities. As we make clear in Section 7 where we extend the model to incorporate private issuance, as long as the Hegemon internalizes the welfare of private issuers, the incentives to devalue are governed by the total (public and private) gross external debt position of the Hegemon. Furthermore, public internalization (perhaps through ex-post bailouts) of private repayments blurs the distinction between public and private balance sheets in times of stress, so that an external problem can easily morph into a fiscal problem.

In the early part of the 1920s, central banks realized that the real value of gold, at the chosen parities, was too low to accommodate a growing world economy and the ensuing demand for liquid/safe assets. At the Genoa conference in 1922, central banks created a gold-exchange standard by expanding the role of monetary assets, in particular those considered safest and most liquid, to be used as international reserves. Of course, the creators of the system understood that the benefits of an increased supply of reserve assets came with risks. Indeed, in 1931 there was a run on Sterling in part due to the attempt by France, at the time a large holder of reserves in Sterling, to liquidate some of its reserves into gold. The vulnerability of Sterling was due to Britain's fiscal imbalances—a high government debt to GDP ratio (in excess of 150%) compounded by the need to shore up the banking system, which had suffered large losses following the 1931 financial crisis in Germany (Accominotti (2012)). Ultimately, Britain devalued its currency by 40% against gold and most foreign currencies; the devaluation was so sudden that the Banque de France, which still had substantial pound reserves, was technically bankrupt and had to be recapitalized by the French

[15] Indeed, the value function is independent of α at the boundary $\underline{b}$ of the Safety zone and is continuous and monotonically decreasing in α in the Instability zone. With $\alpha = 1$, we always have $V(\underline{b}) > V(\min\left\{b^{FC},\bar{b}\right\})$; with $\alpha = 0$, we always have $V(\underline{b}) < V(\min\left\{b^{FC},\bar{b}\right\})$.

Treasury. The Sterling crisis caused a global run on monetary reserves, which contributed to the 1933 Dollar devaluation. The model captures both the run element of these collapses of the IMS and the fact that the fragility is ultimately rooted in fiscal problems.

A similar dynamic played a role in the decision of the U.S. (the Hegemon of the time) to devalue in 1971-1973 and put an end to the Bretton Woods system. Dollar-denominated external liabilities of the U.S. sharply increased from 6% in 1952 to 20% in 1973 and the U.S. official balance of payments significantly deteriorated.[16] At the same time fiscal pressures were accumulating in part as a result of the Vietnam War. In 1971, the Nixon administration reacted to foreign attempts to liquidate dollar reserves and the ensuing pressure on the Dollar by first devaluing the Dollar and suspending general convertibility of the Dollar to gold, while maintaining convertibility for foreign central banks (the "Nixon shock"). Ultimately, the U.S. administration had to further devalue the Dollar and abandon all convertibility and let the Dollar float.

Immediately after the collapse of Bretton Woods, there were serious concerns that the Dollar would suffer the fate of Sterling after the 1931 devaluation and ultimately lose its reserve-currency status. Indeed, Figure 1 Panel (d) shows that Sterling went into a slow decline as a reserve currency (in part slowed down by WWII and the use of the pound in the former British empire) that quickly accelerated after WWII. However, Figure 1 Panel (d) also shows that the Dollar did not suffer a similar fate after its devaluations of 1971-73. This suggests that τ is best interpreted as the expectation of a stochastic punishment, an interpretation that we develop formally in Section 7 in an infinite-horizon model in which a devaluation leads to a probabilistic loss of reputation and future monopoly rents.

Our model, while consistent with the dilemma of the "consensus view" put forth by Triffin (1961), is also consistent with the "minority view", articulated by Despres, Kindleberger and Salant (1966), of the U.S. acting as a world banker that collects a safety/liquidity premium on its gross assets/liabilities. However, it shares the perspective of the modern finance literature that banking is a fragile activity (Diamond and Dybvig (1983)) subject to self-fulfilling panics that can have macroeconomic consequences (Gertler and Kiyotaki (2015)). The problem is exacerbated in our context by the absence of a plausible LoLR with sufficient fiscal capacity to support the Hegemon world banker.

Understanding the fragility of the world banker is even more relevant today since, as documented by Gourinchas and Rey (2007*a*,*b*), the U.S. activities as a world banker are today being performed on a much grander scale than when originally debated, or, in other words, the "bank" has gotten bigger.

Indeed, Triffin-like concerns have arisen again recently even though the current IMS is no longer under the gold-exchange standard. This is not surprising in light of our model. The model makes it clear that Triffin's dilemma is present both under a fixed and a floating exchange rate regime. Furthermore, the dilemma is exacerbated in periods when the global demand for reserves outstrips the safe debt capacity of the Hegemon, a situation that characterized both the last part of the Bretton Woods era and, more recently, the post-Asian-crisis global-imbalances era, as emphasized in the global savings glut/safe asset shortage literature (e.g. Bernanke (2005), Caballero, Farhi and Gourinchas (2008)). Our model stresses that the current situation, with the U.S. external debt at 158% of its GDP, 85% of which is denominated in dollars,

[16]See Branson (1971), Bach (1972), Gourinchas and Rey (2007*a*).

raises the possibility of a Triffin-like event.[17] Most prominently, Obstfeld and Rogoff (2001, 2007) have argued that the U.S. current account would one day have to reverse and that this would come with a 30% depreciation of the Dollar.

4 Welfare Consequences of the Triffin Dilemma

In the previous section, we formalized the Triffin dilemma as the choice of a monopolistic Hegemon issuer of reserve assets between issuing fewer assets that are certain to be safe and issuing more assets that may turn out to be risky. The Hegemon maximizes expected net monopoly rents (producer surplus) without taking into account RoW expected utility (consumer surplus). In this section, we consider social welfare (social surplus) that adds expected net monopoly rents and RoW expected utility. We always evaluate welfare from the perspective of expected utility at time $t = 0^{-}$, before the sunspot is selected.

One might naively conjecture that, because of a standard monopoly distortion, there would be under-issuance of reserve assets from a social welfare perspective. While this can certainly occur in our model, we also show that there can be over-issuance. We trace this surprising result to the fact that the options faced by the Hegemon involve two dimensions which are endogenously interrelated in the model: the traditional quantity dimension and a novel risk dimension.

We consider the relevant case in which there is a meaningful Triffin dilemma: a trade-off between issuing in the Safety zone or in the Instability zone (cases 2 and 3 in Proposition 2). In this configuration, the Hegemon faces a choice between a safe option with low issuance $\underline{b}$ at the upper bound of the Safety zone and a risky option with higher issuance in the Instability zone $\min(b^{FC}, \bar{b}) > \underline{b}$ (either at the full-commitment issuance level or at the upper bound of the Instability zone, whichever yields higher monopoly rents). We compare the rankings of these two options from the perspective of the Hegemon, RoW, and social welfare. If the Hegemon prefers the high-issuance risky option to the low-issuance safe option, but RoW would have preferred the opposite option, then we say that there is over-issuance from the perspective of RoW. Similarly, if the Hegemon prefers the low-issuance safe-option to the high-issuance risky-option, but RoW would have preferred the opposite option, then we say that there is under-issuance from the perspective of RoW. Under- and over-issuance from the perspective of social welfare are defined analogously.

Thus far we have restricted our attention to a linear demand curve in the interest of tractability. Since the crux of the welfare argument hinges on the shape of the demand curve, we consider a more general demand function allowing for non-linearities. In particular, we found that a tractable model that still captures these more general effects can be rendered via a piece-wise linear demand curve with a single

[17] In 2015, U.S. external liabilities (excluding financial derivatives) were \$28.28trn against a GDP of \$17.94trn (source: Bureau of Economic Analysis). U.S. external liabilities are mostly denominated in U.S. Dollar, 85% on average, while U.S. external assets are mostly denominated in foreign currency, 61% on average. Source: Bénétrix, Lane and Shambaugh (2015), average for the period 1990-2012. The b in our model is a pure gross Dollar liability of the U.S., since in the model the Hegemon has no incentives to lend in its currency to RoW. Mapping our model to the data, therefore, requires netting any foreign assets of the U.S. that are Dollar denominated. The resulting net dollar debtor position of the U.S. is still a gross position from the international investment position (IIP) perspective.

kink, which for simplicity we assume to coincide with the upper bound $\underline{b}$ of the Safety zone, so that[18]

$$R^s(b) = \bar{R}^r - 2\gamma(w^* - b)\sigma^2 - 2\gamma_L(\underline{b} - b)\mathbf{1}_{\{b \le \underline{b}\}}, \tag{10}$$

where $\gamma_L > 0$, so that the resulting $R^s(b)$ is concave in b. In the language of monopolistic production analysis (for a formal analysis see later in this section), it is more convenient to think of the demand curve directly in terms of the risk premium $\bar{R}^r - R^s(b)$, which is convex in b.

One way to obtain this type of demand curve is to augment the preferences of RoW to include a "bond in the utility" function component $-\gamma_L \left(\underline{b} - \min(b, \underline{b})\mathbf{1}_{\{\mathbb{E}^+[e]=1\}}\right)^2$, where $\mathbb{E}^+[e] = 1$ if and only if the debt is expected to be safe, as described in Appendix A.1. If the debt is expected to be safe, then $R = R^s(b)$ so that there is an extra liquidity component for all $b \le \underline{b}$. If the debt is expected to be risky, then $R = R^r_H$, so that risky debt is a perfect substitute for the risky asset. This setup lends itself to welfare evaluation as the "area under the demand curve", which conveniently allows for intuitive and graphical representation of welfare. RoW expected utility can be computed as

$$V_{RoW}(b) = V_{RoW}(0) + (1 - \alpha(b)) \int_{R^s(0)}^{R^s(b)} b(\tilde{R}^s) d\tilde{R}^s, \tag{11}$$

where $b(R^s)$ expresses the amount of debt being demanded as a function of the interest rate, as in equation (10). We refer the reader to Lemma A.1 for details. It should be clear that although liquidity preferences are a simple and plausible way to obtain a convex demand curve, this is by no means the only way. For example, we could use alternative specifications of risk aversion by moving away from mean-variance preferences. Our exact representation of welfare as the area under the demand curve holds as long as the resulting preferences over portfolios (safe and risky asset holdings) are quasilinear. The convexity of the demand curve then obtains when the marginal utility of risky assets decreases at a decreasing rate (as opposed to a constant rate for a linear demand curve) with risky asset holdings. This captures the notion that for given wealth and asset prices, the first few units of safe assets are much more important than the last few.

Figure 4 Panel (a) illustrates the piecewise-linear demand function in equation (10) and allows us to visualize RoW expected utility as the area under the demand curve. For example, RoW expected utility when the Hegemon issues at the upper bound of the Safety zone $\underline{b}$ is represented by the green area. Similarly, RoW expected utility when the Hegemon issues at the upper bound of the Instability zone $\bar{b}$ is represented by the orange area. This latter area is shrunk compared to the total area under the demand curve in line with equation (11) to account for the fact that the equilibrium issuance $\bar{b}$ is safe only with probability $1 - \alpha$.

The Hegemon net expected monopoly rents are given by

$$V(b) = (1 - \alpha(b))b(\bar{R}^r - R^s(b)) - \alpha(b)\lambda\tau(1 - e_L). \tag{12}$$

[18] We impose the parameter restriction $\bar{R}^r - 2\gamma w^* \sigma^2 - 2\gamma_L \underline{b} > 0$, by analogy with the previous sections.

The green rectangle in Figure 4 Panel (b) represents the net expected monopoly rents when issuance is at the upper bound of the Safety zone $\underline{b}$. The orange rectangle represents the net expected monopoly rents when issuance is at the upper bound of the Instability zone $\bar{b}$. This latter area is shrunk compared to the total area $\bar{b}(\bar{R}^r - R^s(\bar{b})) - [\alpha/(1-\alpha)]\lambda\tau(1-e_L)$ in line with equation (9), to account for the fact that the equilibrium issuance $\bar{b}$ is safe only with probability $1-\alpha$. The function $[[\alpha/(1-\alpha)]\lambda\tau(1-e_L)]/b$, displayed as the red dotted line in Figure 4 Panel (b), is a renormalized version of the average (not marginal) cost of the monopolist.

Intuitively, higher convexity of the demand curve ($\uparrow \gamma_L$) increases RoW expected utility in the green area in Figure 4 Panel (a). This increases the (infra-marginal) RoW expected utility loss in case of a collapse of the IMS when the Hegemon issues at the upper bound of the Instability zone $\bar{b}$ rather than at the upper bound of the Safety zone $\underline{b}$. For a given probability of collapse α, the higher the convexity of the demand curve, the higher RoW expected utility losses from issuance in the Instability zone. However, the Hegemon does not internalize this loss when choosing between $\bar{b}$ and $\underline{b}$. Indeed, Figure 4 Panel (b) illustrates that the comparison the Hegemon makes in choosing optimal issuance is independent of infra-marginal demand from RoW for $b < \underline{b}$, as long as the Hegemon does not find it optimal to issue in the interior of the Safety zone. This opens up the possibility of socially excessive issuance of reserve assets.

When the convexity of the demand curve is low, and always in the limit of no convexity and linear-demand for safe debt, there is under-issuance from a social perspective, as in standard monopoly problems. When the demand curve is sufficiently convex, there is over-issuance from a social perspective. For some values of the probability of collapse α, the monopolist chooses to issue $\bar{b}$ but RoW would have been better off with the safe issuance at $\underline{b}$, so much so that social welfare is higher at $\underline{b}$.

In order to formalize the above intuition, it is convenient to define the following three thresholds: α_m^*, α_{RoW}^*, α_{TOT}^*. In Section 3.0.1 we have discussed α_m^*, the cutoff probability of the collapse outcome that makes the Hegemon indifferent between issuing at the upper bound of the Safety zone ($\underline{b}$) or issuing at the local maximum in the Instability zone $\min\{b^{FC}, \bar{b}\}$. We now similarly define α_{RoW}^* to be the cutoff probability that equalizes RoW expected utility at the upper bound of the Safety zone $\underline{b}$ and at the local maximum $\min\{b^{FC}, \bar{b}\}$ in the Instability zone. The analogous cutoff for social welfare is α_{TOT}^*. The proof of Proposition 3 in the online appendix shows that α_{RoW}^* and α_{TOT}^* are unique and in the interval $(0,1)$.

These thresholds have intuitive implications for over- and under-issuance of reserve assets. For example, if $\alpha_m^* > \alpha_{RoW}^*$, then for all probabilities $\alpha \in (\alpha_{RoW}^*, \alpha_m^*)$, the Hegemon over-issues from the perspective of RoW. Similarly, if $\alpha_m^* < \alpha_{RoW}^*$, then for all probabilities $\alpha \in (\alpha_m^*, \alpha_{RoW}^*)$, the Hegemon under-issues from the perspective of RoW. Similar conclusions can be drawn by comparing α_m^* and α_{TOT}^*, but now from the perspective of social welfare.

It is also convenient to parametrize the degree of convexity of the demand curve as $\gamma_L = \eta\bar{\gamma}_L(\tau)$, where $\bar{\gamma}_L(\tau)$ is the largest value of the liquidity preference for which the Hegemon does not want to issue inside the Safety zone and $\eta \in [0,1]$. In what follows, we refer to higher values of η as increasing the convexity of the demand curve, with $\eta = 0$ being the linear case. The proof of Proposition 3 in the online appendix shows how the upper bound on the degree of convexity $\bar{\gamma}_L(\tau)$ is determined.

Proposition 3 ***(Over-issuance by a Hegemon).*** *If $\gamma_L = 0$, so that the demand curve is linear, then in equilibrium the cutoff probabilities are ranked as follows:*

$$\alpha_m^* < \alpha_{TOT}^* < \alpha_{RoW}^*,$$

and the Hegemon under-issues for $\alpha \in (\alpha_m^*, \alpha_{RoW}^*)$ from the perspective of RoW, and for $\alpha \in (\alpha_m^*, \alpha_{TOT}^*)$ under-issues from a social perspective.

There exists $\bar{\gamma}_L(\tau) > 0$, which makes the demand curve sufficiently convex, such that for all $\eta \in (0,1]$, when τ is sufficiently small, and when $\gamma_L \in [\eta\bar{\gamma}_L(\tau), \bar{\gamma}_L(\tau)]$, the cutoff probabilities are ranked as follows:

$$\alpha_m^* > \alpha_{TOT}^* > \alpha_{RoW}^*,$$

and the Hegemon over-issues for $\alpha \in (\alpha_{RoW}^*, \alpha_m^*)$ from the perspective of RoW, and for $\alpha \in (\alpha_{TOT}^*, \alpha_m^*)$ over-issues from a social perspective.

Proof. In the interest of intuition and brevity we provide here the full proof of the first statement: for linear demand the monopolist under-issues from a social perspective. The online appendix provides the proof of the second statement, that there can be over-issuance for sufficiently convex demand curves.

Assume $\gamma_L = 0$. Define $b^* = \min\{b^{FC}, \bar{b}\}$ to be the optimal level of issuance that the Hegemon chooses conditional on issuing in the Instability zone. RoW expected utility is equalized at issuance levels $\underline{b}$ and b^* for a threshold probability of collapse α_{RoW}^*:

$$(1-\alpha_{RoW}^*)b^{*2} = \underline{b}^2.$$

Indeed, these are the areas under the demand curve as described in equation (11). Similarly, Hegemon net expected monopoly rents are equalized at issuance levels $\underline{b}$ and b^* for a threshold probability of collapse α_m^*:

$$(1-\alpha_m^*)2\gamma\sigma^2(w^*-b^*)b^* - \alpha_m^*\lambda\tau(1-e_L) = (w^*-\underline{b})2\gamma\sigma^2\underline{b},$$

where we recall that $R^s(w^*) = \bar{R}^r$. We conclude that:

$$1-\alpha_m^* = \frac{w^*-\underline{b}}{w^*-b^*}\frac{\underline{b}}{b^*} + \frac{\alpha_m^*\lambda\tau(1-e_L)}{2\gamma\sigma^2 b^*(w^*-b^*)} > \frac{\underline{b}}{b^*} > \left(\frac{\underline{b}}{b^*}\right)^2 = 1-\alpha_{RoW}^*.$$

Since α_{TOT}^* is a convex combination of α_{RoW}^* and α_m^* with interior non-vanishing weights on each of the elements, we obtain the result in the Proposition.

Note that in this derivation, the shape of the demand curve only enters through the sufficient statistics b^* and $\tau/(2\gamma\sigma^2)$. The ranking $\alpha_{RoW}^* > \alpha_m^*$ does not depend on the precise choice of b^* or on the precise value of $\tau/(2\gamma\sigma^2)$. This clarifies why changes in the slope of the demand curve are not sufficient to overturn this ranking. However, changes in the degree of convexity of the demand curve are sufficient as proved in the continuation of this proof in the online appendix. ■

We can relate our notion of over- and under-issuance, as a choice between the safe and the risky option in the Triffin dilemma, to another connected notion. We define $b^*_m(\alpha)$, $b^*_{RoW}(\alpha)$, and $b^*_{TOT}(\alpha)$ as the levels of issuance that maximize Hegemon net expected monopoly rents, RoW expected utility, and social welfare, respectively. We say that there is over-issuance from the perspective of RoW if $b^*_{RoW} < b^*_m$, and under-issuance from the perspective of RoW if $b^*_{RoW} > b^*_m$. The concept of over- and under-issuance from the perspective of social welfare is defined analogously.

A consequence of the above proposition is that: if $\gamma_L = 0$, then $b^*_m(\alpha) < b^*_{TOT}(\alpha) < b^*_{RoW}(\alpha)$ for every $\alpha \in [0,1]$, so that there is under-issuance from the perspective of RoW and of social welfare; there exists $\bar{\gamma}_L(\tau) > 0$ such that for τ sufficiently small, then for $\alpha \in (\alpha^*_{RoW}, \alpha^*_m)$, $b^*_m(\alpha) > b^*_{RoW}(\alpha)$, so that there is over-issuance from the perspective of RoW, and for $\alpha \in (\alpha^*_{TOT}, \alpha^*_m)$, $b^*_m(\alpha) > b^*_{TOT}(\alpha)$ so that there is over-issuance from the perspective of social welfare.

Comparative statics for over- and under-issuance. Figure 5 illustrates the main drivers of the welfare results in Proposition 3. The figure plots the threshold probabilities α^*_m and α^*_{RoW} as a function of the degree of commitment indexed by the fixed cost τ and the curvature of the demand curve indexed by the parameter η. These threshold probabilities are the probabilities for which respectively the Hegemon and RoW are indifferent between issuance at the upper bound $\underline{b}$ of the Safety zone and issuance in the Instability zone at $min(b^{FC}, \bar{b})$.

In line with Proposition 3, Figure 5 shows that α^*_m is independent of η for $\eta \in [0,1]$ since the issuance choice of the Hegemon is unaffected by the degree of convexity of the demand curve.[19] Figure 5 also shows that α^*_m is decreasing in τ. Intuitively, as the fixed cost associated with a devaluation decreases ($\downarrow \tau$), the incentives of the Hegemon to issue in the Instability zone increase so that a higher probability of the risky realization of the sunspot ($\uparrow \alpha^*_m$) is needed in order to make the Hegemon indifferent between the two levels of issuance. The area below (above) the α^*_m surface in Figure 5 is the region of the parameter space in which the Hegemon prefers to issue in the Instability (Safety) zone. Overall, the Hegemon is more likely to issue in the Instability zone when the cost of devaluation is low, independently of the convexity of the demand curve.

Figure 5 shows that α^*_{RoW} decreases in the degree of convexity of the demand curve η. Intuitively, a more convex demand curve implies that more RoW surplus is lost if the debt turns out to be risky since RoW is then left without any safe assets to invest in. Figure 5 also shows that α^*_{RoW} increases in the fixed cost of devaluation τ. To understand this latter effect, recall that both $\bar{b}$ and $\underline{b}$ decrease with τ since lower commitment levels shrink both the Safety and the Instability zones. For low levels of τ, both $\bar{b}$ and $\underline{b}$ and their difference are approximately proportional to τ, so that the additional benefits to RoW from an

[19]Formally, $\gamma_L = \eta \bar{\gamma}_L(\tau)$, where $\bar{\gamma}_L(\tau)$ is the largest value of the liquidity preference for which the Hegemon does not want to issue inside the Safety zone. We could allow for $\eta > 1$ by extending the model to incorporate a realistic strictly positive minimal amount of debt issuance $b_{\min}$ by the Hegemon in order to capture a situation in which the Hegemon must finance some incompressible expenditures and cannot mobilize enough taxes at $t = 0$. In the special case in which $b_{\min} = \underline{b}$, the analysis would be unchanged. This would allow us to consider even more convex demand curves which, in turn, would make over-issuance both arbitrarily more likely and arbitrarily worse.

increase in issuance from $\underline{b}$ to $\bar{b}$ if debt turns out to be safe are small compared to the welfare losses that RoW incurs if debt turns out to be risky. The area below (above) the α^*_{RoW} surface in Figure 5 is the region of the parameter space in which RoW is better off with issuance in the Instability (Safety) zone. Overall, RoW is more likely to be better off with issuance in the Instability zone when the convexity of the demand curve is low and when the fixed cost of devaluation is high.

The intersection of the surfaces α^*_{RoW} and α^*_m in Figure 5 delimits the over- and under-issuance regions of the parameter space. There is over-issuance when commitment (τ) is sufficiently low, the demand curve is sufficiently convex (η sufficiently high), and the probability of the risky realization of the sunspot is intermediate. Conversely, there is under-issuance when commitment (τ) is sufficiently high, the degree of convexity of the demand curve is sufficiently low (η sufficiently low), and the probability of the risky realization of the sunspot is intermediate.

Area A in Figure 5 corresponds to the parameter region in which over-issuance obtains. In this area and for intermediate levels of the probability of the risky realization of the sunspot $\alpha^*_{RoW} < \alpha < \alpha^*_m$, the Hegemon issues in the Instability zone, but RoW would have been better off with issuance in the Safety zone. Area B in Figure 5 corresponds to the parameter region in which under-issuance obtains. In this area and for intermediate levels of the probability of the risky realization of the sunspot $\alpha^*_m < \alpha < \alpha^*_{RoW}$, the Hegemon issues in the Safety zone, but RoW would have been better off with issuance in the Instability zone. Areas M and Z in Figure 5 highlight the role of the probability α in generating a misalignment between the incentives of the Hegemon and RoW welfare: if the probability of a risky realization of the sunspot α is sufficiently high as in Area M (sufficiently low as in Area Z) then both the Hegemon and RoW are better off with issuance in the Safety zone (Instability zone). Intuitively, private and social incentives are aligned with either low or high probabilities of risky sunspot realizations, but diverge with intermediate probabilities of risky sunspot realizations.

Throughout the paper we have favored simplicity, tractability, and pencil-and-paper solutions; therefore, the figures above are to be interpreted as illustrative qualitative examples and not as realistic calibrations that, by necessity, would require adding a number of additional channels and (almost surely) numerical solutions. Nonetheless, our model has intriguing connections with the empirical evidence provided in Krishnamurthy and Vissing-Jorgensen (2012). They estimate a convex demand curve for safe U.S. debt (Treasuries): the difference in rates of returns between safe-liquid U.S. Treasuries and safe but not as liquid AAA rated-U.S. corporate bonds decreases at a decreasing rate with increases in the supply of Treasuries.

Holmström and Tirole (2011) interpret this empirical regularity as an indication of liquidity needs that become progressively satiated as the supply of Treasuries increases. They argue that it is consistent with liquidity-based asset pricing models in which the convexity of the demand curve is driven by the fact that increases in the supply of Treasuries initially drive down both the liquidity premium and the risk premium, and then eventually, as liquidity needs become satiated faster than safety needs, only reduce the risk premium. The model in this section can be seen as a possible rendition of such a liquidity-based model.[20] Our analysis works out the implications for over- and under-issuance of this concrete rationale for the convexity of the demand curve.

An analogy with the provision of quality under monopoly. Our normative analysis features an interesting analogy with that of the standard monopoly theory of quality put forth by Spence (1975). Consider a monopolist supplier of a good. The monopolist can choose both the quantity q and the quality z of the good, and the equilibrium price $P(q,z)$ of the good depends on both attributes. In this context, it is well understood that, from a social perspective, at the margin, a monopolist: (i) always under-supplies quantity by equating the marginal cost of supplying quantity $C_q(q,z)$ to the marginal revenue $P(q,z)+qP_q(q,z)$ instead of the price $P(q,z)$; but (ii) might under- or over-supply quality by equating the average marginal cost of supplying quality $C_z(q,z)/q$ to the marginal valuation for quality of the marginal buyer $P_z(q,z)$ instead of that of the average buyer $\left(\int_0^q P_z(\tilde{q},z)d\tilde{q}\right)/q$, depending on which of these two valuations is higher, i.e. on the shape of the demand curve.

Although we are not aware of any paper examining this case, one can imagine that quality z is a decreasing function $Z(q)$ of quantity q, perhaps because of an inherent trade-off in production. Then the monopolist might under- or over-supply quantity, depending on the mapping and on the shape of the demand curve. Indeed, the monopolist equates marginal cost $C_q(q,Z(q))+qZ'(q)C_z(q,Z(q))/q$ to marginal revenue $P(q,Z(q))+qP_q(q,Z(q))+qZ'(q)P_z(q,Z(q))$ instead of the sum of marginal revenue and marginal consumer surplus $P(q,Z(q))+qZ'(q)\left(\int_0^q P_z(\tilde{q},Z(q))d\tilde{q}\right)/q$. The difference between the two marginal benefits $-qP_q(q,Z(q))+qZ'(q)\left[\left(\int_0^q P_z(\tilde{q},Z(q))d\tilde{q}\right)/q-P_z(q,Z(q))\right]$ depends both on the standard quantity monopoly distortion (the first term) and on the quality distortion (the second term). It can either be positive or negative, depending on the shape of the demand curve and on the semi-elasticity of quality with respect to quantity.

The analogy with the reduced-form problem of the Hegemon can be described as follows. The good is the asset supplied by the Hegemon. Quantity q is issuance b. Quality z is a binary variable which is equal to s if the asset is safe and r otherwise. The mapping Z from quantity to quality is probabilistic when production is decided but the underlying uncertainty is resolved before consumers buy the product: quality z is equal to r or s with probabilities $\alpha(b)$ and $1-\alpha(b)$ respectively. The price $P(q,z)$ is the risk premium on the asset, which is equal to $\bar{R}^r-R^s(b)$ if the asset is safe ($z=s$) and 0 if it is risky ($z=r$). The cost $C(q,z)$, given the realization of quality z, is 0 if $z=s$ and $\lambda\tau(1-e_L)$ if $z=r$, so that the expected cost $\mathbb{E}^-\left[C(q,Z(q))\right]$ when production is decided is $\alpha(b)\lambda\tau(1-e_L)$. In this analogy, quality, quantity, and the shapes of the demand and cost curves are jointly and endogenously determined as the result of a coordination problem. There can be both under- or over-issuance from a social perspective, depending on the shapes of $R^s(b)$ and of $\alpha(b)$. Given our selection for $\alpha(b)$, the more concave $R^s(b)$, the more convex the demand curve $\bar{R}^r-R^s(b)$, the greater the tendency of the Hegemon to over-issue.

We emphasize that the mapping from quality to quantity (which plays the role of Z in our model) is

[20] We follow the reduced-form modeling strategy of Stein (2012) by putting safe bonds directly in the utility function to capture their liquidity benefits. See Appendix A.2.5 for a fuller discussion.

an endogenous object determined by the equilibrium of our model. It depends on the coordination of the investors' expectations and portfolio choices as a function of the quantity of Hegemon debt issued. This highlights two sorts of additional externalities that are not internalized by atomistic RoW investors in the choice of their portfolios: they ignore its impact on the ex-post decision of the Hegemon to devalue as well as on the ex-ante issuance of the Hegemon. These externalities play a crucial role in our comparison of the optimal level of issuance from the perspective of the Hegemon and from the perspective of social welfare.[21]

5 Gold-Exchange Standard and Floating Exchange Rates

In this section we introduce nominal rigidities and analyze two different exchange rate regimes: a system of floating exchange rates, and a gold-exchange standard. We draw a parallel between the economics of the IMS under the gold-exchange standard, and under floating exchange rates at the ZLB. This shows that the lessons of the 1920s and 1960s are relevant today in the wake of the Great Recession.

5.1 Floating Exchange Rates and ZLB

We augment our baseline model to allow for production and nominal rigidities.

Production and investable wealth. We assume that there is a unit mass of competitive firms at time $t = 0$ and at $t = 1$ in RoW. They can produce goods from labor using a one-for-one linear technology. In both periods, labor is supplied without disutility up to a level $\bar{L}$ and with a large disutility for any amount of labor in excess of this level. We assume that this disutility is sufficiently large that $\bar{L}$ is the natural level of output (without nominal rigidities).[22] Output is produced instantaneously at $t = 0^+$ and at $t = 1$. Importantly, note that the decision to produce at $t = 0$ takes place after the equilibrium sunspot has been realized.

Investable wealth originates both from an endowment, as in the previous sections, and from labor income generated in production. We extend the previous notation and denote endowment wealth by w^{*e} and endogenous labor income by $w^{*\ell}$. Therefore, total investable wealth by RoW agents at time $t = 0^+$ is $w^* = w^{*e} + w^{*\ell}$ and RoW demand for reserve assets is given by

$$R^s(b; w^{*\ell}) = \bar{R}^r - 2\gamma\sigma^2(w^{*e} + w^{*\ell} - b). \tag{13}$$

In the absence of nominal rigidities, the real wage is equal to one, labor and output are at their natural level $\bar{L}$ (a situation we refer to as full employment), and $w^{*\ell} = \bar{L}$. The model is then exactly equivalent to the baseline model in Section 2.1 with $w^* = w^{*e} + \bar{L}$ and $R^s(b) = R^s(b; \bar{L})$. Note that without nominal

[21] Note that we purposefully refrain from introducing the kind of instruments that could directly influence the portfolio choices of RoW investors and therefore fully correct these externalities, and which we think are not very realistic in our context.

[22] By analogy with the OLG model that we introduce in Section A.2.1, we assume that the labor in period $t = 1$ is supplied by a new generation of RoW households.

rigidities, negative safe interest rates $R^s(b;\bar{L}) < 1$ can be achieved through inflation Π^* in excess of nominal interest rates $\tilde{R}^*$ in accord with the Fisher equation $R^s(b) = \tilde{R}^*/\Pi^*$. As we shall see, this is no longer possible once nominal rigidities are introduced.

Nominal rigidities and monetary policy. We assume that while prices are fully flexible, wages $\bar{w}^*$ are completely rigid in RoW currency in both periods. Workers supply whatever amount of labor is demanded by the firms. For simplicity, we take $\bar{w}^* = 1$. At the competitive equilibrium price $p^* = 1$ in both periods, inflation is zero $\Pi^* = 1$, real labor income is $w^{*\ell} = \ell^*$, and firms make zero profits and are indifferent with respect to their level of production (output ℓ is an equilibrium variable which is "demand determined"). For simplicity, we select an equilibrium in which period 1 output is at full employment. This allows us to focus on endogenous output determination at $t = 0^+$. We omit time subscripts from now on.[23]

We denote the nominal RoW interest rate as $\tilde{R}^*$. Monetary policy in RoW is determined by a truncated Taylor rule: $\tilde{R}^* = 1 + \phi \max(-(\bar{L} - \ell), 0)$. We consider the limit of an infinitely reactive Taylor rule with $\phi \uparrow \infty$.[24] The result is that the central bank either sets the RoW nominal interest rate at a level consistent with full employment or at the ZLB: either $\ell = \bar{L}$ and $\tilde{R}^* \geq 1$ or $\ell < \bar{L}$ and $\tilde{R}^* = 1$.

The nominal interest rate in the currency of the Hegemon $\tilde{R}$ depends on whether the currency is expected to depreciate, and is determined as follows: if the currency is not expected to depreciate in a disaster, then $\tilde{R} = \tilde{R}^*$; if the currency is expected to depreciate in a disaster, then $\tilde{R} = R^r_H$. Inflation in the Hegemon currency is zero in the former case, and $(1 - e_L)/e_L$ in the latter case.

Full-commitment equilibrium. We first consider the case in which the Hegemon has full commitment. The Hegemon then chooses never to devalue its currency.

Define the ZLB threshold

$$b_{ZLB} = \frac{1 - \bar{R}^r + 2\gamma\sigma^2(w^{*e} + \bar{L})}{2\gamma\sigma^2}.$$

It is positive if and only if $R^s(0;\bar{L}) = \bar{R}^r - 2\gamma\sigma^2(w^{*e} + \bar{L}) < 1$, which we assume from now on. Then for a given level of issuance b, the ZLB binds if and only if $b < b_{ZLB}$.

We start by analyzing the equilibrium for a given level of issuance b. If the ZLB does not bind ($b \geq b_{ZLB}$), the nominal interest rate is $\tilde{R}^* = R^s(b,\bar{L})$, which achieves full employment with output at its natural level $\bar{L}$. If the ZLB binds ($b < b_{ZLB}$), monetary policy cannot achieve full employment. In this case, with $\tilde{R}^* = 1$ and at full employment, the reserve asset market is in disequilibrium: there is a shortage of (excess demand for) reserve assets. This disequilibrium cannot be resolved by a reduction in interest rates. Instead, equilibrium output endogenously drops below potential, reducing investable wealth, the demand for reserve assets, and bringing the reserve asset market back to equilibrium. The equilibrium value of utilized labor ℓ is the solution of the following implicit equation

$$R^s(b;\ell) = 1. \tag{14}$$

[23] One could have in principle picked a different equilibrium at date $t = 1$, our results would be unchanged under alternative selections because all decisions at $t = 0$ are independent of output at time $t = 1$.

[24] Technically, we consider the limit as ϕ goes to infinity of a sequence of economies indexed by ϕ.

An alternative but equivalent representation of the equilibrium determination of utilized labor can be obtained by focusing on the goods market rather than on the safe asset market. The demand for and supply of goods can be described by a Keynesian cross AS-AD diagram $AS(\ell) = AD(\ell)$ with

$$AS(\ell) = w^{*e} + \ell, \quad \text{and} \quad AD(\ell) = b + \frac{\bar{R}^r - \tilde{R}^*}{2\gamma\sigma^2},$$

where $(\bar{R}^r - \tilde{R}^*)/(2\gamma\sigma^2)$ is investment in the risky technology by RoW agents and b is the sum of consumption and investment in the risky technology by Hegemon agents. Crucially, the supply of reserve assets acts as a positive AD shifter. Reductions in the supply of reserve assets b that cannot be accommodated by a reduction in interest rate $\tilde{R}^*$ at the ZLB, lead to a reduction in utilized labor ℓ and output. This makes clear that at the ZLB, the quantity ℓ is an equilibrium variable which is determined endogenously by a fixed point equation, very much in the same way that prices are determined by a fixed point equation in a standard Walrasian equilibrium.

We now turn to determination of the level of issuance b. A crucial property of the demand curve for reserve assets is that it is perfectly elastic at $R^s = 1$ in the region in which the ZLB binds. An immediate consequence of this property is that a Hegemon with full commitment always optimally chooses to supply enough safe assets $b^{FC}_{ZLB} > b_{ZLB}$ that the ZLB does not bind and there is full employment. The reason is that for levels of issuance $b < b_{ZLB}$, the Hegemon can issue more debt without increasing the associated interest rate, and hence capture higher monopoly rents. For $b \geq b_{ZLB}$ instead, the interest rate increases with issuance, which reduces monopoly rents and leads to a finite optimal level of issuance.[25]

Limited-commitment equilibrium. Under limited commitment, the zones of the IMS are analogous to those of the baseline model in Section 2.1, with the only difference being that the upper bound of the Instability zone $\bar{b}$ is now potentially affected by the ZLB, and thus we denote it by $\bar{b}_{ZLB}$. The upper bound of the Safety zone $\underline{b}$ is unchanged at τ/R^r_H since it is independent of the safe interest rate. The upper bound of the Instability zone $\bar{b}_{ZLB}$ is now $\bar{b}_{ZLB} = \min\left(\bar{b}, \tau\right)$, where $\bar{b}$ is given by the expression in equation (8) with $w^* = w^{*e} + \bar{L}$. Intuitively, either the upper bound of the Instability zone is reached at positive interest rates, in which case the bound is analogous to that in equation (8), or it is reached while still at the ZLB, in which case $\bar{b}_{ZLB} = \tau$.

We analyze two polar cases in which, compared to safe debt capacity, the ZLB threshold b_{ZLB} is either low in the Safety zone ($b_{ZLB} < \underline{b}$), or high in the Collapse zone ($b_{ZLB} > \bar{b}_{ZLB}$). If the ZLB threshold is in the Safety zone ($b_{ZLB} < \underline{b}$), then by the same logic as the one outlined in the full-commitment case, the Hegemon never issues less than the ZLB threshold b_{ZLB} since RoW demand is completely inelastic in that zone. Optimal issuance can then either be in the remaining part of the Safety zone $[b_{ZLB}, \underline{b}]$ or in the Instability zone $(\underline{b}, \bar{b}_{ZLB}]$. In the former case, the ZLB does not bind and there is full employment. In the latter case, the ZLB does not bind if the debt is safe since the supply of safe assets is b, in which case the economy is at full employment; the ZLB binds if the debt is risky since the supply of safe assets is then

[25] This configuration is illustrated in Figure 6 Panel (a): the Hegemon value function (the dotted line) is linear and increasing for all $b \in [0, b_{ZLB}]$ and concave for $b > b_{ZLB}$.

zero, in which case there is a recession determined by $R^s(0;\ell) = 1$.[26]

If the ZLB threshold is in the Collapse zone ($b_{ZLB} > \bar{b}_{ZLB}$), then the Hegemon either issues at the upper bound of the Instability zone $\bar{b}_{ZLB}$ or at the upper bound of the Safety zone $\underline{b}$, whichever generates the higher net expected monopoly rents. In both cases the ZLB binds and there is a recession. If the Hegemon issues in the Instability zone, then the recession is less severe if the debt is safe, in which case output is determined by $R^s(b;\ell) = 1$, than if it is risky, in which case output is determined by $R^s(0;\ell) = 1$ since the supply of reserve assets is then zero. We collect the above results in the proposition below.[27]

Proposition 4 ***(Floating Exchange Rates and ZLB with a Hegemon).*** *If the ZLB threshold is in the Safety zone ($b_{ZLB} < \underline{b}$), then if the Hegemon finds it optimal to issue in the Safety zone, it chooses $b \in [b_{ZLB}, \underline{b}]$, the ZLB does not bind and the economy is at full employment ($\ell = \bar{L}$). If the Hegemon finds it optimal to issue in the Instability zone, then, either its debt is safe and there is full employment, or its debt is risky, the ZLB binds, and output is below potential ($\ell < \bar{L}$).*

If the ZLB threshold is in the Collapse zone ($b_{ZLB} > \bar{b}_{ZLB}$), then the Hegemon either issues at the upper bound of the Instability zone $\bar{b}_{ZLB}$ or at the upper bound of the Safety zone $\underline{b}$, whichever generates the higher net expected monopoly rents. In both cases the ZLB binds and output is below potential ($\ell < \bar{L}$). If the Hegemon debt is risky, then there is a more severe recession (lower ℓ).

Figure 6 Panel (a) illustrates a parametrization in which the ZLB binds for all levels of debt up to the upper bound of the Instability zone $\bar{b}_{ZLB}$. Under full commitment, the Hegemon issues b^{FC} and achieves full employment. Under limited commitment, not only is that level of issuance no longer attainable, but the Hegemon actually finds it optimal (if α is sufficiently high) to issue at the upper bound of the Safety zone. The result is a binding ZLB and a recession. This configuration helps understand why a scarcity of reserve assets might be recessionary as emphasized by the safe-asset shortage literature (see e.g. Caballero and Farhi (2014), Caballero, Farhi and Gourinchas (2016), Eggertsson and Mehrotra (2014), Eggertsson et al. (2016)), but importantly also why the U.S. may have chosen not to issue a sufficient amount of debt to emerge from the ZLB during and after the Great Recession, perhaps for fear of a confidence crisis.

5.2 Gold-exchange Standard

The previous section dealt with a system of floating exchange rates. In this section, we consider a different exchange rate regime in the form of a gold-exchange standard.

We maintain the same production structure and nominal rigidity assumptions as in the previous section. We introduce gold in the model as an asset that pays a real dividend D for sure at time $t = 1$. One can think

[26] $R^s(0;\ell)$ is the equilibrium safe rate that clears the market for safe assets at a zero quantity of the assets. In this collapse equilibrium and at the ZLB, output and savings (ℓ) adjust to clear the market for safe assets at a zero interest rate and with zero safe assets.

[27] The results in Proposition 4 also apply to an extension in which production also takes place in the Hegemon economy in a setup entirely analogous to that of RoW. The Hegemon production reinforces its incentives to issue as much debt as possible to avoid a recession. To highlight that this element is not necessary for our result, we have omitted it from the main text, but include it here for realism.

of the dividend as a liquidity or hedonic service from holding gold that materializes independently from the state of the economy. We assume that the asset is in infinitesimal supply for tractability. Since gold is safe, it is discounted at the same rate as risk-free debt. Because the price level in units of the foreign currency is 1 in both periods, the nominal price of gold in units of the foreign currency is $p_G = D/\tilde{R}^*$.

The world economy operates under a gold-exchange standard in which the price of gold p_G is constant at $\bar{p}_G$ in all currencies. RoW monetary policy is no longer described by a Taylor rule. Instead monetary policy is dictated by the imperative of maintaining gold parity[28]

$$\tilde{R}^* = \bar{R}^G > 1, \qquad \text{with} \quad \bar{R}^G = \frac{D}{\bar{p}_G}. \tag{15}$$

If the Hegemon debt is safe, no arbitrage implies that $R^s(b;\ell) = \bar{R}^G$.[29] If the Hegemon debt is risky, its rate of return is the same as that of the risky asset $R = R^r_H$.

Under a gold-exchange standard, the demand for reserve assets is perfectly elastic at $\bar{R}^G$. Changes in the supply of reserve assets b are not accommodated by changes in the interest rate R^s and lead to variations in output according to $R^s(b;\ell) = \bar{R}_G$ if the debt is expected to be safe, and $R^s(0;\ell) = \bar{R}_G$ otherwise. This determination of output is similar to that obtained at the ZLB, with the difference that the interest rate is fixed at $\bar{R}_G > 1$ instead of 1. By analogy with the ZLB analysis, we define the full-employment threshold b_G to be the amount of reserve assets that are consistent with both maintaining the gold parity and full employment

$$b_G = \frac{\bar{R}_G - \bar{R}^r + 2\gamma\sigma^2(w^{*e} + \bar{w}\bar{L})}{2\gamma\sigma^2},$$

and we assume parameter restrictions such that $b_G > 0$. The upper bound of the Safety zone $\underline{b}$ is the same as that in the baseline model. The upper bound of the Instability zone $\bar{b}_G$ is the highest safe debt level that the Hegemon can sustain under the gold-exchange standard

$$\bar{b}_G = \min\left(b_G, \frac{\tau}{\bar{R}^G}\right).$$

As in the previous subsection with the ZLB, we analyze two polar cases in which, compared to safe debt capacity, the full-employment threshold b_G is either low in the Safety zone $b_G < \underline{b}$ or high in the Collapse zone $b_G > \bar{b}_G$.

[28]The level of the gold parity $\bar{p}_G$ is exogenous, one could think of it having been set by an international conference, and "being on the gold standard" means that both countries adopt monetary policies consistent with maintaining the gold parity. Since the model only has one period, the price of gold is only defined at $t = 0$ and no gold is traded at $t = 1$. Consistent with Section 5.1 on ZLB and nominal rigidities, we choose the $t = 1$ equilibrium to have full employment. In a dynamic model, the price of gold in each period would be determined by the future expected path of monetary policy.

[29]In this section we have assumed gold to be in infinitesimal supply. This is most tractable, but we could easily relax this assumption and assume that there is a positive supply $G > 0$ of gold. In this case the demand curve for reserve assets would be defined implicitly by $R^s(b;\ell) = \bar{R}^r - 2\gamma\sigma^2(w^{*e} + \ell - b - DG/R^s(b;\ell))$. Under the gold standard, $R^s(b\mathbf{1}_{\{safe\}};\ell) = \bar{R}^G$ and DG acts like a reduction in w^{*e}, and our analysis follows similarly. Under a floating exchange rate system at the ZLB, $R^s(b\mathbf{1}_{\{safe\}};\ell) = 1$ and once again our analysis follows identically by relabelling the endowment to be $w^{*e} - DG$. This also shows that in the presence of nominal rigidities, the ZLB places an upper bound on the real value of gold at DG.

Proposition 5 ***(Gold-exchange Standard with a Hegemon).*** *The Hegemon chooses to issue either at the upper bound of the Safety zone $\underline{b}$ or at the upper bound of the Instability zone $\bar{b}_G$, whichever generates the higher expected monopoly rents. If the Hegemon issues at the upper bound of the Safety zone $\underline{b}$, a recession ($\ell < \bar{L}$) occurs if the full-employment threshold is higher ($b_G > \underline{b}$), and otherwise there is a boom ($\ell > \bar{L}$). If the Hegemon issues at the upper bound of the Instability zone $\bar{b}_G$ and the debt is safe, a recession occurs if the full-employment threshold is higher ($b_G > \bar{b}_G$), and otherwise there is a boom. If the Hegemon issues at the upper bound of the Instability zone $\bar{b}_G$ and the debt is risky, a recession occurs independently of the full-employment threshold b_G. In all three cases the recession is more severe or the boom more shallow, the higher is the full-employment threshold b_G.*

These results allow us to rationalize the concerns voiced by Keynes (1923) who argued against the return to a gold standard at pre-WWI parities on the grounds that this would lead to a policy of tight money and trigger recessionary forces. Our model also clarifies that this dire warning rests on the assumption that the expansion of reserve assets beyond gold to include monetary reserves, as decided at the Genoa conference in 1922, would be insufficient to absorb the excess demand for reserves.[30]

Our results are also consistent with the evidence presented in Temin (1991) that the worldwide demise of the gold-exchange standard in the mid 1930s significantly contributed to ending the Great Depression. Indeed, in our model, if all countries devalue against gold by the same amount ($\bar{p}'_G > \bar{p}_G$), the resulting monetary accommodation ($\bar{R}^{G'} < \bar{R}^G$) stimulates the economy at a given level of reserve asset issuance ($b'_G < b_G$). If all countries decide to float their currencies, then the only potential remaining obstacle to achieving full employment is the ZLB, as highlighted in the previous section.

The above proposition also highlights that the gold-exchange standard, by making the demand for reserve assets perfectly elastic, always increases the incentives of the Hegemon to issue more debt both within and across zones. This helps in understanding why concerns about stability were particularly severe under the gold-exchange standards of the 1920s and 1960s. Figure 6 Panel (b) illustrates this point by showing that the Hegemon value function is linear (within zones) and increasing in the amount of debt b issued. In this configuration with a full-employment threshold in the Collapse zone ($b_G > \bar{b}_G$), and α sufficiently low, the Hegemon chooses to issue at the upper bound of the Instability zone $\bar{b}_G$.

[30] We can also formalize the concerns of Keynes (1923) that gold is an unsuitable asset for a monetary standard since it ties monetary policy to non-monetary shocks to the demand for and supply of gold:

> If we restore the gold standard, are we to return also to the pre-war conceptions of bank-rate, allowing the tides of gold to play what tricks they like with the internal price-level, and abandoning the attempt to moderate the disastrous influence of the credit-cycle on the stability of prices and employment? In truth, the gold standard is already a barbarous relic. Keynes, 1923, A Tract on Monetary Reform

One way to capture non-monetary shocks to the supply and demand for gold is via one-time unexpected shocks to D. Under the gold-exchange standard these shocks are accommodated one-for-one by changes in $R^G = D/\bar{p}_G$ which in turn result in fluctuations in b_G and output.

5.3 Expenditure Switching Effects and the Incentives to Devalue

In the model the incentive to devalue is the fiscal benefit of lower real debt repayment by the Hegemon. We now consider an important additional motive: stimulating domestic (Hegemon) output via expenditure switching. The analysis below applies both to floating exchange rates and to a gold-exchange standard.

We introduce a non-traded good in the Hegemon country at $t = 0$ and $t = 1$. The good is produced from labor by a unit mass of competitive firms via a linear one-for-one technology. Firms hire local labor at a rigid wage $\bar{w}$ in Hegemon currency. Competitive pricing implies that $p_{NT} = \bar{w}$.

Hegemon agents supply labor with no disutility up to a maximum $\bar{L}$ and have a large disutility for any amount beyond that level. We assume that the disutility is sufficiently large that $\bar{L}$ is the natural level of output. We extend Hegemon agents preferences by including a (potentially time and state dependent) separable utility value of non-tradable consumption. The per-period utility function is now $C_t + v_t(C_{NT,t})$, where v_t is strictly increasing, strictly concave, and smooth.[31] The first-order condition governing the consumption of non-traded goods is: $\bar{w}\mathscr{E}_t = v_t'(C_{NT,t})$, where $\mathscr{E}_t$ is the level of the exchange rate at time t.

We normalize the exchange rate at time $t = 0$ to $\mathscr{E}_0 = 1$. With this convention, we have $\mathscr{E}_1 = e$ where e continues to denote the change in the exchange rate, with $e = 1$ if no disaster has occurred, and $e \in \{1, e_L\}$ if a disaster occurs, depending on whether or not the Hegemon devalues its currency. We define the decreasing function $C_{NT,t}(\mathscr{E}) = v_t'^{-1}(\mathscr{E}\bar{w})$. In equilibrium we have $Y_{NT,t} = C_{NT,t} = C_{NT,t}(\mathscr{E}_t)$.

If output is below potential at $t = 1$, so much so that $C_{NT,1}(e_L) \leq \bar{L}$, then the Hegemon gets an additional benefit $v(C_{NT,1}(e_L)) - v(C_{NT,1}(1))$ from devaluing its currency at $t = 1$ because it stimulates domestic output. The model is then isomorphic to the baseline one but with an adjusted value of τ now given by[32]

$$\tilde{\tau} = \tau - \frac{v(C_{NT,1}(e_L)) - v(C_{NT,1}(1))}{1 - e_L} < \tau.$$

This analysis helps rationalize an important reason behind the collapse of the gold-exchange standard in the 1930s and of the Bretton Woods system in the 1970s. In all these historical episodes, the decision by the Hegemon(s) to devalue was both the result of external factors (confidence crises) and internal factors (fiscal pressures and recessions). For example, the British economy in 1931 was severely depressed and the British unilateral and unexpected decision to devalue and go off gold contributed to alleviating the U.K. recession.[33] Similarly, stimulating the U.S. economy was an important reason behind the U.S. abandonment of the gold parity in 1933. Analogously, the U.S. decision to go off gold and devalue the

[31] For generality, we allow the function v_t to depend on the realization of R^r, which allows us to capture variations in the natural exchange rate over time and across states.

[32] The only difference is that if the domestic recession at $t = 1$ in case of a disaster is severe enough, the Hegemon might be better off not trying to commit not to devalue its currency. In this case, the Hegemon issues risky debt, there is no commitment problem, and the equilibrium is trivial. We place ourselves in the alternative case in which under limited commitment, the Hegemon chooses to try to commit not to devalue, and only fails to do so in equilibrium when it issues in the Instability zone and expectations are unfavorable. Note that under flexible wages, then there is no further benefit from devaluing $\tilde{\tau} = \tau$. Output is always at potential $Y_{NT,t} = C_{NT,t} = \bar{L}$ and the condition $w_t/w_t^*\mathscr{E}_t = v_t'(\bar{L})$ simply pins down the relative wage w_t/w_t^*. The model is then completely isomorphic to the baseline model.

[33] Eichengreen and Sachs (1985) and Bemanke and James (1991) document that countries that went off gold earlier recovered faster than those that stayed on gold longer.

dollar in 1971-73 was in part the result of domestic recessionary pressures (the 1969 recession). Looking forward, this factor may continue to play an important role in the future.

6 The Multipolar Model

We have so far focused on an IMS dominated by a Hegemon with a monopoly over the issuance of reserve assets. Of course, this is a simplification and the real world, while currently dominated by the U.S., features other competing issuers as illustrated in Figure 1 Panel (d). Indeed, the Euro and the Yen already already play a limited role and there is speculation that other reserve currencies might appear in the future, such as the Chinese Renminbi. Historically, the IMS has always been very concentrated with at most a few meaningful issuers of reserve assets, but it has oscillated between almost Hegemonic configurations (e.g.: the U.S. during and since Bretton Woods (1944 to present); the U.K. during the classical gold standard (1870-1914)) and more multipolar configurations (e.g.: U.S. and U.K. in the 1920s).[34]

In this section we explore the equilibrium consequences of the presence of multiple reserve issuers. We characterize the conditions under which a multipolar world is likely to be beneficial by increasing the total quantity of reserve assets, as predicted by Eichengreen (2011) among others, or detrimental by fostering more instability, as warned by Nurkse (1944). All in all, our analysis suggests that the benefits of a more multipolar world might be U-shaped in the number of reserves issuers: a large number of reserve currencies is beneficial, but a small number of reserve currencies might be of limited benefit or even be worse than a single reserve currency.

6.1 The Benefits of a Multipolar World

We introduce n multiple symmetric reserve issuers. Issuers engage in quantity competition à la Cournot by issuing reserves denominated in their own currency. At $t = 1$ in a disaster, each issuer must decide whether or not to devalue its exchange rate by $e_L < 1$. Disasters are global in the sense that disaster states are the same for all issuers. As a consequence, all the debts of the different issuers that are safe are perfect substitutes if they are safe, and likewise for the debts that are risky.

Full-commitment equilibrium. We focus first on the case of full commitment. The RoW demand function for safe debt of country i is

$$R^s(b_i, b_{-i}) = \bar{R}^r - 2\gamma\sigma^2(w^* - b_i - b_{-i}),$$

where b_i is the quantity of safe debt issued by country i and b_{-i} is the total quantity of safe debt issued by all other $n-1$ countries. The slope of this demand function is still given by $\partial R^s(b_i, b_{-i})/\partial b_i = 2\gamma\sigma^2$ as in the monopolist case and optimal issuance is still given by $b_i = [\bar{R}^r - R^s(b_i, b_{-i})]/(2\gamma\sigma^2)$ as in equation

[34] These classifications are open to debate. For example, Lindert (1969) shows that the U.K.'s role before 1914, while dominant, was accompanied by substantial issuance of reserves by France (although largely held by Russia alone) and Germany (although largely held by the Austro-Hungarian Bank).

(5). Of course, the safety premium now depends on total issuance by all countries. The best response by country i given b_{-i} is

$$b_i = \frac{1}{2}(w^* - b_{-i}) \geq 0.$$

There exists a unique equilibrium and it is symmetric. Individual and total issuance are given by

$$b_i^{FC} = \frac{1}{n+1} w^*, \qquad B_n^{FC} = \frac{n}{n+1} w^*.$$

The equilibrium interest rate on safe debt is

$$R^s\left(B_n^{FC}\right) = \bar{R}^r - \frac{2}{n+1}\gamma\sigma^2 w^*.$$

Perfect competition obtains in the limit of a large number of issuers such that $\lim_{n\to\infty} B_n^{FC} = w^*$ and $\lim_{n\to\infty} R^s\left(B_n^{FC}\right) = \bar{R}^r$. As already previewed in Lemma 1, in this limit, the exorbitant privilege is completely dissipated, there are no monopoly rents, and RoW obtains full insurance. Competition under full commitment is thus a powerful force: it increases total issuance towards the first best. Furthermore, the largest benefits of competition come from the first few entrants, since total issuance increases in $n/(n+1)$. This provides one possible rationalization of the common support, among academics and policymakers (Eichengreen (2011)), for a multipolar IMS.

Limited-commitment equilibrium. Under limited commitment, the size of the Safety zone (the interval $[0, \bar{b} = \tau/R_H^r]$) does not depend on the equilibrium interest rate on reserve assets and is therefore unaffected by competition. With a sufficiently large number of reserve issuers, each issuer finds it optimal to issue debt within its Safety zone, and the equilibrium is then identical to that which obtains under full commitment. Therefore, a lot of competition (large n) is beneficial since it increases total issuance of reserve assets and makes the IMS more stable. However, as we shall see next, the benefits of a little (as opposed to a lot of) competition (small n) are more uncertain.

6.2 Nurkse Instability under Oligopoly

We formalize the warning by Nurkse (1944) that a potential disadvantage of the presence of multiple competing reserve issuers is that it introduces coordination problems across a priori substitutable reserve currencies. Nurkse famously pointed to the instability of the IMS during the interregnum between Dollar and Sterling in the 1920s. He diagnosed the increased difficulty to coordinate on the ultimate reserve asset by noticing the frequent switches in the holdings of reserves of these two issuers at other central banks. Eventually, this instability led to the collapse of this gold-exchange standard with the successive devaluations of the U.K. and the U.S. in 1931 and 1933, respectively (see Figure 1 Panels (a) and (b)).

To capture the possibility of additional instability arising from worsened coordination problems, we propose two stylized configurations of the model under a duopoly of issuers of reserve assets indexed by $i \in \{1, 2\}$. These configurations correspond to two different equilibrium selections reflecting different coordinations of investors' expectations.

In the first configuration one country faces the most favorable expectations regarding the stability of its currency $\alpha_i = 0$, while the other one faces the least favorable expectations $\alpha_{-i} = 1$. This configuration boils down to Cournot competition of firms under heterogenous capacity constraints; here the capacity constraints refer to the two boundaries $\bar{b}_i$ and $\underline{b}_{-i}$. To the extent that these capacity constraints are binding, country i issues more than country $-i$. We interpret the switches over time in RoW reserve holdings between Dollar and Sterling as unexpected inversions in the ranking of countries.

Nurkse's conjecture that it is easier to coordinate expectations towards a favorable outcome when there is a Hegemon issuer compared to a duopoly of issuers can be rendered in our model by assuming that a Hegemon would have faced $\alpha = 0$. Under this configuration, coordination problems reduce the benefits of competition (lower total issuance) compared to an ideal situation in which both duopoly issuers would have faced favorable expectation $\alpha_i = \alpha_{-i} = 0$.

In the second configuration exactly one country $\tilde{i}$ out of the two is selected at random at $t = 0^+$ to face the most favorable expectations, while the other country $-\tilde{i}$ faces the least favorable expectations. As above, we assume that a true Hegemon would have faced the most favorable expectations $\alpha = 0$.

For this second configuration, we focus on two interesting subcases. The first case arises when the demand for reserve assets is so high that a true Hegemon (under monopoly) would have chosen $\bar{b}$ even when facing $\alpha = 0.5$. Under duopoly, there can be multiple equilibria, but we show that it is always an equilibrium for both issuers to issue $\bar{b}$, and we focus on that case.[35] Then, both under monopoly and under duopoly, each issuer chooses to issue $\bar{b}$. Total issuance is therefore twice as high under duopoly as under monopoly. However, the total supply of safe debt is the same under both configurations, since the debt of the Hegemon is safe for sure under monopoly, but the debt of each issuer is only safe with probability 0.5 under duopoly.[36] In addition, the duopoly world features instability with the collapse of one of the two currencies occurring for sure, while the monopoly world is stable. Therefore, social welfare is lower under duopoly than under monopoly since the same effective amount of safe assets is supplied in equilibrium, but the duopoly incurs devaluation costs.

The second case arises when the demand for reserve assets is intermediate, so that a true Hegemon issues $\bar{b}$ when $\alpha = 0$ but prefers to cut back issuance to $\underline{b}$ when $\alpha = 0.5$. Going from monopoly to duopoly can then reduce the total effective supply of safe assets because under duopoly each issuer might issue at the upper boundary $\underline{b}$ of its Safety zone because of the higher probability of collapse, leading to lower total issuance than under monopoly as long as $2\underline{b} < \bar{b}$.[37] Social welfare is lower under duopoly than under

[35]The only other possible equilibrium in this case is one in which both issuers issue in the Safety zone below $\underline{b}$. This may or may not be an equilibrium. We either focus on cases in which it is not, or, in cases in which it is, we select the other equilibrium.

[36]This occurs because going from monopoly to duopoly: the boundaries $\bar{b}$ and $\underline{b}$ are unchanged; the (equilibrium) expected payoff to each issuer from issuing $\bar{b}$ is unchanged, because when they issue in the Instability zone, the competing issuers under duopoly do not actually compete since one is safe when the other is risky and vice versa; the (out of equilibrium) expected payoff to each issuer from issuing $\underline{b}$ is lower since that issuer competes with the other issuer who issues at $\bar{b}$ with probability 0.5

[37]Recall that the upper boundary of the Safety zone $\underline{b}$ is independent of the degree of competition. On the other hand, the upper boundary of the Instability zone is lower in the presence of another issuer that issues in its Safety zone than under monopoly. Suppose that the first issuer chooses not take the risk of a collapse and issues $\underline{b}$. Then the second issuer might issue either at the

monopoly for a different reason from the one analyzed above: duopoly reduces total issuance of safe assets even though it does not increase instability. In Section 7 and Appendix A.2.1 we discuss a related mechanism whereby going from monopoly to unstable duopoly erodes the future monopoly rents of each issuer, thus endogenously lowering commitment, and prove analytically that this force can be so strong as to reduce effective total issuance.

The analysis above makes clear that a multipolar IMS can be, but does not have to be, more unstable than a hegemonic system. In the model, many equilibrium outcomes are possible, some of them embed a worsening of coordination problems with competition and thereby provide a possible formalization of the type of arguments put forward by Nurkse, but others do not. Our purpose is not to take a stand on which outcome is more likely, but rather only to characterize the different possibilities.

The historical experience with multipolar systems has been mixed. Lindert (1969) argues that the IMS between 1870 and 1914 had some features of multipolarity (with France and Germany the other two significant issuers in addition to the U.K.) and yet was remarkably stable. By contrast, Nurkse stresses the instability of the IMS in the 1920s.[38]

7 Generalizing the Framework

In this section we show how our baseline model can be extended to capture a number of key aspects of the functioning of the IMS. Taken together, these extensions highlight the versatility of our framework, and the fruitfulness of our approach. In the interest of space, we only provide brief summaries here and refer the reader to the appendix for a formal treatment. We plan to pursue these ideas in future work.

Loss of reputation in infinite horizon. Our baseline model is static and requires an exogenous devaluation cost τ. In Appendix A.2.1, we develop an infinite-horizon version of the model where reserve issuers face overlapping generations of RoW investors in a repeated policy game. We study trigger strategies equilibria in which devaluations are followed by a (probabilistic) loss of reputation associated with adverse expectations in all future periods.

These equilibria can be represented as equilibria of the static game where the devaluation cost τ is micro-founded as the expected net present value of future monopoly rents accruing to a particular reserve

upper boundary of the Safety zone $\underline{b}$ or issue in the Instability zone below $\bar{b}$. In both cases, the second issuer makes less profits that if it were acting under monopoly with $\alpha = 0.5$ because of the competition of the other issuer. As long as the difference between the reduction in profits from competition when issuing in the Safety zone and when issuing in the Instability zone is not too large (see Appendix A.1 for some sufficient conditions), then the second issuer will choose to issue in the Safety zone at $\underline{b}$ because a Hegemon would have done so. In this case both issuers issuing at $\underline{b}$ is an equilibrium under duopoly.

[38] We emphasize that in mapping the model to Nurkse's facts about the 1920s gold-exchange standard, the quantity b refers not to the total stock of debt but to the part of this stock held abroad. The instability, therefore, can manifest itself in debt switching hands between foreign and domestic residents and not necessarily in the total amount being issued. Similarly, b could be extended along the lines of Section 2.1 to include private issuance and much of the collapse in total issuance could take place in the private issuance rather than the public issuance. Accominotti (2012) provides evidence that private safe asset issuance (via acceptance guarantees) by London merchant banks was substantially curtailed during and after the Sterling crisis in 1931.

issuer, which we refer to as its "franchise value". Crucially, this devaluation cost τ is now an endogenous equilibrium object.

In particular, the devaluation cost τ is endogenous to entry: it goes down with the number of issuers because total monopoly rents have to be shared among a larger number of issuers, and so the franchise value of each issuer is reduced. This force limits the benefits of competition even in the absence of any coordination problem by eroding the commitment of each individual reserve issuer. In fact, we show that in certain configurations, this force can be so strong as to completely eliminate the positive effects of entry on the total amount of reserves and on welfare.

Furthermore, the devaluation cost τ is also endogenous to coordination problems: it decreases with their intensity because future coordination problems increase the risk of a future devaluation by a given issuer, and thereby reduce the franchise value of each issuer. As a result, it is not just present coordination problems that are a source of present instability as in our baseline model, but also future coordination problems because they endogenously reduce the present commitment of each individual issuer. In the model, it is possible for coordination problems to be exacerbated by entry, leading to a bigger reduction in τ via the two aforementioned mechanisms combined. We show that competition can foster instability, decrease the total amount of reserves, and reduce welfare.

This line of argument draws an interesting parallel with arguments in the banking literature that competition can lead to financial instability by reducing the franchise value of competing banks and leading them to adopt riskier strategies (Keeley (1990), Demsetz, Saidenberg and Strahan (1996), Repullo (2004)).[39]

Private issuance of reserve assets. In our baseline model only governments issue reserve assets. In practice, reserve assets are composed not only of government securities, but also of highly-rated private debt securities. In Appendix A.2.4, we extend the model to allow for private issuance. If the government has access to capital controls, then private issuance is essentially irrelevant since it leads to the exact same equilibrium allocations. But in the absence of capital controls, a key difference between private and public issuance becomes consequential: while the latter internalizes its effects on equilibrium interest rates, the former does not. Private issuance mitigates the monopoly power of the government by confronting it with a more elastic residual demand curve, but does not eliminate it as long as private issuance is not infinitely elastic. In the extended model, the proper notion of reserve supply is given by the total external debt: it is the basis for the monopoly rents of the country, and it also governs the incentives of the government to devalue.

We also consider an extension that accounts for issuance in the reserve currency by third parties, private or public, that are based in countries other than the Hegemon. Historically, these external third parties were issuing predominantly in Sterling and are currently issuing in Dollar (see Appendix Figure

[39] Our work is also related to the literature on competing monies. Our result that under full commitment in the perfect competition limit, the model delivers the efficient outcome of full insurance and no safety premium for the RoW is consistent with the Hayek (1976) view that competition in the supply of monies is beneficial, and runs counter to the opposite view articulated by Friedman (1960). This limit result breaks down under limited commitment even in the absence of coordination problems among investors. This result is related to arguments by Klein (1974), Tullock (1975), Taub (1990), Marimon, Nicolini and Teles (2012).

A.1). In our model, issuers that are subject to *original sin* face a trade off in the choice of foreign currency for the denomination of their debt: issuing in reserve currency lowers ex-ante yields on debt, but comes with higher ex-post costs since the real value of debt remains high during global crises.

Fiscal capacity. In our baseline model, taxes are not distortionary. In Appendix A.2.6, we extend the model to capture the distortionary costs of taxation. We incorporate a social cost of public funds which proxies for a country's fiscal capacity. In practice, a country's fiscal capacity could be influenced by several factors, such as its size, the development of its tax administration, the strength of its legal system, and its enforcement capacity, etc.

In general, larger fiscal capacities lead to more reserves issuance. In a multipolar model with heterogenous issuers, the equilibrium is an asymmetric Cournot equilibrium where issuers with larger fiscal capacities have larger equilibrium market shares.

Currency of goods pricing. Historically, a dominant position as a reserve currency has often been associated with dominance in the currency denomination of goods and other contracts. In other words, prices of tradable goods are disproportionately quoted in the dominant reserve currency, in Dollar at present and in Sterling in the 1920s, a fact dubbed the International Price System (IPS) by Gopinath (2015).

In Appendix A.2.6, we investigate the interaction between reserve currency status and currency of goods pricing and the rationales for their association. The more goods are priced (and sticky) in a given reserve currency, the safer is the debt denominated in this currency, since a given nominal devaluation of this currency leads to a smaller erosion of the real value of the debt. In a multipolar model, this characteristic confers an advantage to the issuer of this currency.

Liquidity, network effects, and the endogenous emergence of a Hegemon. In our baseline model, the key characteristic of reserve assets is their safety, and their demand arises from the risk aversion of RoW investors. In practice, reserve assets are distinguished not only by their safety but also by their liquidity. In Appendix A.2.5, we extend the model to capture the liquidity benefits of reserve assets via a "bond–in-the-utility" formulation. We allow the individual marginal liquidity benefits of holding the reserve asset to increase with the holdings of other agents, in order to capture the fundamental increasing returns or network property of liquidity.[40]

In a multipolar model, the increasing returns or network effects associated with liquidity can amplify the impact of differences (fiscal capacity, reputation, currency of goods pricing) across issuers and lead to the endogenous emergence of a Hegemon. This captures the widely-held notion that the depth and liquidity of U.S. financial markets, and in particular of U.S. Treasuries, is key in consolidating the role of the U.S. Dollar as the dominant reserve currency.

Endogenous entry and natural monopoly. In our baseline model, entry is exogenous. In Appendix A.2.7, we extend the model to allow for endogenous entry. We add an ex-ante stage at the beginning of

[40]For a search-theoretic foundation of these increasing returns or network property of liquidity in the context of international monies see Matsuyama, Kiyotaki and Matsui (1993).

the game where issuers can incur an entry cost to increase their reputation by increasing their subsequent devaluation cost τ.

We have in mind the various costs and delays in acquiring a reputation for sound policy. In practice, this could involve resisting the pressure to devalue in times of crisis at a potentially large economic cost. Furthermore, the opportunities to demonstrate good behavior to boost reputation might be very infrequent.

The consequence is that the reserve currency market could have the characteristics of a natural monopoly with large fixed costs and low variable costs. Entry costs must be recouped with a share of future total monopoly rents, and these might be too small to sustain entry by a large number of issuers. This line of explanation offers yet another rationale for the historically high concentration of the reserve currency market and for its limited contestability. It also offers another perspective on the endogenous emergence of a Hegemon. Indeed, to the extent that the entry cost is sunk, the identity of the Hegemon (say the U.S. at present) could to some extent be the result of a historical accident through a form of first-mover advantage. A reserve country that was at some point in the past in a dominant position on fundamental grounds, preserves its central position simply because it is already present in the market. This might impart persistence and lock-in effects to reserve currency status.

Risk-sharing and LoLR. One avenue to mitigate the Triffin Dilemma and the associated instability of the IMS is to introduce policies that reduce the demand for reserve assets. Policies to this effect have often been proposed by economists looking to reform the IMS (Keynes (1943), Harrod (1961), Machlup (1963), Meade (1965), Rueff (1963), Farhi, Gourinchas and Rey (2011)). In their most recent incarnation, they have included swap lines amongst central banks, credit lines by the IMF as a LoLR, and international reserve sharing agreements such as the Chiang Mai initiative.

In Appendix A.2.8, we augment our framework to make sense of these global financial safety net proposals. We assume that each of the many countries in RoW faces idiosyncratic shocks. We also assume that risk aversion increases with the amount of risk faced by individual investors. This captures a form of precautionary saving motive whereby higher idiosyncratic risk leads to a higher demand for reserve assets.

A risk-sharing arrangement between RoW countries mitigates the impact of idiosyncratic shocks and tilts portfolios away from reserve assets. Over and above its immediate idiosyncratic risk-sharing benefits, such an arrangement is beneficial because it reduces the demand for reserve assets, lowers the pressure for the Hegemon to stretch itself by issuing in the Instability zone and exposing itself to a confidence crisis, and mitigates the Triffin dilemma.

8 Conclusions

We have provided a simple and tractable framework for understanding the IMS. The framework helps rationalize a number of historical episodes, including the emergence and collapse of the gold-exchange standard in the 1920s, the emergence and collapse of the Bretton Woods system, the recessionary forces associated with gold-exchange standards, and the role of the U.S. as a Hegemon in the current floating exchange rate system. The framework provides foundations for and refines prominent conjectures regarding the workings and stability of the IMS, including the Triffin dilemma, the Nurkse instability, and the beneficial nature of multipolar systems. Our analysis characterizes: the possibility that a Hegemon issuer of reserve assets might over- or under- issue from a social welfare perspective, the parallel between the gold-exchange standard and a system of floating exchange rates at the ZLB, and the potential perverse effects of competition among reserve issuers.

References

Accominotti, Olivier. 2012. "London merchant banks, the central European panic, and the sterling crisis of 1931." *The Journal of Economic History*, 72(01): 1–43.

Aguiar, Mark, Satyajit Chatterjee, Harold Cole, and Zachary Stangebye. 2016. "Self-Fulfilling Debt Crises, Revisited: The Art of the Desperate Deal."

Aliber, Robert Z. 1964. "The costs and benefits of the US role as a reserve currency country." *The Quarterly Journal of Economics*, 442–456.

Aliber, Robert Z. 1967. "Gresham's Law, asset preferences, and the demand for international reserves." *The Quarterly Journal of Economics*, 628–638.

Arellano, Cristina, and Yan Bai. 2013. "Linkages across sovereign debt markets." National Bureau of Economic Research.

Azzimonti, Marina, and Vincenzo Quadrini. 2016. "The politics of sovereign default under financial integration."

Azzimonti, Marina, Eva De Francisco, and Vincenzo Quadrini. 2014. "Financial globalization, inequality, and the rising public debt." *The American Economic Review*, 104(8): 2267–2302.

Bach, Christopher. 1972. "US balance-of-payments problems and policies in 1971." *Review*.

Bemanke, Ben, and Harold James. 1991. "The gold standard, deflation, and financial crisis in the Great Depression: An international comparison." In *Financial markets and financial crises*. 33–68. University of Chicago Press.

Bénétrix, Agustín S, Philip R Lane, and Jay C Shambaugh. 2015. "International currency exposures, valuation effects and the global financial crisis." *Journal of International Economics*, 96(1): S98–S109.

Bernanke, Ben. 2005. "The Global Saving Glut and the U.S. Current Account Deficit." *Sandridge Lecture, Virginia Association of Economists*.

Branson, William H. 1971. "The Balance of Payments in 1970." *Brookings Papers on Economic Activity*, 1971(1): 219–225.

Caballero, Ricardo J, and Arvind Krishnamurthy. 2009. "Global Imbalances and Financial Fragility." *The American Economic Review*, 99(2): 584–588.

Caballero, Ricardo J, and Emmanuel Farhi. 2014. "The safety trap." National Bureau of Economic Research.

Caballero, Ricardo J, Emmanuel Farhi, and Pierre-Olivier Gourinchas. 2008. "An Equilibrium Model of Global Imbalances and Low Interest Rates." *The American Economic Review*, 98(1): 358–393.

Caballero, Ricardo J, Emmanuel Farhi, and Pierre-Olivier Gourinchas. 2016. "Global Imbalances and Currency Wars at the ZLB." National Bureau of Economic Research.

Calvo, Guillermo A. 1988. "Servicing the public debt: The role of expectations." *The American Economic Review*, 647–661.

Cole, Harold L, and Timothy J Kehoe. 2000. "Self-fulfilling debt crises." *The Review of Economic Studies*, 67(1): 91–116.

Cooper, Richard N. 1975. "Prolegomena to the Choice of an International Monetary System." *International Organization*, 29(1): 63–97.

Cooper, Richard N. 1987. *The international monetary system: essays in world economics.* MIT Press Cambridge, Mass.

Dang, Tri Vi, Gary Gorton, and Bengt Holmstrom. 2015. "The Information Sensitivity of a Security." MIT MIT mimeo.

Demsetz, Rebecca S, Marc R Saidenberg, and Philip E Strahan. 1996. "Banks with something to lose: The disciplinary role of franchise value." *Economic Policy Review*, 2(2).

Despres, E., C.P. Kindleberger, and W.S. Salant. 1966. *The Dollar and World Liquidity: A Minority View. Brookings Institution, Reprint*, Brookings Institution.

Diamond, Douglas W, and Philip H Dybvig. 1983. "Bank runs, deposit insurance, and liquidity." *The journal of political economy*, 401–419.

Eaton, Jonathan, and Mark Gersovitz. 1981. "Debt with potential repudiation: Theoretical and empirical analysis." *The Review of Economic Studies*, 48(2): 289–309.

Eggertsson, Gauti B, and Neil R Mehrotra. 2014. "A model of secular stagnation." National Bureau of Economic Research.

Eggertsson, G., N. Mehrotra, S. Singh, and L. Summers. 2016. "A Contagious Malady? Open Economy Dimensions of Secular Stagnation." *Working Paper*.

Eichengreen, Barry. 2011. *Exorbitant Privilege: The rise and fall of the Dollar and the Future of the International Monetary System.* Oxford University Press.

Eichengreen, Barry, and Jeffrey Sachs. 1985. "Exchange rates and economic recovery in the 1930s." *The Journal of Economic History*, 45(04): 925–946.

Eichengreen, Barry, and Marc Flandreau. 2009. "The rise and fall of the dollar (or when did the dollar replace sterling as the leading reserve currency?)." *European Review of Economic History*, 13(3): 377–411.

Eichengreen, Barry, Arnaud Mehl, and Livia Chitu. 2017. *International Currencies: Past, Present and Future: Two Views from Economic History.* Princeton University Press, forthcoming.

Eichengreen, Barry, Livia Chitu, and Arnaud Mehl. 2016. "Stability or upheaval? The currency composition of international reserves in the long run." *IMF Economic Review*, 64(2): 354–380.

Farhi, Emmanuel, Pierre-Olivier Gourinchas, and Hélène Rey. 2011. *Reforming the international monetary system.* CEPR.

Fleming, J Marcus. 1966. "Use and Acceptance of Reserve Claims." *IMF Staff Papers*, 13(3): 443.

Friedman, Milton. 1960. *A program for monetary stability.* Vol. 541, Fordham University Press New York.

Gennaioli, Nicola, Andrei Shleifer, and Robert Vishny. 2012. "Neglected risks, financial innovation, and financial fragility." *Journal of Financial Economics*, 104(3): 452–468.

Gennaioli, Nicola, Andrei Shleifer, and Robert W Vishny. 2013. "A model of shadow banking." *The Journal of Finance*, 68(4): 1331–1363.

Gertler, Mark, and Nobuhiro Kiyotaki. 2015. "Banking, Liquidity, and Bank Runs in an Infinite Horizon Economy." *American Economic Review*, 105(7): 2011–43.

Gopinath, Gita. 2015. "The international price system." National Bureau of Economic Research.

Gorton, Gary, and George Penacchi. 1990. "Financial Intermediaries and Liquidity Creation." *Journal of Finance*, 45(1): 49–71.

Gorton, Gary, and Guillermo Ordonez. 2014. "Collateral Crises." *American Economic Review*, 104(2): 343–378.

Gorton, Gary B., and Guillermo Ordonez. 2013. "The Supply and Demand for Safe Assets." National Bureau of Economic Research, Inc NBER Working Papers 18732.

Gourinchas, Pierre-Olivier, and Helene Rey. 2007*a*. "From world banker to world venture capitalist: US external adjustment and the exorbitant privilege." In *G7 Current Account Imbalances: Sustainability and Adjustment*.

Gourinchas, Pierre-Olivier, and Hélène Rey. 2007*b*. "International financial adjustment." *Journal of Political Economy*, 115(4): 665–703.

Gourinchas, Pierre-Olivier, Nicolas Govillot, and Hélène Rey. 2011. "Exorbitant Privilege and Exorbitant Duty." *Unpublished manuscript, UC Berkeley and LBS*.

Greenwood, Robin, Samuel Hanson, and Jeremy C. Stein. 2015. "A Gap-Filling Theory of Corporate Debt Maturity Choice." *Journal of Finance*, 117(3): 449–469.

Hagemann, Helmut A. 1969. "Reserve Policies of Central Banks and Their Implications for US Balance of Payments Policy." *The American Economic Review*, 62–77.

Harrod, Roy. 1961. "A Plan for Increasing Liquidity: A Critique." *Economica*, 28(110): 195–202.

Hart, Oliver, and Luigi Zingales. 2014. "Banks are where the Liquidity is." National Bureau of Economic Research.

Hayek, F. 1976. *Denationalization of Money.*

He, Zhiguo, Arvind Krishnamurthy, Konstantin Milbradt, et al. 2015. "A model of the reserve asset."

Holmström, Bengt, and Jean Tirole. 2011. *Inside and outside liquidity.* MIT press.

Keeley, Michael C. 1990. "Deposit Insurance, Risk, and Market Power in Banking." *The American Economic Review*, 80(5): 1183–1200.

Kenen, Peter B. 1960. "International liquidity and the balance of payments of a reserve-currency country." *The Quarterly Journal of Economics*, 572–586.

Kenen, Peter B. 1963. *Reserve-asset preferences of central banks and stability of the gold-exchange standard.* International Finance Section, Dept. of Economics, Princeton University.

Kenen, Peter B, and Elinor B Yudin. 1965. "The demand for international reserves." *The Review of Economics and Statistics*, 242–250.

Keynes, J.M. 1943. *Proposal for an International Clearing Union.* British Government Publication, Cmd 6437.

Keynes, John Maynard. 1923. *A Tract on Monetary Reform.* Macmillan.

Klein, Benjamin. 1974. "The competitive supply of money." *Journal of Money, Credit and Banking*, 6(4): 423–453.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen. 2012. "The aggregate demand for treasury debt." *Journal of Po-*

litical Economy, 120(2): 233–267.

Leeper, Eric M. 1991. "Equilibria under 'active' and 'passive' monetary and fiscal policies." *Journal of Monetary Economics*, 27(1): 129–147.

Lindert, Peter H. 1969. *Key currencies and gold, 1900-1913.* International Finance Section, Princeton University.

Lizarazo, Sandra. 2009. "Contagion of financial crises in sovereign debt markets."

Machlup, Fritz. 1963. "Reform of the international monetary system." *World Monetary Reform: Plans and Issues,(Stanford University Press and Oxford University Press, Stanford, CA and London 1963)*, 253–260.

Maggiori, Matteo. 2012. "Financial Intermediation, International Risk Sharing, and Reserve Currencies." *Unpublished manuscript, Harvard University*.

Marimon, Ramon, Juan Pablo Nicolini, and Pedro Teles. 2012. "Money is an experience good: Competition and trust in the private provision of money." *Journal of Monetary Economics*, 59(8): 815–825.

Matsuyama, Kiminori, Nobuhiro Kiyotaki, and Akihiko Matsui. 1993. "Toward a theory of international currency." *The Review of Economic Studies*, 60(2): 283–307.

Meade, James E. 1965. "The future of international payments." *World Monetary Reform: Plans and Issues*.

Mendoza, Enrique G, Vincenzo Quadrini, and Jose-Vıctor Rıos-Rull. 2009. "Financial Integration, Financial Development, and Global Imbalances." *Journal of Political Economy*, 117(3).

Moreira, Alan, and Alexi Savov. 2014. "The Macroeconomics of Shadow Banking." National Bureau of Economic Research, Inc NBER Working Papers 20335.

Nurkse, Ragnar. 1944. *International currency experience: lessons of the interwar period.* League of Nations.

Obstfeld, M, and K Rogoff. 2001. "Perspectives on OECD Capital Market Integration: Implications for the US current account adjustment." *In Global Economic Integration: Opportunities and Challenges, 169–208*, Kansas City, MO: Federal Reserve Bank of Kansas City.

Obstfeld, Maurice. 2011. "International liquidity: the fiscal dimension." National Bureau of Economic Research.

Obstfeld, Maurice, and Kenneth Rogoff. 2007. "The unsustainable US current account position revisited." *In R.H. Clarida, ed., G7 current account imbalances: Sustainability and adjustment, 339–376*, Chicago, IL: University of Chicago Press.

Repullo, Rafael. 2004. "Capital requirements, market power, and risk-taking in banking." *Journal of financial Intermediation*, 13(2): 156–182.

Rueff, Jacques. 1963. "Gold exchange standard a danger to the West." *reprinted in H. Grubel (ed.) World Monetary Reform*, 320–8.

Sargent, Thomas J., and Neil Wallace. 1981. "Some unpleasant monetarist arithmetic." *Quarterly Review*, , (Fall).

Sims, Christopher A. 1994. "A Simple Model for Study of the Determination of the Price Level and the Interaction of Monetary and Fiscal Policy." *Economic Theory*, 4(3).

Spence, A Michael. 1975. "Monopoly, quality, and regulation." *The Bell Journal of Economics*, 417–429.

Stein, Jeremy C. 2012. "Monetary Policy as Financial Stability Regulation." *The Quarterly Journal of Economics*, 127: 57–95.

Taub, B. 1990. "Private Fiat Money with Many Suppliers." *Milton Friedman: Critical Assessments*, 3: 164.

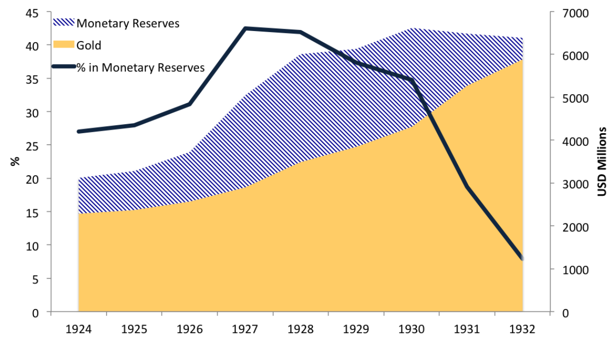
Temin, Peter. 1991. *Lessons from the great depression.* MIT Press.

Triffin, Robert. 1961. *Gold and the Dollar Crisis: The future of convertibility.* New Haven, Yale University Press, Connecticut.

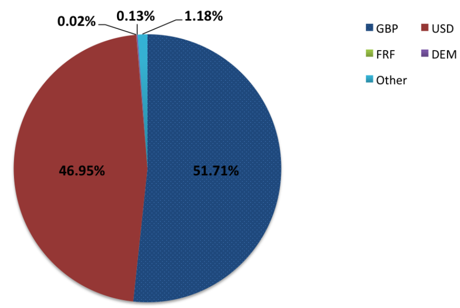
Tullock, Gordon. 1975. "Competing monies." *Journal of Money, Credit and Banking*, 7(4): 491–497.

Woodford, Michael. 1994. "Monetary Policy and Price Level Determinacy in a Cash-in-Advance Economy." *Economic Theory*, 4(3): 345–80.

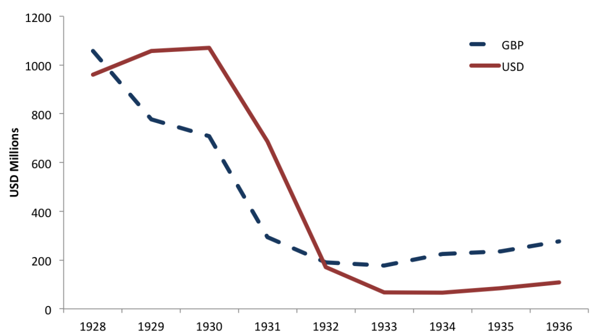
Figure 1: History of the International Monetary System



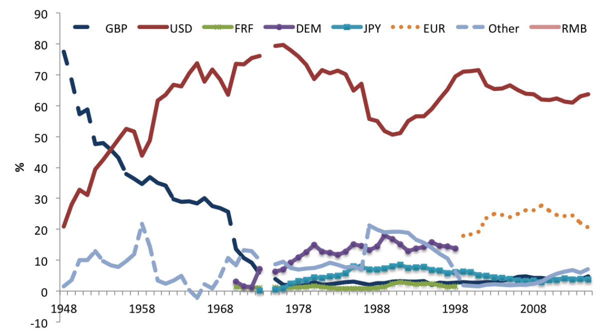
(a) Gold-exchange standard 1924-1932



(b) Currency composition of reserves in 1928



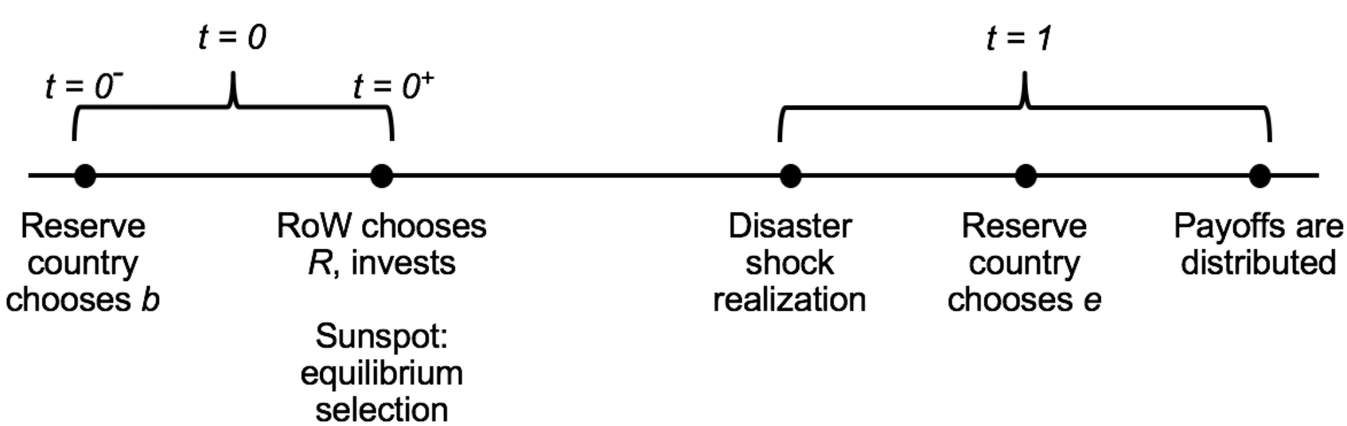
(c) Collapse of reserves in Dollar and Sterling in 1931-33



(d) Currency composition of reserves during Bretton Woods and modern float

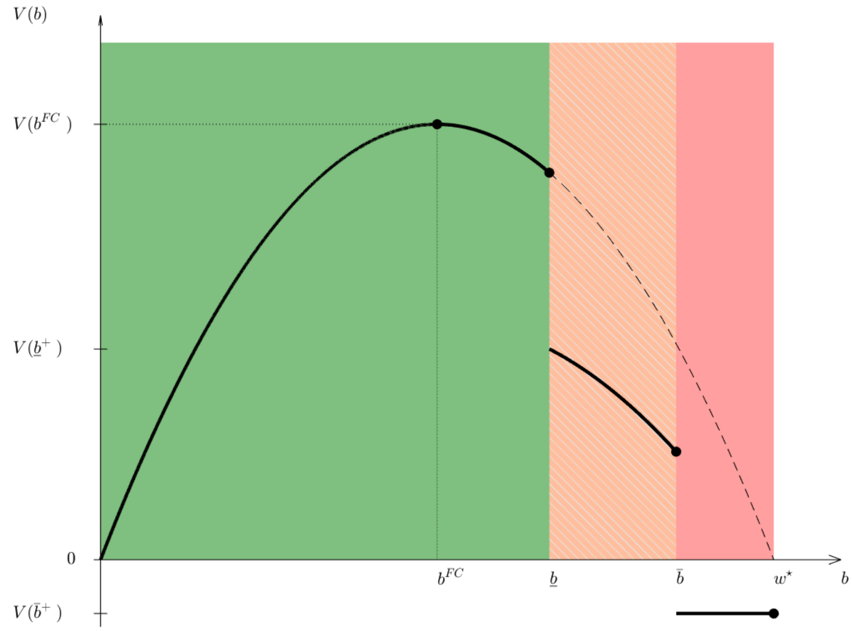
Note: Panel (a) illustrates the value in millions of U.S. dollars (right axis) of gold and monetary reserves held by 24 central banks (mostly European, excluding the U.S. and U.K.) during the gold-exchange standard (1924-32). The panel also illustrates the percentage (left axis) of total reserves (gold + monetary reserves) accounted for by monetary reserves. Source: Nurkse (1944) Appendix II. Panel (b) illustrates the currency composition of monetary reserves in 1928. Panel (c) illustrates the value in millions of U.S. dollars of reserves held in pounds and dollars by a balanced panel of 15 central banks (excluding the U.S. and U.K.). Panel (d) illustrates the currency composition (in percentage) of foreign exchange reserves held by a panel of central banks over the Bretton Woods period (1948-1973) and the modern float period (1973-2015). Sources for Panels (b) to (d) are Eichengreen and Flandreau (2009), Eichengreen, Chitu and Mehl (2016), Eichengreen, Mehl and Chitu (2017) and sources therein.

Figure 2: Timeline

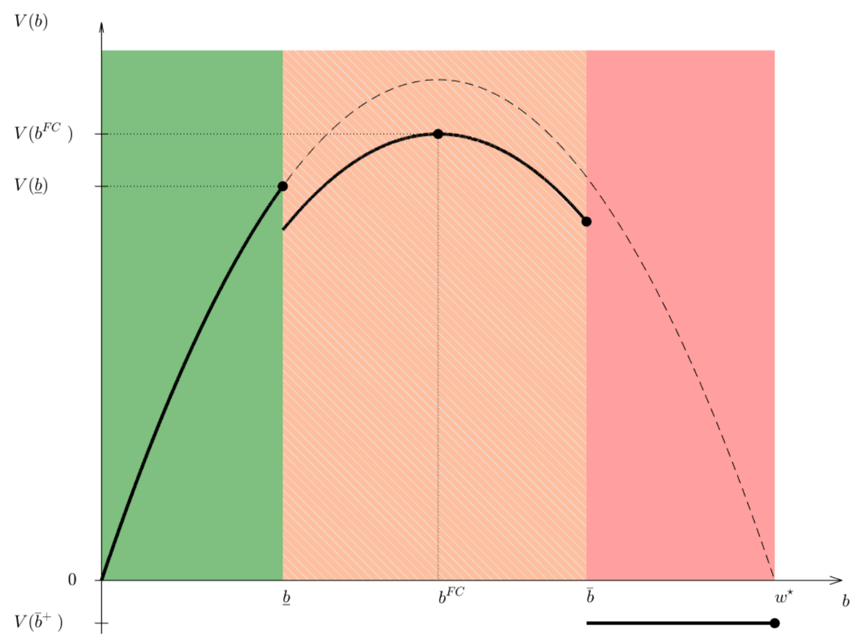


Note: The timeline of decisions for the one-period model.

Figure 3: Hegemon Optimal Debt Issuance



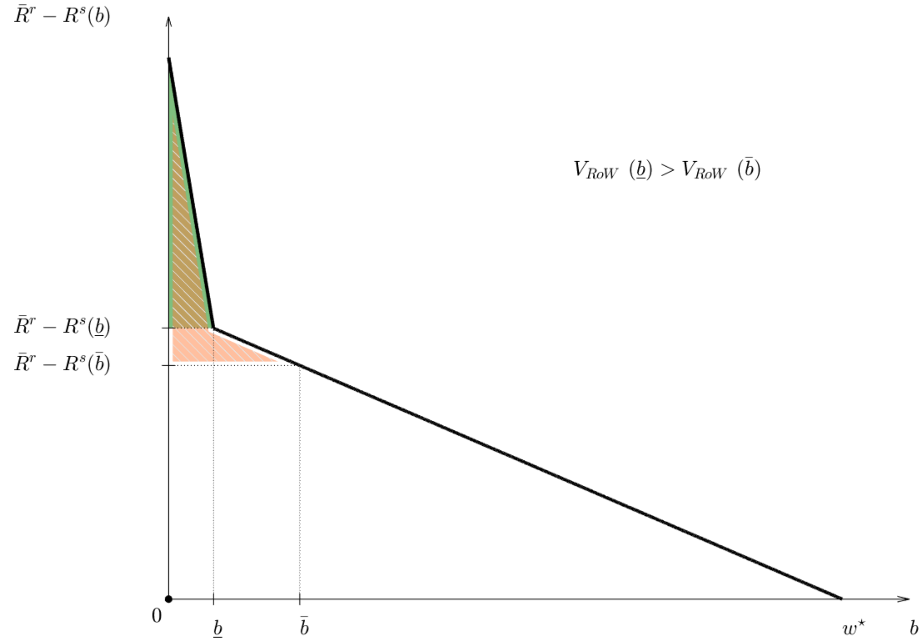
(a) Optimal issuance in Safety zone



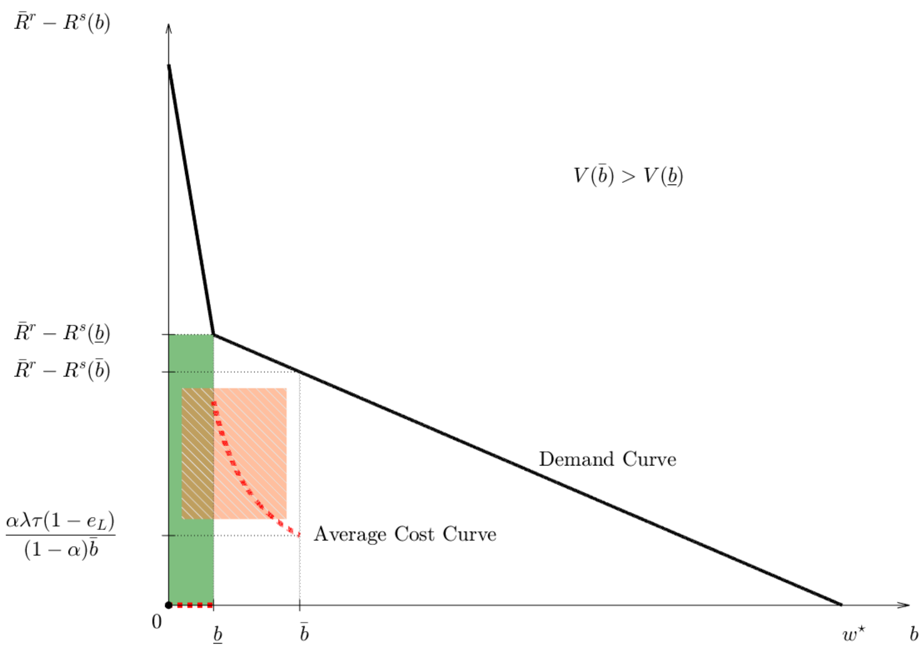
(b) Optimal issuance in Instability zone

Note: Panel (a) illustrates a parameter configuration in which full-commitment issuance b^{FC} can be achieved in the Safety zone. Panel (b) illustrates a parameter configuration in which full-commitment issuance b^{FC} can only be achieved in the Instability zone. Optimal issuance under limited commitment still occurs at the full-commitment level in both panels.

Figure 4: Welfare Consequences of the Triffin Dilemma



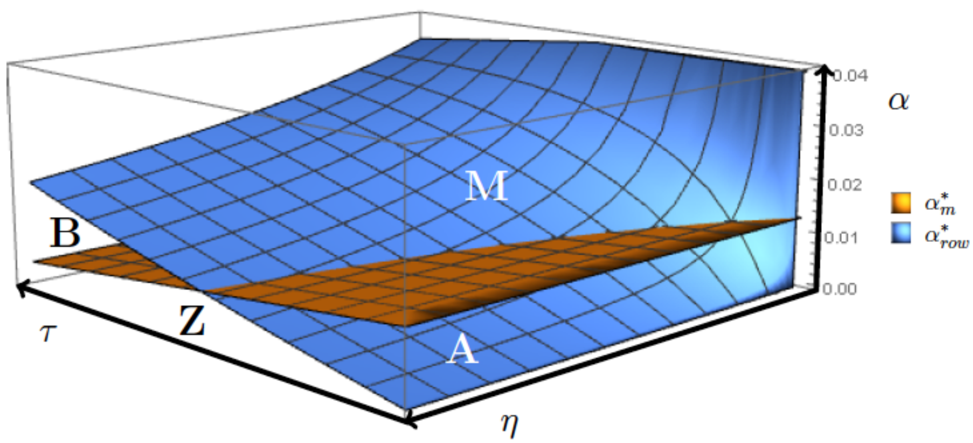
(a) RoW expected utility



(b) Hegemon net expected monopoly rents

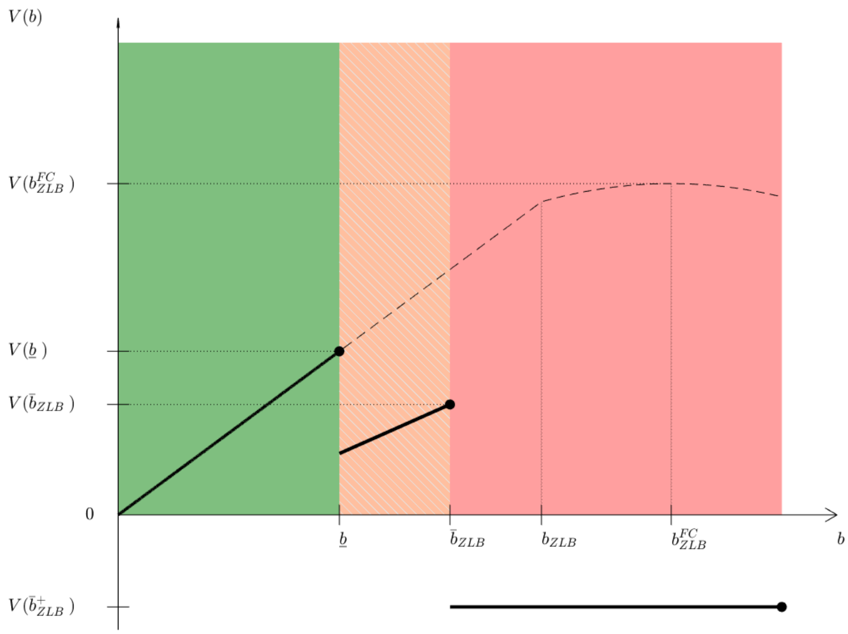
Note: Panel (a) illustrates RoW expected utility resulting from the Hegemon decision to issue either at the upper bound of the Safety zone $\underline{b}$ (green) or at the upper bound of the Instability zone $\bar{b}$ (orange). Under the parameter configuration, RoW would have preferred issuance to be in the Safety zone at $\underline{b}$. Panel (b) illustrates net expected monopoly rents for the Hegemon issuance of either $\underline{b}$ (green) or $\bar{b}$ (orange). A parameter configuration is chosen such that the Hegemon finds it optimal to issue $\bar{b}$.

Figure 5: Welfare Consequences of the Triffin Dilemma: Over- and Under-Issuance

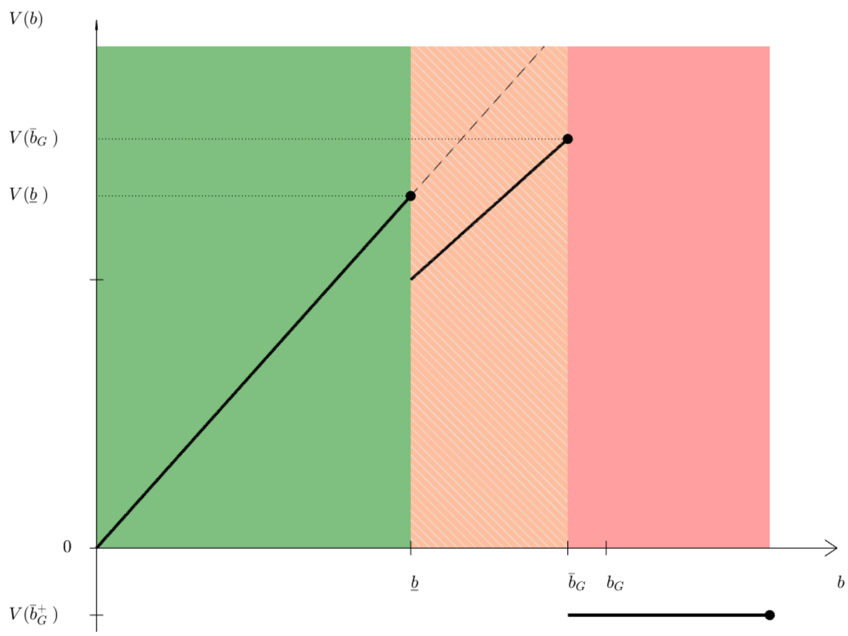


Note: The Figure illustrates the threshold probabilities α_{row}^* and α_m^* that make the RoW and Hegemon indifferent between issuance at the upper bound of the Safety zone $\underline{b}$ and at the upper bound of the Instability zone $\bar{b}$. The figure illustrates the values of α_{row}^* and α_m^* as functions of the level of commitment τ and the degree of convexity of the demand curve η. Parameter values for this numerical example: $R_H^r = 1.03,\ R_L^r = 0.83,\ \lambda = 0.05,\ \gamma = 3.5,\ w^* = 1$.

Figure 6: Gold-Exchange Standard and Floating Exchange Rates at the ZLB



(a) Zero lower bound under floating exchange rates



(b) Gold-exchange standard

Note: Panel (a) illustrates optimal issuance by the Hegemon at the ZLB and under floating exchange rates. A parameter configuration is chosen such that optimal issuance takes place at the upper bound of the Safety zone $\underline{b}$. Panel (b) illustrates optimal issuance by the Hegemon on a gold-exchange standard. A parameter configuration is chosen such that optimal issuance takes place at the upper bound of the Instability zone $\bar{b}_G$.

Appendix to "A Model of the International Monetary System"

Emmanuel Farhi Matteo Maggiori

Not for Publication. November 2016

A.1 Proofs and Further Details for the Main Body of the Paper

Here we provide the full details of the derivation of the RoW demand function for Hegemon debt in equation (1).

Proposition A.1 *Focusing only on demand functions for debt that depend positively on its expected return, we conclude that either RoW agents are expecting debt to be safe and the demand function is*

$$R^s(b) = \bar{R}^r - 2\gamma(w^* - b)\sigma^2,$$

or, if the agents are expecting the debt to be risky, it is priced identically to the risky asset and demand is indeterminate.

Proof. We start with the the generic maximization problem

$$\max_{b, C_1^*} \quad \mathbb{E}^+[C_1^*] - \gamma Var^+(C_1^*),$$

$$w^* R^r + b(Re - R^r) = C_1^*, \quad b \geq 0.$$

The optimality condition is

$$R\bar{e} - \bar{R}^r = \gamma[2b(R^2\sigma_e^2 + \sigma^2 - 2R\ \sigma\ \sigma_e) + 2w^*\ R\ \sigma\ \sigma_e - 2w^*\ \sigma^2], \tag{A.1}$$

where $\bar{e} = \mathbb{E}^+[e]$ and $\sigma_e = Var^+(e)$. Suppose agents were expecting debt to be safe, then $\bar{e} = 1$ and $\sigma_e = 0$, so we have

$$R^s(b) = \bar{R}^r + \gamma[2b\sigma^2 - 2w^*\ \sigma^2] = \bar{R}^r - 2\gamma(w^* - b)\sigma^2.$$

This proves the first part of the proposition.

Suppose agents were expecting Hegemon debt to be risky, then $\bar{e} = \bar{R}^r / R_H^r$ and $\sigma_e = \sigma / R_H^r$ since we assumed $e_L = R_L^r / R_H^r$. Substituting these expressions into (A.1) and solving for R as a function of b, we have two roots

$$R_- = R_H^r \quad \text{and} \quad R_+ = R_H^r \left(1 + \frac{\frac{\bar{R}^r}{2\gamma\sigma^2} - w^*}{b}\right).$$

The first root, which we will select, implies that the risky bond is now a perfect substitute for the risky asset and demand for the bond is therefore indeterminate. We exclude the second root on economic grounds (and by assumption in this proposition) since it generates a backward bending demand function: higher expected rates of returns on debt lower the demand for debt. ■

Here we provide the conditions under which the full-commitment equilibrium prices in Proposition 1 are free of arbitrage.

Proposition A.2 ***(Absence of Arbitrage under Full Commitment).*** *The full-commitment equilibrium prices are arbitrage free if and only if $R_H^r > R^s(b^{FC}) > R_L^r$, i.e. if and only if $\gamma w^* \sigma^2 < (R_H^r - R_L^r)(1 - \lambda)$.*

Proof. Let M be a valid SDF in this economy. We have two states and two linearly independent securities, so markets are complete, hence M is unique. Absence of arbitrage is equivalent to M being strictly positive. Requiring that M prices the two assets we have

$$\mathbb{E}[M]R^s(b^{FC}) = 1,$$

$$\mathbb{E}[MR^r] = 1.$$

These are two equations in two unknowns. Solving for M we obtain

$$M_H = \frac{1}{1-\lambda}\frac{R^s(b^{FC}) - R^r_L}{R^s(b^{FC})(R^r_H - R^r_L)},$$

$$M_L = \frac{1}{\lambda}\frac{R^r_H - R^s(b^{FC})}{R^s(b^{FC})(R^r_H - R^r_L)}.$$

Therefore $M_L > 0$. We have $M_H > 0$ if and only if $R^s(b^{FC}) > R^r_L$, i.e. if and only if $\gamma w^* \sigma^2 < (R^r_H - R^r_L)(1-\lambda)$. ■

We note that the condition $\bar{R}^r - 2\gamma w^* \sigma^2 > 0$, imposed in the main text, is not sufficient to guarantee the absence of arbitrage, but that the stronger condition $\bar{R}^r - 2\gamma w^* \sigma^2 > 1$ is.

Proof of Proposition 2. We proceed by proving some useful claims

Claim 1 *The Hegemon never chooses to issue so much debt $b > \bar{b}$ as to lose the safety premium for sure.*

Proof. Note that $V(0) = 0$ and $V(b) = -\lambda\tau(1-e_L) < 0 \quad \forall b \in (\bar{b}, w^*]$. ■

Claim 2 *If the full-commitment equilibrium level of debt b^{FC} lies in the Safety zone, then the Hegemon issues that level of debt and the only equilibrium is the safe equilibrium.*

Proof. Recall $b^{FC} = argmax(V^{FC}(b))$. If $b^{FC} \leq \underline{b}$ then $max(V^{FC}(b)) = \max(V(b))$ since $V^{FC}(b) \geq V(b)$ and equality holds only for $b \in [0, \underline{b}]$. ■

Let us create a pseudo value function $\tilde{V}(b) = (1-\alpha)V^{FC}(b) - \alpha\lambda\tau(1-e_L)$. Notice that $\tilde{V}(b) = V(b)$ $\forall b \in (\underline{b}, \bar{b}]$. If $b^{FC} > \underline{b}$ we could have several cases that are summarized below.

Claim 3 *Assume $b^{FC} > \underline{b}$, then the Hegemon issues either $b = \underline{b}$ or $\min(b^{FC}, \bar{b})$, whichever generates higher expected profits. If the Hegemon issues $\underline{b}$ there is a unique safe equilibrium. If the Hegemon issues $\min(b^{FC}, \bar{b})$ there are multiple equilibria: the safe and the collapse equilibria.*

Proof. In the zone of debt issuance in which only the safe equilibrium is possible ($b \in [0, \underline{b}]$), the local maximum of V is achieved at the upper boundary for $b = \underline{b}$. To verify this claim recall the assumption $b^{FC} = argmax(V^{FC}(b)) > \underline{b}$, the fact that $V(b) = V^{FC}(b)$ for all $b \in [0, \underline{b}]$, and that $V^{FC}(b)$ is a strictly concave function.

The Hegemon therefore issues $b = \underline{b}$ iff this local maximum is also the global maximum, i.e. when $V^{FC}(\underline{b}) \geq \max_{b \in (\underline{b}, \bar{b}]} V$. Note that by claim 1, we can ignore the Collapse zone since $argmax(V(b)) \in (0, \bar{b}]$.

Suppose $V^{FC}(\underline{b}) < \max_{b \in (\underline{b}, \bar{b}]} V$, then the Hegemon issues b^{FC} if $b^{FC} \in (\underline{b}, \bar{b}]$ and otherwise issues $\bar{b}$. To verify this claim notice that globally $argmax(\tilde{V}(b)) = argmax(V^{FC}(b))$, since $\tilde{V}(b) = aV^{FC}(b) + c$ with constants $a > 0$ and $c < 0$. Furthermore $\tilde{V}(b)$ is a strictly concave function. Therefore, $argmax_{b \in (\underline{b}, \bar{b}]} V(b)$ takes value b^{FC} if $\bar{b} \geq b^{FC}$ or equals the upper bound $\bar{b}$. ■

The claims above prove items 1, 2, and 3 of the Proposition. The presence of an ex-ante safety premium in all equilibria follows from the expected return on debt

$$\mathbb{E}^{-}[R(b,\omega)e(b,\omega)] = (1-\alpha(b))R^s(b) + \alpha(b)\bar{R}^r$$

noticing that the optimal issuance level is always below w^*, so that at the optimal issuance one has $R^s(b) < \bar{R}^r$, and $\alpha(b) < 1$. We conclude that $\mathbb{E}^{-}[R(b,\omega)e(b,\omega)] < \bar{R}^r$ and there is an exorbitant privilege. ■

The next proposition verifies under which conditions equilibrium prices in the model with limited commitment are arbitrage-free.

Proposition A.3 ***(Absence of Arbitrage under Limited Commitment).*** *The equilibrium prices at time $t = 0^+$, conditional on debt being safe, are arbitrage free if and only if $R^r_H > R^s(b^*) > R^r_L$, where b^* is the equilibrium issuance, i.e. if and only if $2\gamma\sigma^2(w^* - b^*) < (R^r_H - R^r_L)(1-\lambda)$. If issuance takes place at $b^* = b^{FC}$ then this condition is the same as that of Proposition A.2. If issuance takes place at $b^* = \underline{b}$ then this condition is less stringent than the requirement in Proposition A.2. Conversely, if issuance takes place at $b^* = \bar{b}$ then this condition is more stringent than the requirement in Proposition A.2.*

Proof. The proof is entirely analogous to that of Proposition A.2. ■

Here we provide details for the derivations in Section 4. RoW solves the following maximization problem

$$\max_{b,C_1^*} \quad \mathbb{E}^{+}[C_1^*] - \gamma Var^{+}(C_1^*) - \gamma_L\left(\hat{b} - \min(b,\hat{b})\mathbf{1}_{\{\mathbb{E}^{+}[e]=1\}}\right)^2,$$

$$s.t. \quad w^*R^r + b(Re - R^r) = C_1^*, \qquad b \geq 0,$$

where $\gamma_L > 0$, $\hat{b}$ is an exogenous threshold, and $\mathbf{1}_{\{\mathbb{E}^{+}[e]=1\}}$ is the indicator function that takes value one if its argument is satisfied. If debt is safe (i.e. $\mathbb{E}^{+}[e] = 1$), then the extra utility (liquidity) value of owning bonds is $\gamma_L(\hat{b} - b)^2$ for $b < \hat{b}$ and zero otherwise. If debt is risky (i.e. $\mathbb{E}^{+}[e] < 1$), then the extra utility loss $\gamma_L\hat{b}^2$ is the one that would have occurred if the agent had chosen $b = 0$ in the presence of safe debt.

We assume, for simplicity, that $\hat{b} = \underline{b} = \tau/R_H$. This implies that if debt is expected to be safe, then the demand curve is given by[41]

$$R^s(b) = \bar{R}^r - 2\gamma(w^* - b)\sigma^2 - 2\gamma_L(\underline{b} - b)\mathbf{1}_{\{b\leq\hat{b}\}}. \tag{A.2}$$

The above equation is the demand curve reported in the main body of the paper in equation (10). If debt is expected to be risky, which can only happen for $b > \underline{b}$, then the result from Proposition A.1 applies and $R = R^r_H$, so that risky debt is a perfect substitute for the risky asset. Therefore, if the debt is safe, the demand function has an extra liquidity component for all $b \leq \underline{b}$ and is otherwise identical to the one considered in the previous sections.

We now introduce a Lemma that proves equation (11).

Lemma A.1 ***(Welfare as the Area Under the Demand Curve).*** *RoW welfare can be computed according to*

$$V_{RoW}(b) = V_{RoW}(R^s(0)) + (1-\alpha(b))\int_{R^s(0)}^{R^s(b)} b(\tilde{R}^s)d\tilde{R}^s,$$

where $b(R^s)$ is given by

$$b(R^s) = \frac{R^s - \bar{R}^r + 2\gamma\sigma^2 w^* + 2\gamma_L\underline{b}\mathbf{1}_{\{b\leq\underline{b}\}}}{2\gamma\sigma^2 + 2\gamma_L\underline{b}\mathbf{1}_{\{b\leq\underline{b}\}}},$$

[41] We impose the parameter restriction $\bar{R}^r - 2\gamma w^*\sigma^2 - 2\gamma_L\hat{b} > 0$, by analogy with the previous sections.

and

$$V_{RoW}(0) = w^*\bar{R}^r - \gamma\sigma^2 w^{*2} - \gamma_L \underline{b}^2.$$

Proof. The maximization problem of RoW is

$$\max_{b,s^*,C_1^*} \quad \mathbb{E}^+[C_1^*] - \gamma Var^+(C_1^*) - \gamma_L(\underline{b} - \min(b,\underline{b})\mathbf{1}_{\{\mathbb{E}^+[e]=1\}})^2,$$

$$s.t. \quad s^* R^r + bRe = C_1^*, \qquad b + s^* = w^*, \qquad b \geq 0.$$

Assume the debt is safe, then we can write the problem as

$$\max_{b,s^*} \quad bR^s + s^*\bar{R}^r - \gamma s^{*2}\sigma^2 - \gamma_L(\underline{b} - w^* + s^*)^2 \mathbf{1}_{\{w^*-s^* \leq \underline{b}\}} = bR^s + \nu(s^*) \quad s.t. \quad s^* + b = w^*.$$

This problem leads to optimality conditions that describe demand functions $b(R^s)$ and $s^*(R^s)$. In particular, optimality requires

$$R^s = \nu'(s^*). \tag{A.3}$$

We then write $V^s_{RoW}(R^s) = b(R^s)R^s + \nu(w^* - b(R^s))$, and take the partial derivative w.r.t. R^s to get

$$V'_{RoW}(R^s) = b(R^s) + b'(R^s)R^s + \nu'(w^* - b(R^s))b'(R_s).$$

Substituting in the above equation the optimality condition in equation (A.3), we obtain $V'(R^s) = b(R^s)$. Integrating over both sides we obtain

$$V^s_{RoW}(R^s) = V_{RoW}(R^s_0) + \int_{R^s_0}^{R^s} b(\tilde{R}^s)d\tilde{R}^s,$$

where $R^s_0 = \bar{R}^r - 2\gamma\sigma^2 w^* - 2\gamma_L \underline{b}$, and $V_{RoW}(R^s_0) = w^*\bar{R}^r - \gamma\sigma^2 w^{*2} - \gamma_L \underline{b}^2$.

If instead we assume that debt is risky, then RoW welfare is given by

$$V^r_{RoW} = w^*\bar{R}^r - \gamma\sigma^2 w^{*2} - \gamma_L \underline{b}^2.$$

Note that $V^r_{RoW} = V^s_{RoW}(R^s_0)$.

We define RoW welfare from an ex-ante perspective, before the equilibrium sunspot is selected, to be

$$V_{RoW}(b) = (1-\alpha(b))V^s_{RoW}(R^s(b)) + \alpha(b)V^r_{RoW},$$

where we have found it convenient to write $V_{RoW}(b)$ as a function of b and $V^s_{RoW}(R^s)$ as a function of R^s. We conclude that

$$V_{RoW}(b) = V_{RoW}(R^s(0)) + (1-\alpha(b))\int_{R^s(0)}^{R^s(b)} b(\tilde{R}^s)d\tilde{R}^s.$$

■

Continuation of the Proof of Proposition 3. We continue the proof initiated in the main text. We prove the second statement of the proposition: for a demand curve that is sufficiently convex one can have over-issuance by the Hegemon.

We start by deriving a bound on $\bar{\gamma}_L(\tau)$ such that the Hegemon does not want to issue in the interior of the Safety zone for $b^{FC} > \underline{b}(\tau)$. Recall that the value function within the Safety zone is: $V(b) = (\bar{R}^r - R^s(b))b$ for $b \in [0,\underline{b}]$. Hence, in that zone $V'(b) = \bar{R}^r - R^s(b) - bR'^s(b)$. Since $V'(0) > 0$, and $V(b)$ is concave, then to have that $V'(b) > 0$ for $b \in [0, \underline{b}]$, it is sufficient to have $V'(\bar{b}) > 0$ which imposes the bound

$$\gamma_L < \gamma\sigma^2 \left(\frac{w^*}{\underline{b}(\tau)} - 2 \right).$$

We define the function $\bar{\gamma}_L(\tau)$ to be the highest value (as a function of τ) that γ_L can take in the above bound

$$\bar{\gamma}_L(\tau) = \gamma\sigma^2 \left(\frac{w^* R^r_H}{\tau} - 2 \right).$$

In what follows, we assume $\gamma_L \in [\eta\bar{\gamma}_L(\tau), \bar{\gamma}_L(\tau)]$ for $\eta \in (0,1]$. We take the limit as $\tau \downarrow 0$, so that $b^{FC} = w^*/2 > \bar{b}(\tau)$ since $\lim_{\tau\downarrow 0} \bar{b}(\tau) = 0$. In this limit, and as described in the text more generally in Section 3.0.1, there exists $\alpha^*_m \in (0,1)$ s.t. the Hegemon issues $\bar{b}(0)$ for all $\alpha \le \alpha^*_m$ and issues $\underline{b}(0)$ for all $\alpha > \alpha^*_m$. Below we prove that in this limit we have

$$\lim_{\tau\downarrow 0} \alpha^*_m(\tau) = \frac{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} - \frac{2\gamma\sigma^2 w^*}{R^r_H}}{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} + \lambda(1-e_L)} \in (0,1). \tag{A.4}$$

Similarly, we can compute a threshold $\alpha^*_{row}(\tau)$ such that RoW investors would have preferred the equilibrium issuance $\bar{b}(\tau)$ for all lower αs and otherwise would have preferred the lower issuance $\underline{b}(\tau)$.

We change the notation slightly from Lemma A.1 and define the welfare of RoW investors to be the function $V_{RoW}(b,\alpha)$, to make the dependence on α more explicit. At issuance level $\underline{b}(\tau)$, we have

$$V_{RoW}(\underline{b},0) = \underline{b}R^s(\underline{b}) + (w^* - \underline{b})\bar{R}^r - \gamma(w^* - \underline{b})^2\sigma^2.$$

Similarly welfare of RoW at issuance level $\bar{b}$ is given by

$$\begin{aligned} V_{RoW}(\bar{b},\alpha) &= (1-\alpha)\left(\bar{b}R^s(\bar{b}) + (w^* - \bar{b})\bar{R}^r - \gamma(w^* - \bar{b})^2\sigma^2\right) + \alpha(w^*\bar{R}^r - \gamma w^{*2}\sigma^2 - \gamma_L \underline{b}^2) \\ &= V_{RoW}(\bar{b},0) - \alpha(V_{RoW}(\bar{b},0) - V_{RoW}(0,0)). \end{aligned}$$

Notice that $V_{RoW}(\underline{b},0)$ is independent of α and $V_{RoW}(\bar{b},\alpha)$ is continuous and decreasing in α. Furthermore, $V_{RoW}(\bar{b},0) > V_{RoW}(\underline{b},0)$ and $V_{RoW}(\bar{b},1) < V_{RoW}(\underline{b},0)$. So that we conclude $V_{RoW}(\underline{b},0) = V_{RoW}(\bar{b},\alpha^*_{RoW})$, with

$$\alpha^*_{RoW} = \frac{V_{RoW}(\bar{b},0) - V_{RoW}(\underline{b},0)}{V_{RoW}(\bar{b},0) - V_{RoW}(0,0)}.$$

Below we prove that in the limit $\tau \downarrow 0$, we have

$$\lim_{\tau\downarrow 0} \alpha^*_{RoW}(\tau) = 0. \tag{A.5}$$

We conclude that for $\eta \in (0,1]$ and $\gamma_L \in [\eta\bar{\gamma}_L(\tau), \bar{\gamma}_L(\tau)]$, in the limit at $\tau \downarrow 0$ one has

$$\lim_{\tau\downarrow 0} \alpha^*_{RoW}(\tau) = 0 < \frac{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} - \frac{2\gamma\sigma^2 w^*}{R^r_H}}{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} + \lambda(1-e_L)} = \lim_{\tau\downarrow 0} \alpha^*_m(\tau).$$

Since $\alpha^*_{TOT}(\tau)$ is a convex combination of $\alpha^*_{RoW}(\tau)$ and $\alpha^*_m(\tau)$ with interior non-vanishing weights on each of the elements, we obtain the result in the Proposition.

We now prove the limits in equations (A.4) and (A.5). We prove the results only for $\eta = 1$. The generalization is straightforward. We start by proving that $\lim_{\tau\downarrow 0}\alpha^*_{RoW}(\tau)=0$. For small τ, we have

$$\bar{\gamma}_L(\tau)=\frac{\gamma\sigma^2 w^* R^r_H}{\tau}-2\gamma\sigma^2,$$

$$\underline{b}(\tau)=\frac{\tau}{R^r_H},$$

$$\bar{b}(\tau)=\frac{\tau}{\bar{R}^r-2w^*\gamma\sigma^2}+O(\tau^2),$$

$$R^s(0)=\bar{R}^r-4\gamma\sigma^2 w^*+4\gamma\sigma^2\frac{\tau}{R^r_H},$$

$$R^s(\underline{b}(\tau))=R^s(0)+2\gamma\sigma^2 w^*-2\gamma\sigma^2\frac{\tau}{R^r_H},$$

$$R^s(\bar{b}(\tau))=R^s(\underline{b}(\tau))+2\gamma\sigma^2\left[\frac{\tau}{\bar{R}^r-2\gamma\sigma^2 w^*}-\frac{\tau}{R^r_H}\right]+O(\tau^2).$$

We can now compute consumer welfare using the area under the demand curve formula

$$V_{RoW}(\underline{b}(\tau),\alpha)=V_{RoW}(0,\alpha)+\int_{R^s(0)}^{R^s(\underline{b}(\tau))}b(R^s)dR^s.$$

We get

$$V_{RoW}(\underline{b}(\tau),\alpha)=V_{RoW}(0,\alpha)+\frac{2\gamma\sigma^2 w^*+2\bar{\gamma}_L(\tau)\underline{b}(\tau)-\bar{R}^r}{2\gamma\sigma^2+2\bar{\gamma}_L(\tau)}[R^s(\underline{b}(\tau))-R^s(0)]+\frac{1}{2}\frac{(R^s(\underline{b}(\tau)))^2-(R^s(0))^2}{2\gamma\sigma^2+2\bar{\gamma}_L(\tau)},$$

which yields

$$V_{RoW}(\underline{b}(\tau),\alpha)=V_{RoW}(0,\alpha)+\frac{\gamma\sigma^2 w^*}{R^r_H}\tau+O(\tau^2).$$

We use

$$V_{RoW}(\bar{b}(\tau),\alpha)=V_{RoW}(0,\alpha)+(1-\alpha)[V_{RoW}(\underline{b}(\tau),\alpha)-V_{RoW}(0,\alpha)]+(1-\alpha)\int_{R^s(\underline{b}(\tau))}^{R^s(\bar{b}(\tau))}b(R^s)dR^s.$$

We get

$$V_{RoW}(\bar{b}(\tau),\alpha)=V_{RoW}(0,\alpha)+(1-\alpha)[V_{RoW}(\underline{b}(\tau),\alpha)-V_{RoW}(0,\alpha)]+O(\tau^2).$$

This immediately implies that

$$\alpha^*_{RoW}(\tau)=O(\tau).$$

We can also compute Hegemon welfare

$$V(\underline{b}(\tau),\alpha)=\frac{2\gamma\sigma^2 w^*}{R^r_H}\tau+O(\tau^2),$$

$$V(\bar{b}(\tau),\alpha)=(1-\alpha)\frac{R^r_H}{\bar{R}^r-2w^*\gamma\sigma^2}V(\underline{b}(\tau),\alpha)-\alpha\lambda(1-e_L)\tau+O(\tau^2).$$

This implies that

$$\alpha_m^*(\tau) = \frac{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} - \frac{2\gamma\sigma^2 w^*}{R_H^r}}{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} + \lambda(1-e_L)} + O(\tau),$$

where

$$\frac{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} - \frac{2\gamma\sigma^2 w^*}{R_H^r}}{\frac{2\gamma\sigma^2 w^*}{\bar{R}^r - 2w^*\gamma\sigma^2} + \lambda(1-e_L)} \in (0,1).$$

■

Conditions for Footnote 37. The reduction in profits from competition when issuing in the Safety zone is $2\gamma\sigma^2\underline{b} \times \underline{b}$, where $2\gamma\sigma^2\underline{b}$ is the increase in the interest rate arising from the issuance of $\underline{b}$ by the the first issuer and $\underline{b}$ is the issuance by the second issuer. Under some conditions stated below, the reduction in profits from competition when issuing in the Instability zone is bounded below by $2\gamma\sigma^2\underline{b} \times 1/2 \times \bar{b}$, which is greater than the corresponding reduction when issuing in the Safety zone. The term $-2\gamma\sigma^2\underline{b}$ is the increase in the interest rate arising from the issuance of $\underline{b}$ by the the first issuer, $1/2$ is the probability that there is no collapse and that, therefore, the debt of the second issuer is safe. A sufficient condition for this lower bound to hold is that $\bar{b}$ be less than the full commitment level that the second issuer would have chosen to issue with a zero probability of collapse in the presence of the first issuer issuing $\underline{b}$. For example, this condition holds for sure when τ is low enough and is both compatible with $2\underline{b} < \bar{b}$ and with the condition that a true Hegemon issues $\bar{b}$ when $\alpha = 0$ but prefers to cut back issuance to $\underline{b}$ when $\alpha = 0.5$. Under these conditions, both issuers issuing in the Safety zone is an equilibrium under duopoly.

A.2 Details for Generalizing the Framework

A.2.1 Endogenous Reputation, Coordination, and Competition

In this section, we present an infinite-horizon extension of the baseline model. Time is discrete and the horizon is infinite. Reserve countries issue one-period bonds in each period. The issuers are infinitely lived, risk neutral, and have rate of time preference $\delta \in (0,1)$. We maintain the assumption that $\delta^{-1} = \bar{R}^r$. RoW is populated by overlapping generations with each generation alive for 1 period. The young are born at period t with constant endowment w^* and invest in the bonds and the risky technology. The young have mean-variance preferences over consumption at the end of their lives at $t+1$ and consume all proceeds of investment at that time. We dispense entirely with the exogenous fixed costs of devaluation ($\tau = 0$).

The timing of decisions within each date is identical to the one-period model. At each date the issuers choose the devaluation of the exchange rate $e_t = \{1, e_L\}$. Disasters are i.i.d. over time, with per-period probability λ.

Consider first this model with a Hegemon under full commitment. The Hegemon decides to not devalue in bad times, the debt is safe, and the equilibrium is characterized by exactly the same equations as in Proposition 1. Similarly, the equilibrium with n issuers, who compete in quantities à la Cournot under full commitment, is a repeated version of that in Section 6.1 and also converges to perfect competition as the number of issuers increases to infinity.

We now turn to limited commitment. We assume that if an issuer chooses to devalue in bad times at time t when ex-ante facing an interest rate consistent with expectations of no devaluation ($R_{t-1}^s(b_i) < R_H^r$), then with some probability χ, it is punished forever by a bad continuation equilibrium in which RoW agents expect a devaluation of the currency conditional on disaster, which indeed occurs in equilibrium.[42] In that bad continuation equilibrium, RoW demand for this issuer's debt is perfectly elastic at $R^s_z(b_i) = R^r_H$ for $z > t$. There is, instead, no punishment going forward for devaluations by an issuer who is currently facing the interest rate R^r_H and has not previously devalued as described in the previous case. While we are allowing for non-Markovian strategies to depend on interest rates for safe debt R and past default, we are not allowing the strategies to depend on the history of issuances.

A.2.2 The Hegemon Model with Endogenous Reputation

We first analyze the equilibrium for a given amount of debt issued by a single issuer. Since the trigger strategies that we consider do not punish a devaluation following a period in which $R = R^r_H$, the issuer always devalues ex-post (if a disaster occurs) when ex-ante facing $R = R^r_H$. We assume that this equilibrium outcome, which can occur for all levels of b, is selected with probability $\alpha \in (0,1)$ for levels of debt when a safe debt equilibrium also exists, and otherwise with probability 1. By analogy with the main text we abuse the notation and denote this criterion by a function $\alpha(b)$.

The expected value for the issuer of issuing debt b forever and not devaluing, unless faced with interest rate R^r_H, is

$$V(b) = \sum_{z>t} \delta^{(z-t)} b(1-\alpha(b)) E^s_t [\bar{R}^r - R_z e] = b(1-\alpha(b)) \frac{\bar{R}^r - R^s(b)}{\bar{R}^r - 1}.$$

A devaluation at time t, when facing the favorable interest rate ($R^s(b) < R^r_H$), causes this real expected value to be lost with probability χ: in that case the trigger strategy imposes $\alpha(b) = 1$ in the continuation equilibrium for all levels of b, and the continuation value is zero. Hence the long-term expected cost of a devaluation is

$$\chi V(b) = \chi b(1-\alpha(b)) \frac{\bar{R}^r - R^s(b)}{\bar{R}^r - 1}.$$

The one-off short-term benefit of a devaluation is $bR^s(b)(1-e_L)$. The issuer therefore decides not to devalue if and only if

$$\chi b(1-\alpha(b)) \frac{\bar{R}^r - R^s(b)}{\bar{R}^r - 1} \geq bR^s(b)(1-e_L).$$

Substituting in the condition above the demand for safe debt $R^s(b) = \bar{R}^r - 2\gamma\sigma^2(w^* - b)$, we obtain the upper bound for the issuance of safe debt

$$\bar{b}^\infty_\alpha = w^* - \frac{\bar{R}^r(\bar{R}^r - 1)}{2\gamma\sigma^2 \left[\frac{\chi(1-\alpha)}{1-e_L} + \bar{R}^r - 1\right]}. \tag{A.6}$$

We use the superscript ∞ to distinguish the variables in this infinite-horizon model from the analogous concepts in the one period model. Note that $b^\infty_{\alpha=0} > 0$ and finite, $b^\infty_{\alpha=1} = 0$, and the upper boundary decreases in the probability of the collapse equilibrium selection: $\partial \bar{b}^\infty_\alpha / \partial \alpha < 0$.

The problem of the Hegemon is

$$\max_{b \in [0, \bar{b}^\infty_\alpha]} \quad (1-\alpha) b \frac{\bar{R}^r - R^s(b)}{\bar{R}^r - 1} = (1-\alpha) V^{FC}(b),$$

[42] While for simplicity we have made our trigger strategies very stark, so that a devaluation in a disaster runs the risk of losing the privilege forever, one could study more lenient punishments with finite duration. The Nixon shock of 1971 and the float of the U.S. Dollar in 1973 did not cause a major drop in the use of the Dollar as an international reserve currency (see Figure 1 Panel (d)). This can be rationalized in our model with stochastic punishment as a "lucky draw" whereby the Hegemon devalues but ends not being punished for this deviation.

$$s.t. \quad R^s(b) = \bar{R}^r - 2\gamma\sigma^2(w^* - b).$$

The Hegemon chooses to issue $b^{FC} = w^*/2$, if it is credible, or $\bar{b}_{\infty,\alpha}$, if it is not. Hence Hegemon issuance can be written as

$$\min(b^{FC}, \bar{b}^{\infty}_{\alpha}).$$

A.2.3 The Multipolar Model with Endogenous Reputation

Competition with endogenous reputation and the erosion of franchise value. We now analyze the multipolar world with n competing issuers. We set $\alpha = 0$ for simplicity. By analogy with the above analysis of the Hegemon, issuer i's best response to total issuance b_{-i} from other issuers is to issue the minimum between what it would have issued in best response under full commitment and the maximum credible amount that it can issue

$$b_i = \min\left(b_i^{FC}(b_{-i}), \bar{b}^{\infty}(b_{-i})\right).$$

Crucially the upper bound of credible issuance depends on the other players' total issuance

$$\bar{b}^{\infty}(b_{-i}) = w^* - b_{-i} - \frac{\bar{R}^r(\bar{R}^r - 1)}{2\gamma\sigma^2\left[\frac{\chi}{1-e_L} + (\bar{R}^r - 1)\right]}.$$

The upper boundary decreases faster than the full-commitment best response issuance: $\partial\bar{b}^{\infty}(b_{-i})/\partial b_{-i} = -1 < -1/2 = \partial b_i^{FC}(b_{-i})/\partial b_{-i}$.

We construct and analyze a symmetric equilibrium in which all issuers issue at their upper bound.[43] We denote the symmetric issuance at the upper bound by

$$\bar{b}^{\infty}_n = \frac{1}{n}\left[w^* - \frac{\bar{R}^r(\bar{R}^r - 1)}{2\gamma\sigma^2\left[\frac{\chi}{1-e_L} + (\bar{R}^r - 1)\right]}\right],$$

and restrict parameters such that $\bar{b}^{\infty}_1 < w^*/2 = b^{FC}$ so that the Hegemon would have issued the maximum credible amount $\bar{b}^{\infty}_1$. We emphasize that $\bar{b}^{\infty}_n = \bar{b}^{\infty}_1/n$ and conclude that as the number of issuers increases ($n \to \infty$) the total supply of the reserve assets remains constant at the level $\bar{b}^{\infty}_1$ that the Hegemon would have issued alone. We collect the result in the proposition below.

Proposition A.4 ***(Competition and the Erosion of Franchise Value).*** *Assume that debt is always safe ($\alpha = 0$), then if the Hegemon would have chosen to issue the maximum credible amount of reserve assets $\bar{b}^{\infty}_1$, competition never increases the total amount of reserve assets. As the number of competing issuers increases to infinity, the equilibrium does not converge to perfect competition, and instead total issuance stays constant at the level optimally chosen by a Hegemon: $\bar{b}^{\infty}_n = \bar{b}^{\infty}_1/n$. All issuers share equally the equilibrium monopoly rents.*

The key intuition for this proposition is that equilibrium issuance and per-period profits of a given issuer are inversely proportional to the number of issuers. To see why this is indeed an equilibrium, note that the short-term benefits of devaluing are proportional to equilibrium issuance, and that the long-term costs of devaluing are proportional to per-period profits. As a result, as the number of issuers increases, both the benefits and costs of devaluing decrease proportionately along the equilibrium path.

[43] Asymmetric equilibria exist but all feature the same amount of total issuance. Since the emphasis of this section is on total issuance, we focus on symmetric equilibria.

In the context of competition among private banks within a country Jiang, Levine and Lin (2017) provide empirical evidence supporting the notion that competition erodes discipline (commitment) due to loss of franchise value.[44]

Nurkse instability and the erosion of franchise value. To highlight the interaction between competition and coordination we extend the modeling of Nurkse instability from Section 6.2 to the repeated model setup of this section.

We reintroduce the assumption from Section 6.2 that in a duopoly, exactly one country $\tilde{i}$ out of the two is selected at random at $t = t^+$ to face the most favorable expectations for that period, while the other country $-\tilde{i}$ faces the least favorable expectations. The selection of which country faces which expectations is i.i.d. over time. Each country i now optimally behaves as a Hegemon with $\alpha_i = 0.5$. As in Section 6.2, we assume that a true Hegemon would have faced the most favorable expectations $\alpha = 0$.

In each period, the issuer that faces unfavorable expectations devalues ex post if a disaster occurs since there is no punishment in this case. In each period, the issuer that faces favorable expectations does not devalue ex post, conditional on a disaster, if and only if

$$\frac{1}{2}\chi b \frac{\bar{R}^r - R^s(b)}{\bar{R}^r - 1} \geq bR^s(b)(1 - e_L).$$

This leads to an upper boundary on the amount of credible debt equivalent to that of a true Hegemon facing the most favorable investors expectations with 50% probability: $\bar{b}^{\infty}_{\alpha=.5}$, as defined in equation (A.6).

In each period, each issuer decides how much debt to issue before knowing which investor expectations it will face. Each issuer i, therefore, anticipates that either it will face the perfectly elastic demand at R^r_H and make no expected profits for that period, or it will face the demand $R^s(b_i) = \bar{R} - 2\gamma\sigma^2(w^* - b_i)$. Each issuer solves the problem given below

$$\max_{b_i \in [0, \bar{b}^{\infty}_{\alpha=.5}]} \quad \frac{1}{2} b_i \frac{\bar{R}^r - R^s(b_i)}{\bar{R}^r - 1} = \frac{1}{2} V^{FC}(b_i)$$

where

$$R^s(b) = \bar{R}^r - 2\gamma\sigma^2(w^* - b).$$

The optimal issuance is $\min(b^{FC}, \bar{b}^{\infty}_{\alpha=.5})$. We collect the result in the Proposition below.

Proposition A.5 ***(Nurske Instability and the Erosion of Franchise Value).*** *Assume that a true Hegemon faces the most favorable investor expectations ($\alpha = 0$) in every period, but that in a duopoly exactly one country $\tilde{i}$ out of the two is selected at random at $t = t^+$ to face the most favorable expectations for that period, while the other country $-\tilde{i}$ faces the least favorable expectations. The selection of which country faces which expectations is i.i.d. over time. Optimal issuance for each issuer in the duopoly is given by*

[44] Marimon, Nicolini and Teles (2012) analyze monopolistic competition among issuers of differentiated monies in the presence of limited commitment and find that each issuer's choice of issuance does not depend on the elasticity of substitution between different monies. The equilibrium is inefficient and is associated with real balances that are too low, and both inflation and nominal interest rates that are too high. We model competition as an increase in the number of issuers of safe assets in a Cournot equilibrium, rather than as an increase in the elasticity of substitution between monies. In their model, total issuance, individual issuance, the individual short-term benefits of inflating, and the individual long-term costs in terms of lost future rents, are all independent of the degree of competition. In our model, total issuance is also independent of the degree of competition, but individual issuance, the individual short-term benefits of devaluing, and the individual long-term costs in terms of lost future rents, all decrease with the degree of competition and are exactly inversely proportional to the number of issuers.

$\min(b^{FC}, \bar{b}^{\infty}_{\alpha=.5})$. *The effective total stock of reserve assets is lower under a duopoly than under a Hegemon if* $\bar{b}^{\infty}_{\alpha=.5} < b^{FC}$.

Coordination undercuts commitment by reducing the expected future monopoly rents for each issuer. In this case, since each issuer only expects monopoly rents in 50% of the periods, the present value of future monopoly rents is cut by exactly 50%. Each issuer, therefore, behaves as a true Hegemon who faces the favorable expectations only half of the time. In a world of high demand for reserves ($\bar{b}^{\infty}_{\alpha=.5} < b^{FC}$), the entrance of a second issuer and the emergence of coordination problems then reduces the total effective supply of reserve assets.

A.2.4 Private issuance of reserve assets

Private issuance within each country. We extend the model to allow for private issuance of reserve assets from entities located within the Hegemon country. We assume that there is a mass μ of private issuers within the Hegemon country, each of which can issue one unit of debt denominated in the reserve currency. Each issuer can issue at cost ε; for simplicity, we assume the cost to be uniformly distributed over $[0, \xi]$ across issuers. We denote the total issuance as b^T. Since the marginal private issuer is defined by a cutoff $\bar{\varepsilon} = \bar{R}^r - R^s(b^T)$, we conclude that

$$b^T = b + \frac{\mu}{\xi}(\bar{R}^r - R^s(b^T)),$$

for $\bar{R}^r - R^s(b^T) \in [0, \xi]$. Solving this equation, we derive a simple relationship between total issuance b^T and public issuance b in the form of

$$b^T = \frac{b + \frac{\mu}{\xi} 2\gamma\sigma^2 w^*}{1 + \frac{\mu}{\xi} 2\gamma\sigma^2}.$$

We can then rewrite the demand curve for reserve assets as a function of b in the following way

$$\hat{R}^s(b) = \bar{R}^r - 2\hat{\gamma}\sigma^2(w^* - b),$$

where $\hat{\gamma} = \gamma/[1 + 2(\mu/\xi)\gamma\sigma^2]$. Hence, private issuance decreases the slope of the demand curve $R^s(b)$ for reserve assets, making it more elastic.

If the Hegemon does not take into consideration the welfare of private issuers, then the Hegemon problem is isomorphic to the one solved in Section 2.1, with γ replaced by $\hat{\gamma}$. If, instead, the Hegemon takes into consideration the welfare of private issuers gross of entry costs, then the Hegemon problem is isomorphic to the one solved in Section 2.1, with b and γ replaced by b^T and $\hat{\gamma}$, respectively.[45]

This model is consistent with the empirical regularity that the consolidated (private and public) external balance sheet of the Hegemon consists of low return safe and liquid liabilities and high return risky and illiquid assets, as emphasized by Despres, Kindleberger and Salant (1966), Gourinchas and Rey (2007*a*). In particular, the model is consistent with the notion that it is the private sector — not the government — that holds foreign risky assets, while the government issues safe assets to finance current spending. It is also consistent with the evidence by Accominotti (2012) that private safe assets issued/guaranteed by London

[45] If the Hegemon takes into consideration the welfare of private issuers net of entry costs, then the objective function of the Hegemon as a function of b^T is different and is given by

$$V(b^T) = 2\gamma\sigma^2 b^T(w^* - b^T)) - \frac{\mu}{\xi}\frac{[2\gamma\sigma^2(w^* - b^T)]^2}{2}.$$

merchant banks played an important role in the 1920s gold-exchange standard and the Pound collapse in 1931.

Third-party issuance across countries. We now consider the incentives to issue in Hegemon currency for issuers located outside of the Hegemon country. To sharpen the model, we start by considering an equilibrium in which the Hegemon issues safe debt b and does not devalue its currency in bad times.[46] We introduce a small issuer, located outside the Hegemon country, with time 1 utility function U who must raise real resources κ at date 0 to finance consumption at date 0.

We assume that the small issuer can either denominate its debt in reserve currency (the Hegemon currency) or in a risky currency that depreciates by $(1-e_L)$ in bad times, and that this issuer is too small to influence the equilibrium. The small issuer decides to issue in the Reserve currency if and only if

$$-\kappa R^s(b) > \mathbb{CE}^-[-\kappa R^r], \tag{A.7}$$

where we define $\mathbb{CE}^-[-\kappa R^r] = U^{-1}\left(\mathbb{E}^-[U(-\kappa R^r)]\right)$. This condition makes clear that the small issuer is more likely to issue in Hegemon currency, the lower $R^s(b)$, the higher and the more volatile R^r, and the higher the risk aversion embedded in the utility function U of the small issuer.

This helps rationalize the evidence in Chitu, Eichengreen and Mehl (2014) reproduced in Appendix Figure A.1 showing that third party issuance was predominantly denominated in pounds during the 1920s, when the British pound was the main reserve currency, and has subsequently switched to being denominated in dollars as the U.S. Dollar emerged as the main reserve currency. This also helps understand why countries that suffer from "original sin", so that they cannot issue in their own currency, predominately issue in the reserve currency. Relatedly, Du and Schreger (2015) and Bruno and Shin (2015) show that emerging market corporations predominantly borrow in U.S. dollar.

A.2.5 Liquidity and Networks Effects

We have derived the linear demand curve for reserve assets in equation (1) on the grounds of risk and risk aversion (mean-variance preferences). The reader is encouraged to interpret γ not as a deep parameter of household risk aversion, but as a proxy for features of the world economy that lead RoW to demand reserve assets (institutional constraints, regulatory requirements, financial frictions, etc., see e.g. Maggiori (2012)). In this spirit, we now show that our model can also capture elements of liquidity and network effects, while maintaining the simplicity of the linear demand curve.

We extend the model by adding a "reserve asset in the utility function" component, which captures the extra utility benefits that accrue from holdings of reserve assets. Importantly, we follow Stein (2012) in assuming that these liquidity benefits of holding bonds only arise if the bonds are safe, and are hence reserve assets.[47] We further allow for network effects by assuming that the liquidity benefits depend not only on individual holdings, but also on aggregate holdings (see e.g. Tobin (1980)). This captures in reduced form the notion that a reserve asset becomes increasingly liquid as more people use it; for example, it is easier to find a counterparty and to net out currency risk.

Formally, the RoW utility function now takes the form

$$\mathbb{E}^+[C_1^*] - \gamma Var^+(C_1^*) + (B^T\vec{\omega} + B^T\Omega B)\mathbf{1}_{\{\mathbb{E}^+[e]=1\}},$$

[46] In this section we assume that equilibrium prices are free of arbitrage as in Proposition A.3.

[47] Similarly, a linear demand function could have also been originated by limits to arbitrage theories (Shleifer and Vishny (1997), Gabaix and Maggiori (2015)).

where $B = (b, \tilde{b})^T$ is a vector such that b represents individual holdings and $\tilde{b}$ represents aggregate holdings, $\vec{\omega}$ and Ω are a 2×1 vector and a 2×2 matrix, respectively, and $\mathbf{1}_{\{\mathbb{E}^+[e]=1\}}$ is an indicator function that takes value 1 if the debt is safe, i.e. $E^+[e] = E^s[e] = 1$, and zero otherwise. We assume that $\omega_1 \geq 0$ and $\Omega_{11} \leq 0$, capturing the positive but decreasing marginal liquidity benefits that arise from individual bond holdings. We also assume that $\Omega_{12} = \Omega_{21} \geq 0$, capturing the increase in the marginal liquidity benefits from individual bond holdings with aggregate bond holdings, and that $\Omega_{11} + \Omega_{12} < \gamma\sigma^2$, so that this effect is not too strong and the demand curve is upward sloping.

If the debt is expected to be safe, then the optimality condition for individual portfolios is

$$R^s(b) = \bar{R}^r - 2\gamma\sigma^2(w^* - b) - \omega_1 - 2\Omega_{11}b - (\Omega_{12} + \Omega_{21})\tilde{b}.$$

Imposing the equilibrium condition $b = \tilde{b}$, we obtain the demand curve for reserve assets

$$R^s(b) = \bar{R}^r - 2\gamma\sigma^2 w^* - \omega_1 + 2(\gamma\sigma^2 - \Omega_{11} - \Omega_{12})b,$$

which can be rewritten as

$$R^s(b) = \bar{R}^r - 2\hat{\gamma}\sigma^2(\hat{w}^* - b), \tag{A.8}$$

where $\hat{\gamma} = \gamma - (\Omega_{11} + \Omega_{12})/\sigma^2$ and $\hat{w}^* = w^*\gamma/\hat{\gamma} + \omega_1/(2\hat{\gamma}\sigma^2)$. Therefore, under this formulation, the liquidity benefits and network effects that arise from bond holdings modify the level and the slope of the demand curve $R^s(b)$. They are isomorphic to a renormalized version of the baseline model with different values of w^* and γ. Larger marginal liquidity benefits ($\uparrow \omega_1$) decrease the level of $R^s(b)$, while stronger decreasing returns in liquidity benefits ($\downarrow \Omega_{11}$) increase the level and the slope of $R^s(b)$. Similarly, larger network effects ($\uparrow \Omega_{12}$) decrease the level and the slope of $R^s(b)$.[48] If the debt is expected to be risky, then the demand curve is the same as the one in the basic mean-variance case ($R = R^r_H$). We put this extension to use in Section A.2.6, in which we analyze the endogenous emergence of a Hegemon in the presence of network effects.

Recalling from equation (A.8) that liquidity and network effects are isomorphic to changes in γ and w^*, we conclude that higher liquidity benefits ($\uparrow \omega_1$) and stronger network effects ($\uparrow \Omega_{12}$) increase both the level of issuance and the size of the exorbitant privilege.

A.2.6 Endogenous Emergence of a Hegemon in a Multipolar World

In this section, we analyze whether the IMS has a natural tendency towards a Hegemon and, in this case, what the key determinants of Hegemon status are. We emphasize three characteristics: fiscal capacity, reputation, and currency of pricing in the goods market. We study configurations of the multipolar model in which differences in these characteristics lead to asymmetric equilibria with a large and a small issuer of reserve assets. Such asymmetric equilibria can be interpreted as leading to the natural emergence of a Hegemon. We emphasize how networks effects and the interactions of limited commitment and coordination can amplify small differences in characteristics.

Fiscal capacity. We consider a scenario in which in a duopoly $i \in \{1,2\}$ issuers differ in their fiscal capacity. We model fiscal capacity as the social cost of public funds whereby repaying bR actually requires resources $bR\phi$ with $\phi > 1$. We consider a small difference between the two issuers: $\phi_1 < \phi_2$, with $\phi_2 - \phi_1 < \varepsilon$ and ε arbitrarily small. For simplicity, we assume that $\alpha_i = 0$ for both countries $i \in \{1,2\}$ so that there are no coordination problems. Furthermore, we assume that τ is sufficiently large that the full-commitment

[48] For a liquidity/safety assessment of the demand for US treasuries, see Krishnamurthy and Vissing-Jorgensen (2012). For risk based empirical assessments of Dollar currency premia, see Hassan (2013), Hassan and Mano (2014), Verdelhan (2016).

outcome is outside of the Collapse zone for each country. We introduce liquidity and network effects along the lines of the extension presented in Section 2.1 and we use the corresponding notation. We assume that each RoW household receives marginal liquidity benefits from holding reserve currency i given by $\omega_1 + 2\Omega_{11}(b_i + b_{-i}) + (\Omega_{12} + \Omega_{21})\tilde{b}_i$. In other words, marginal liquidity benefits excluding network effects $\omega_1 + 2\Omega_{11}(b_i + b_{-i})$ depend only on total holdings $b_i + b_{-i}$ while network effects $(\Omega_{12} + \Omega_{21})\tilde{b}_i$ are specific to each reserve currency. The aggregate demand curves for each reserve currency are therefore given by

$$R_i^s(b_i; b_{-i}) = \bar{R}^r - 2\gamma\sigma^2(w^* - (b_i + b_{-i})) - \omega_1 - 2\Omega_{11}(b_i + b_{-i}) - (\Omega_{12} + \Omega_{21})b_i,$$

where we have substituted in the aggregation condition $b_i = \tilde{b}_i$. The difference in equilibrium issuance is given by:

$$b_1 - b_2 = \frac{\bar{R}^r(\frac{1}{\phi_1} - \frac{1}{\phi_2})}{2(\gamma\sigma^2 - \Omega_{11} - \Omega_{12} - \Omega_{21})}, \tag{A.9}$$

where by analogy with the extension in Section 2.1 we assume that $\gamma\sigma^2 - \Omega_{11} - \Omega_{12} - \Omega_{21} > 0$. Note that not only is the issuer with the greater fiscal capacity issuing more ($b_1 > b_2$), but also the difference in fiscal capacities is amplified by network effects $\Omega_{12} + \Omega_{21} > 0$ through a multiplier (the denominator in equation (A.9)). This captures the notion that the depth and liquidity of U.S. financial markets is an equilibrium outcome that amplifies a fiscal capacity advantage and consolidates the role of the U.S. Dollar as the dominant reserve currency.

Reputation. We analyze the role of differences in reputation by studying a duopoly $i \in \{1,2\}$ with differences in the ability to commit $\tau_1 > \tau_2$. For simplicity, we assume that $\alpha_i = 1$ for both countries $i \in \{1,2\}$, capturing severe coordination problems. In this case, both issuers decide to issue inside their respective Safety zones, but issuer 1 has a larger Safety zone $\underline{b}_1 = \tau_1/R_H^r > \tau_2/R_H^r = \underline{b}_2$. This corresponds to a standard Cournot duopoly with heterogenous capacity constraints given here by $\underline{b}_1$ and $\underline{b}_2$. In equilibrium, the issuer with the higher capacity constraint (issuer 1) issues more. These differences in the ability to commit can arise from institutional and historical factors. In the next paragraph we show that they can also arise endogenously from goods pricing.

IMS meets IPS. We consider a duopoly $i \in \{1,2\}$ and assume that prices are fully rigid in one of the two reserve currencies, say $i = 1$, rather than in RoW currency as assumed in Section 5. This captures the empirical regularity that prices are disproportionately quoted in the dominant reserve currency, in U.S. dollars at present and in British sterling in the 1920s, a fact dubbed the International Price System (IPS) by Gopinath (2015).

In this case, the real return of debt denominated in reserve currency 1, in which the goods are priced, is always safe. The crucial consequence is that country 1 endogenously acquires de facto full commitment, while country 2 still faces limited commitment as in our analysis so far.[49] We solve for an illustrative equilibrium by assuming that country 2 faces the least favorable expectations with $\alpha_2 = 1$. This is isomorphic to a standard Cournot model with two firms, one of which has a fixed capacity constraint while the other is unconstrained, where $\underline{b}$ plays the role of the fixed capacity constraint. In equilibrium, country 1 issues more, potentially much more, than country 2. This offers one rationalization for the association in the data between currency of pricing in the goods market and currency denomination of reserve assets.

[49] In practice debt reductions could be engineered either through an exchange rate devaluation or through an outright default. The pricing of goods in the reserve currency reduces the ex-post incentives to devalue. While the incentives to default are unchanged, such defaults are rarer in practice perhaps because of higher true or perceived associated costs.

A.2.7 Endogenous Entry and Natural Monopoly

To model endogenous entry, we add an ex-ante state to the model, where potential reserve issuers choose whether to incur a fixed cost K to increase their reputation from 0 to τ. This entry cost K could proxy for the various costly steps that must be taken over time by countries who desire to play a significant international role, for example by slowly building a reputation for currency stability in times of crisis at the cost of domestic welfare. Not only could these costs be large, but the opportunities to demonstrate good behavior and boost reputation might be very infrequent.

A potential reserve issuer who incurs K faces no cost of devaluing his currency, and hence cannot issue any positive amount of reserve assets since RoW investors rationally expect its debt to be risky. By contrast, a potential reserve issuer who incurs K faces a cost τ of devaluing his currency and can therefore issue some reserve assets and earn some monopoly rents.

Monopoly rents per issuer depend on the number of entrants and on the extent of coordination problems via a particular equilibrium selection. A natural monopoly arises when with large fixed costs and small variable costs, total monopoly rents are too small to sustain entry by a large number of reserve issuers. This tendency to a small number of reserve issuers is accentuated when coordination problems in the post-entry equilibrium worsen with entry.

A.2.8 Risk-sharing, LoLR Arrangements and the Triffin Dilemma

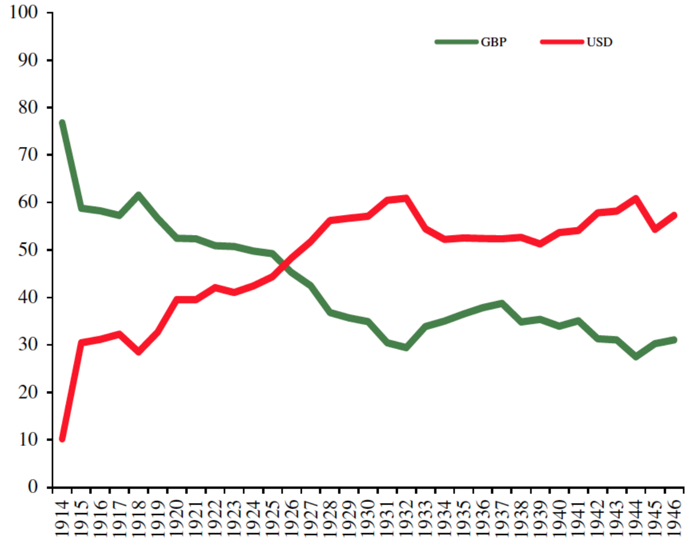
One approach to mitigating the Triffin dilemma and the associated instability of the IMS is to introduce policies that reduce the demand for reserve assets at all levels of global savings w^*. Such policies have often been proposed by economists looking to reform the IMS (Keynes (1943), Harrod (1961), Machlup (1963), Meade (1965), Rueff (1963), Farhi, Gourinchas and Rey (2011)). Their most recent incarnations have included swap lines amongst central banks, credit lines by the IMF as LoLR, and international reserve sharing agreements such as the Chiang Mai initiative.

Our framework can capture the rationale behind these policies with a simple extension of the demand curve for reserve assets in equation (1). We assume that each of the many countries in RoW is saddled with an idiosyncratic background endowment risk ω_i. We also assume that if variance (C_1^*) is above a variance threshold in equilibrium, then international investors penalize variance at the margin with "risk aversion" $\bar{\gamma}$, rather than $\underline{\gamma} < \bar{\gamma}$. This is a simple reduced-form way of capturing a form of precautionary savings. We assume that the variance of ω_i is so large that the variance of future consumption remains above the variance threshold even when the country invests all its savings in reserve assets; however, the variance of future consumption falls below the variance threshold in the absence of idiosyncratic background risk, even when there are no reserve assets. In that case, a sufficiently good idiosyncratic risk-sharing arrangement among RoW countries reduces the equilibrium demand for reserve assets by lowering marginal "risk aversion" to the lower level $\underline{\gamma}$.

In a world with more idiosyncratic risk-sharing and lower "risk aversion", the Hegemon finds issuing in the Safety zone relatively more attractive than issuing in the Instability zone. Indeed, assuming that $\underline{b} < b^{FC} < \bar{b}(\gamma)$ for both values of γ, the profits from issuing b^{FC} are equal to $(1-\alpha)b^{FC}2\gamma\sigma^2(w^* - b^{FC}) - \alpha\lambda\tau(1-e_L)$ and the profits from issuing $\underline{b}$ are equal to $\underline{b}2\gamma\sigma^2(w^* - \underline{b})$. Hence, the profits from issuing b^{FC} decrease more than the profits from issuing $\underline{b}$ when γ drops from $\bar{\gamma}$ to $\underline{\gamma}$.

Appendix Figures

Figure A.1: Third Party Issuance in Reserve Currencies



Note: Source: Chitu, Eichengreen and Mehl (2014). The figure plots the percentage of sovereign debt issued in pounds or dollars as a fraction of all sovereign debt issued in foreign currency by the rest of the world. See original source for details.

Appendix References

Accominotti, Olivier. 2012. "London merchant banks, the central European panic, and the sterling crisis of 1931." *The Journal of Economic History*, 72(01): 1–43.

Bruno, Valentina, and Hyun Song Shin. 2015. "Global dollar credit and carry trades: a firm-level analysis." *BIS working paper*.

Chitu, Livia, Barry Eichengreen, and Arnaud Mehl. 2014. "When did the dollar overtake sterling as the leading international currency? Evidence from the bond markets." *Journal of Development Economics*, 111: 225–245.

Despres, E., C.P. Kindleberger, and W.S. Salant. 1966. *The Dollar and World Liquidity: A Minority View. Brookings Institution, Reprint*, Brookings Institution.

Du, Wenxin, and Jesse Schreger. 2015. "Sovereign Risk, Currency Risk, and Corporate Balance Sheets." *Harvard, Department of Economics Working Paper*.

Farhi, Emmanuel, Pierre-Olivier Gourinchas, and Hélène Rey. 2011. *Reforming the international monetary system.* CEPR.

Gabaix, Xavier, and Matteo Maggiori. 2015. "International Liquidity and Exchange Rate Dynamics." *The Quarterly Journal of Economics*, 130(3): 1369–1420.

Gopinath, Gita. 2015. "The international price system." National Bureau of Economic Research.

Gourinchas, Pierre-Olivier, and Helene Rey. 2007. "From world banker to world venture capitalist: US external adjustment and the exorbitant privilege." In *G7 Current Account Imbalances: Sustainability and Adjustment*.

Harrod, Roy. 1961. "A Plan for Increasing Liquidity: A Critique." *Economica*, 28(110): 195–202.

Hassan, Tarek A. 2013. "Country Size, Currency Unions, and International Asset Returns." *Journal of Finance*, 68(6): 2269–2308.

Hassan, Tarek A, and Rui C Mano. 2014. “Forward and spot exchange rates in a multi-currency world.” National Bureau of Economic Research.

Jiang, Liangliang, Ross Levine, and Chen Lin. 2017. “Does Competition Affect Bank Risk?” National Bureau of Economic Research Working Paper 23080.

Keynes, J.M. 1943. *Proposal for an International Clearing Union.* British Government Publication, Cmd 6437.

Krishnamurthy, Arvind, and Annette Vissing-Jorgensen. 2012. “The aggregate demand for treasury debt.” *Journal of Political Economy*, 120(2): 233–267.

Machlup, Fritz. 1963. “Reform of the international monetary system.” *World Monetary Reform: Plans and Issues,(Stanford University Press and Oxford University Press, Stanford, CA and London 1963)*, 253–260.

Maggiori, Matteo. 2012. “Financial Intermediation, International Risk Sharing, and Reserve Currencies.” *Unpublished manuscript, Harvard University*.

Marimon, Ramon, Juan Pablo Nicolini, and Pedro Teles. 2012. “Money is an experience good: Competition and trust in the private provision of money.” *Journal of Monetary Economics*, 59(8): 815–825.

Meade, James E. 1965. “The future of international payments.” *World Monetary Reform: Plans and Issues*.

Rueff, Jacques. 1963. “Gold exchange standard a danger to the West.” *reprinted in H. Grubel (ed.) World Monetary Reform*, 320–8.

Shleifer, Andrei, and Robert W. Vishny. 1997. “The limits of arbitrage.” *Journal of Finance*, 52(1): 35–55.

Stein, Jeremy C. 2012. “Monetary Policy as Financial Stability Regulation.” *The Quarterly Journal of Economics*, 127: 57–95.

Tobin, James. 1980. “Discussion.” In *Models of monetary economies: proceedings and contributions from participants of a December 1978 conference sponsored by the Federal Reserve Bank of Minneapolis*. , ed. John H Kareken and Neil Wallace. Federal reserve bank of Minneapolis.

Verdelhan, Adrien. 2016. “The share of systematic variation in bilateral exchange rates.” *Forthcoming in the Journal of Finance*.